King Abdullah University of Science and Technology

KAUST

CS 380 - GPU and GPGPU Programming
Lecture 25: GPU Virtual Geometry (and more Virtual Texturing)

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Reading Assignment #13 (until Dec 1)

Read (required):

- Look at Unreal Engine 5 virtual geometry system (Nanite)
  - `https://dev.epicgames.com/documentation/en-us/unreal-engine/nanite-virtualized-geometry-in-unreal-engine/`
- Look at Unreal Engine 5 Nanite tech talk by Brian Karis *(Journey to Nanite)* slides
  - `https://www.highperformancegraphics.org/slides22/Journey_to_Nanite.pdf`
- Look at Unreal Engine 5 Lumen tech talk by Daniel Wright et al. slides
  - `https://advances.realtimerendering.com/s2022/SIGGRAPH2022-Advances-Lumen-Wright%20et%20al.pdf`

Read (optional):

- Look at Unreal Engine 5 Nanite tech talk by Brian Karis *(Journey to Nanite)* talk
  - `https://www.youtube.com/watch?v=NRnj_lnpORU`

GPU Virtual Texturing

Virtual Texturing

Example #2:

Adaptive Shadow Maps (ASM)

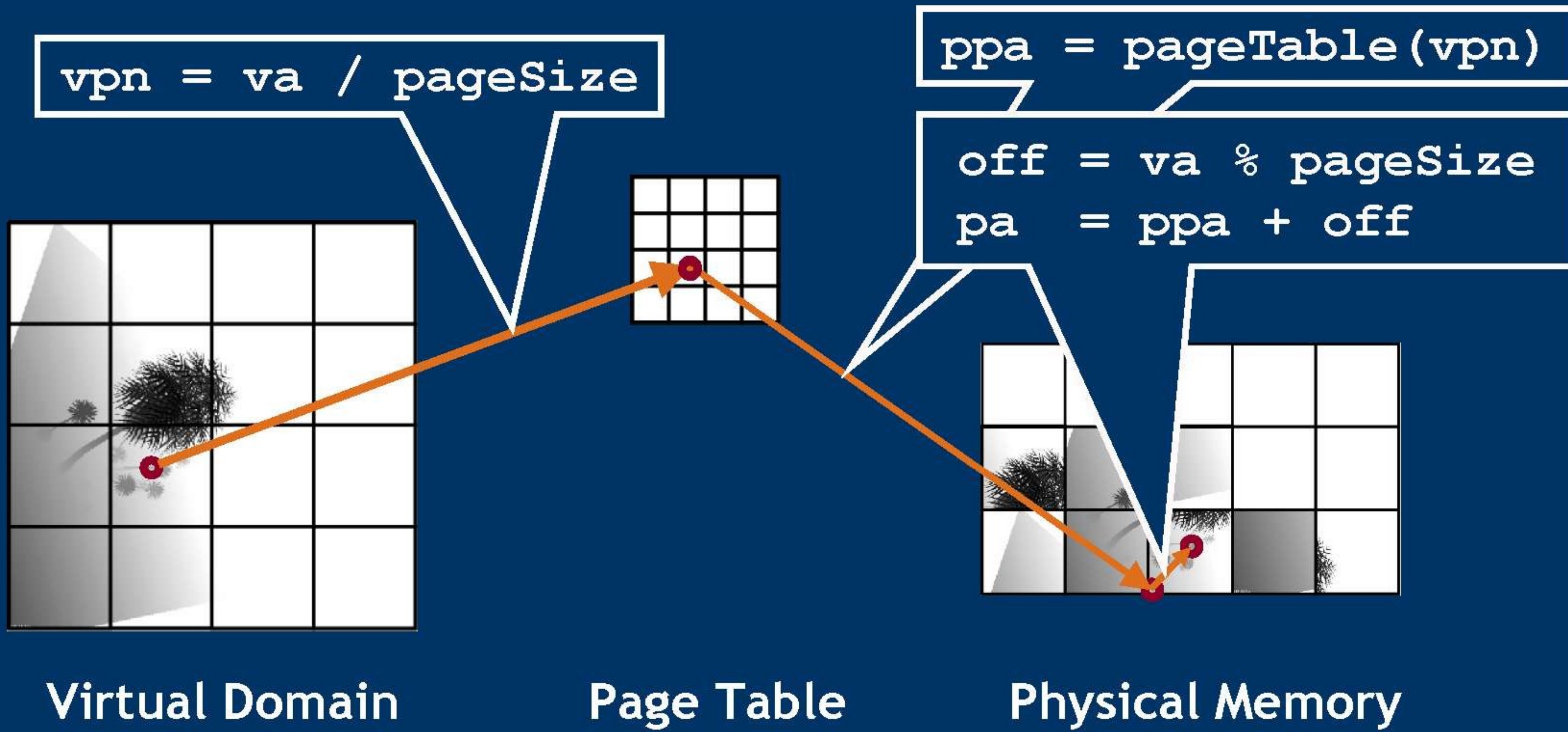
- On CPUs: Fernando et al., ACM SIGGRAPH 2001

Resolution-Matched Shadow Maps

- On GPUs: Aaron Lefohn et al., ACM Transactions on Graphics 2007

ASM Data Structure (Adaptive Shadow Maps)

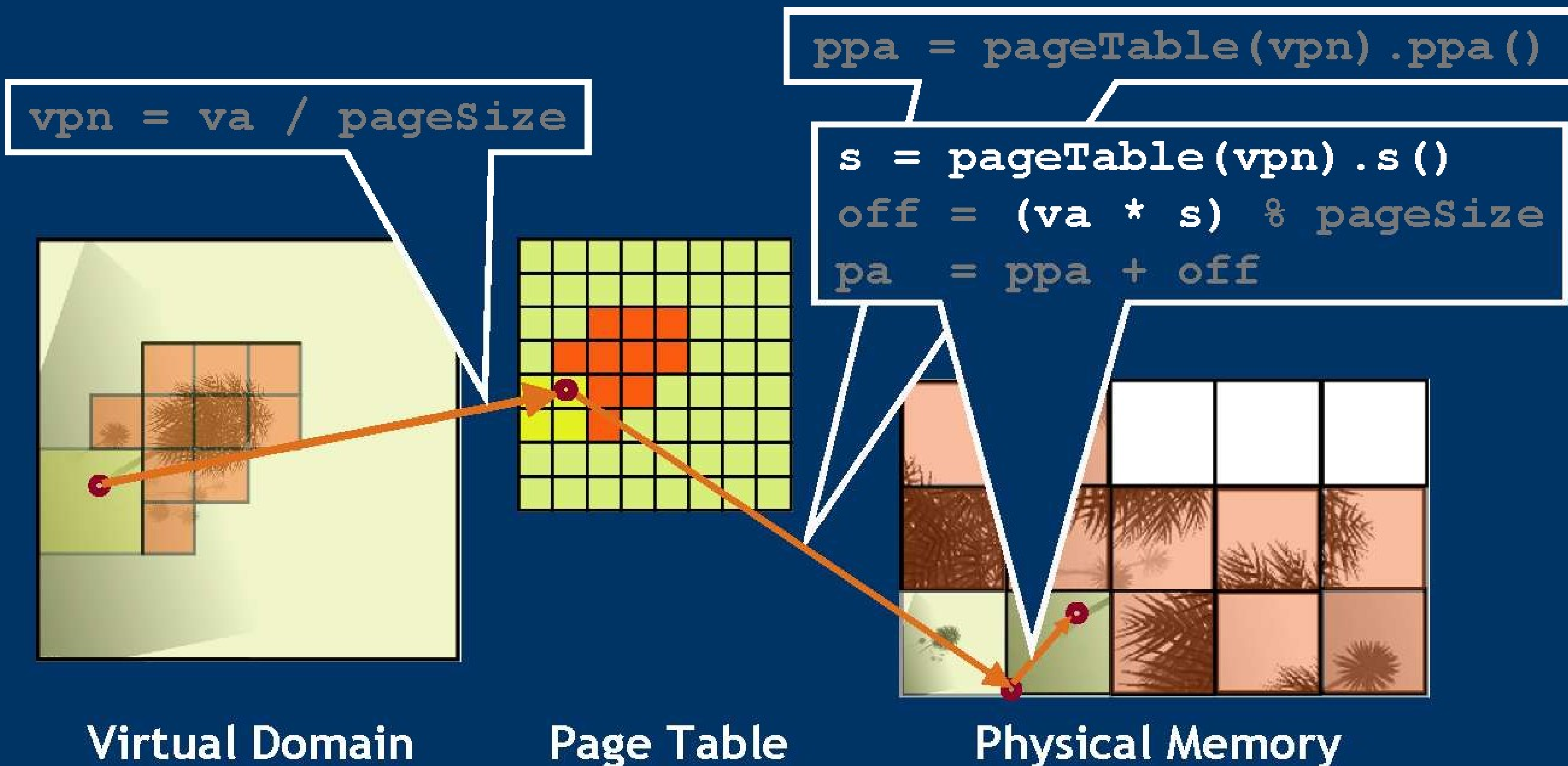
- Page table example



Aaron Lefohn
University of California, Davis

ASM Data Structure (Adaptive Shadow Maps)

- **Adaptive Page Table**
  - Map multiple virtual pages to single physical page



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University of California, Davis

Virtual Texturing

Example #4:

Unreal Engine 5 Virtual Texturing

```
https://dev.epicgames.com/documentation/en-us/unreal-engine/
      virtual-texturing-in-unreal-engine
```

```
https://dev.epicgames.com/documentation/en-us/unreal-engine/
      streaming-virtual-texturing-in-unreal-engine
```

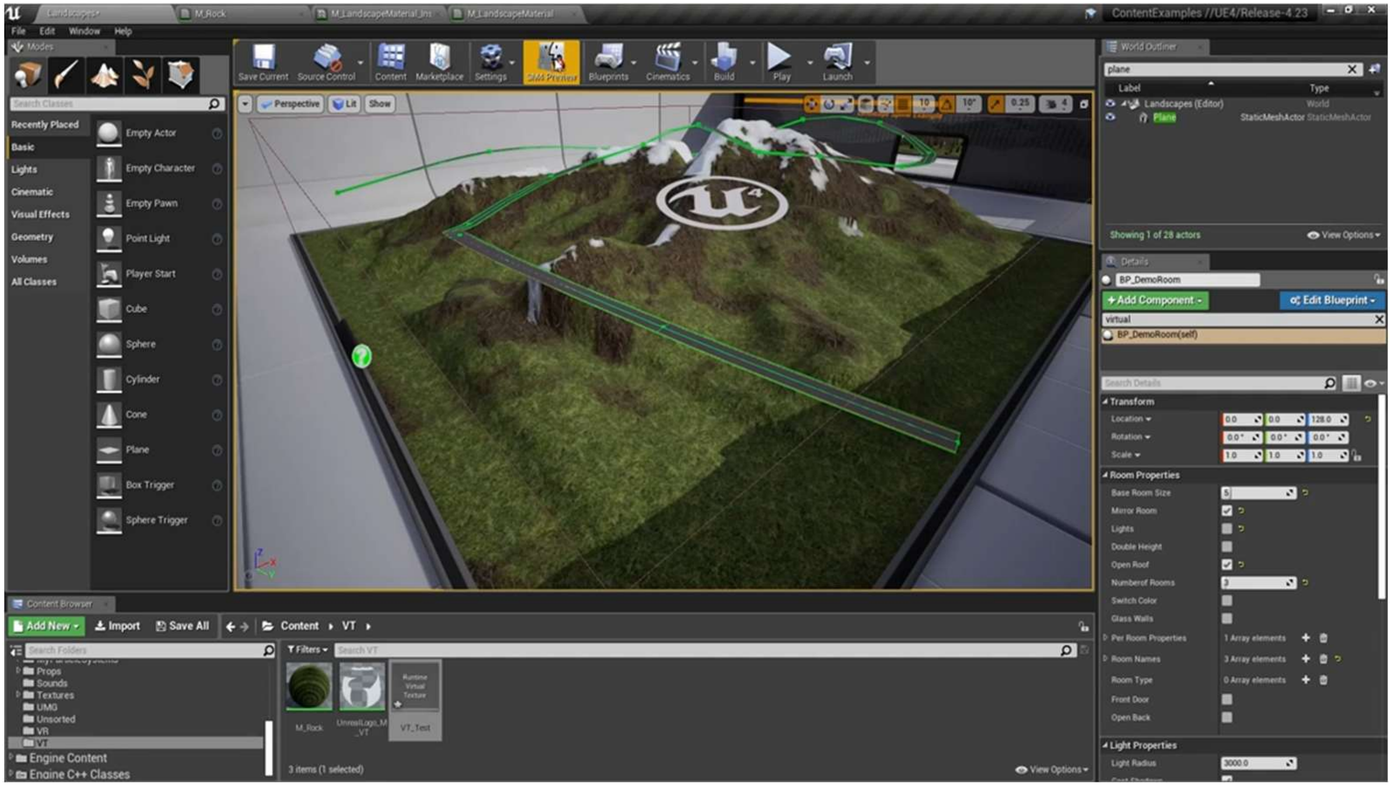
```
https://dev.epicgames.com/documentation/en-us/unreal-engine/
      virtual-texture-memory-pools-in-unreal-engine
```

```
https://dev.epicgames.com/documentation/en-us/unreal-engine/
      virtual-texturing-settings-and-properties-in-unreal-engine
```

Unreal Engine 5 Virtual Texturing

Run-Time Virtual Texturing

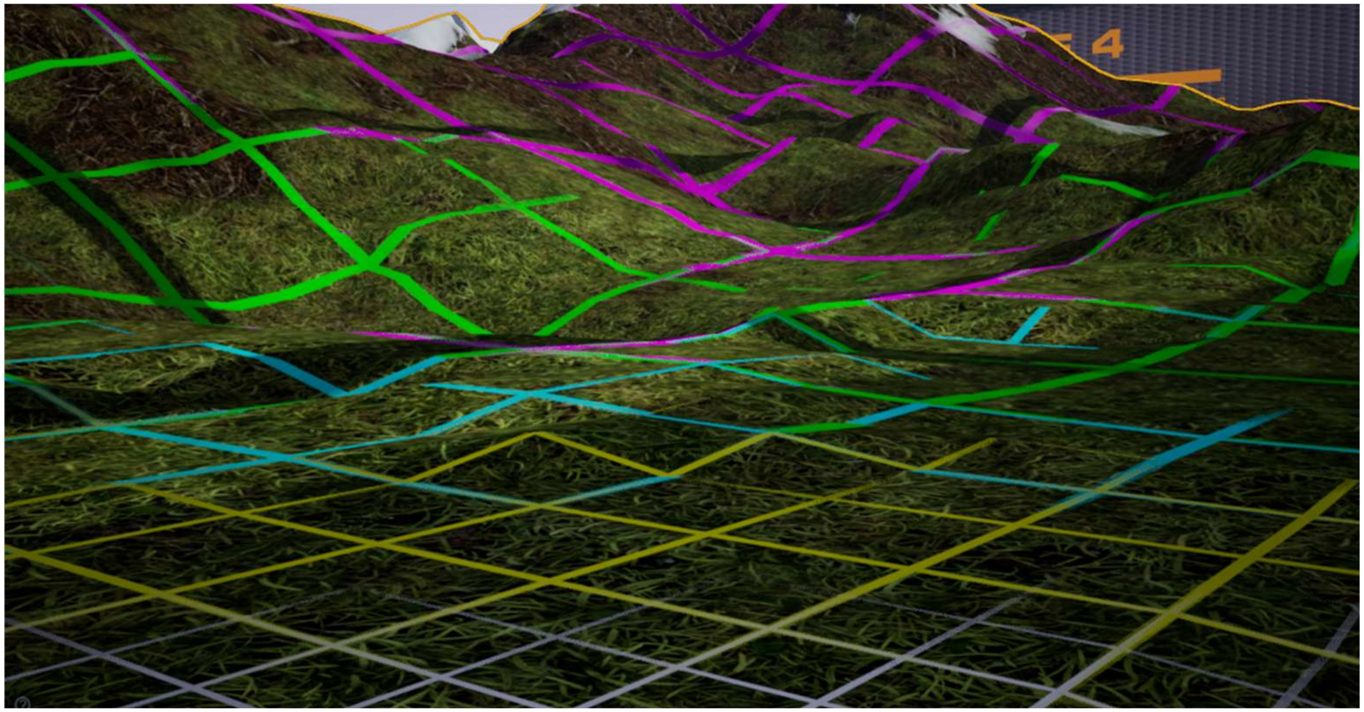
- Procedurally generate hires texture content; materials, etc.



Unreal Engine 5 Virtual Texturing

Streaming Virtual Texturing

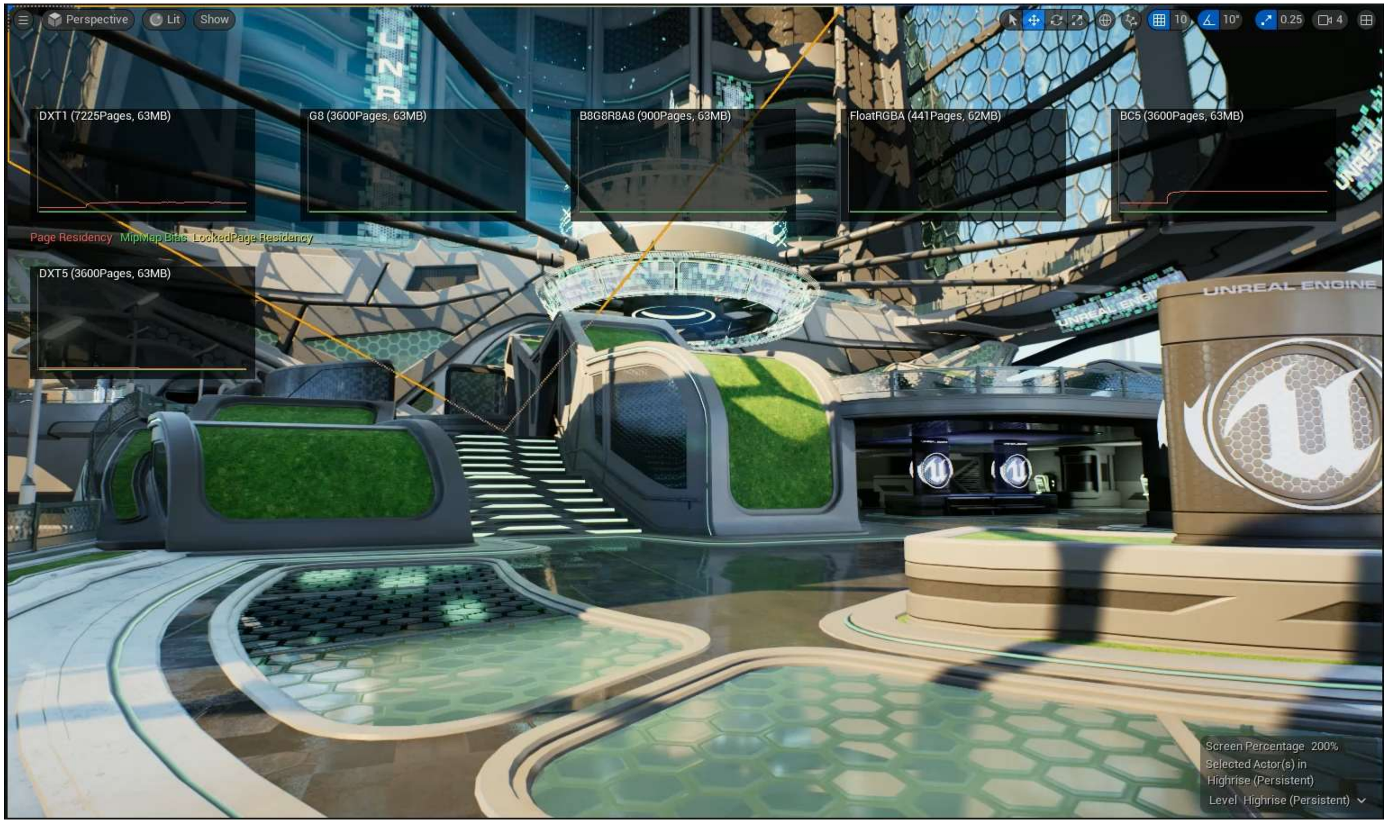
- Stream texture data from disk; default tile size 128, up to 4K tiles
- Also: pre-baked hires light maps, etc.



Unreal Engine 5 Virtual Texture Memory Pools

One pool for virtual textures of each type/format

- Can use *residency mipmap bias* (mipmap LOD bias)



Virtual Texturing

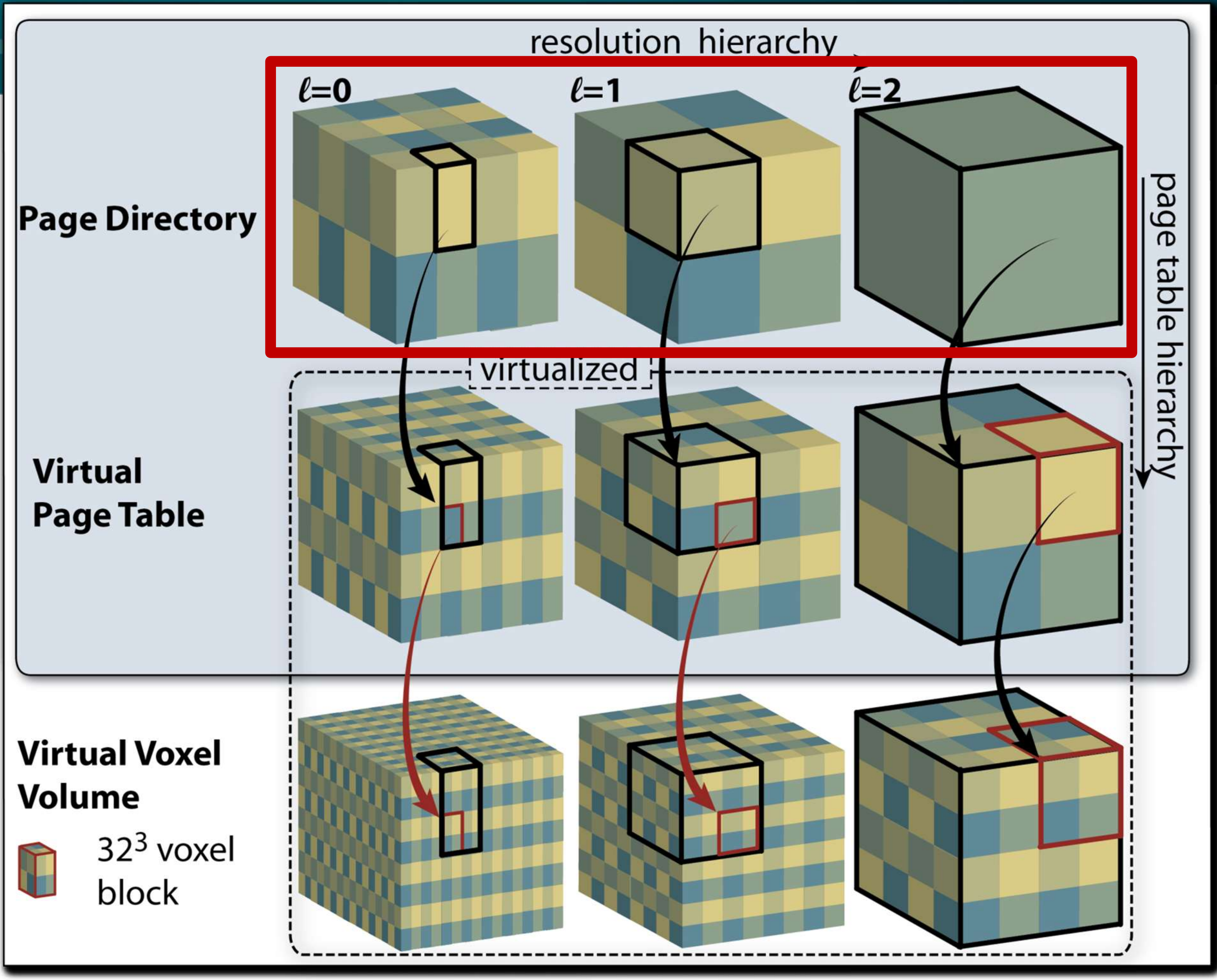
Example #5:

Petascale Volume Rendering

- Interactive Volume Exploration of Petascale Microscopy Data Streams Using a Visualization-Driven Virtual Memory Approach,
  Hadwiger et al., IEEE SciVis 2012

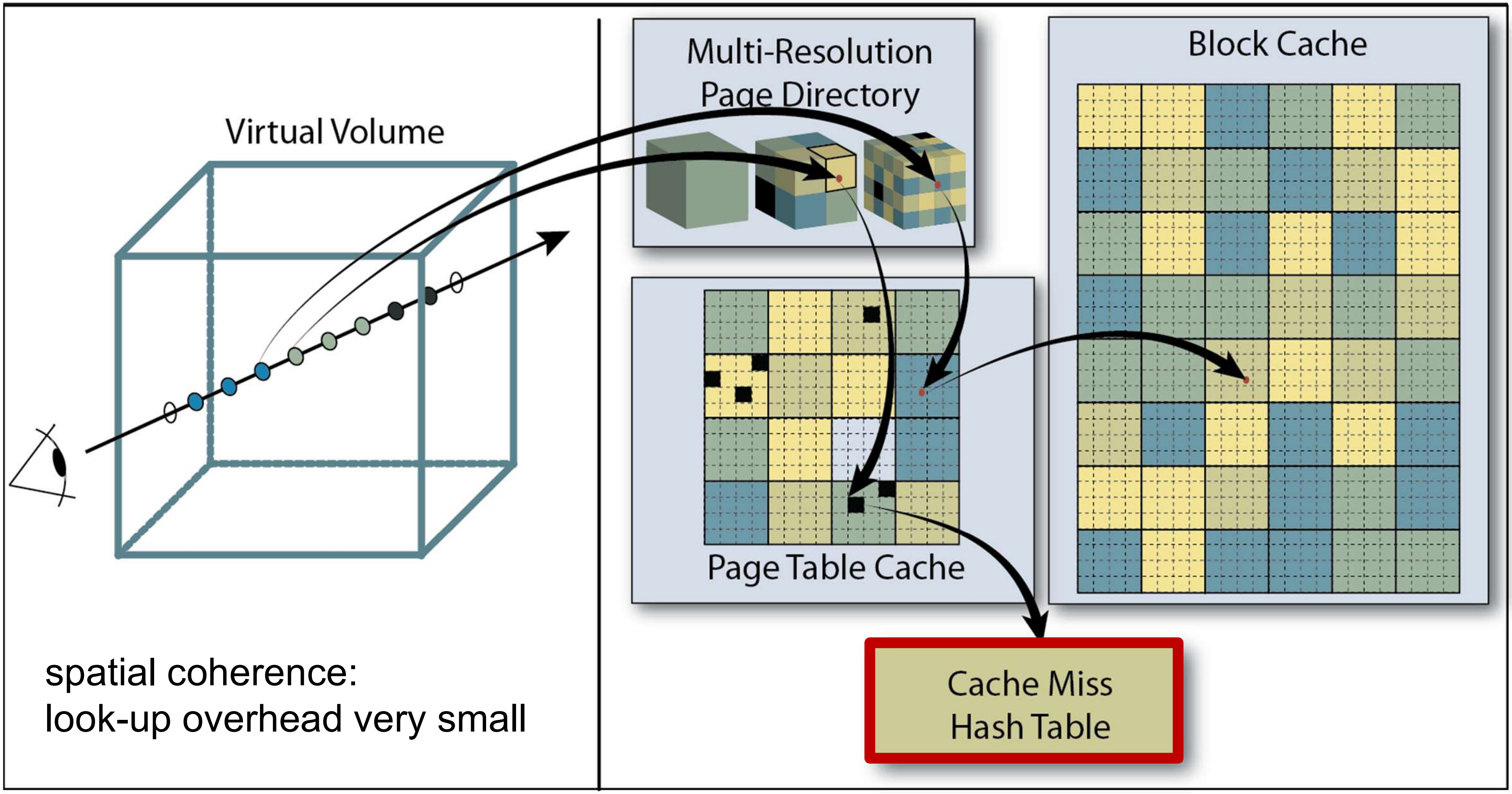
`http://dx.doi.org/10.1109/TVCG.2012.240`

Petascale Volume Rendering



multi-resolution
page directory

Petascale Volume Rendering



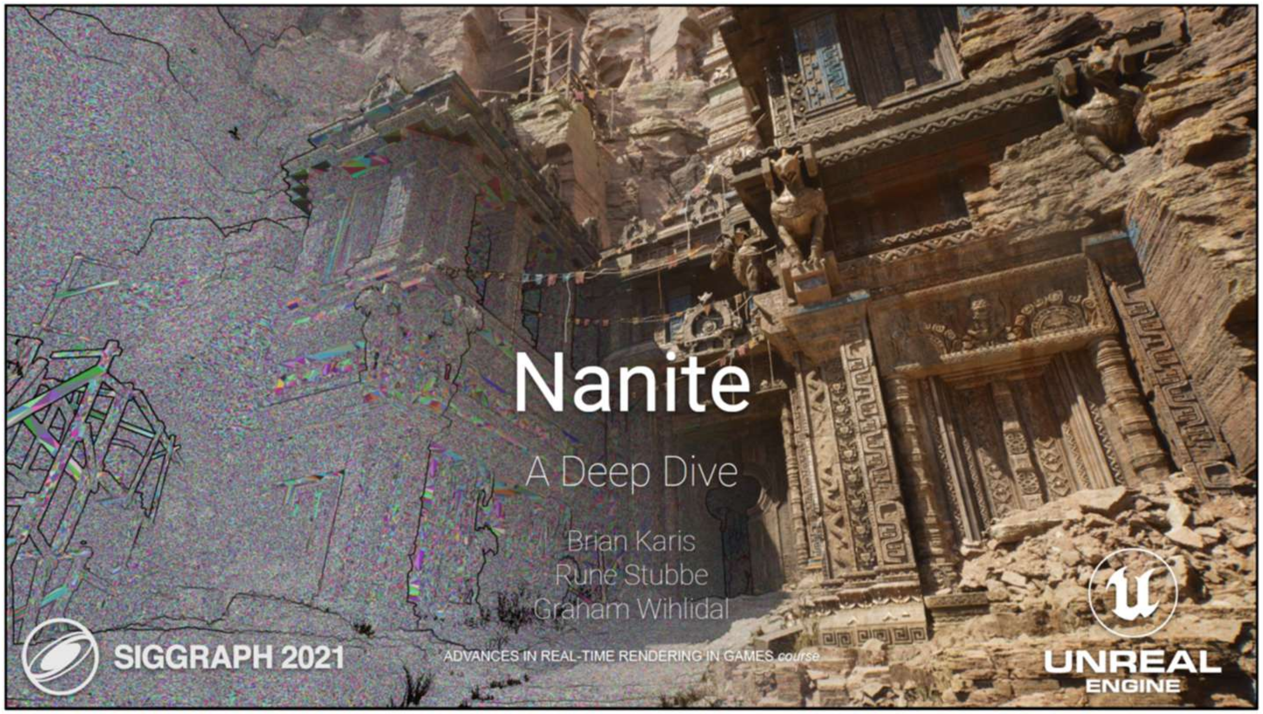
spatial coherence:
look-up overhead very small

Virtual Geometry (and Texturing)

Unreal Engine 5 Virtual Geometry: Nanite

A Deep Dive into Nanite Virtualized Geometry (Siggraph 2021 course talk)
https://www.youtube.com/watch?v=eviSykqSUUw

Brian Karis, Epic Games



See also

- Keynote at HPG 2022:
  Journey to Nanite, Brian Karis
  https://www.youtube.com/watch?v=NRnj_lnpORU
- Lumen: Real-time Global Illumination in Unreal Engine 5 (Siggraph 2022 course talk),
  Daniel Wright et al., Epic Games
  https://advances.realtimerendering.com/s2022/SIGGRAPH2022-Advances-Lumen-Wright%20et%20al.pdf

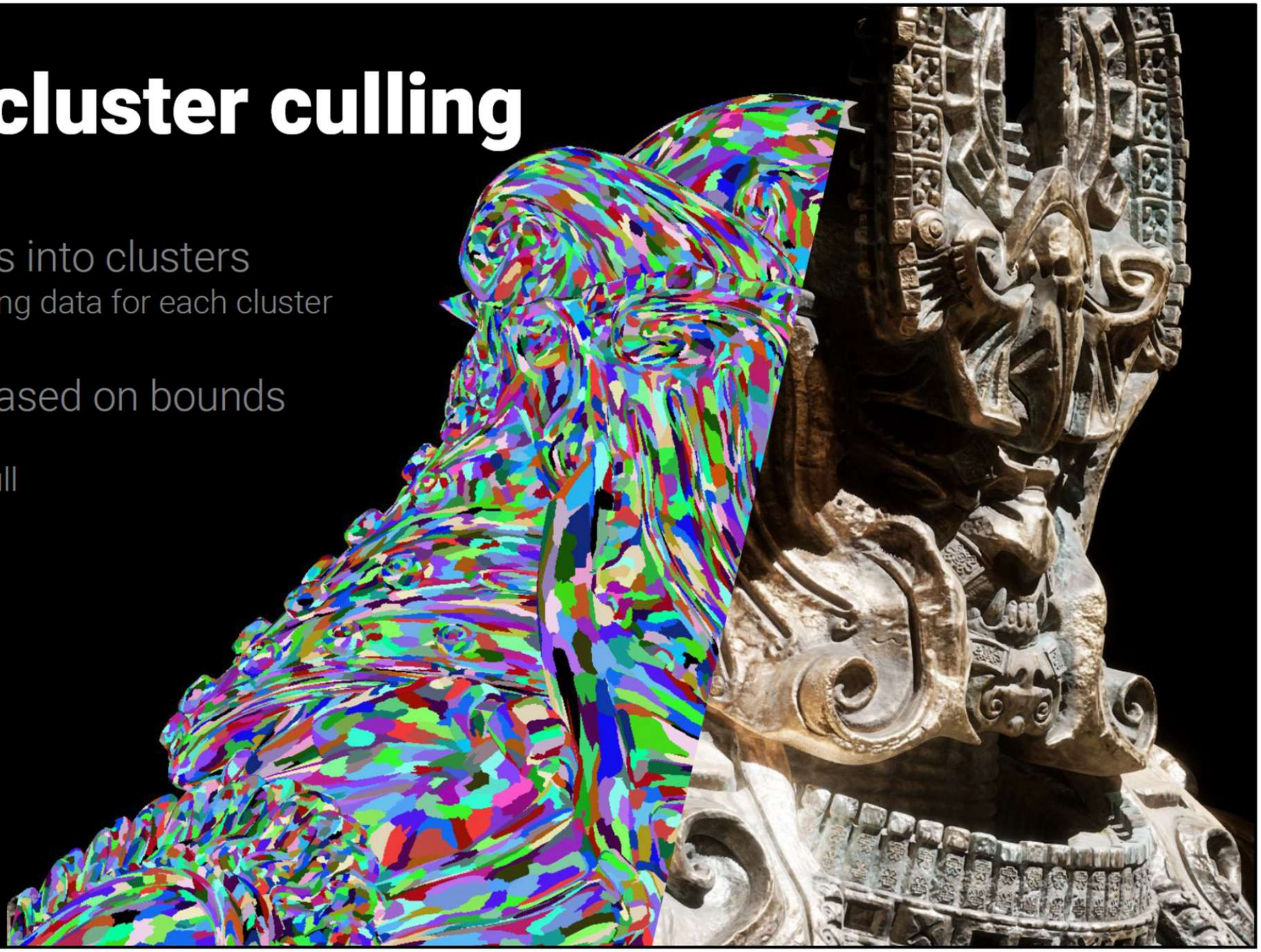
The Dream

- Virtualize geometry like we did textures
- No more budgets
  - Polycount
  - Draw calls
  - Memory
- Directly use film quality source art
  - No manual optimization required
- No loss in quality

Virtual Geometry

Triangle cluster culling

- Group triangles into clusters
  - Build bounding data for each cluster
- Cull clusters based on bounds
  - Frustum cull
  - Occlusion cull

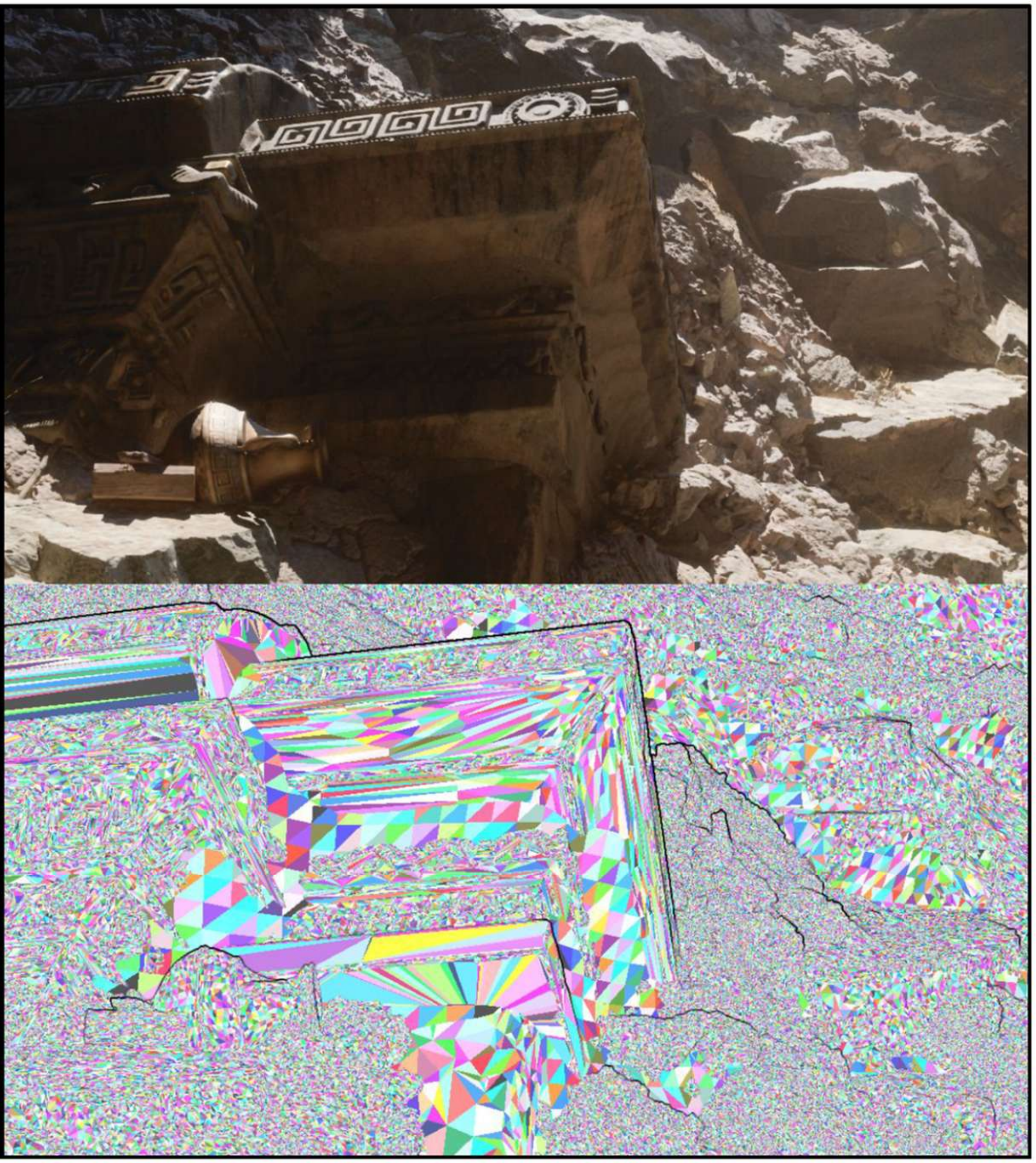


SIGGRAPH 2021

Virtual Geometry

Pixel scale detail

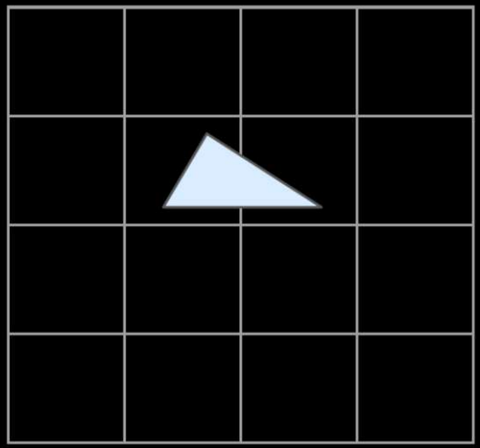
- Can we hit pixel scale detail with triangles > 1 pixel?
  - Depends how smooth
  - In general no
- We need to draw pixel sized triangles



SIGGRAPH 2021

Tiny triangles

- Terrible for typical rasterizer
- Typical rasterizer:
  - Macro tile binning
  - Micro tile 4x4
  - Output 2x2 pixel quads
  - Highly parallel in pixels not triangles
- Modern GPUs setup 4 tris/clock max
  - Outputting SV_PrimitiveID makes it even worse
- Can we beat the HW rasterizer in SW?

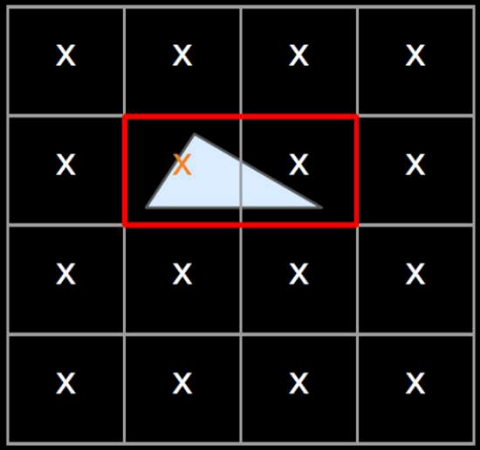


Software Rasterization

3x faster!

Micropoly software rasterizer

- 128 triangle clusters => threadgroup size 128
- 1 thread per vertex
  - Transform position
  - Store in groupshared
  - If more than 128 verts loop (max 2)
- 1 thread per triangle
  - Fetch indexes
  - Fetch transformed positions
  - Calculate edge equations and depth gradient
  - Calculate screen bounding rect
  - For all pixels in rect
    - If inside all edges then write pixel

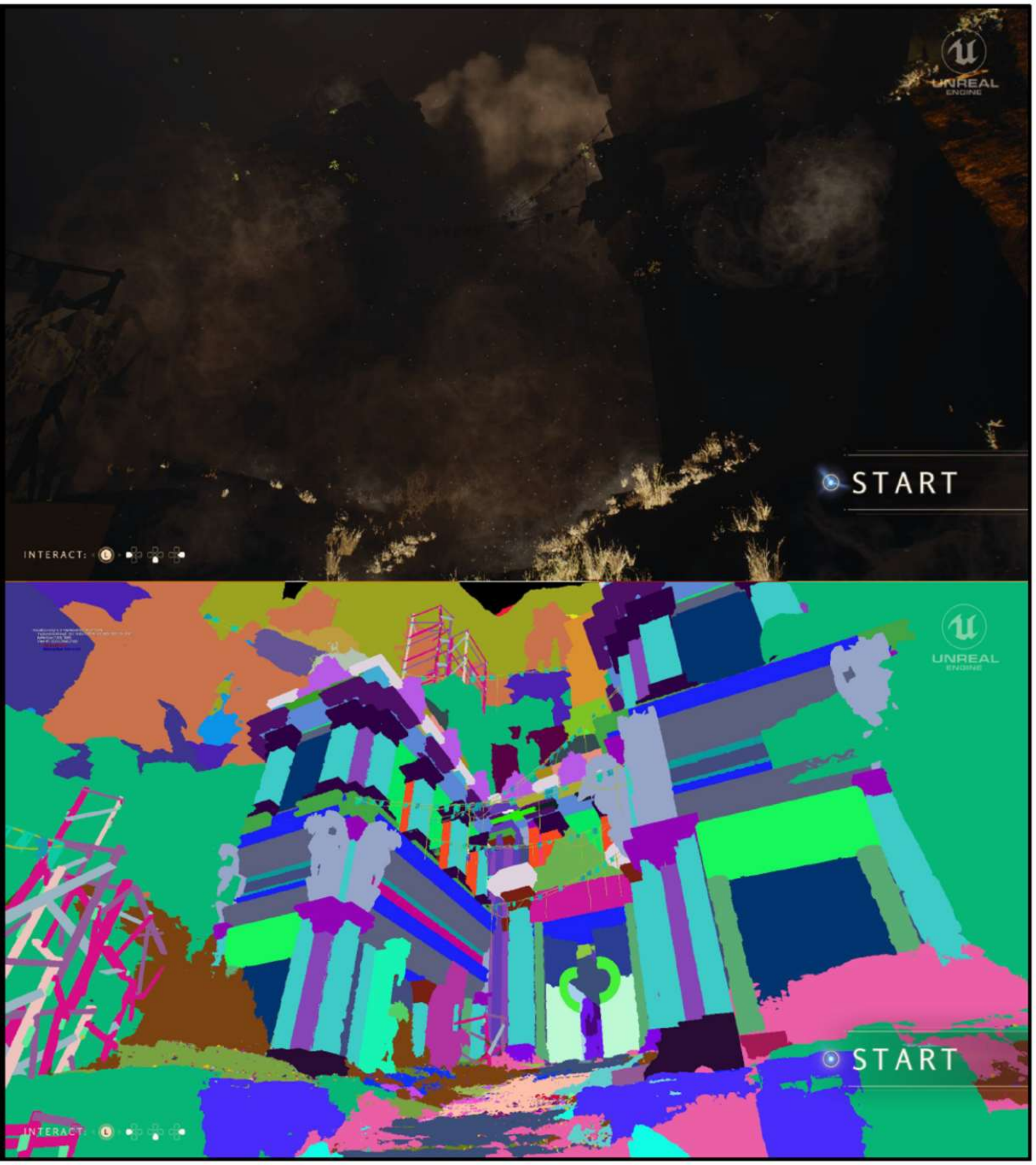


Hardware Rasterization

- What about big triangles?
  - Use HW rasterizer
- Choose SW or HW per cluster
- Also uses 64b atomic writes to UAV

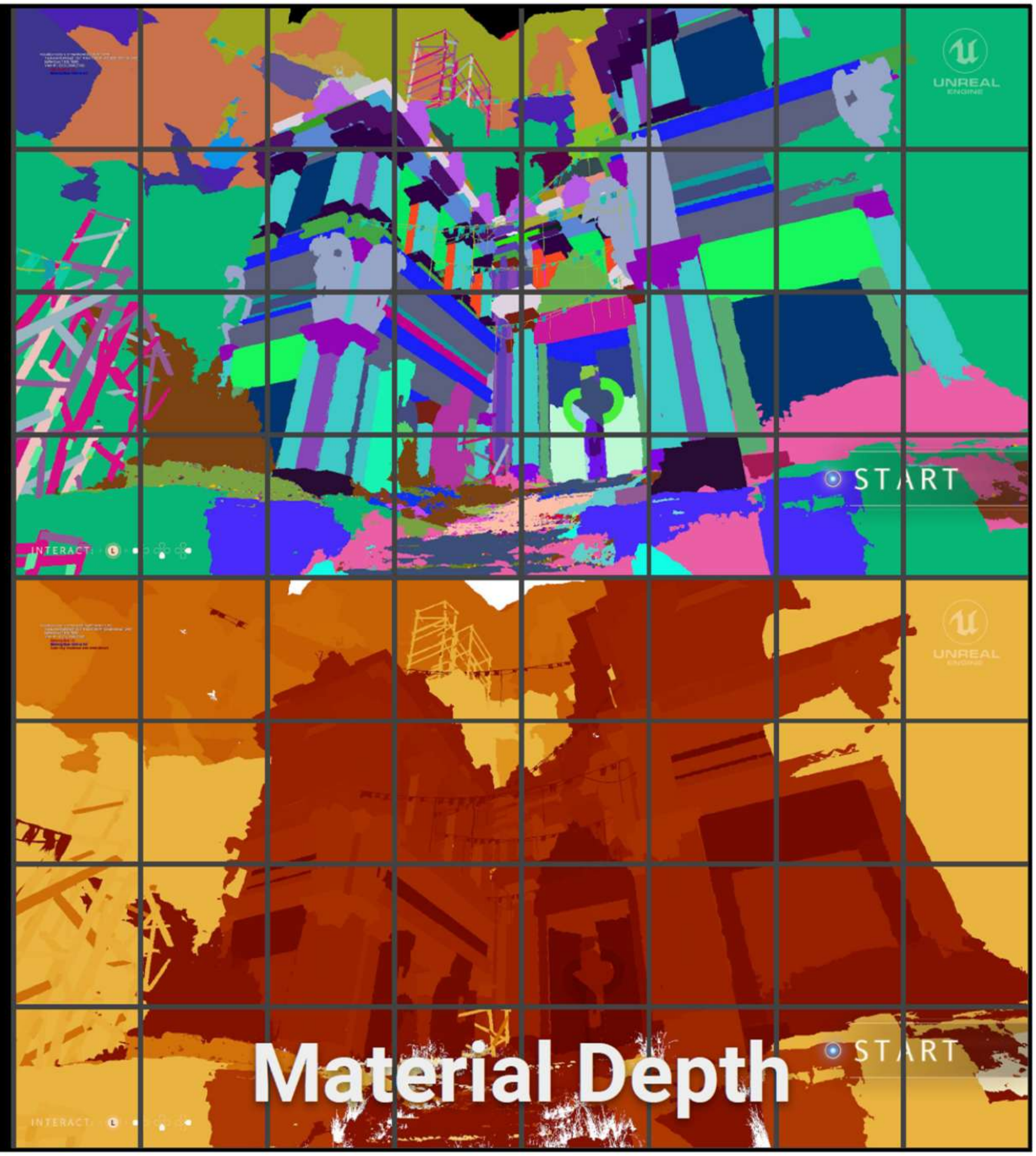
Material shading

- Full screen quad per unique material
- Skip pixels not matching this material ID
- CPU unaware if some materials have no visible pixels
  - Material draw calls issued regardless
  - Unfortunate side effect of GPU driven
- How to do efficiently?
  - Don’t test every pixel for matching material ID for every material pass



Material culling

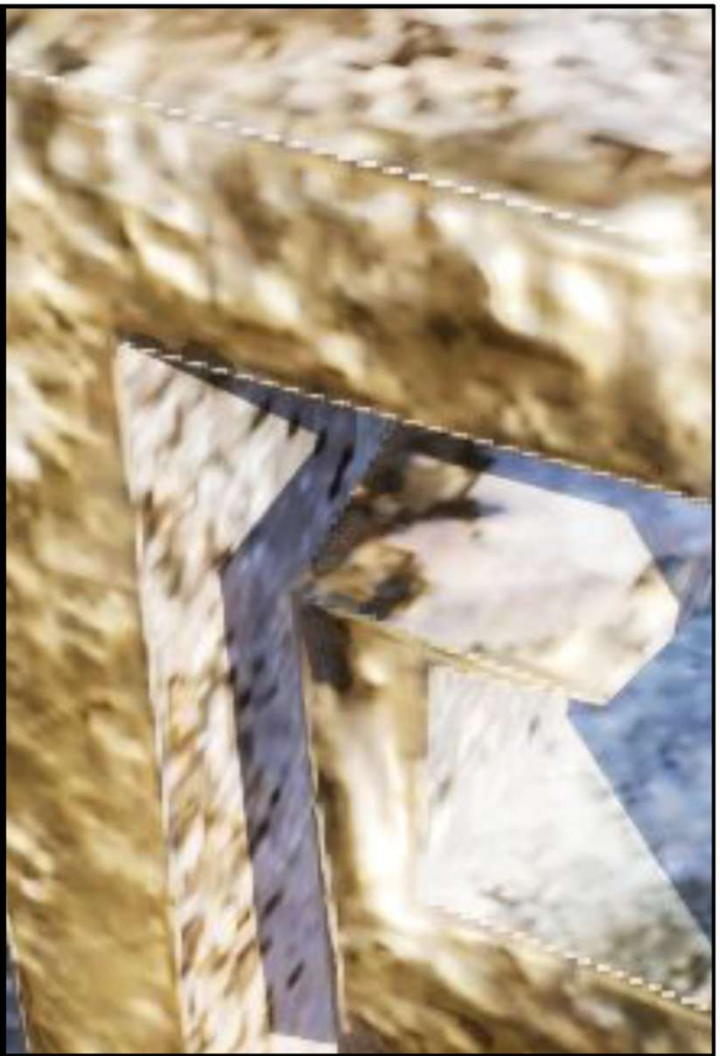
- Material covers small portion of the screen
  - HiZ handles this OK
  - We can do better
- Coarse tile classification / culling
  - Render 8x4 grid of tiles per material
  - Same shading approach as full screen quads
- Tile killed in vertex shader from 32b mask
  - X=NaN



UV derivatives

- Still a coherent pixel shader so we have finite difference derivatives
- Pixel quads span
  - Triangles ⇦ Good!
- Also span
  - Depth discontinuities
  - UV seams
  - Different objects

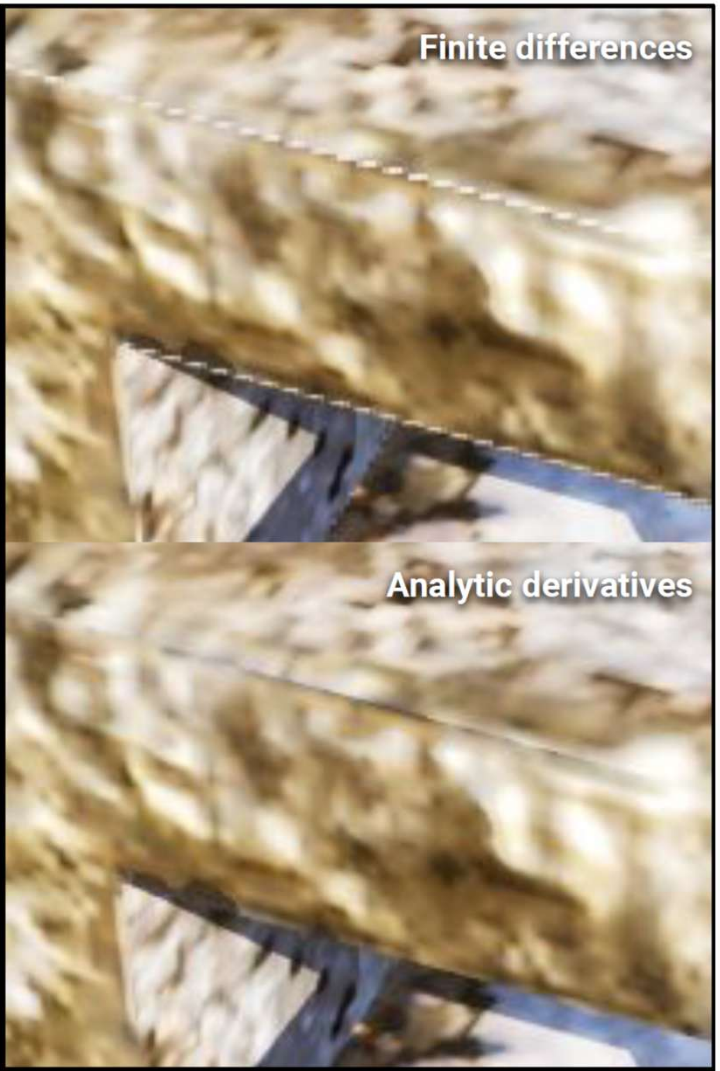
Not good!



Analytic derivatives

- Compute analytic derivatives
  - Attribute gradient across triangle
- Propagate through material node graph using chain rule
- If derivative can’t be evaluated analytically
  - Fall back to finite differences
- Used to sample textures with SampleGrad

- Additional cost tiny
  - <2% overhead for material pass
  - Only affects calculations that affect texture sampling
  - Virtual texturing code already does SampleGrad



Pipeline numbers

Main pass

Instances pre-cull	896322
Instances post-cull	3668
Cluster node visits	39274
Cluster candidates	1536794
Visible clusters SW	184828
Visible clusters HW	6686

Post pass

Instances pre-cull	102804
Instances post-cull	365
Cluster node visits	19139
Cluster candidates	458805
Visible clusters SW	7370
Visible clusters HW	536

Total rasterized

Clusters	199,420
Triangles	25,041,711
Vertices	19,851,262

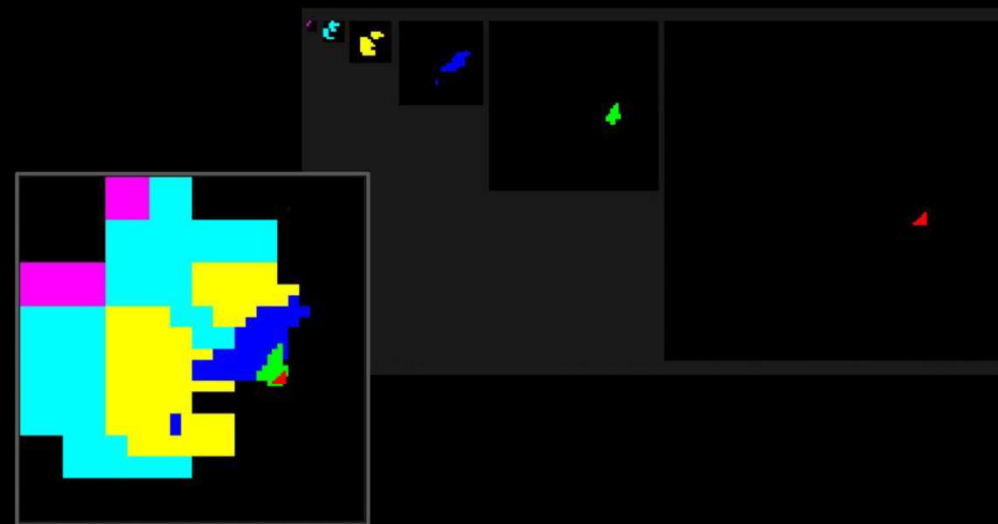
Nanite shadows

- Ray trace?
  - DXR isn't flexible enough
    - Complex LOD logic
    - Custom triangle encoding
    - No partial BVH updates
- Want a raster solution
  - Leverage all our other work
- Most lights don't move
  - Should cache as much as possible

Virtual shadow maps

- Nanite enables new techniques
- 16k x 16k shadow maps everywhere
  - Spot: 1x projection
  - Point: 6x cube
  - Directional: Nx clipmaps
- Pick mip level where 1 texel = 1 pixel
- Only render the shadow map pixels that are visible
- Nanite culled and LODed to the detail required

Virtual shadow maps



- Page size = 128 x 128
- Page table = 128 x 128, with mips

- Mark needed pages
    - Screen pixels project to shadow space
    - Pick mip level where 1 texel = 1 pixel
    - Mark that page

- Allocate physical pages for all needed

- If cached page already exists use that
    - And wasn't invalidated
    - Remove from needed page mask

Lumen: Fully Dynamic Global Illumination

The Dream - dynamic indirect lighting

- Unlock new ways for players to interact with game worlds
- Instant results for lighting artists
    - No more lighting builds
- Huge open worlds that couldn't have ever been baked
- Indoor quality comparable to baked lighting

MegaLights: Stochastic Direct (!) Lighting

Thank you.