RENDERING REALISTIC CAUSTIC EFFECTS IN REAL TIME

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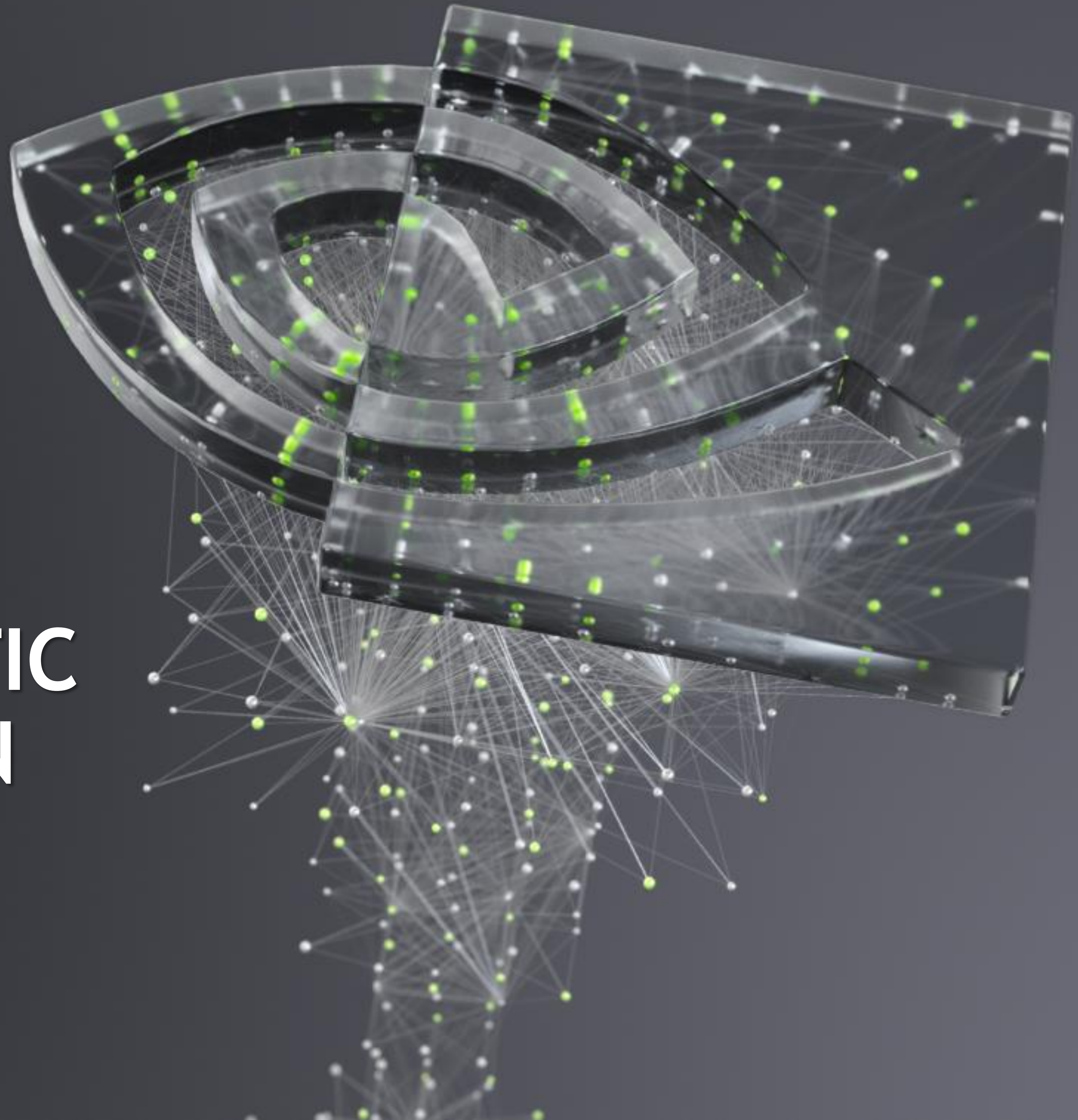
April 12th, 2021



A HISTORICAL RECAP

Multiple Projected Textures: OpenGL Red Book

Procedural Caustics: Crysis

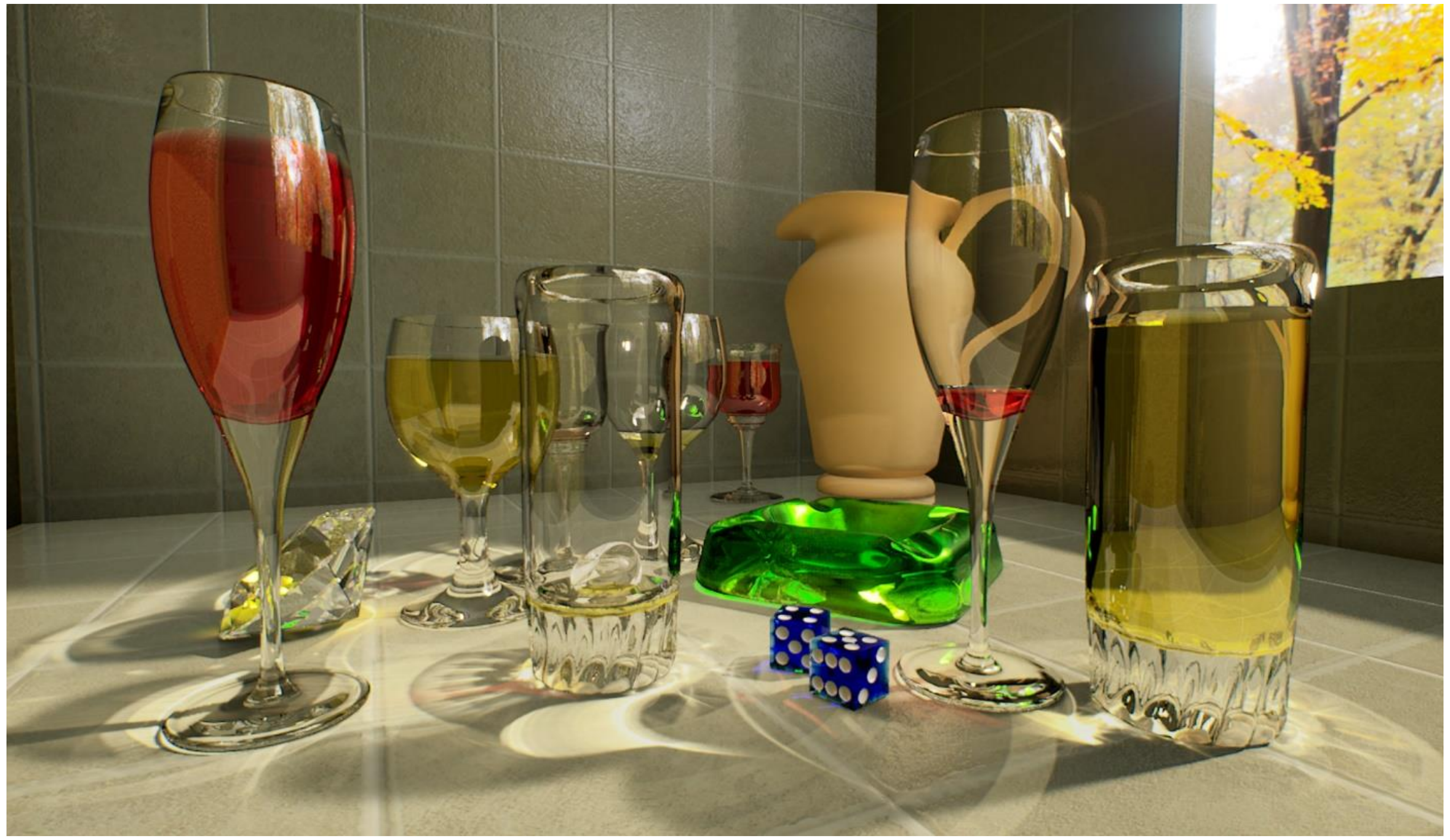
Photon Mapping: Off-line Renderers

Screen Space Caustics

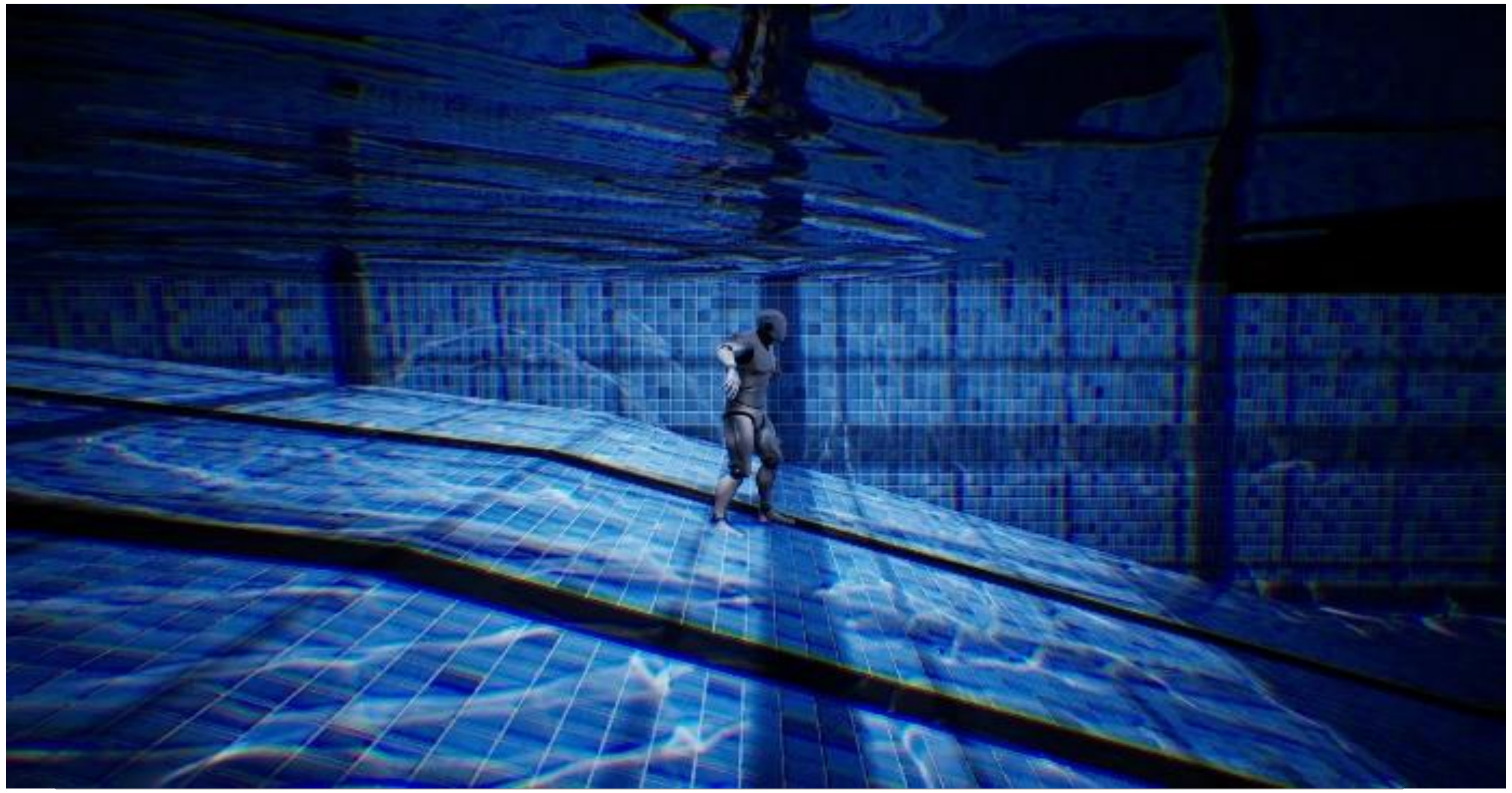
Ray Traced Caustics: Real-time Renders

REAL-TIME RAY TRACED CAUSTICS

Our techniques



Adaptive Anisotropic Photon Scattering
(AAPS in short)



Ray-Guided Water Caustics
(RGWC in short)

AGENDA

Adaptive Anisotropic Photon Scattering

Adaptive ray density

Photon differentials

Ray-Guided Water Caustics

Photon difference scattering

Procedural caustic mesh

Case Study

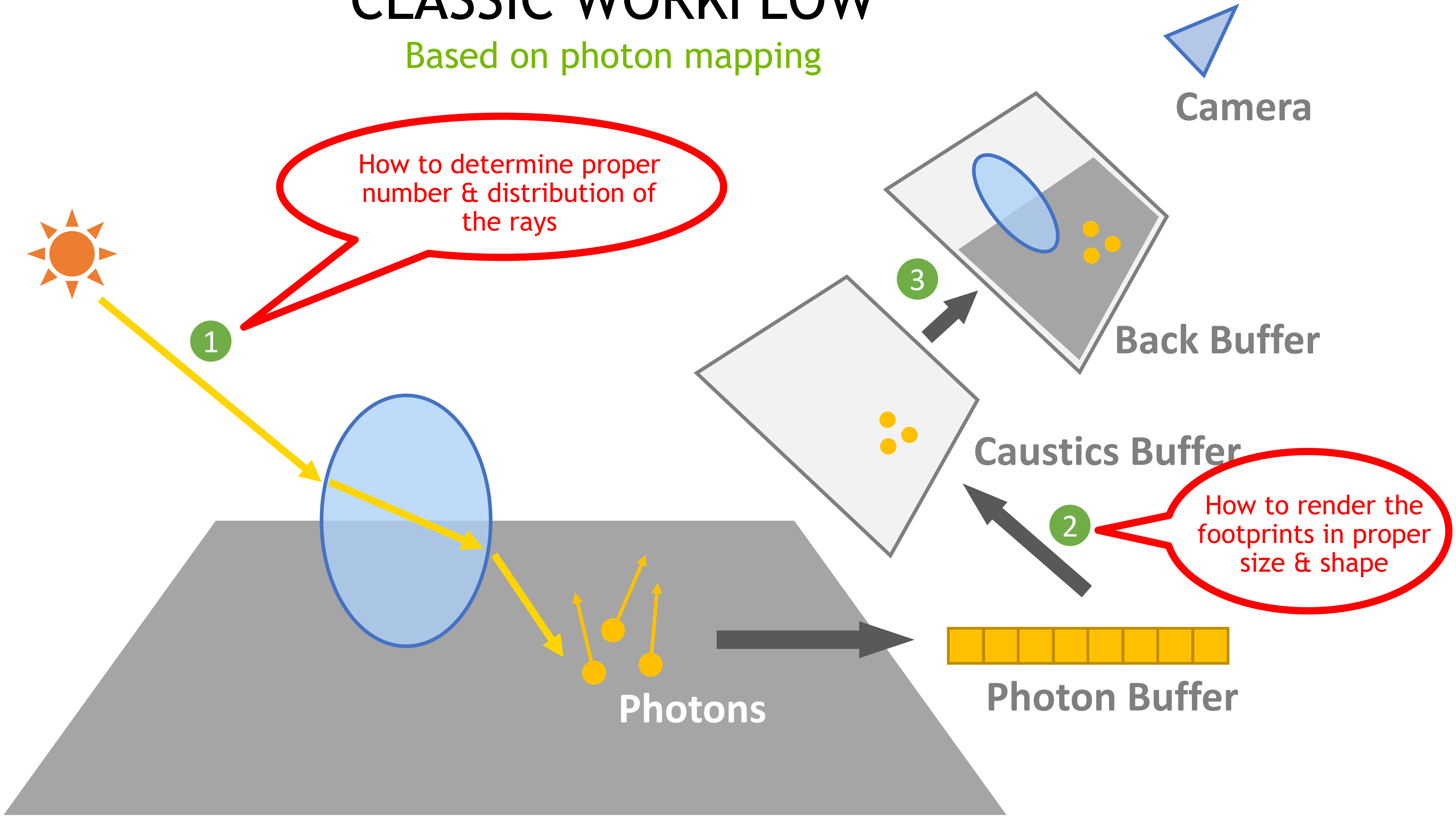
UE4 integration

DEMOs

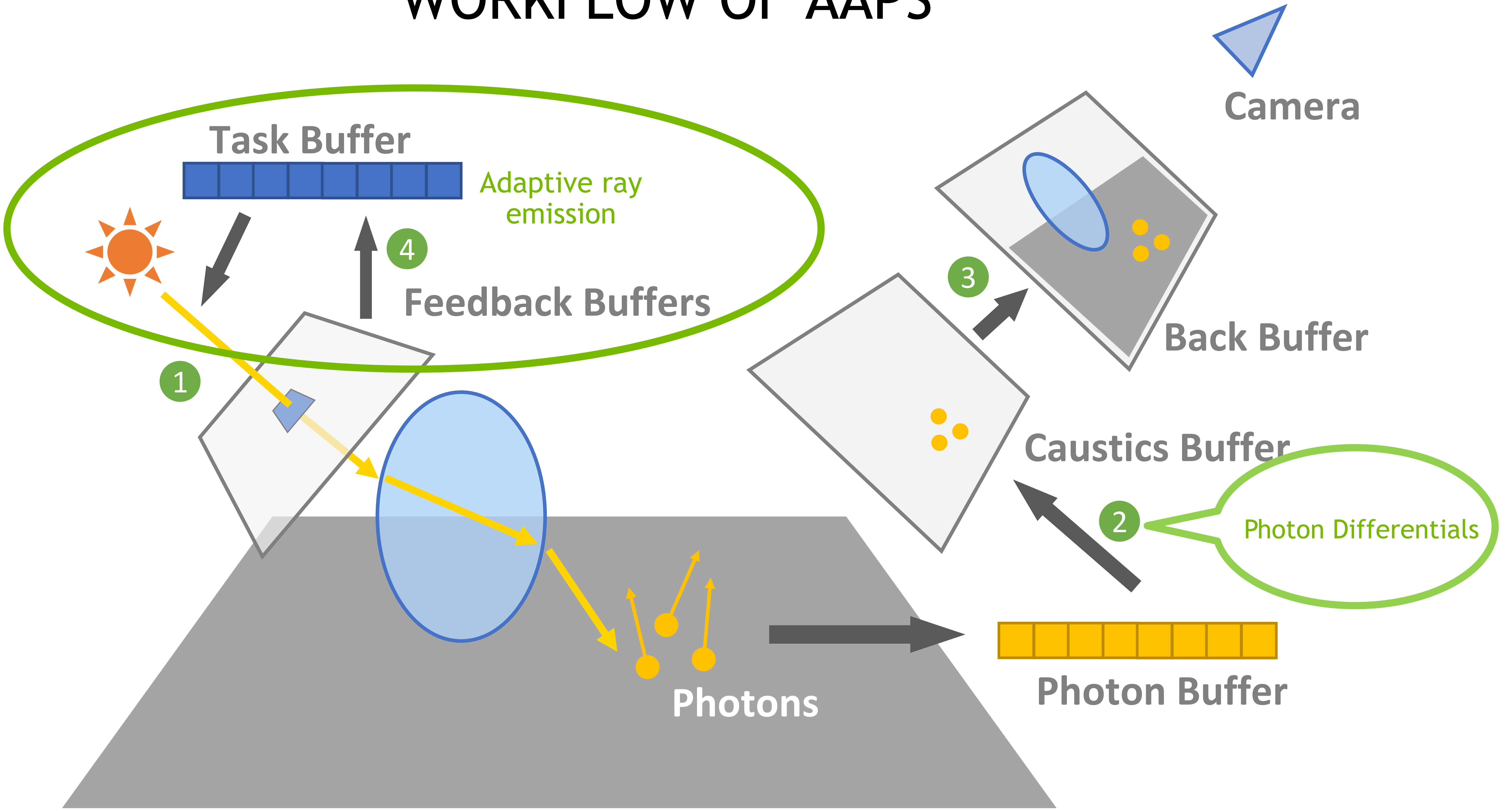
ADAPTIVE ANISOTROPIC PHOTON SCATTERING

CLASSIC WORKFLOW

Based on photon mapping



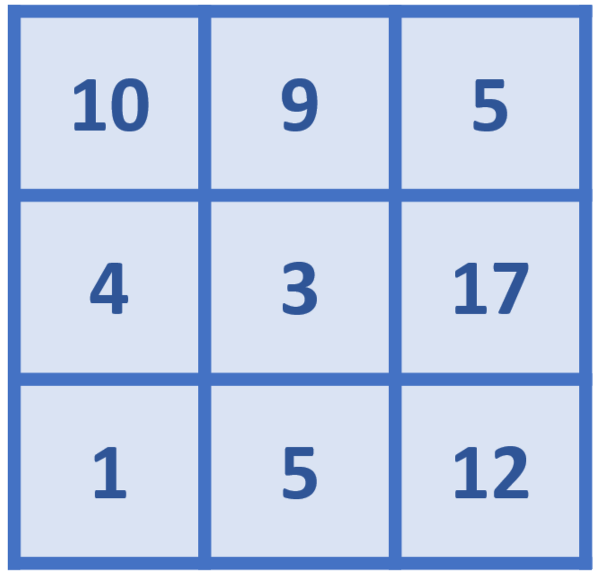
WORKFLOW OF AAPS



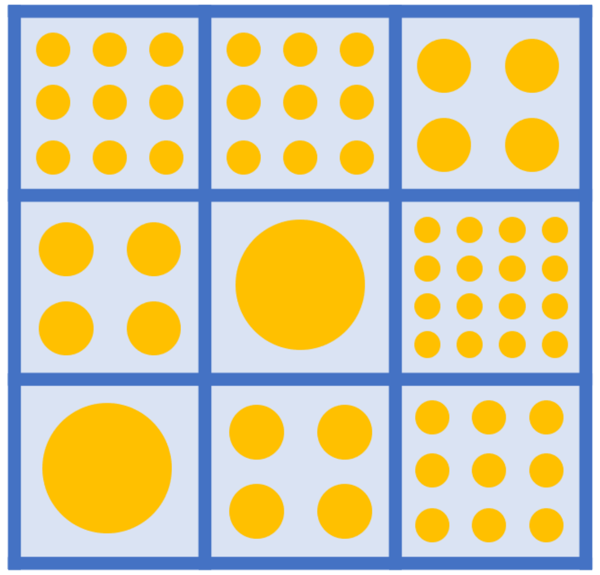
TASK ASSIGNMENT

Subtitle Optional

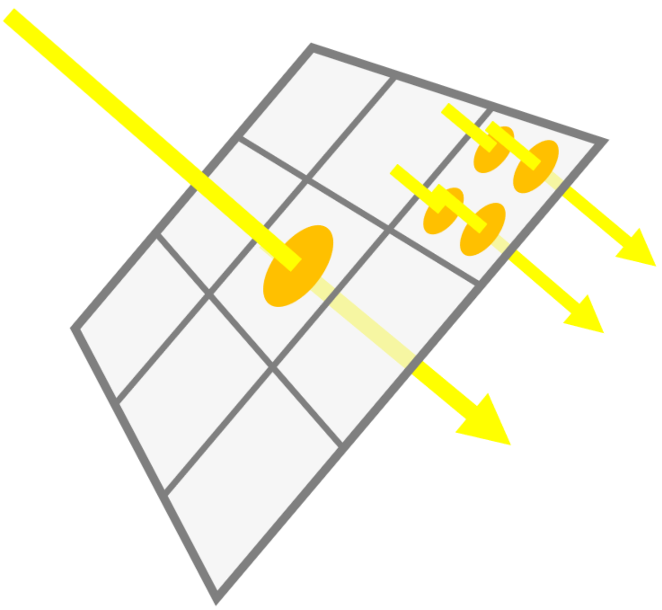
- A density texture to guide ray distribution
  - 2D texture, one for each light
  - Each pixel is mapped to a sub area in the light space
    - The value represents the number of the rays that should be emitted within this area -- Ray Density
    - Density updated every frame according to the value in the feedback buffers



Ray Density



Ray Footprints



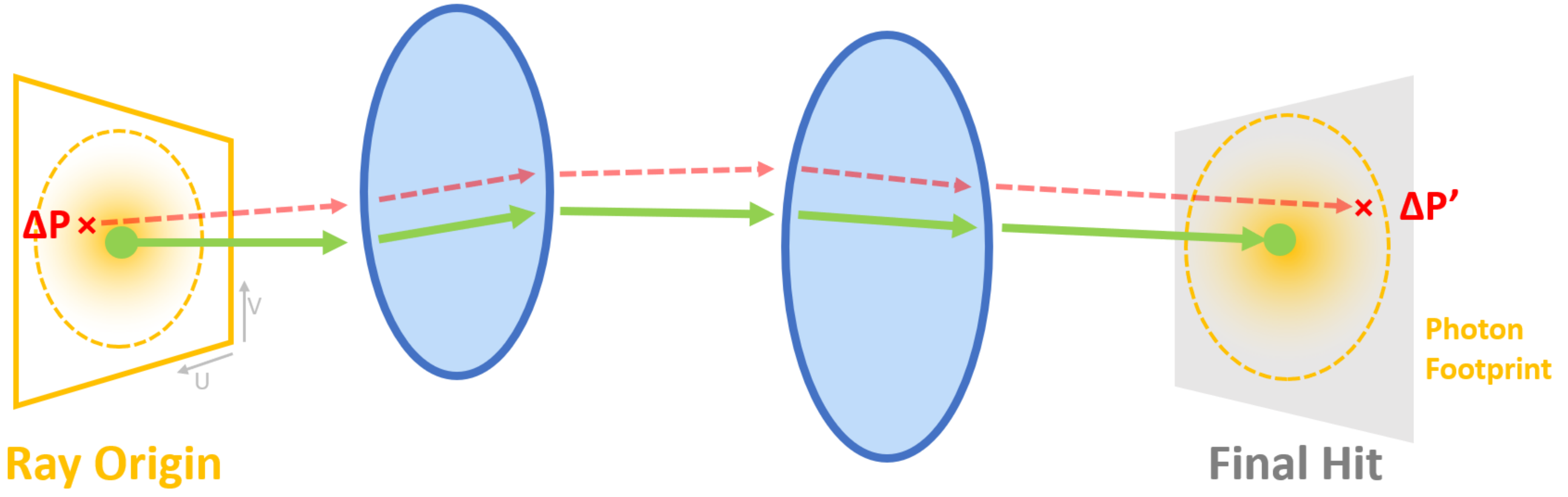
PHOTON SCATTERING

Photon Differentials [*]

- Initialize photon differential vectors at the ray origin
  - Positional differential vectors for directional lights, directional differential vectors for point lights
- Track & calculate the change of the differential vectors during the ray tracing
  - Access material of the receivers
- Use the final differential vectors to determine the new size & shape of the photon footprint

$$\Delta \mathbf{p}'_{\mathbf{u}} \approx \frac{\partial \mathbf{p}'}{\partial u} \Delta u$$

$$\Delta \mathbf{p}'_{\mathbf{v}} \approx \frac{\partial \mathbf{p}'}{\partial v} \Delta v$$



[*] photon differentials: https://dl.acm.org/doi/10.1145/1321261.1321293
ray differentials: https://graphics.stanford.edu/papers/trd/

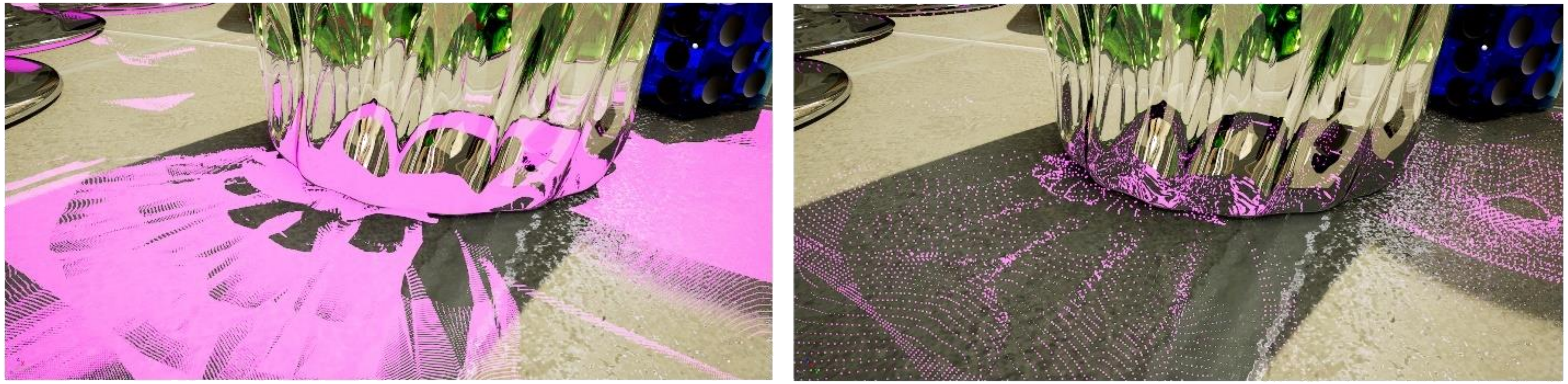
PHOTON SCATTERING

Photon Differentials

- Detailed caustics patterns are well captured without apparent noise

Photon differentials

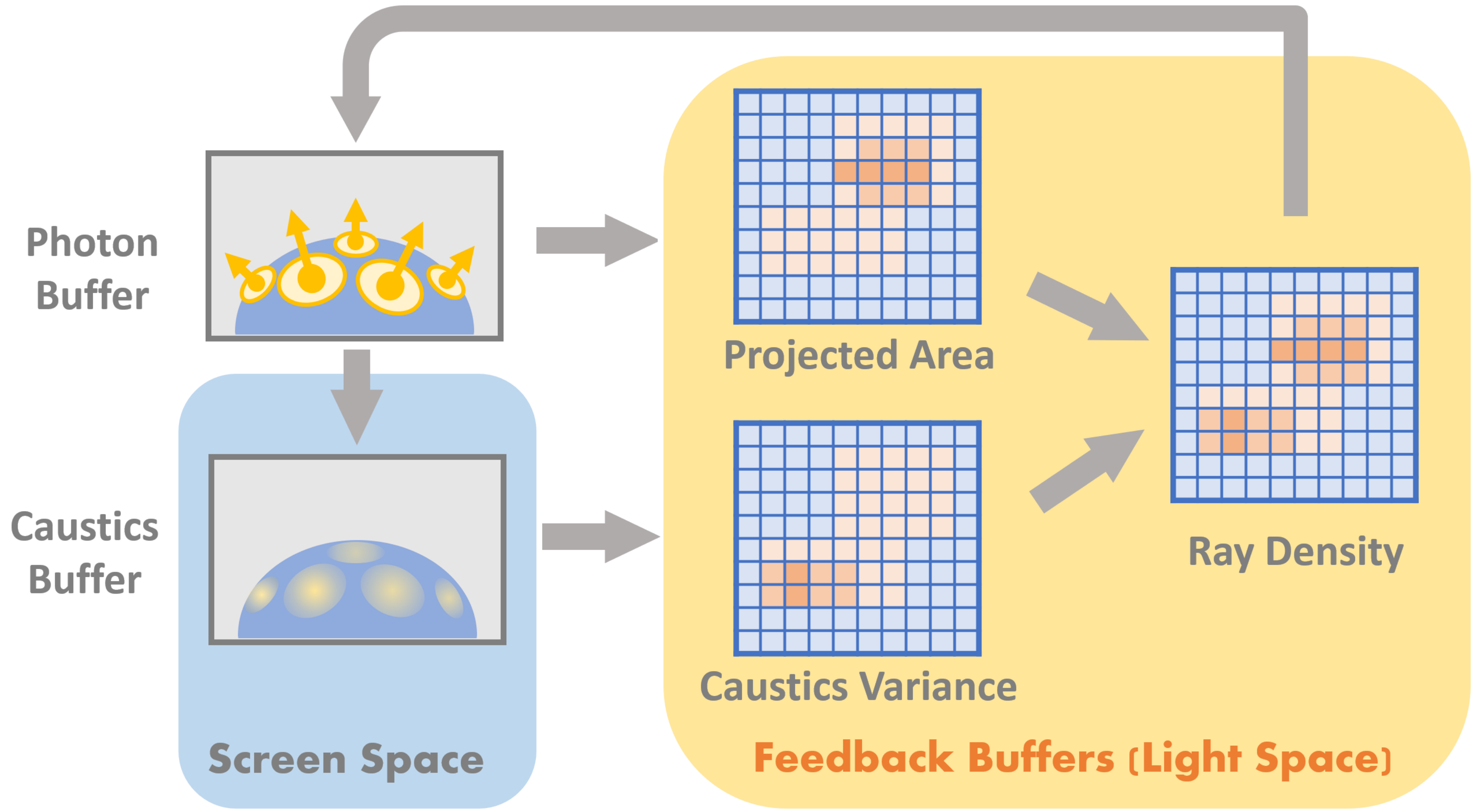
Photons shown in points



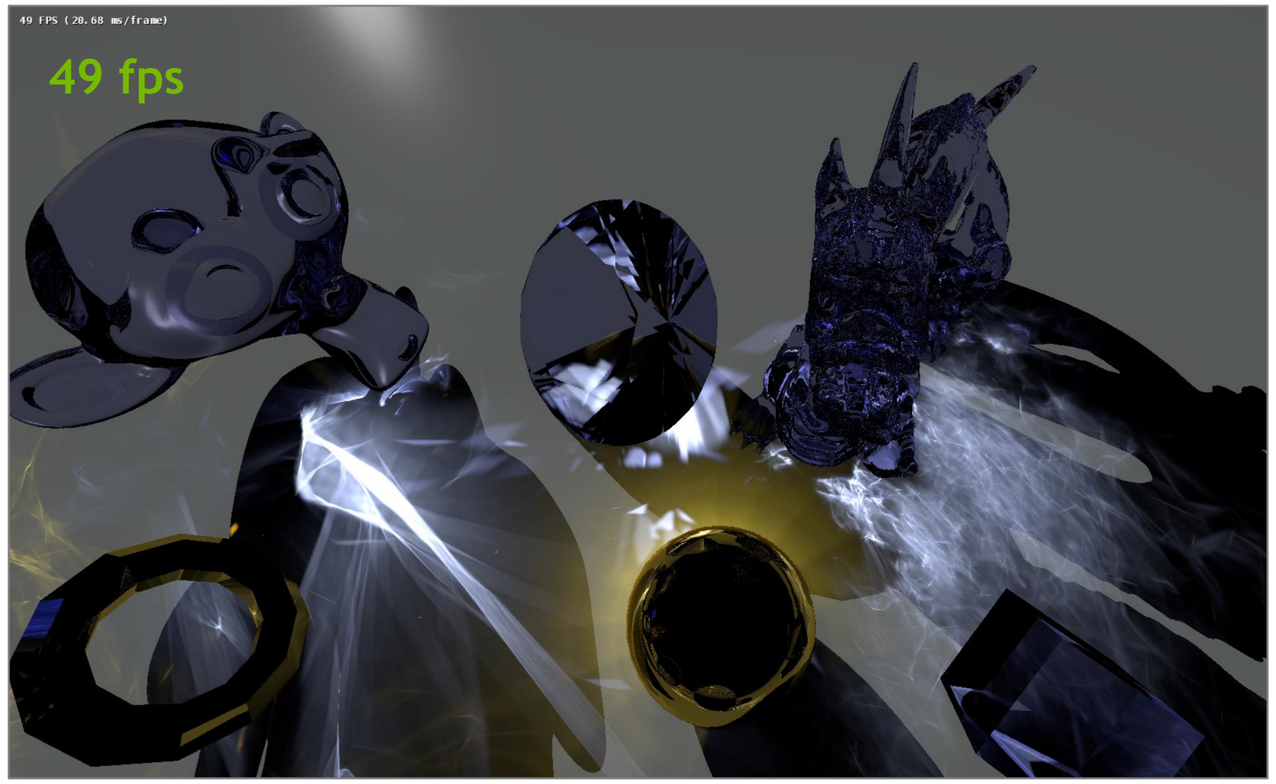
FEEDBACK BUFFERS

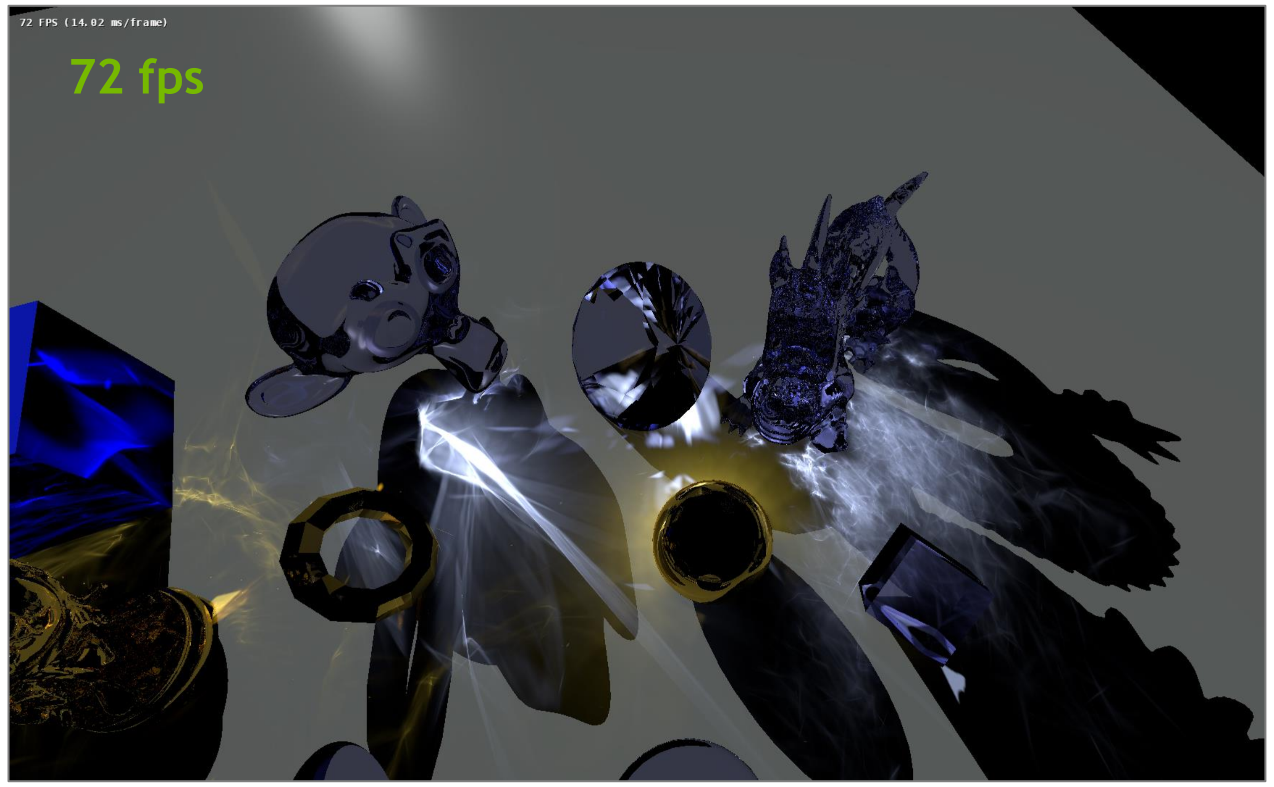
Key step to achieve adaptive ray emission

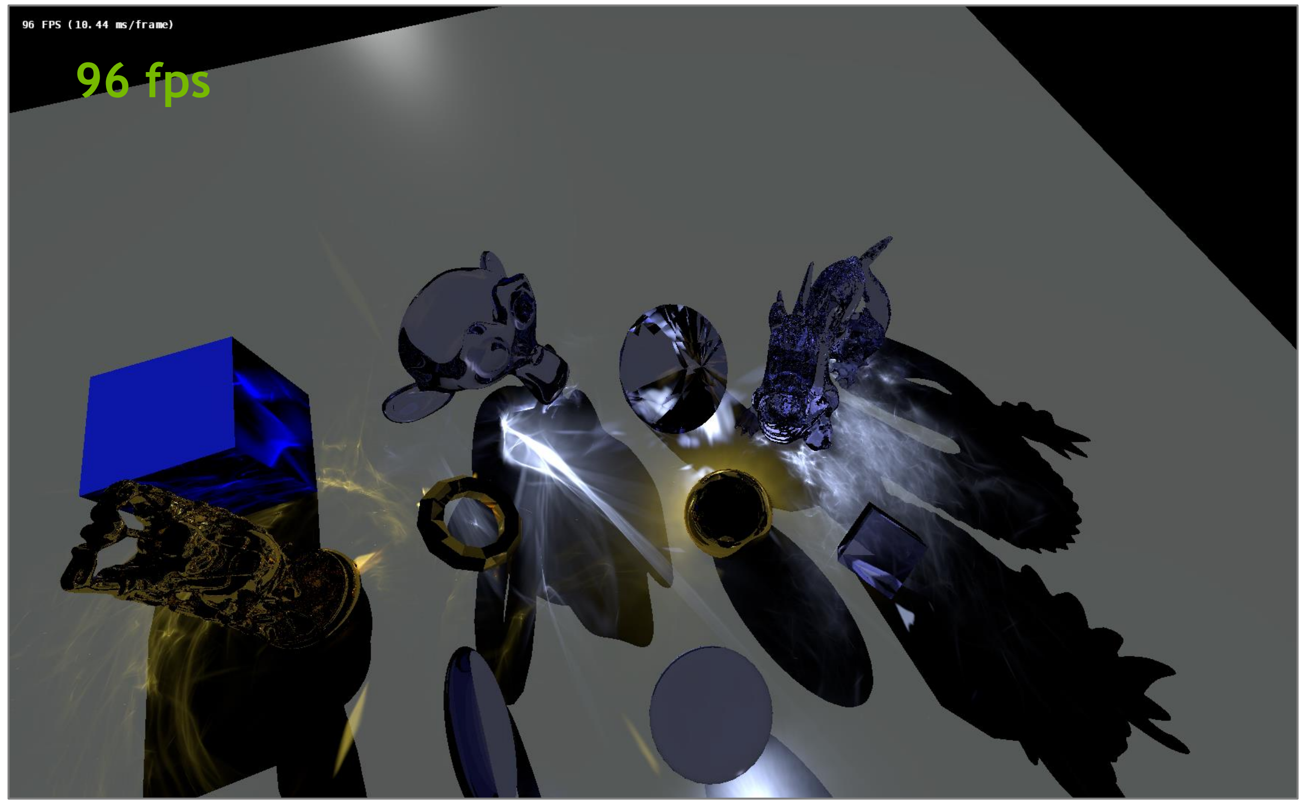
- A couple of textures
  - Coherent to the density texture
- Projected Area Texture
  - Average screen-space area of photon footprints
- Caustics Variance Texture
  - Average caustics variance of the screen pixels covered by photons
- Combine the values in the two textures to compute a "suggested ray density“
  - Larger area, higher variance -> higher density

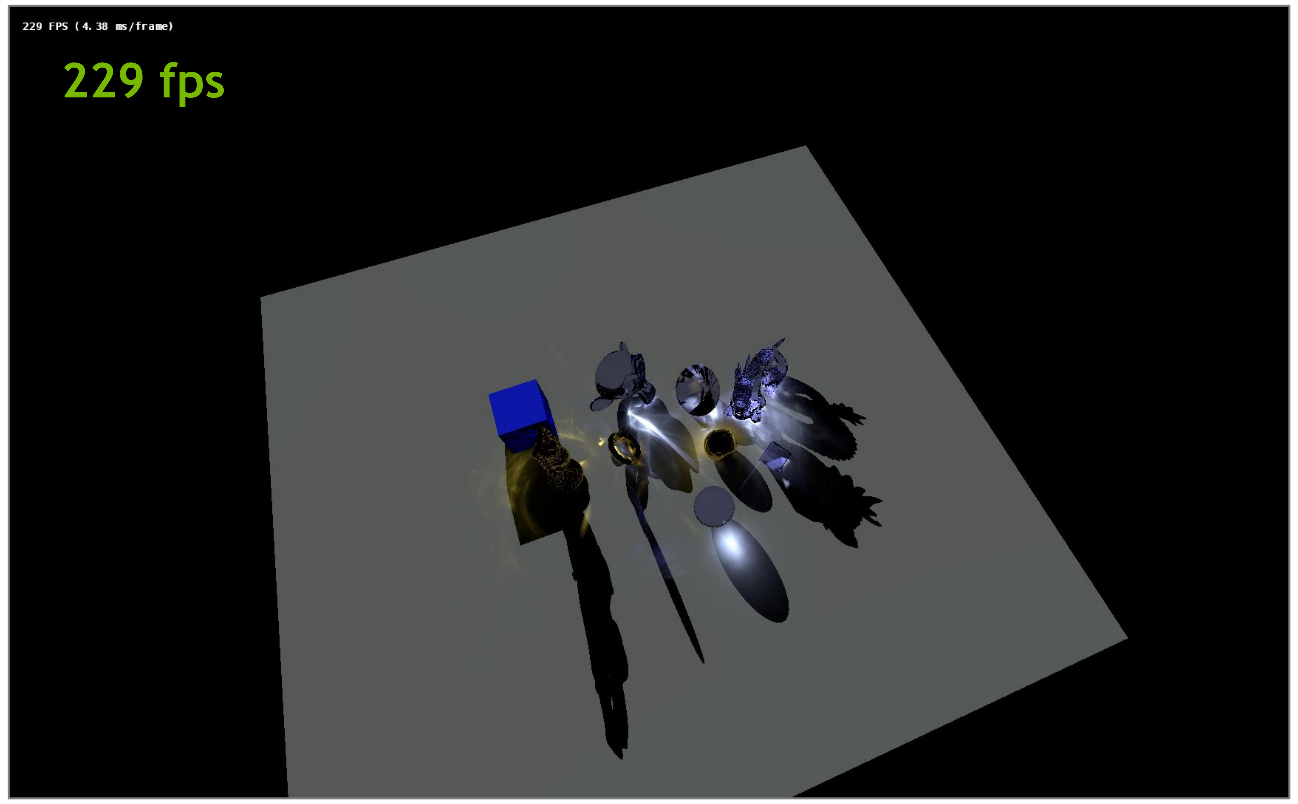


PERF & QUALITY



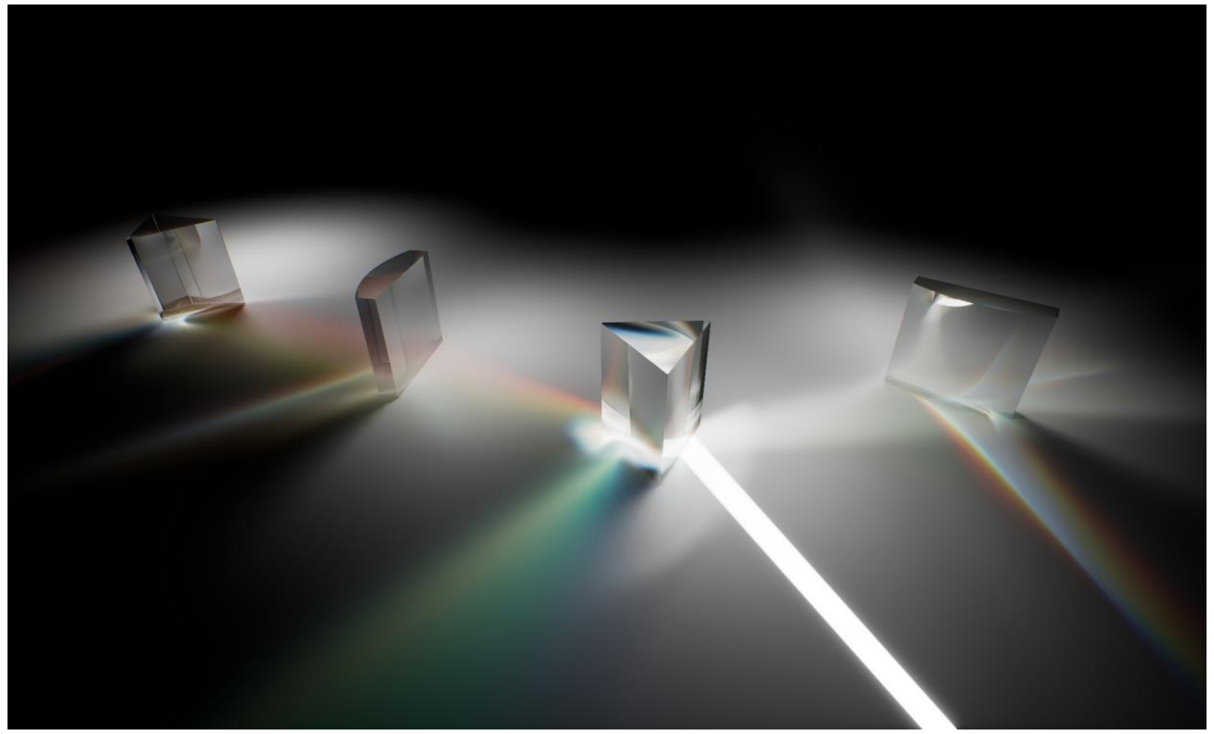


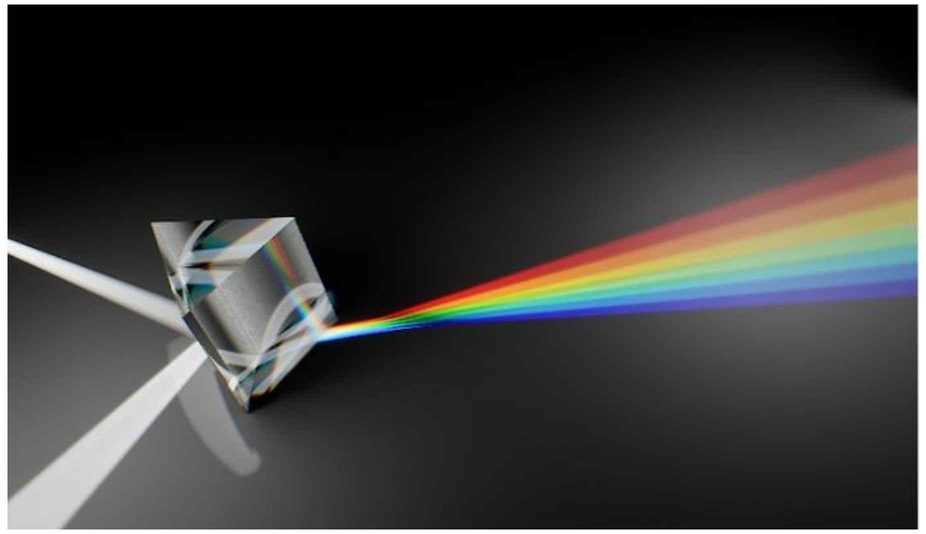




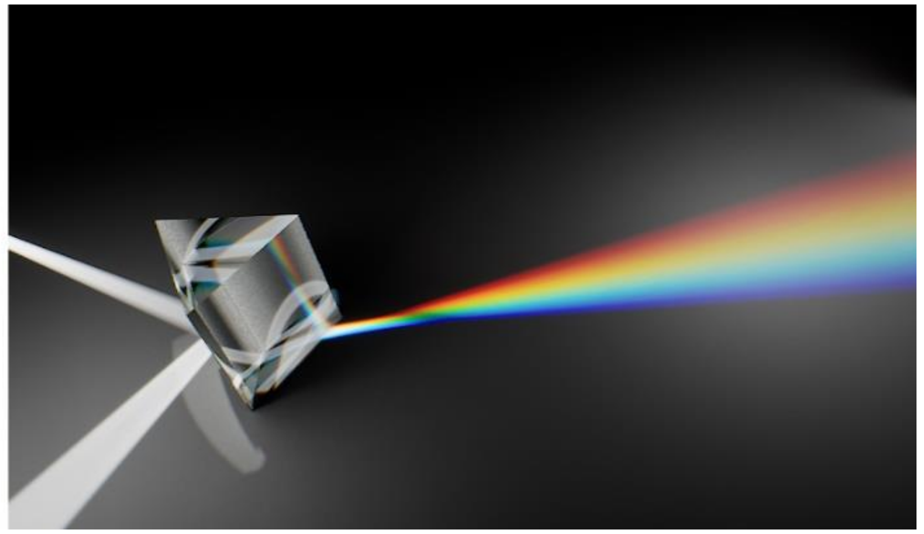
DISPERSION

- No additional rays needed
- Divide white light into several monochromatic lights (e.g. into red, green and blue)
- Assign the monochromatic lights & corresponding IORs (index of refraction) to the rays based on the thread ID
- Multiply the color of the light by the color of the monochromatic light to get the color of the photon
- IOR jittering
  - Make the color distribution smoother





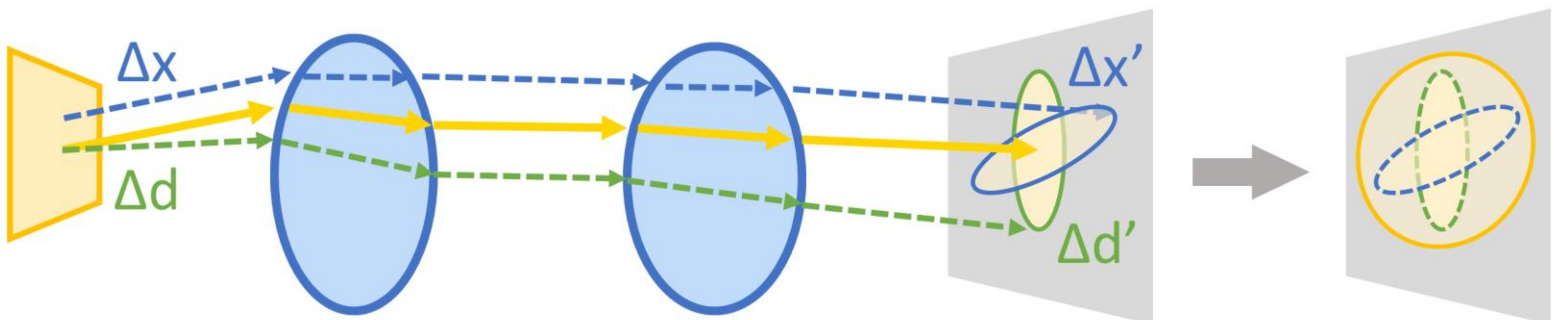
Without IOR jittering

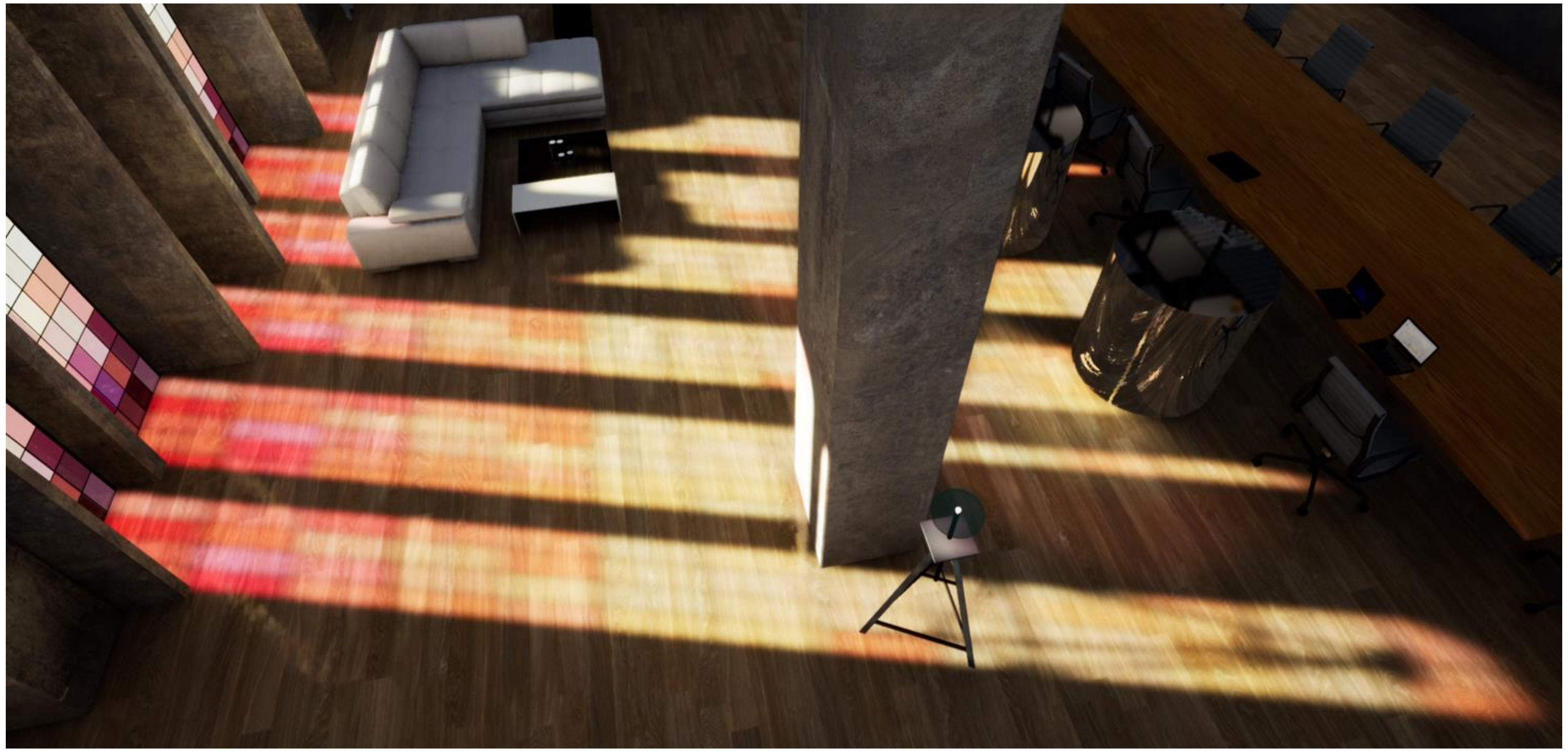


With IOR jittering

SOFT CAUSTICS

- Estimate photon differentials for both positional and directional differentials
- Combine the two photon differentials & apply them to the photon footprint

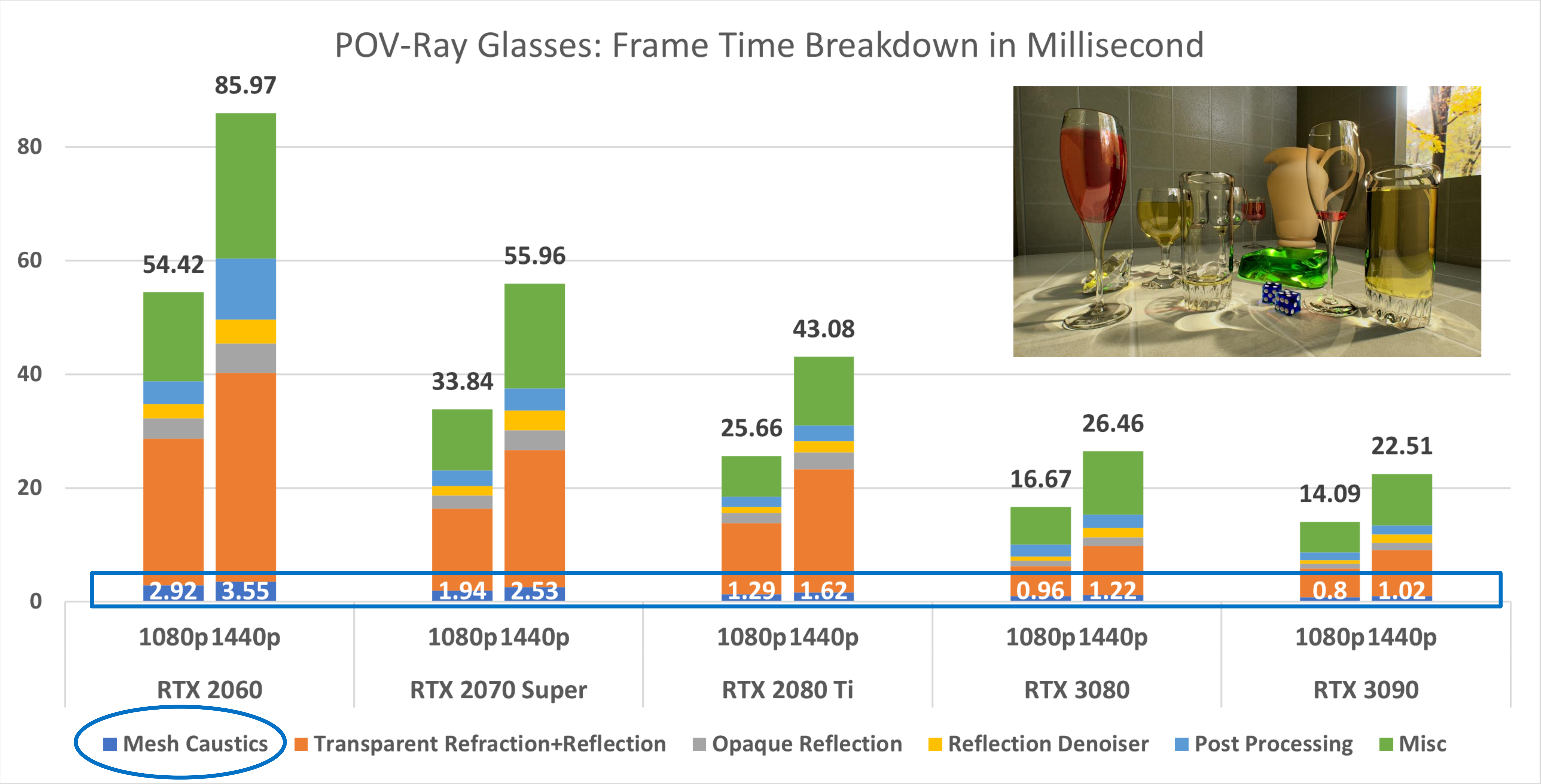




Soft translucent shadows rendered with soft caustics

PERFORMANCE

AAPS



RAY-GUIDED WATER CAUSTICS

RAY-GUIDED WATER CAUSTICS

Highly dynamic and interactive, covering large area

One-bounce light reflection or refraction

A continuation of Holger Gruen's work [*]

[*] Holger Gruen, Ray-Guided Volumetric Water Caustics in Single Scattering Media with DXR, Ray Tracing Gems, pages 183--201

WORKFLOW OVERVIEW

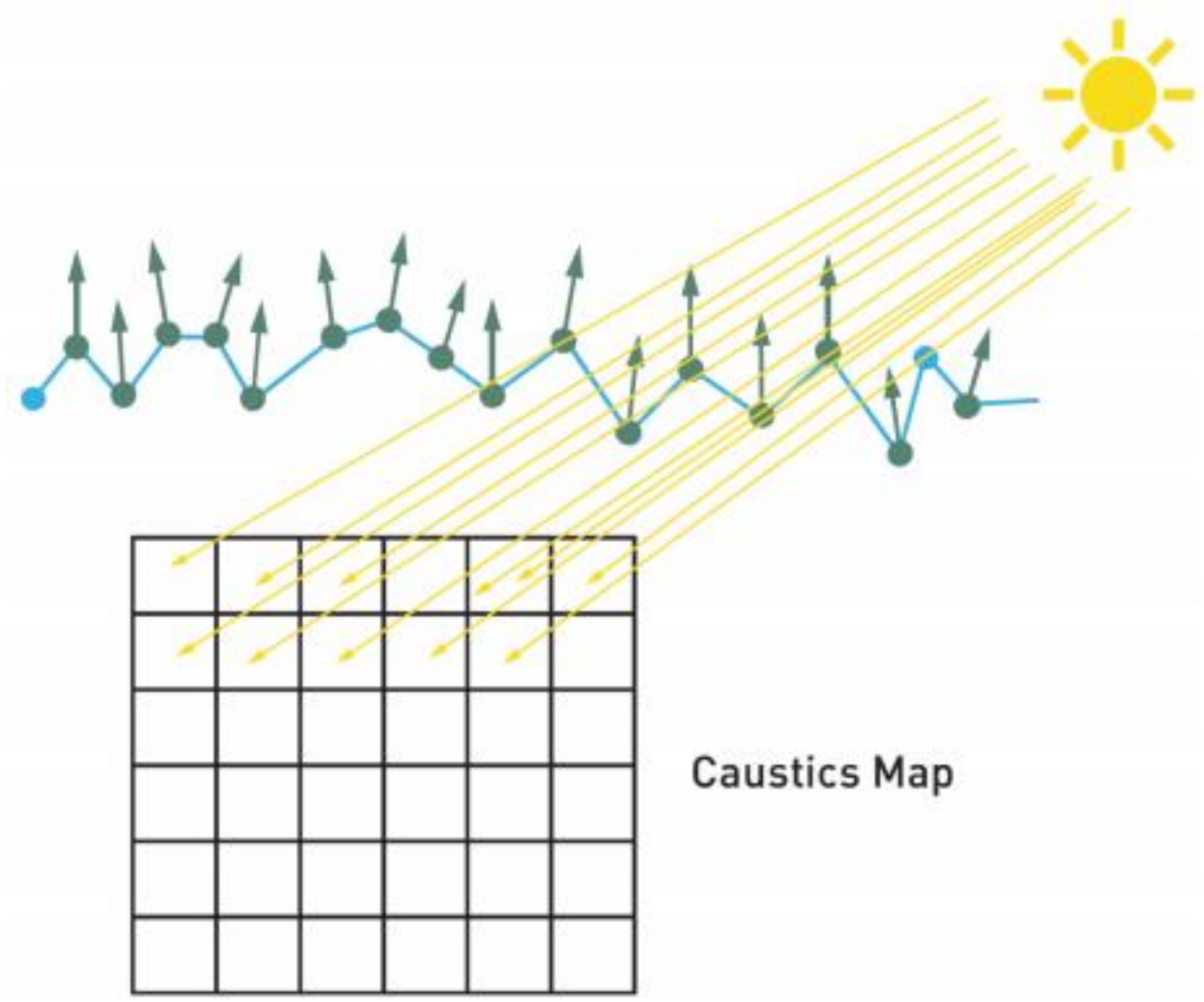
Ray-Guided Water Caustics

1. Render water surfaces into a caustics map from the light view
2. Generate rays using the data recorded in the caustics map. Once the rays hit the scene, record the photon data and the information of hit points.
3. Render caustics into the caustics buffer, which is placed in screen space, using the data obtained in step 2.
    1. Photon Difference Scattering
    2. Procedural Caustic Mesh
4. Perform denoising on the caustics buffer, and composite the result with the scene

CAUSTICS MAP

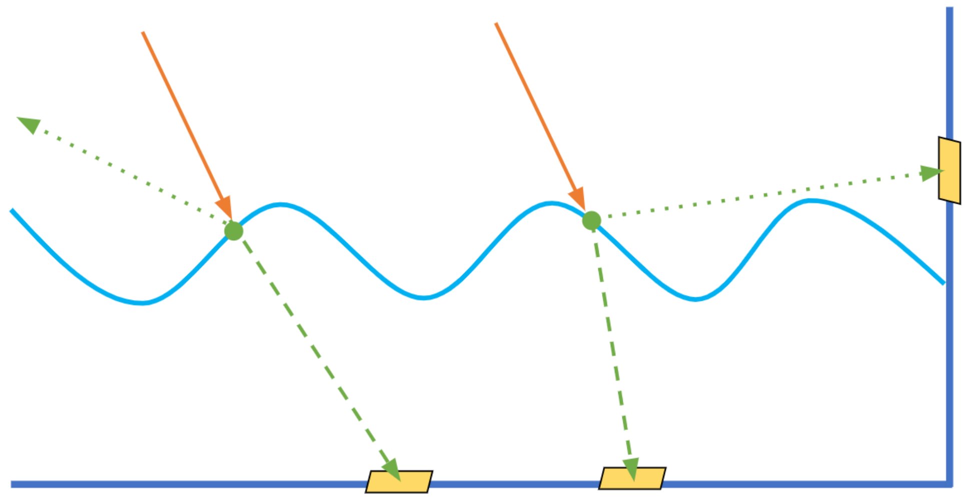
Record geometry data of the water

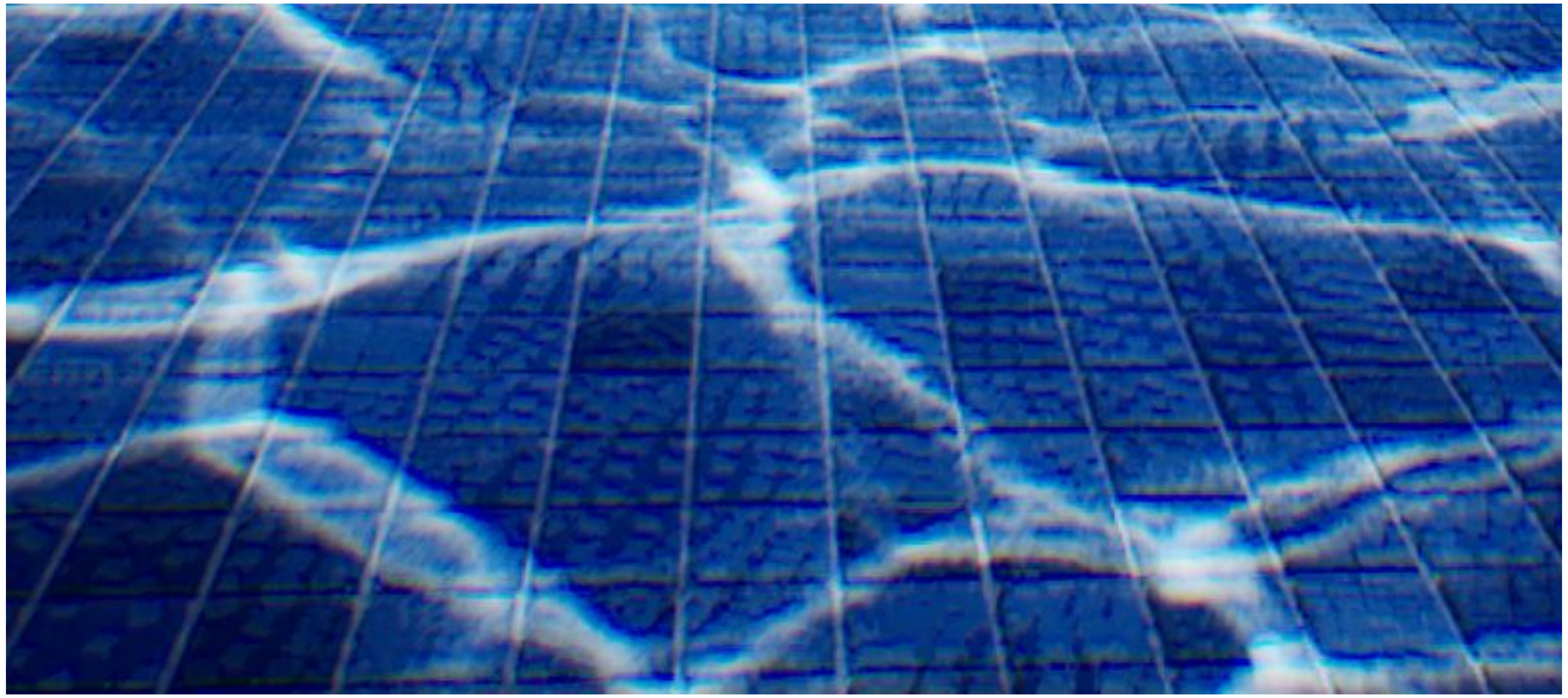
- Render the water mesh into a caustics map in rasterization
  - Record positions & normals, may consist of two textures
- Generate rays using the recorded data in the caustics map
- Avoid the ray tracing between light sources and water surfaces
  - Improve the rendering efficiency



PHOTON SCATTERING

- Treat ray hit points as photon footprints and render them as decal sprites against scene
- Fixed size footprints form correct caustic envelopes, but leave gaps
- Need to find out a proper size for each footprint
- Photon differentials should work, but we have another way

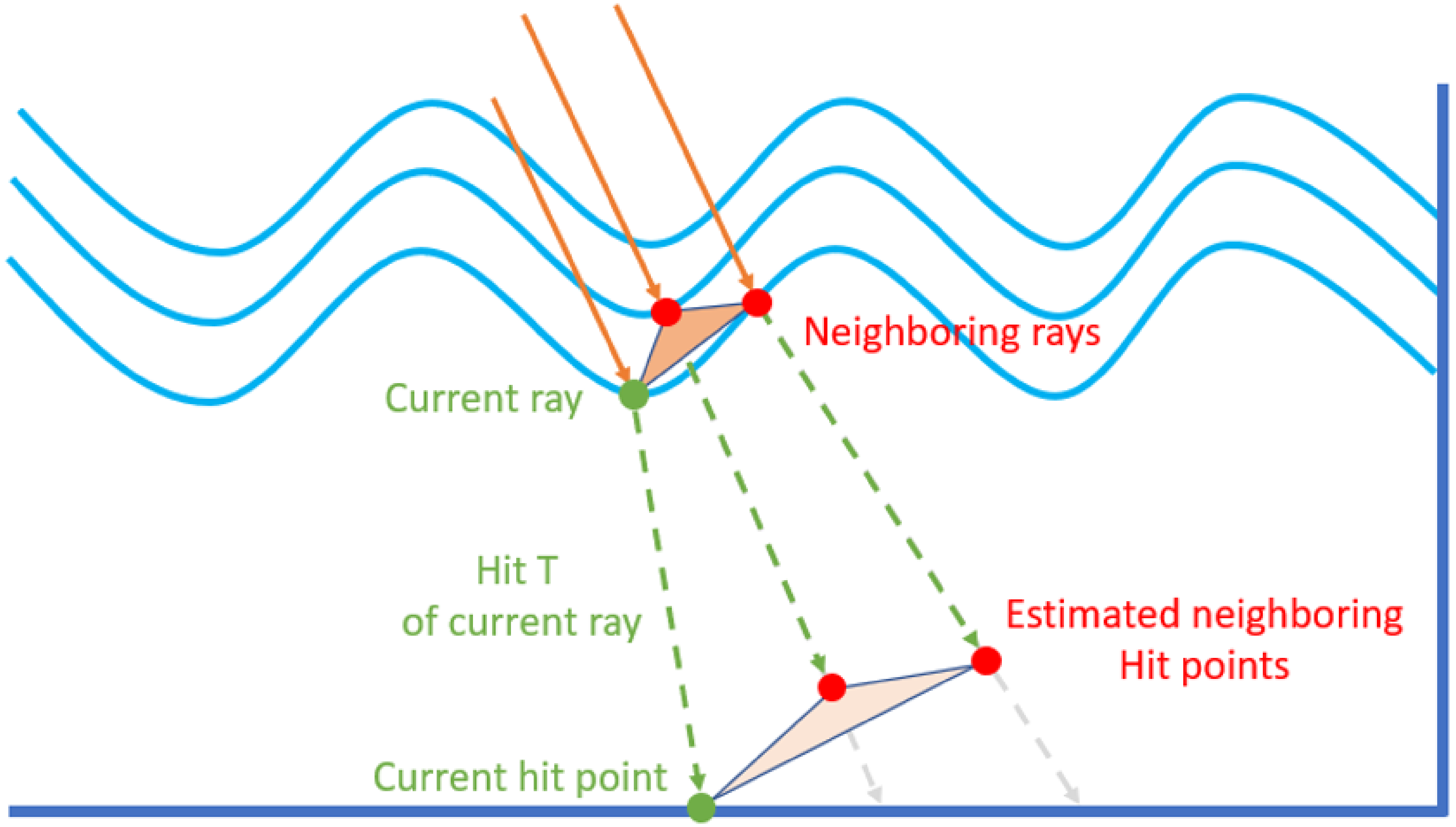




PHOTON DIFFERENCE SCATTERING (PDS)

Step 1/2

- Use finite-difference of nearby rays' data to compute photon coverage
  - Able to calculate accurate ray info using the data in the causitics map
  - Use the hit T of current ray to estimate the hit points of the neighbors
  - Enough for one-bounce trace
- No need to access materials of the receivers

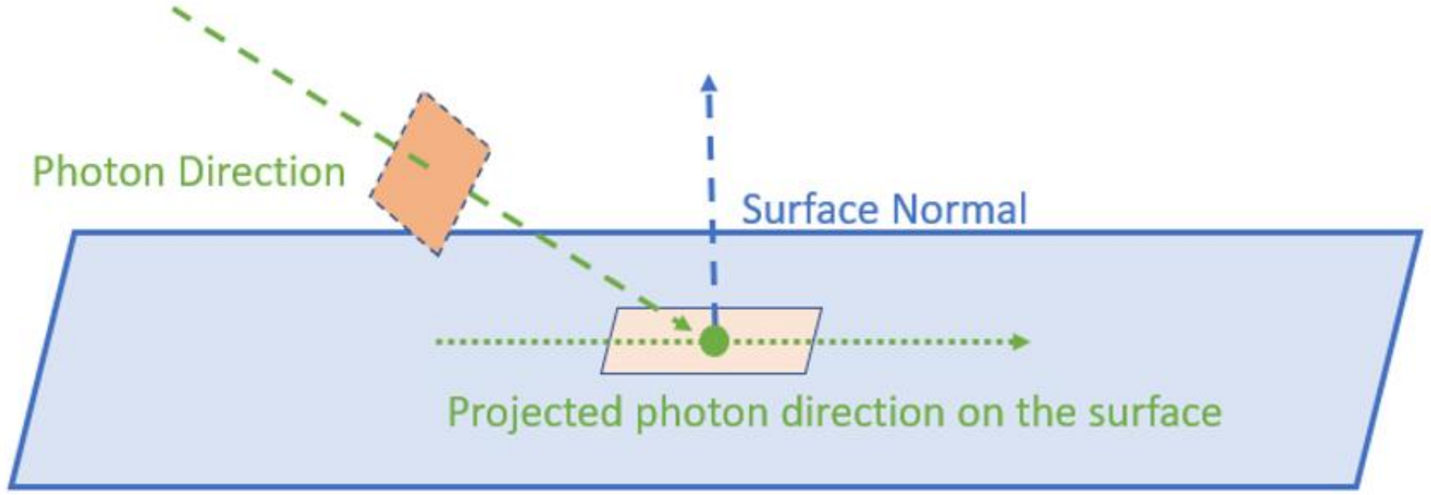


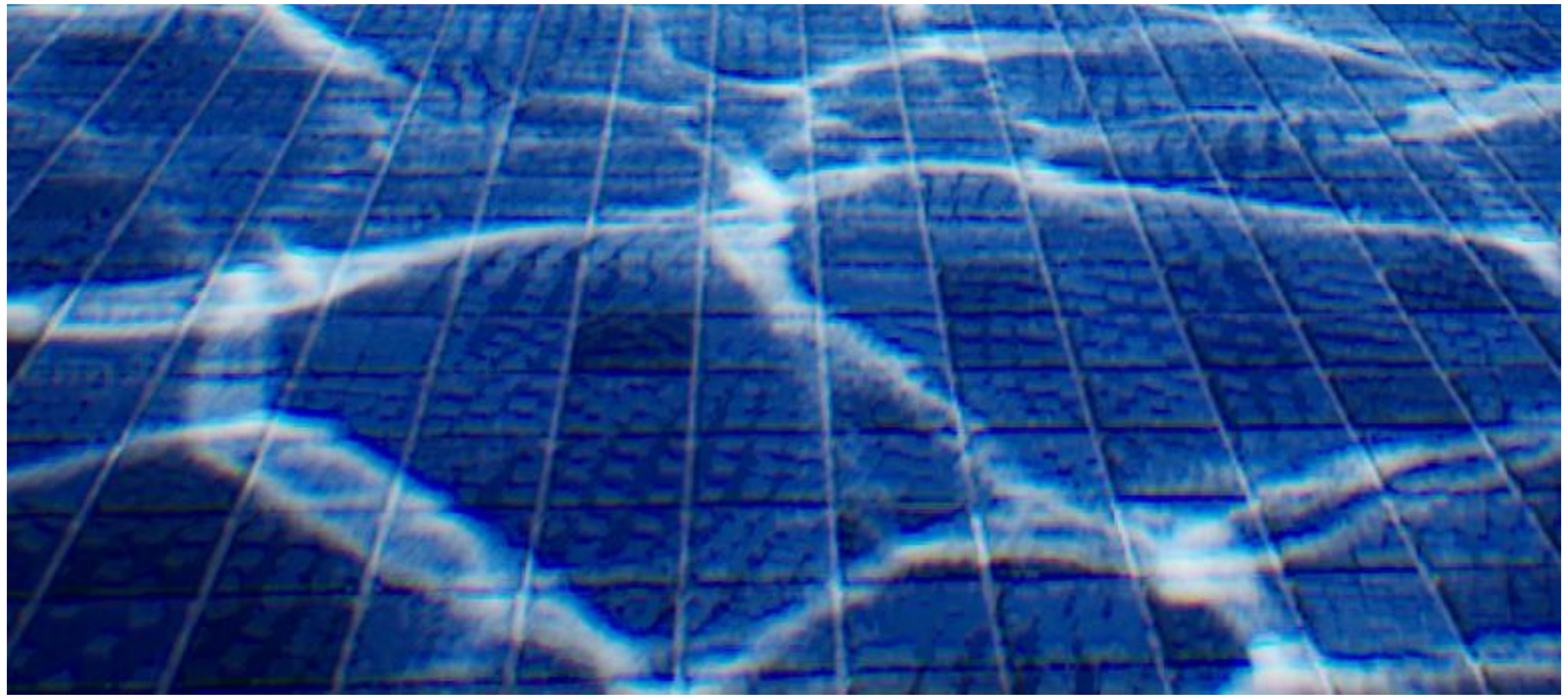
$$Scale = \frac{TriangleArea(hit0, hit1, hit2)}{TriangleArea(pos0, pos1, pos2)}$$

PHOTON DIFFERENCE SCATTERING

Step 2/2

- Project the scaled footprint onto the receiving surface
- Footprint stretched along the projected photon direction on the surface according to the incident photon angle
  - Generate anisotropic footprints





Without PDS

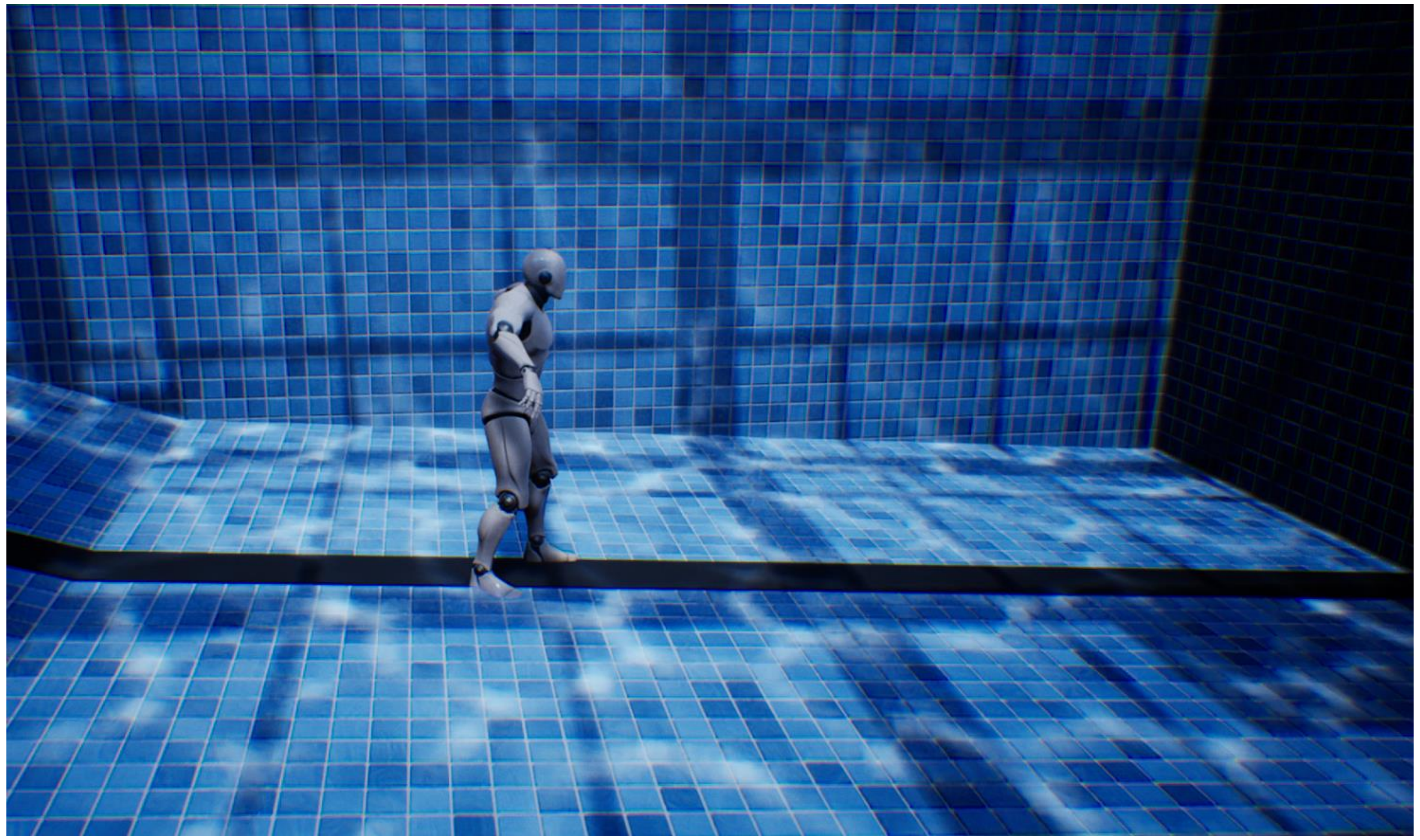
With PDS (without denoising)

PHOTON DIFFERENCE SCATTERING

Quality vs Performance

- Sensitive to the caustics map resolution
  - A low-resolution caustics map covering a large scene area may result in very blurry caustic patterns

Caustics map of 2048x2048

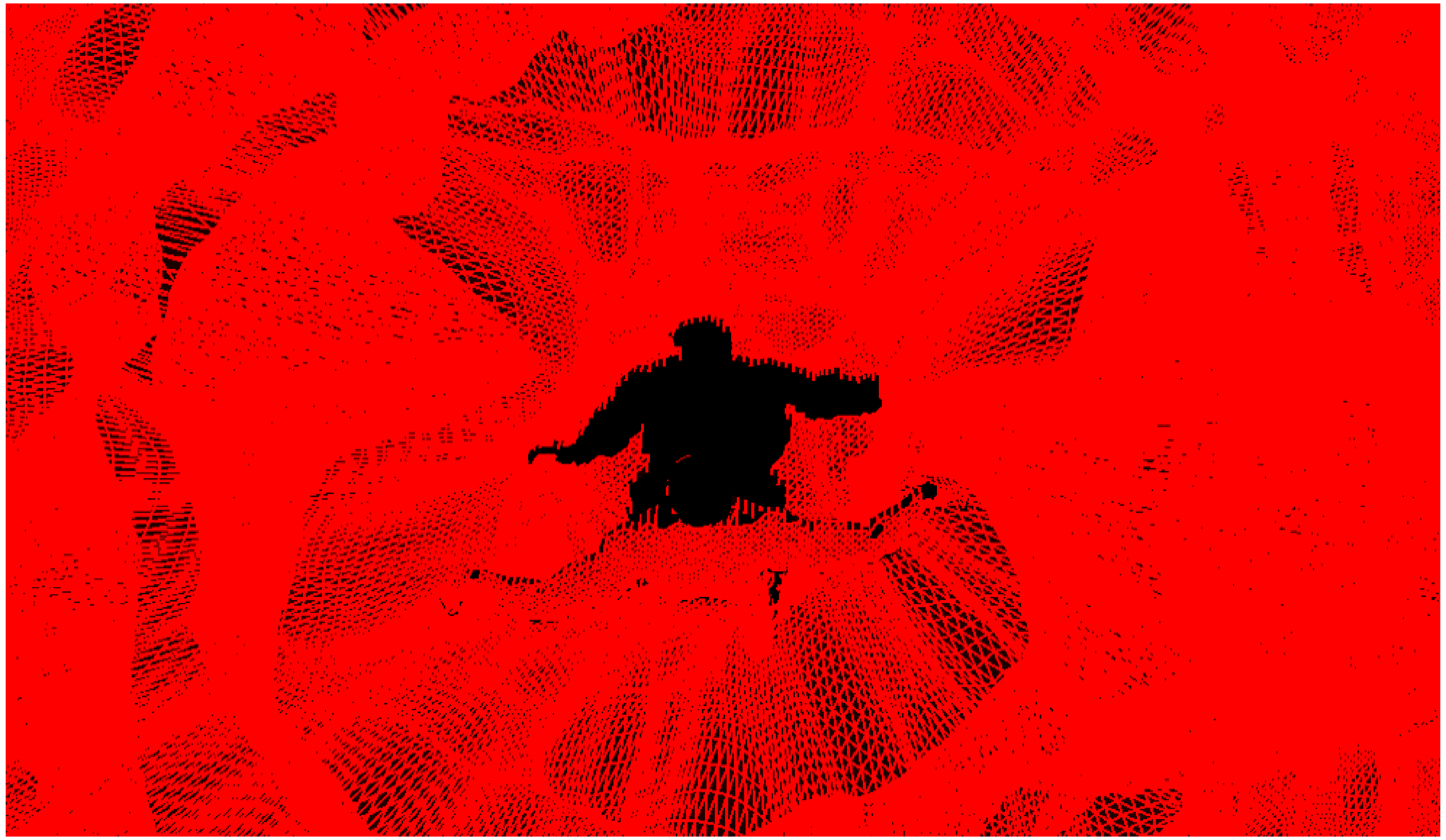


Caustics map of 512x512

PROCEDURAL CAUSTIC MESH (PCM)

Treat photons as vertices

- Convert hit points into an intermediate mesh
- Evaluate the contribution and intensity of each primitive, discards invalid primitives, and generate the index buffer
- Render the meshes in rasterization pass
- Build two procedural caustic meshes for every water object
    - One for reflection and the other for refraction



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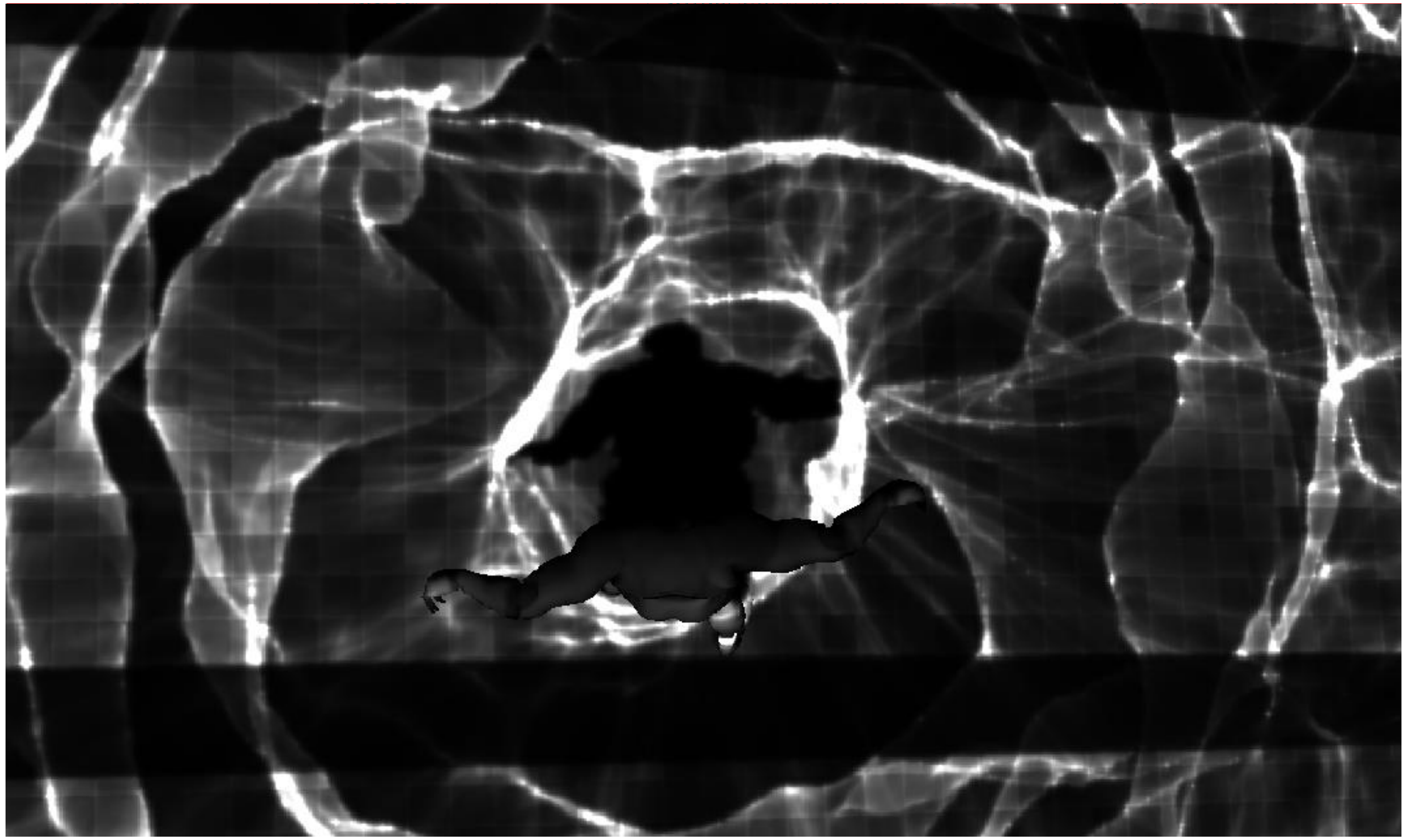
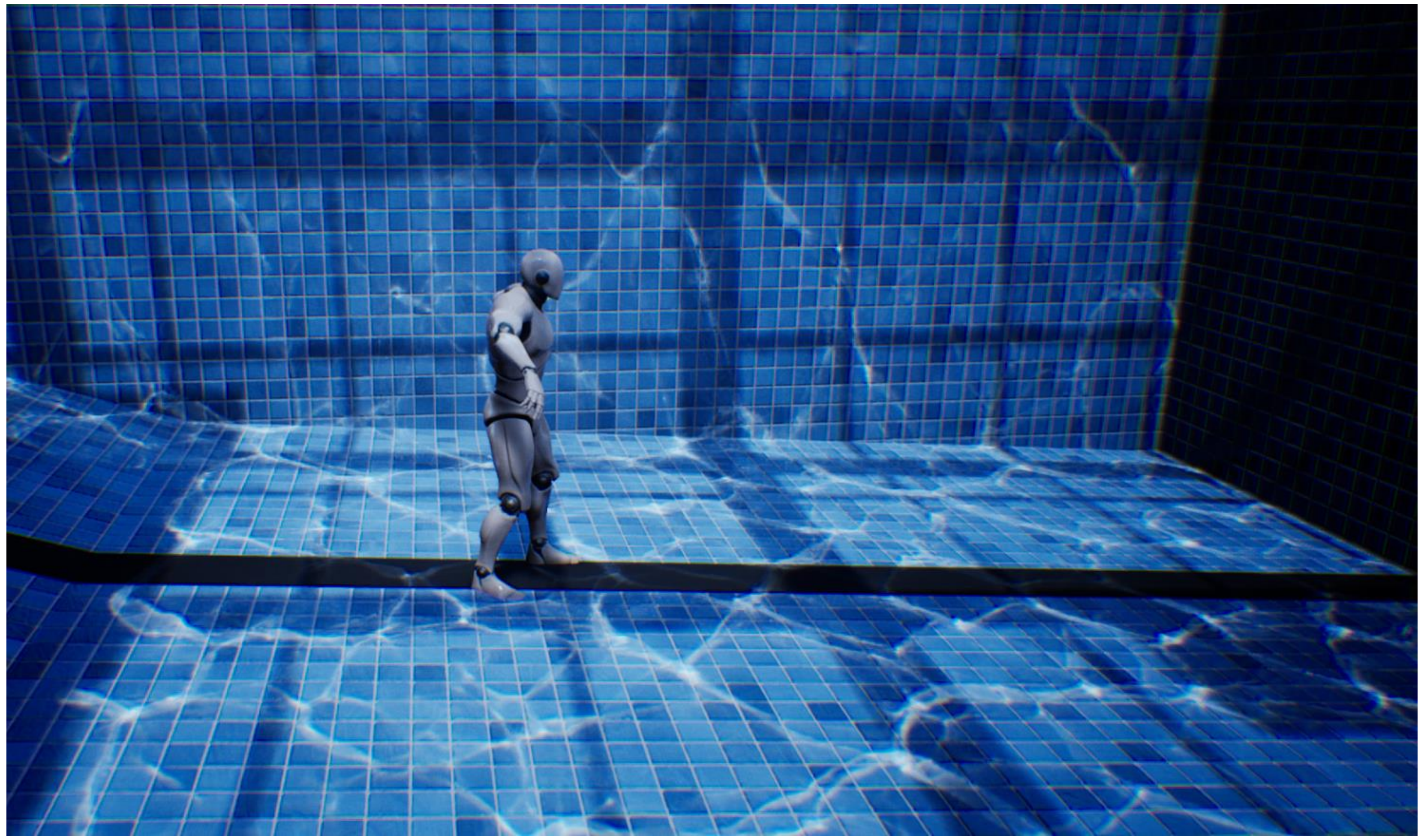


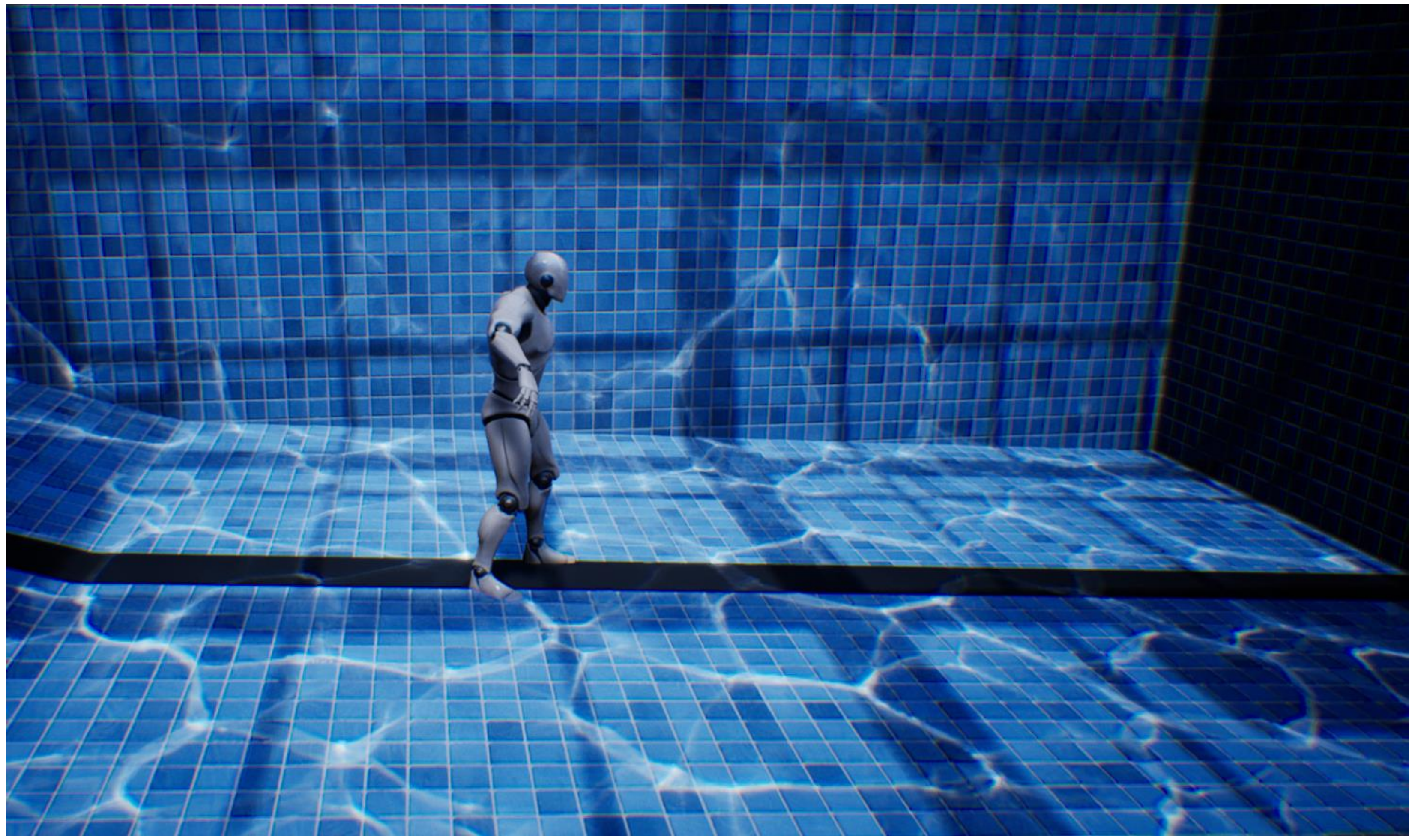
PROCEDURAL CAUSTIC MESH

Quality vs Performance

- Always produce sharp caustic pattern even if the caustics map resolution is very low



Caustics map of 2048x2048

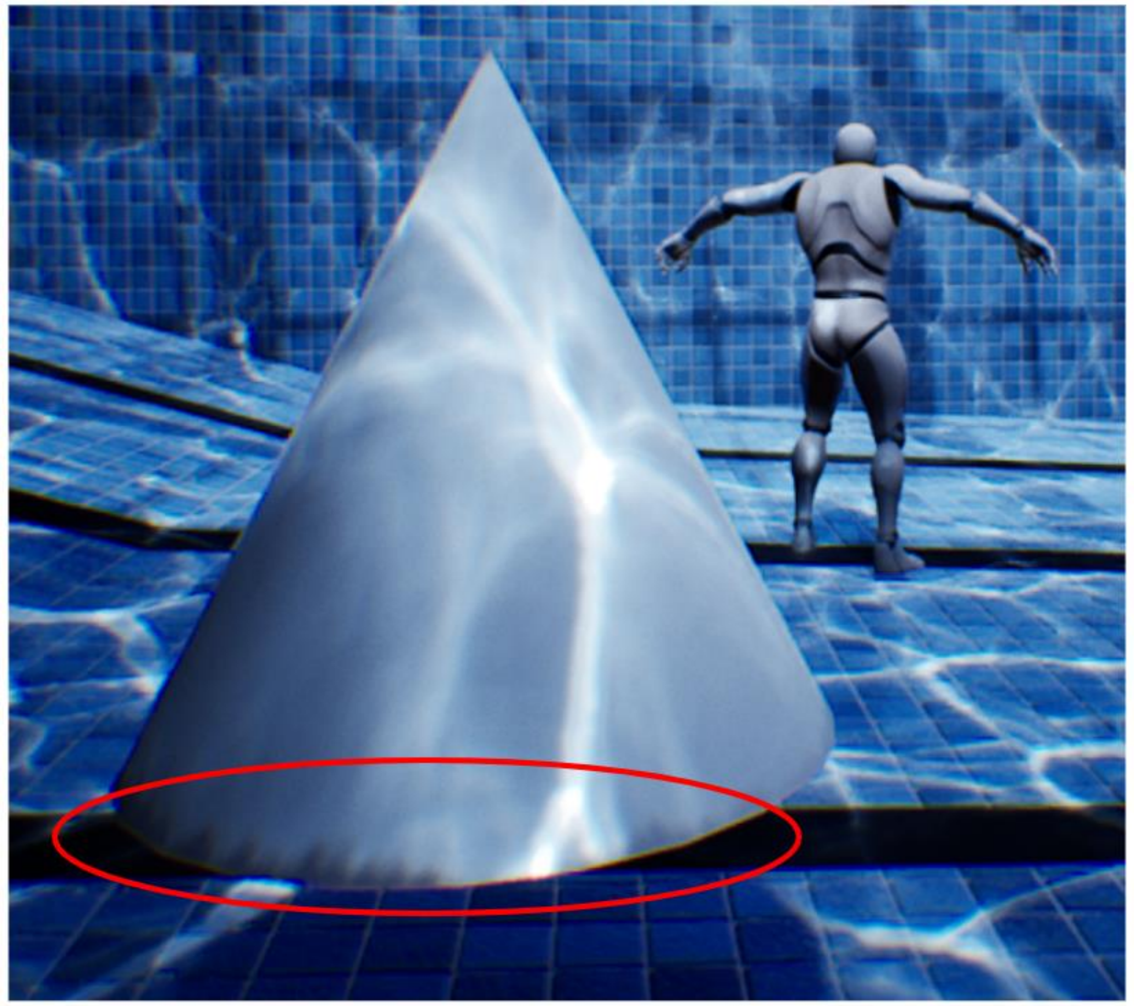


Caustics map of 512x512

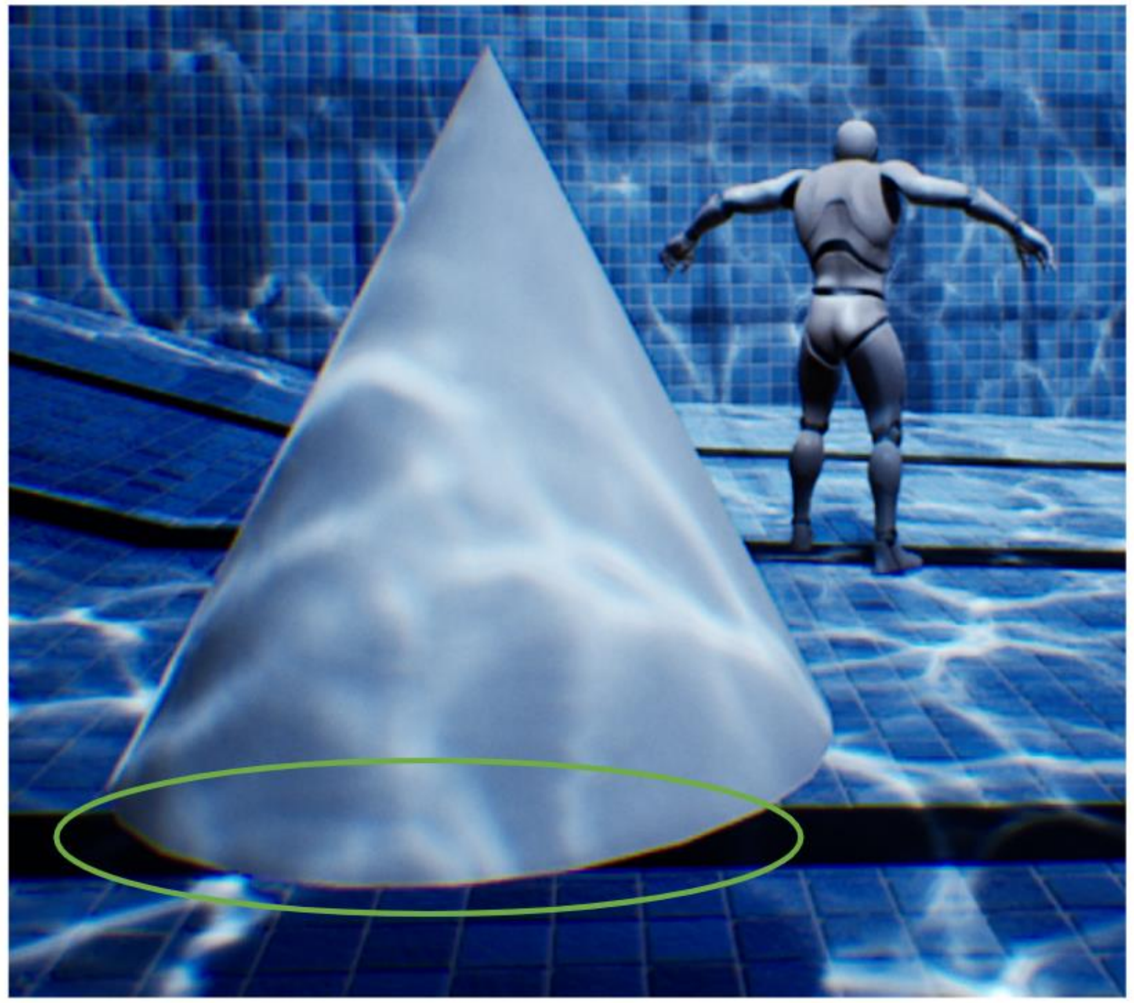
PROCEDURAL CAUSTIC MESH

Trade-off

- PCM may introduce artifacts along the discontinuous edge of the scene geometry due to the culling of triangles



PCM

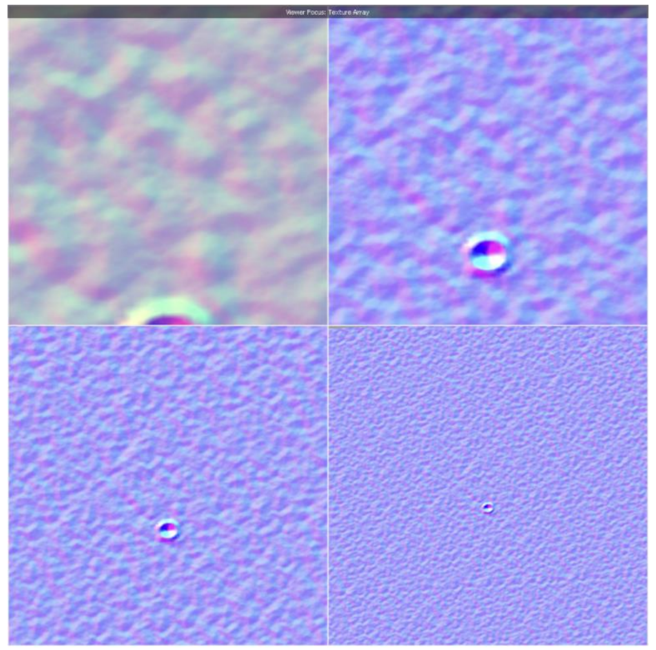


PDS

CASCADED CAUSTICS MAPS

Coupled with PDS

- To generate caustics for large water bodies like the ocean surfaces
  - Extending the application scope of PDS
- Similar to cascaded shadow maps (CSM)
- Directional lights only



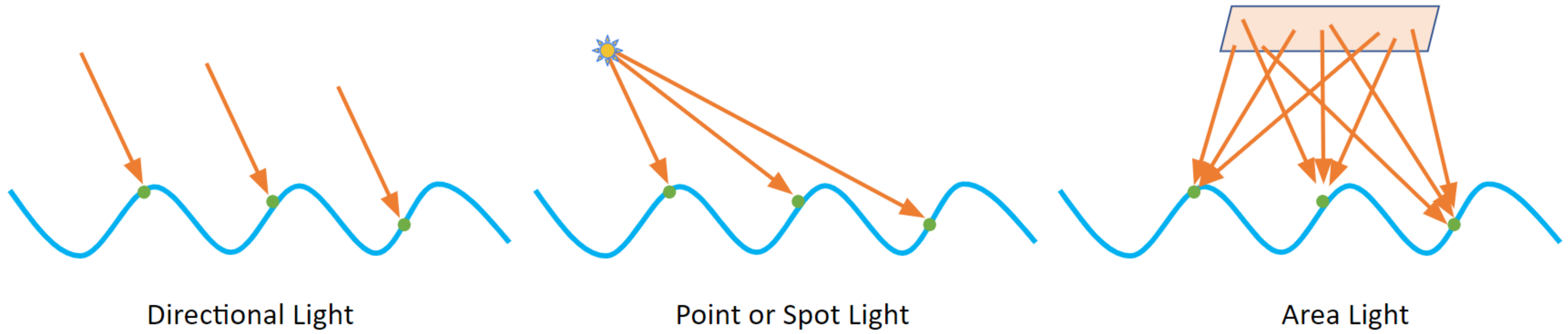
A construction of 4 cascades

Caustics along the coast

SOFT WATER CAUSTICS BY AREA LIGHTS

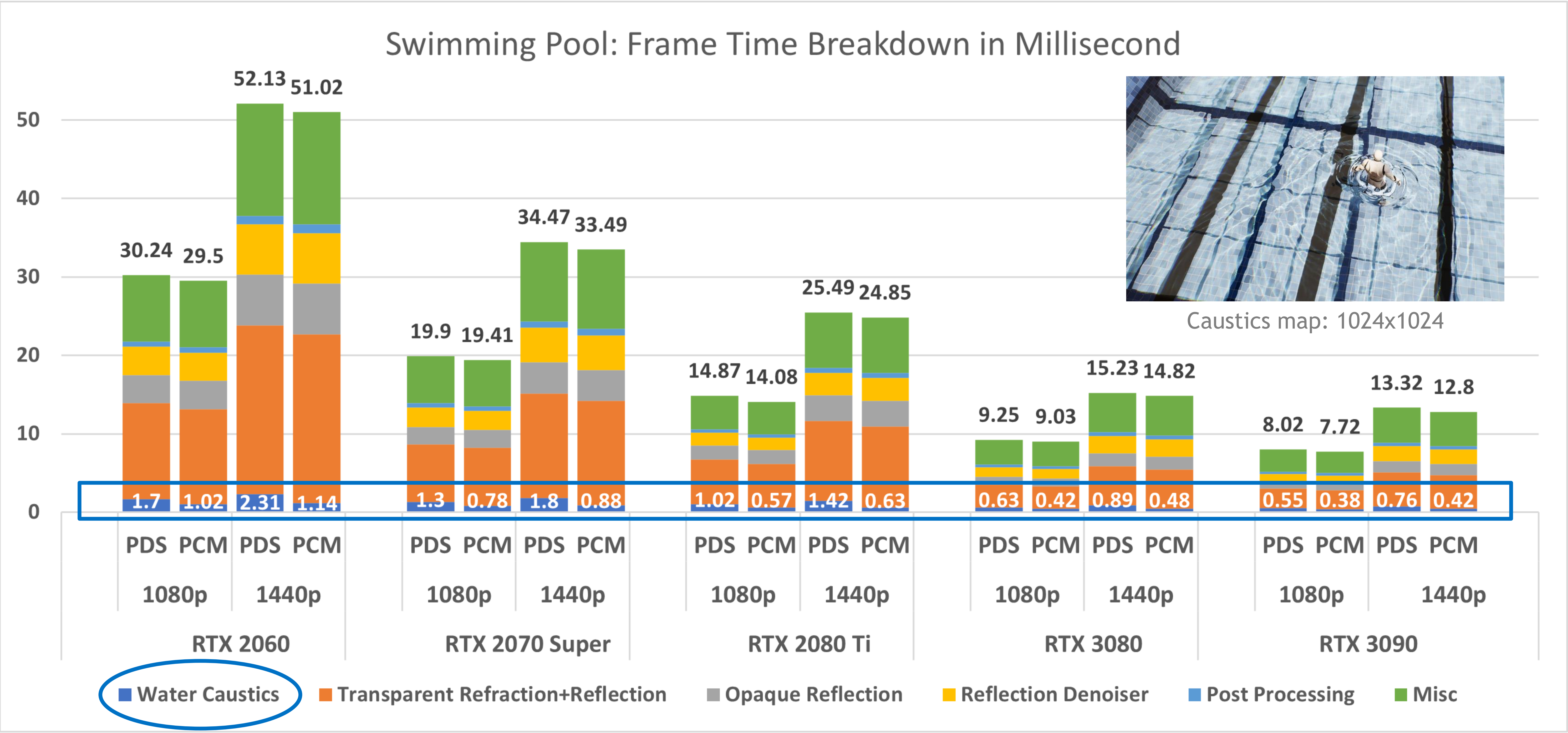
Another extension of the application of PDS

- Select an incident ray from a random point on the area light every frame
- Accumulate the caustics over several frames with a temporal filter to output the soft caustics.



PERFORMANCE

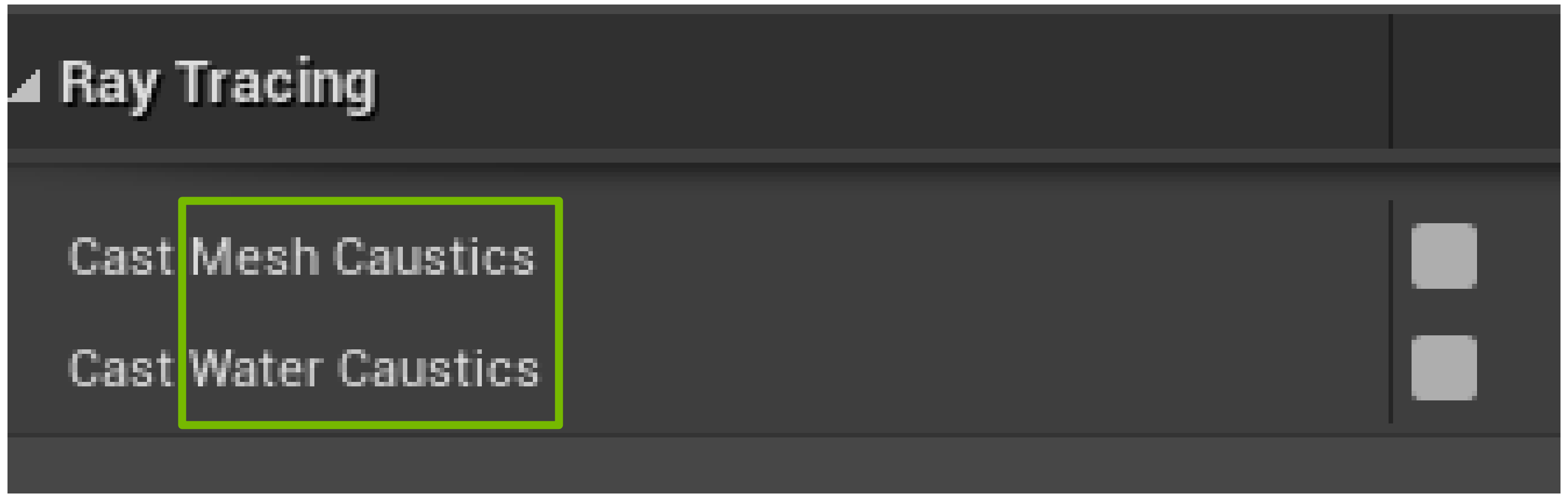
PDS & PCM



CASE STUDY

UE4 INTEGRATION

- NVIDIA RTX Caustics Branch: https://github.com/NvRTX/UnrealEngine/tree/NvRTX_Caustics-4.26
- Terminology in UE4
  - Mesh Caustics: AAPS
    - Metallic and translucent objects
  - Water Caustics: RGWC
    - Water surface



MESH CAUSTICS (AAPS)


55.72 FPS
17.96 ms
Type here to search
ENG
1:21 PM
3/12/2021

WATER CAUSTICS (PCM)


CausticsDemo
File
Edit
Window
Help
Save Current
Source Control
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Marketplace
Settings
Datasmith
Blueprints
Cinematics
Build
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Viewport 1
World Outliner
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rubber46 StaticMeshActor
Rectangle01 StaticMeshActor
Spot01_Target Actor
Spot02_Target Actor
Spot03_Target Actor
Spot04_Target Actor
Spot05_Target Actor
Spot06_Target Actor
Spot07_Target Actor
BP_RT_Quality_Parameters2
CameraActor CameraActor
Cube StaticMeshActor
GameNetworkManager GameNetworkManager
169 actors
View Options
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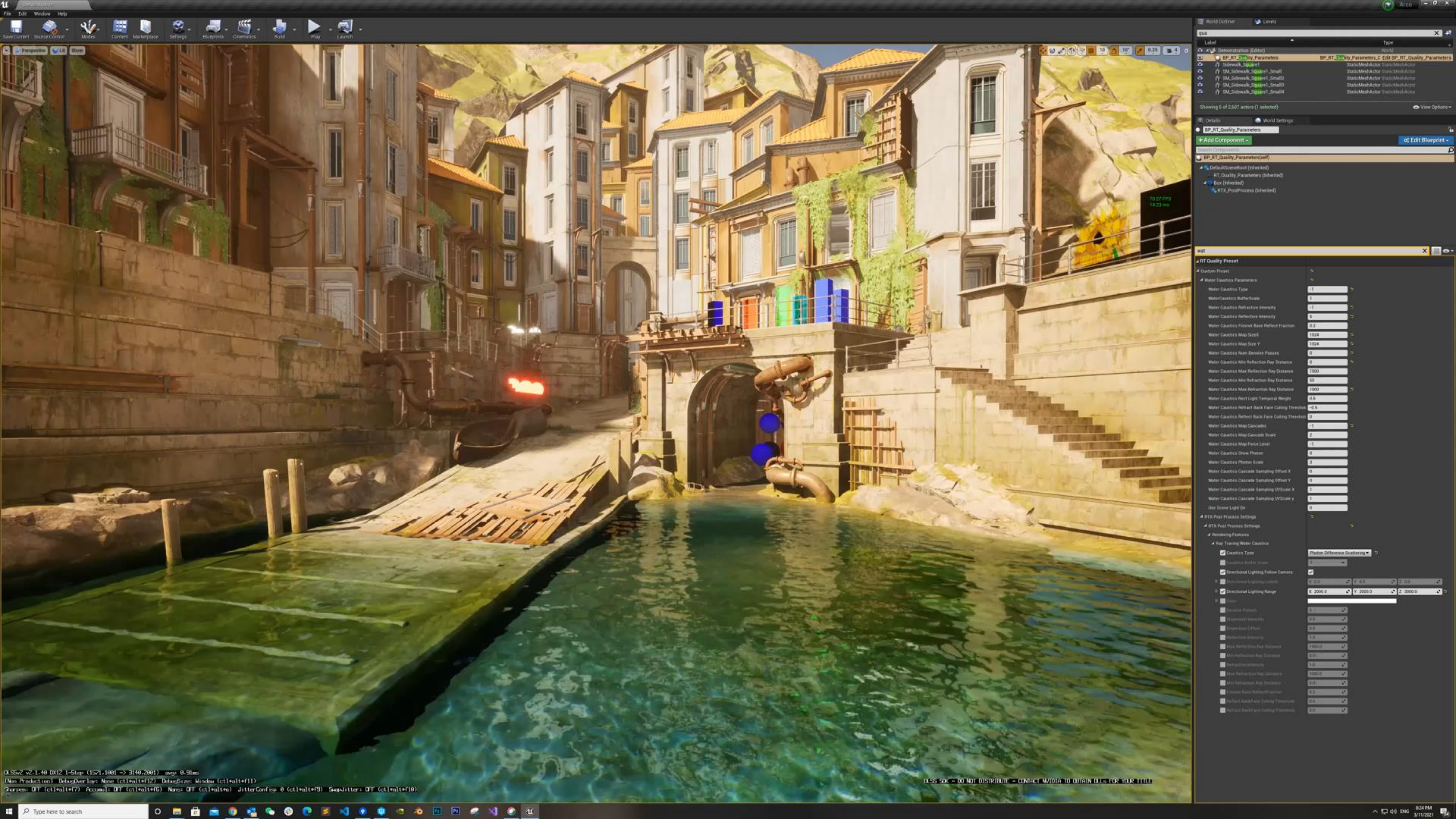
WATER CAUSTICS (PDS+CCM)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Cinematics
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Perspective
Lit
Show
World Outliner
Levels
Label
Type
Details
World Settings
BP_RT_Quality_Parameters
+Add Component
Edit Blueprint
RT Quality Preset
Custom Preset
Water Caustics Parameters
Water Caustics Type -1
WaterCaustics BufferScale 1
Water Caustics Refractive Intensity -1
Water Caustics Reflective Intensity 5
Water Caustics Fresnel Base Reflect Fraction 0.2
Water Caustics Map SizeX 1024
Water Caustics Map Size Y 1024
Water Caustics Num Denoise Passes 0
Water Caustics Min Reflection Ray Distance 0
Water Caustics Max Reflection Ray Distance 1500
Water Caustics Min Refraction Ray Distance 50
Water Caustics Max Refraction Ray Distance 1000
Water Caustics Rect Light Temporal Weight 0.5
Water Caustics Refract Back Face Culling Threshold -0.5
Water Caustics Reflect Back Face Culling Threshold 0
Water Caustics Map Cascades -1
Water Caustics Map Cascade Scale 2
Water Caustics Map Force Level -1
Water Caustics Show Photon 0
Water Caustics Photon Scale 3
Water Caustics Cascade Sampling Offset X 0
Water Caustics Cascade Sampling Offset Y 0
Water Caustics Cascade Sampling UVScale X 1
Water Caustics Cascade Sampling UVScale y 1
Use Scene Light Dir 0
RTX Post Process Settings
RTX Post Process Settings
Rendering Features
Ray Tracing Water Caustics
Caustics Type
Photon Difference Scattering
Directional Lighting Follow Camera
Directional Lighting Range
DLSS SDK - DO NOT DISTRIBUTE - CONTACT NVIDIA TO OBTAIN DLLs FOR YOUR TITLE
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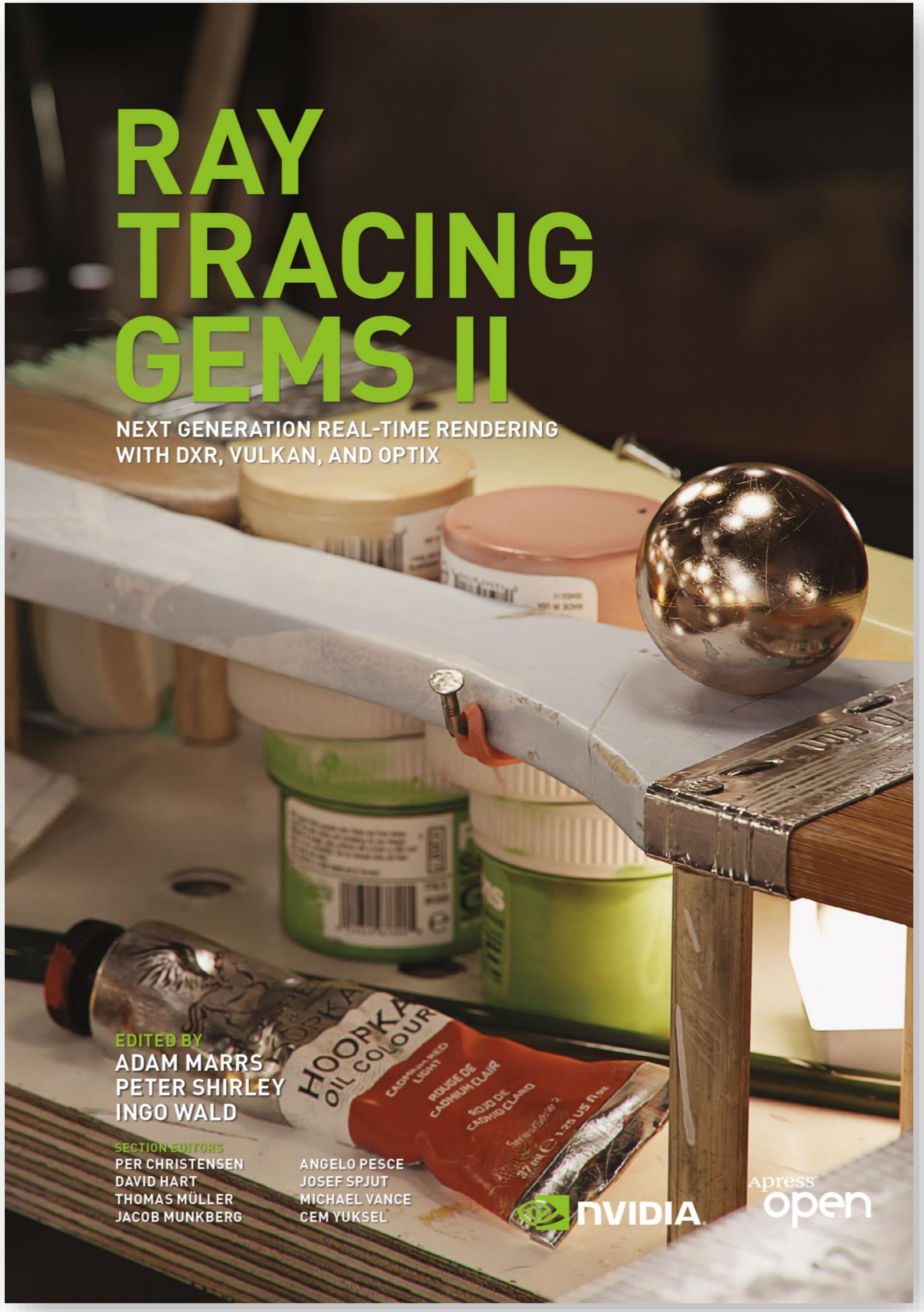

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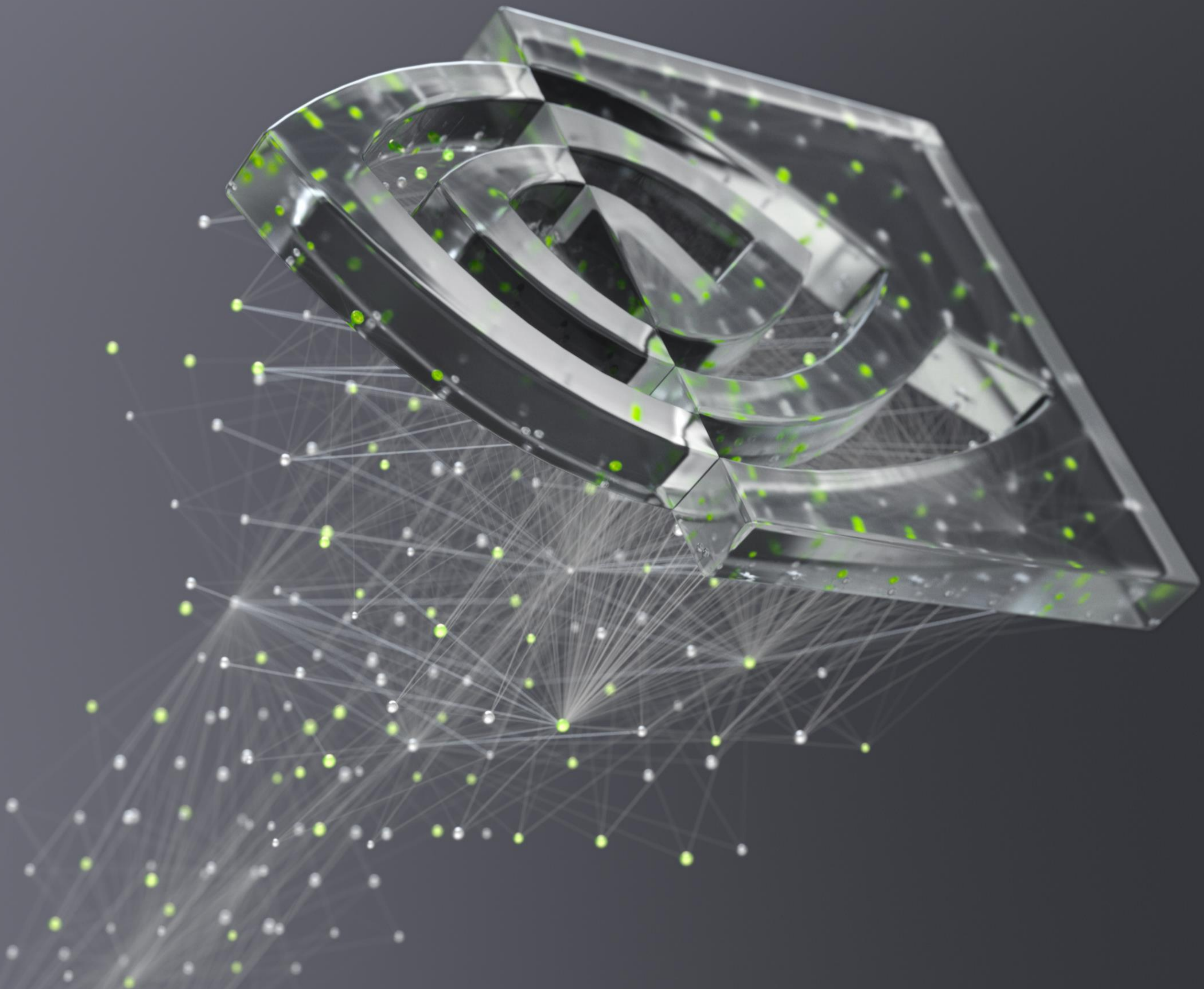
Ray Tracing Gems II brings the community of rendering experts back together and unearths true "gems" for developers of games, architectural applications, visualizations, and more in this exciting new era of real-time rendering.



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