From Terrain To Godrays: Better Use of DX11

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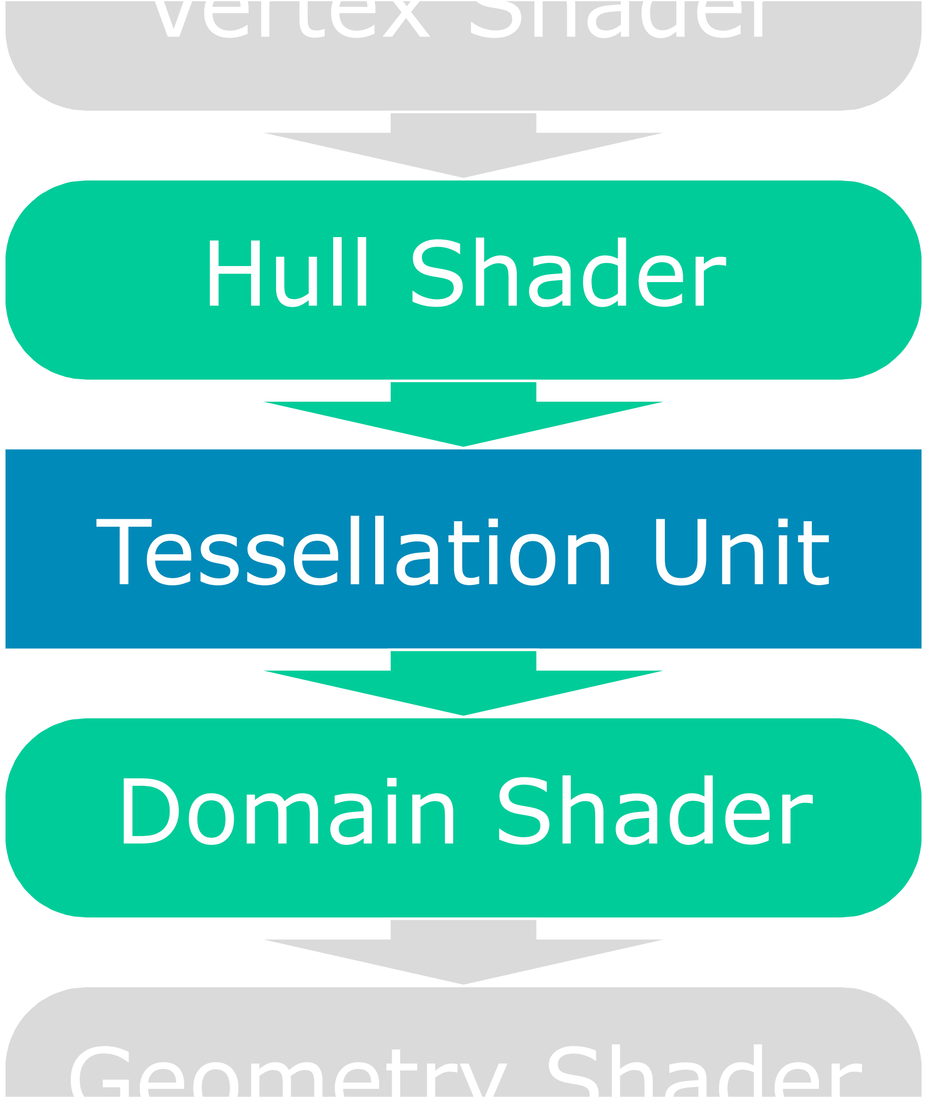
Better Use of Tessellation

- One of the most recent additions to DirectX
- And one of the least explored too



Vertex Shader

Hull Shader

Tessellation Unit

Domain Shader

Geometry Shader

Getting More Adoption

- Originally tessellation was available only on DX11-capable PCs

Getting More Adoption

- Originally tessellation was available only on DX11-capable PCs

- Wasn’t available on consoles
- Tessellation brings special requirements to the content

Getting More Adoption

- Next-generation consoles support it too!

Getting More Adoption

- Some AAA-titles already use it

Metro: Last Light

Batman: Arkham Origins

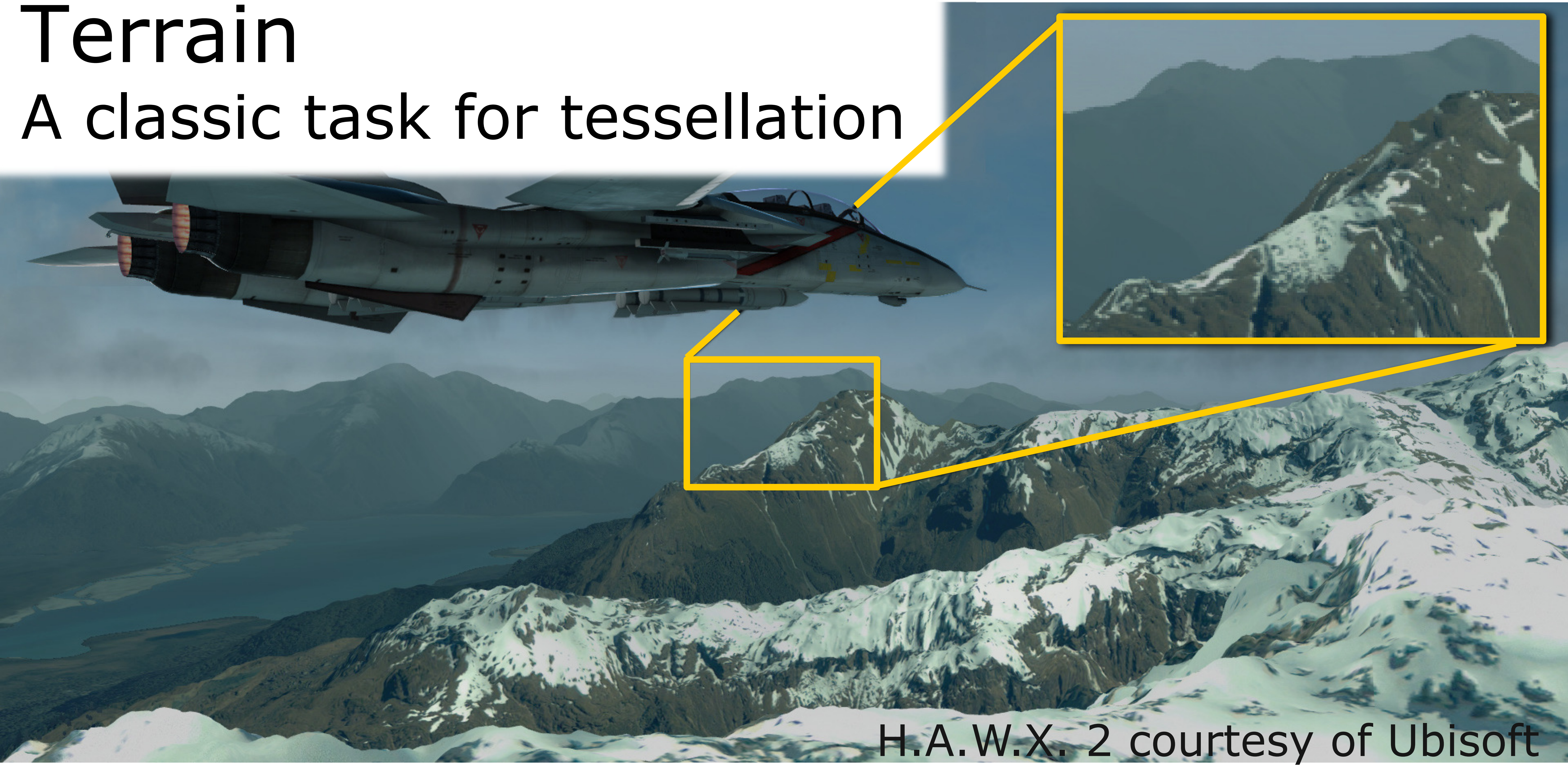
Screenshots were made by Andrew Iain Burnes and published at GeForce.com

Outline

- Common use cases
  - Terrain
  - Super-static objects
- Novel approaches
  - Tessellated particles
  - Godrays
- Tessellation Tips and Tricks

Terrain

A classic task for tessellation



H.A.W.X. 2 courtesy of Ubisoft

Terrain

- Requires
  - Detail at wide range of scales
  - Highly mobile view, e.g., flying
  - Frequent, seamless LOD changes
- H.A.W.X 2
- Frostbite 2: BF3, NFS The Run
- Frostbite 3: BF4, NFS Rivals

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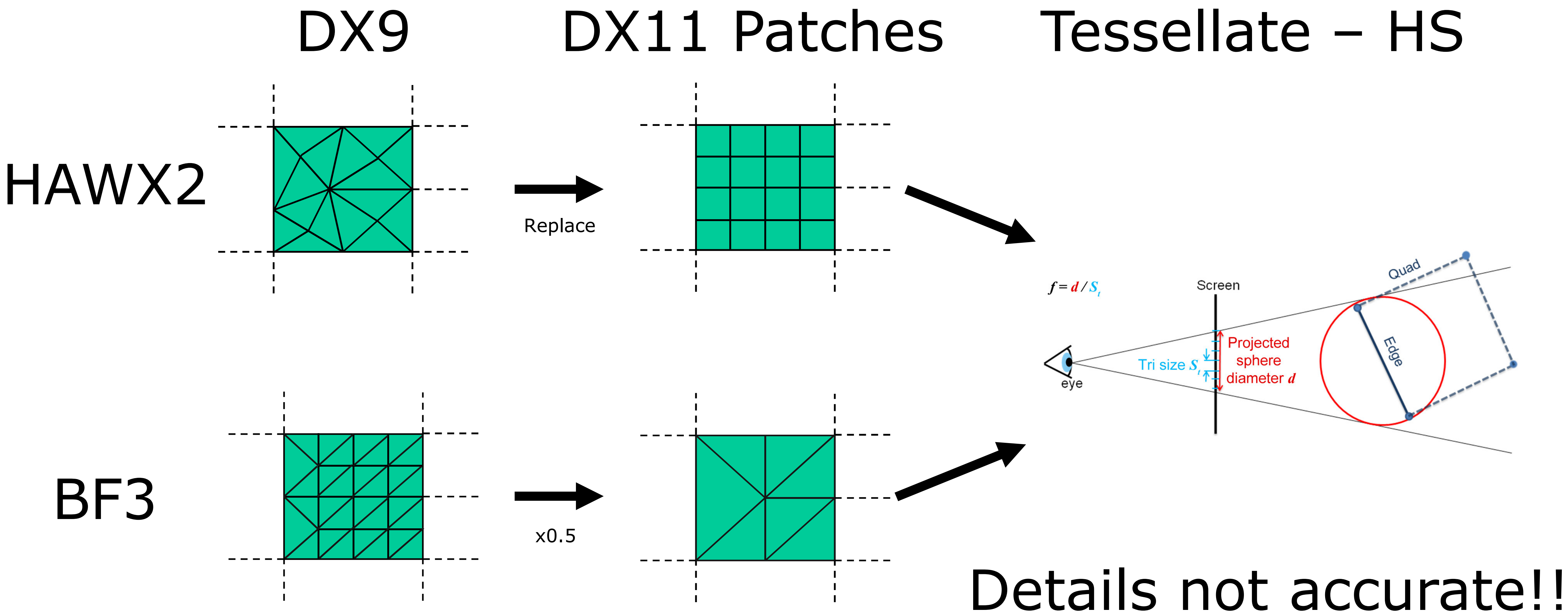
- Frostbite 2: **BF3**, NFS The Run
- Frostbite 3: BF4, **NFS Rivals**

Tessellation Patches



DX9

DX11 Patches

Tessellate – HS

HAWX2

Replace

BF3

x0.5

Details not accurate!!

Extra Detail

HAWX2

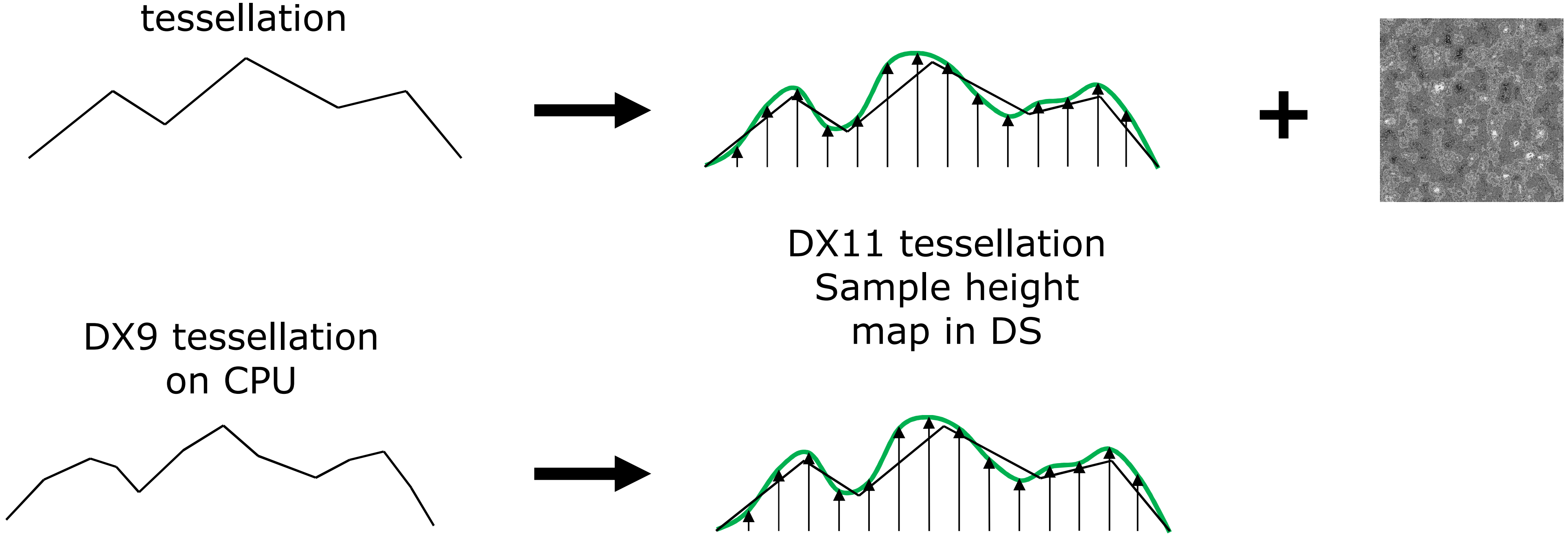
DX9 offline tessellation

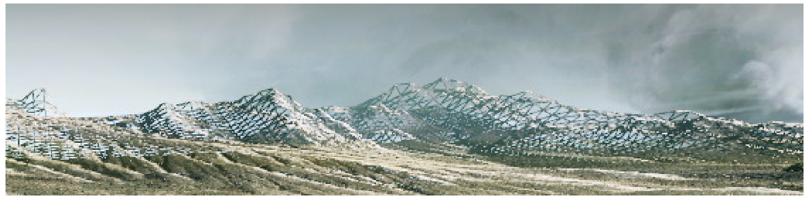
Add fBm detail noise in DS

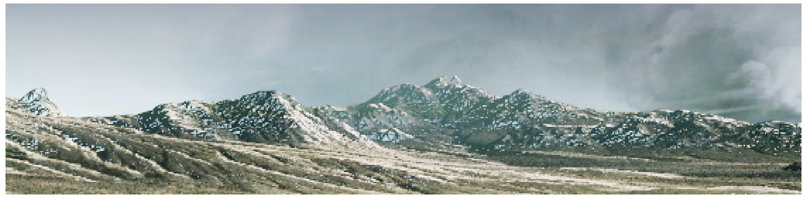
DX11 tessellation
Sample height map in DS

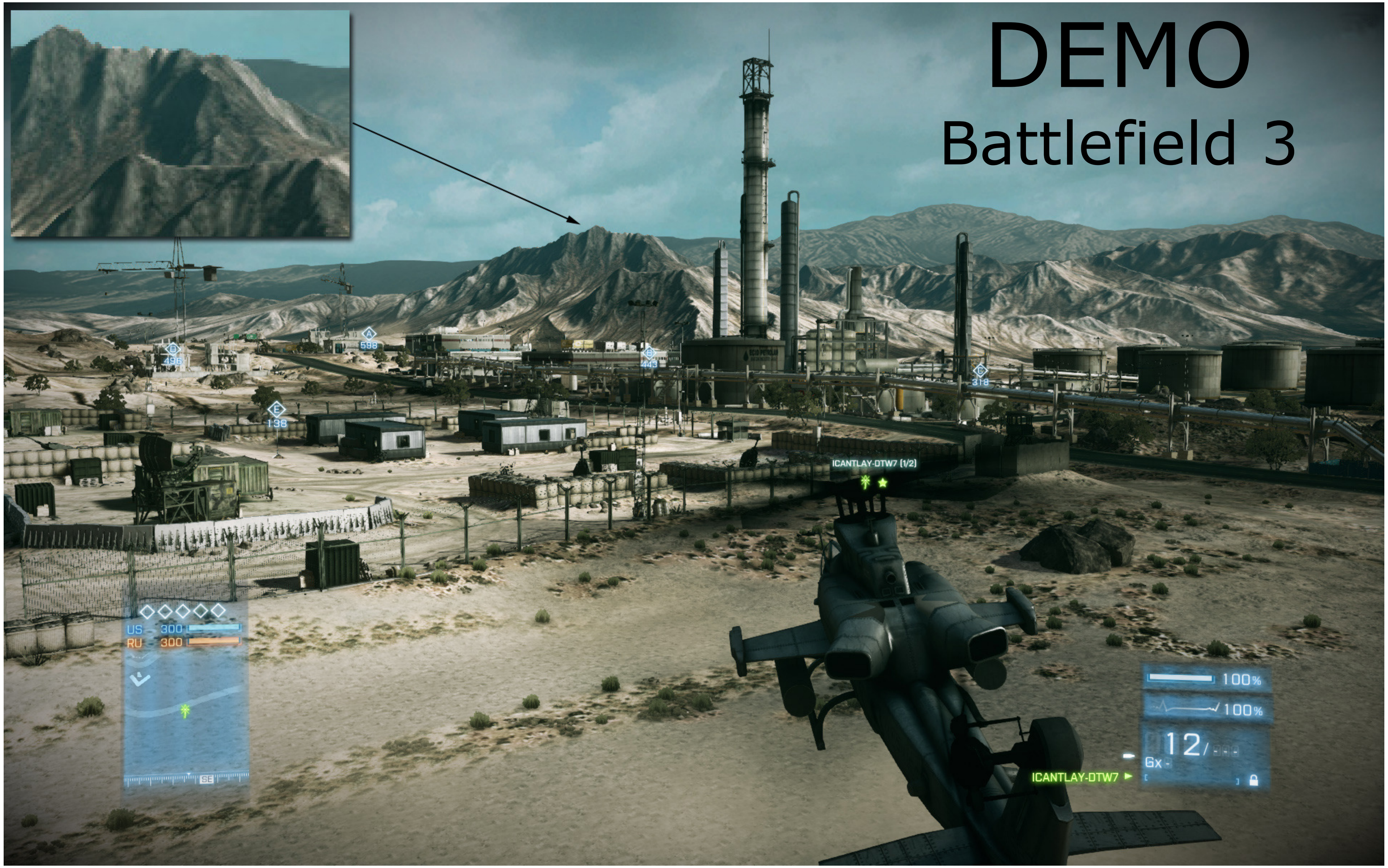
BF3

DX9 tessellation on CPU









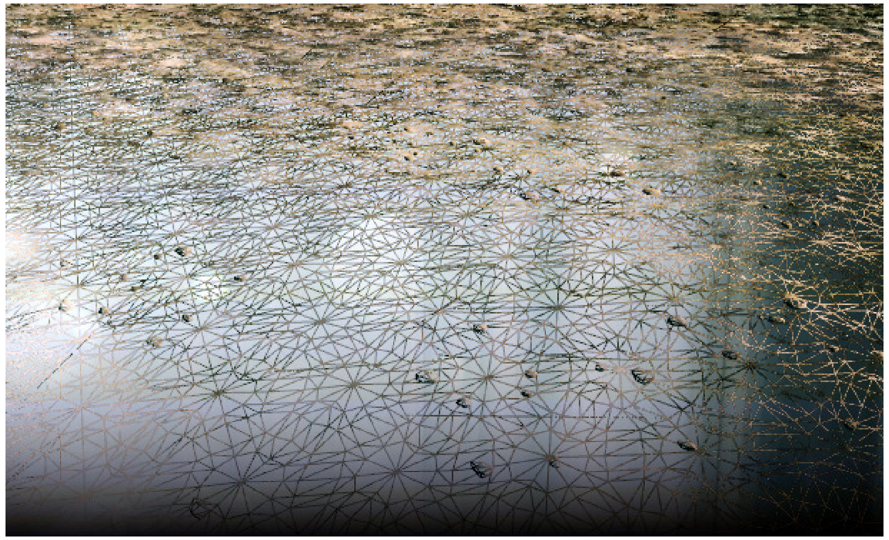
DEMO

Battlefield 3

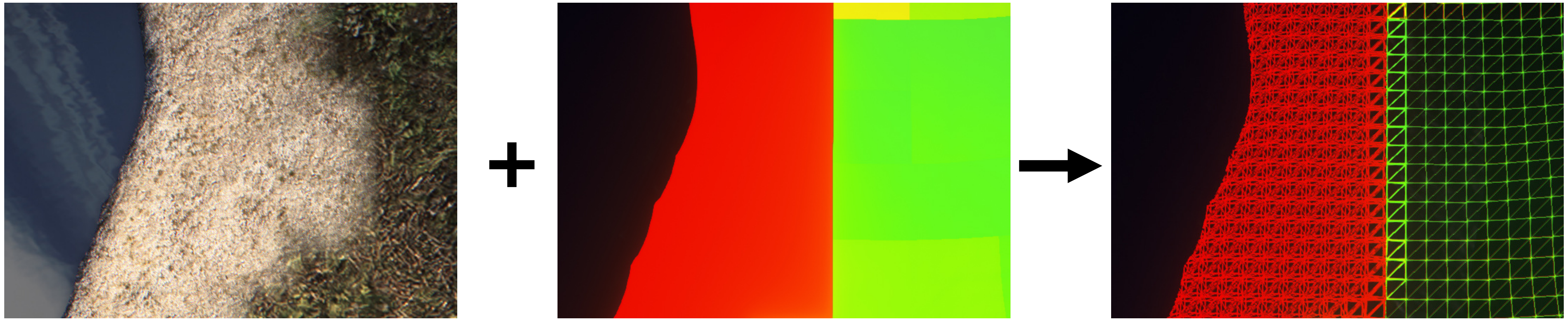
Battlefield 3 courtesy of EA DICE

Adaptive Tessellation

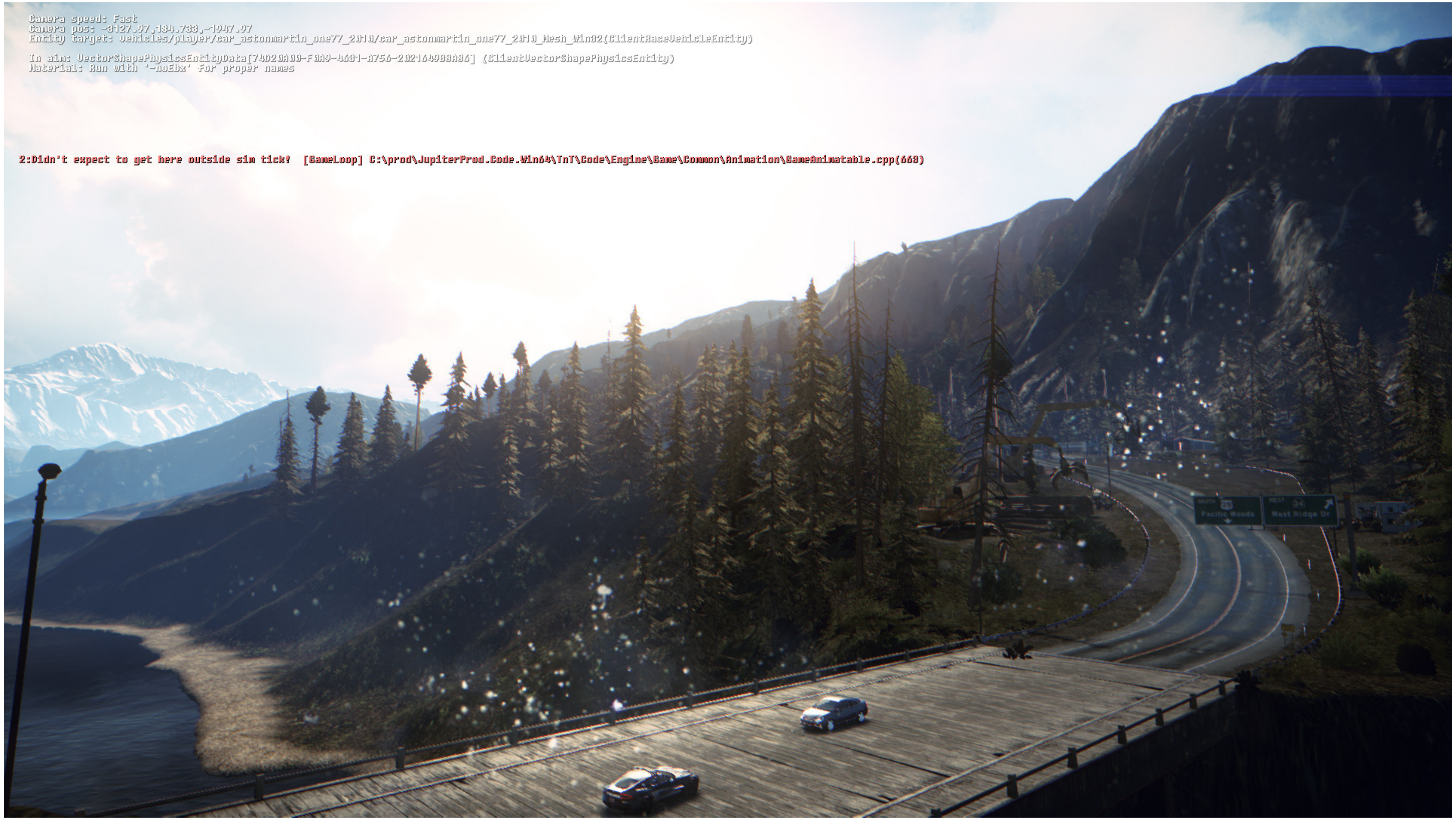
BF3



NFS Rivals



"Density" Map

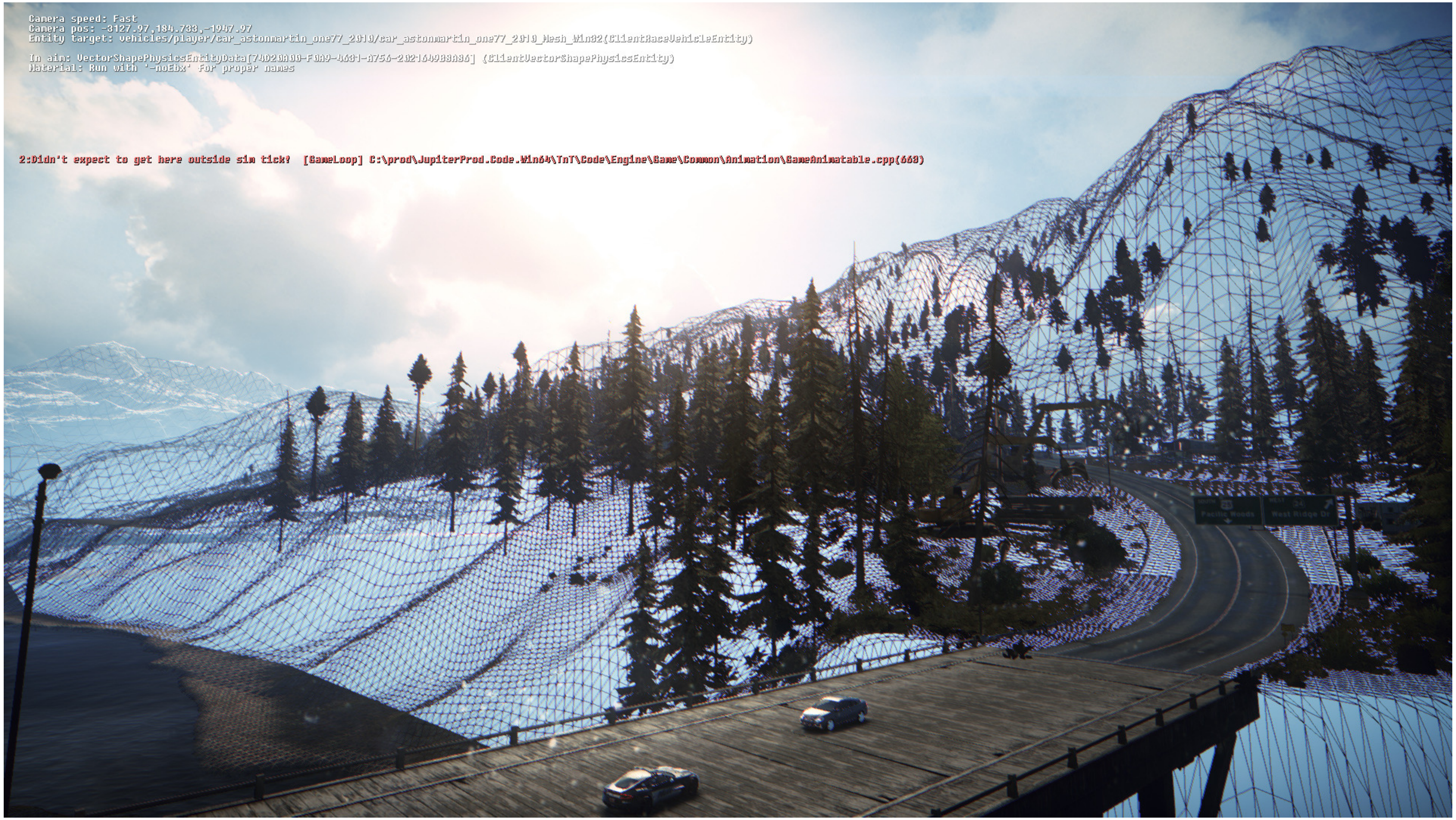


```
Camera speed: Fast
Camera pos: -3127.97,184.733,-1947.97
Entity target: vehicles/player/car_astonmartin_one77_2010/car_astonmartin_one77_2010_Mesh_Win32(ClientRaceVehicleEntity)

In aim: VectorShapePhysicsEntityData[74D20A00-F0A9-4631-A756-2021649B8A86] (ClientVectorShapePhysicsEntity)
Material: Run with '-noEbx' for proper names
```

```
2:Didn't expect to get here outside sim tick?  [GameLoop] C:\prod\JupiterProd.Code.Win64\TnT\Code\Engine\Game\Common\Animation\GameAnimatable.cpp(663)
```

Need For Speed Rivals courtesy of Ghost Games and EA



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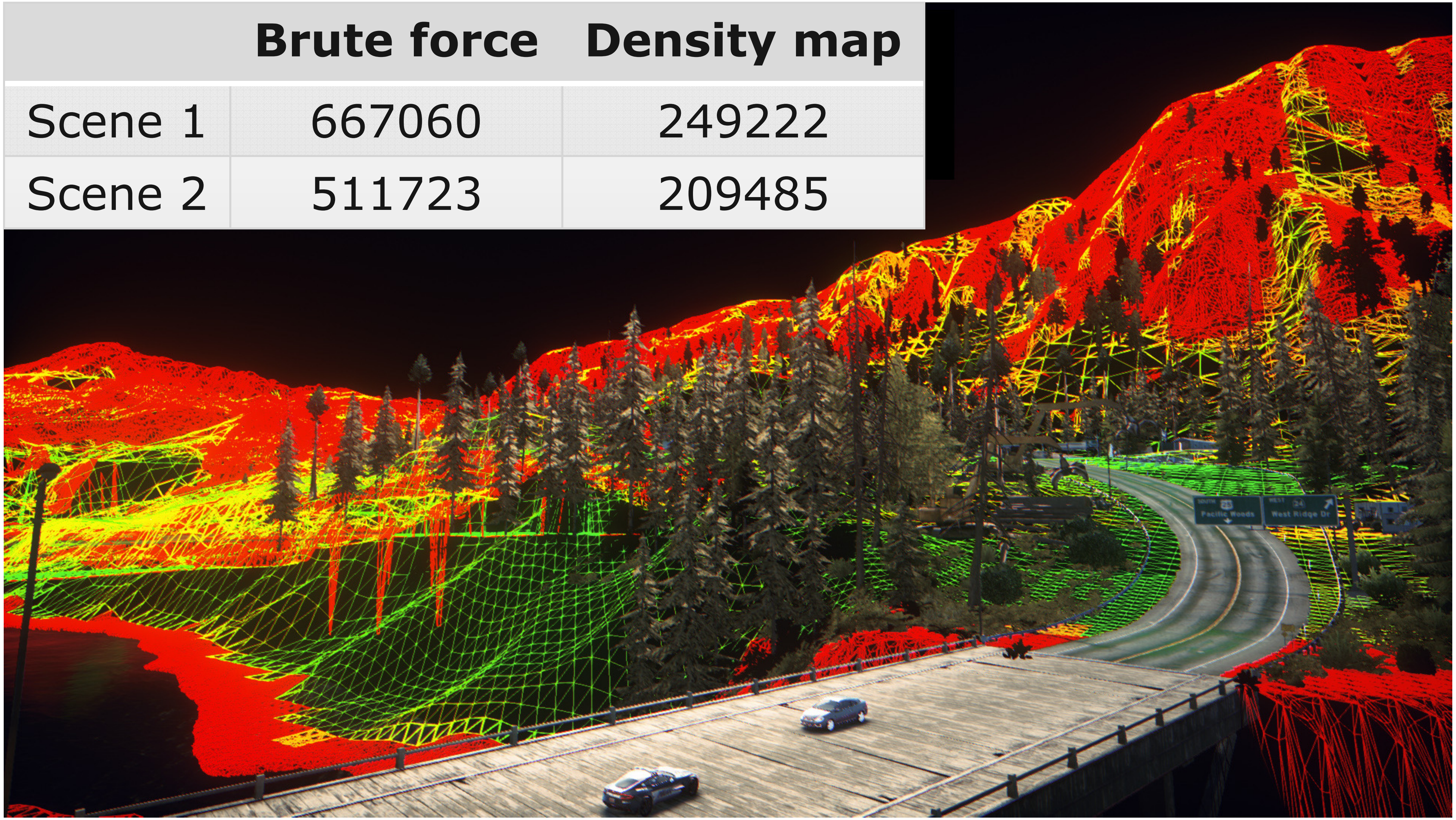


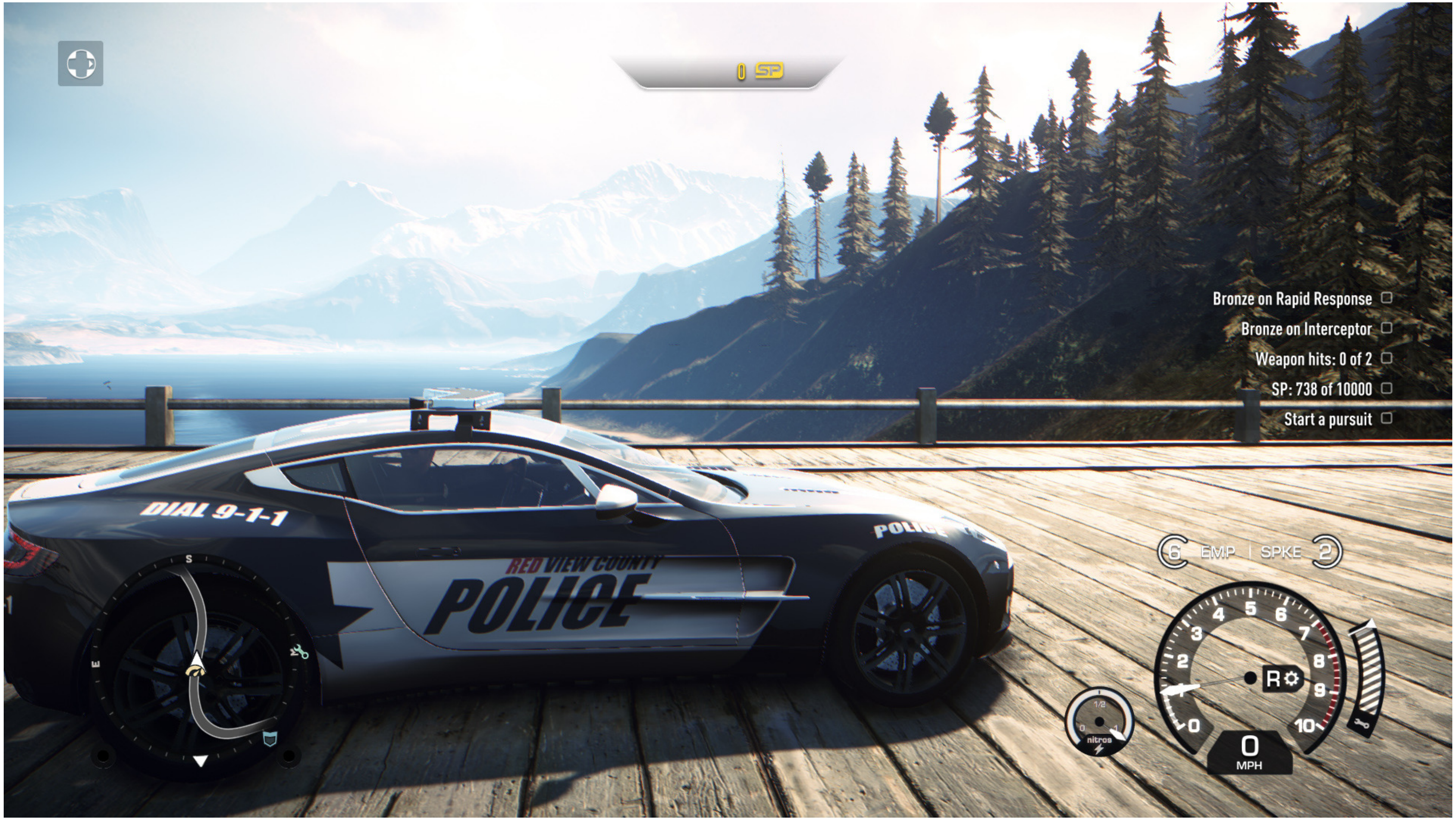
	Brute force	Density map
Scene 1	667060	249222
Scene 2	511723	209485

Need For Speed Rivals courtesy of Ghost Games and EA

Performance and Conclusions

- Add detail easily !/$
- Natural fit to terrain
- High perf on many platforms

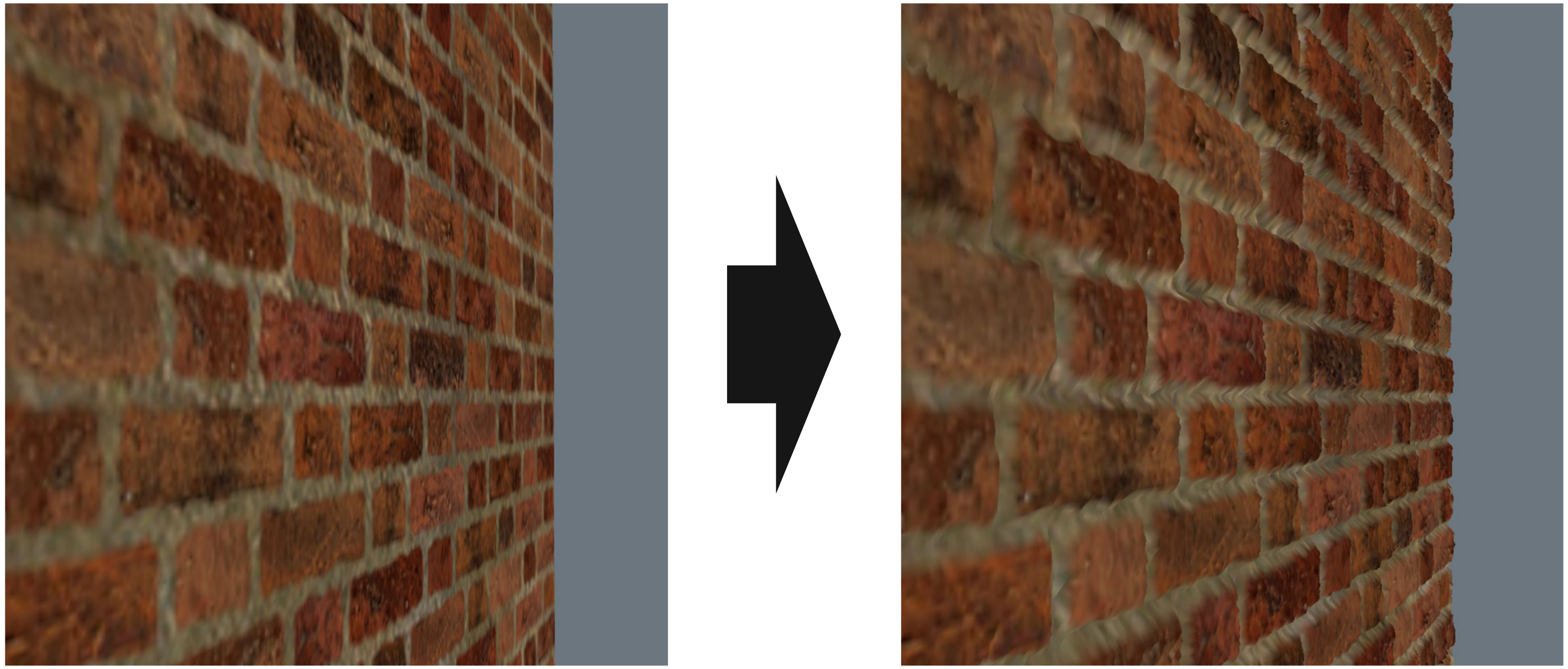
Battlefield 3 DX11	1920x1200		
	terrain medium	ultra	%
GTX 750 Ti (2GB)	46.1	**43.7**	95%
GTX 760 (2GB)	78.1	**73**	94%
GTX 770 (2GB)	91.8	**86.7**	94%
R7 260X (2GB)	43.9	**40.5**	92%
R9 270X (2GB)	65.4	**60.3**	92%
R9 280X (3GB)	92.5	**83.2**	90%



Need For Speed Rivals courtesy of Ghost Games and EA

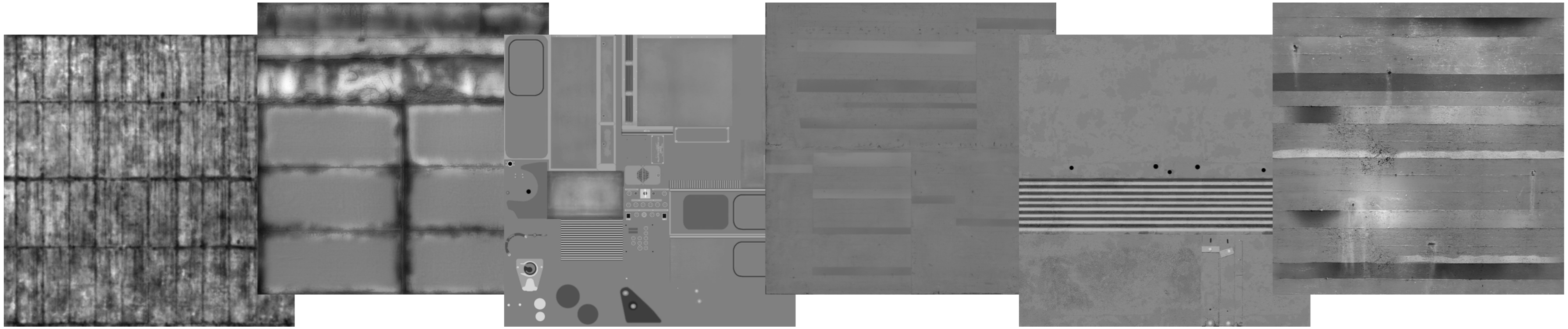
Tessellating super-static objects

- Super-static objects are good candidates for tessellation

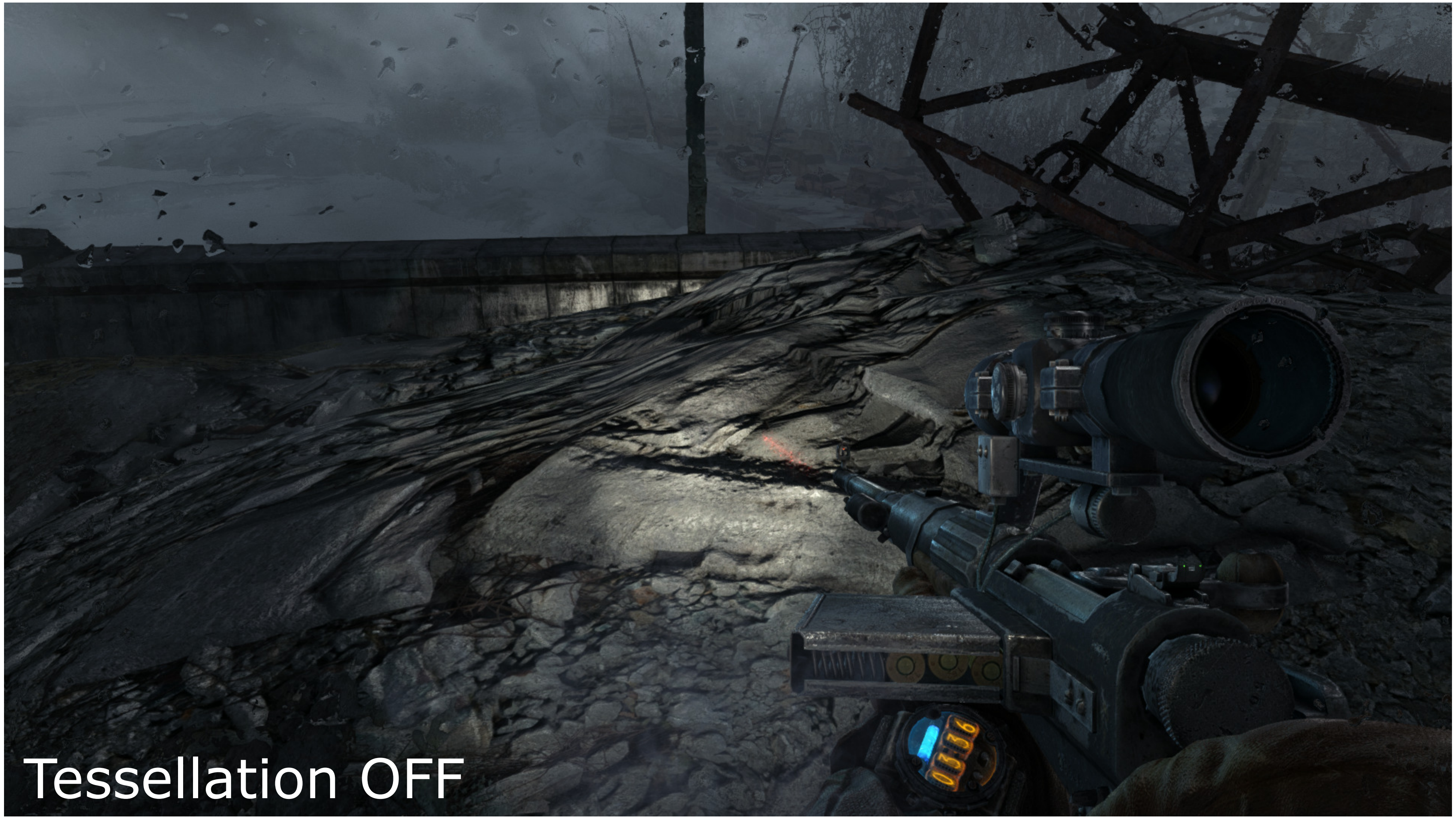


We did this in Metro: Last Light

- A joint project of 4A Games and NVIDIA
  - Use super-static geometry that has bump maps
  - Implement hull and domain shaders
  - Add displacement to the geometry

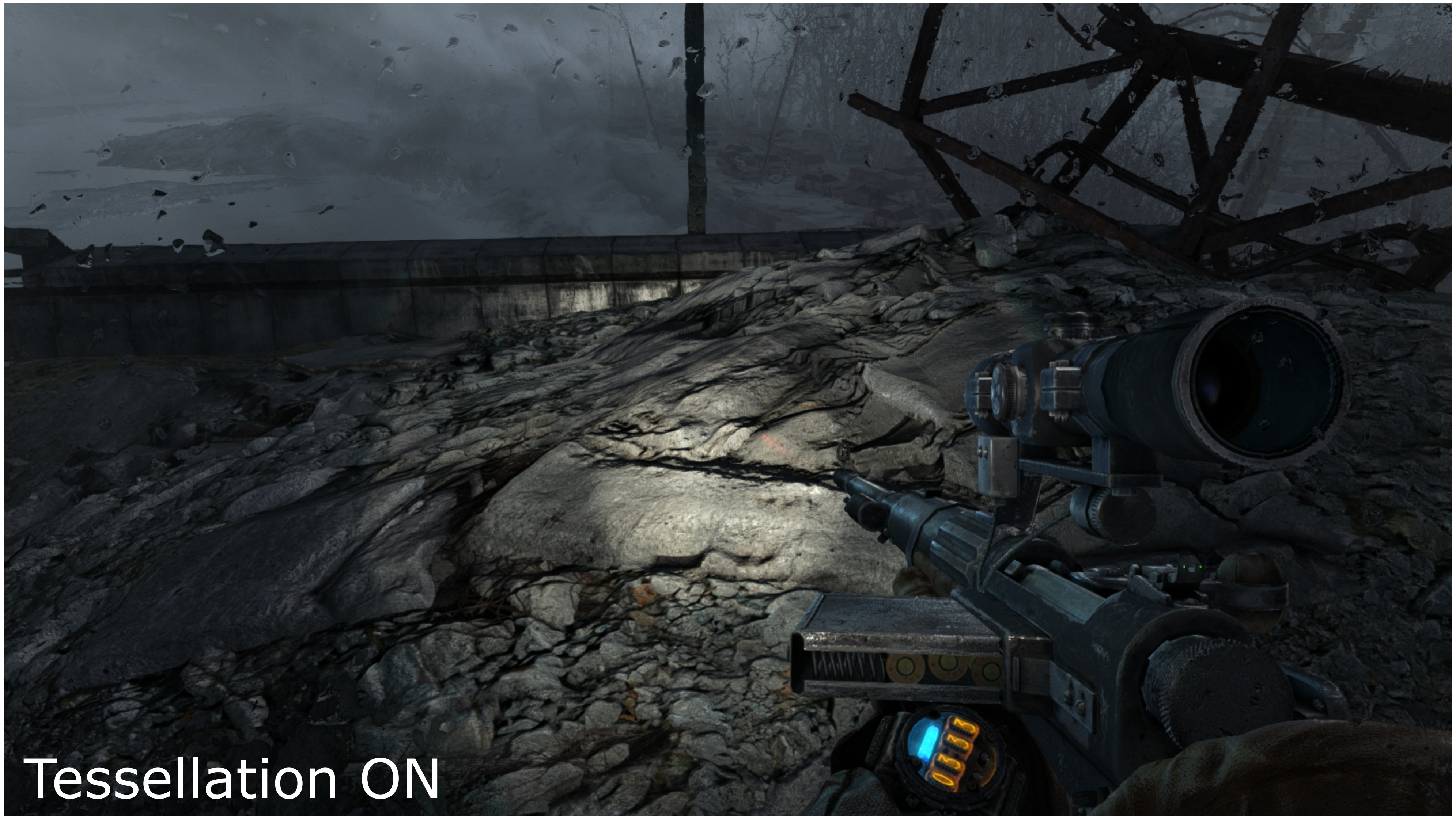


Metro: Last Light



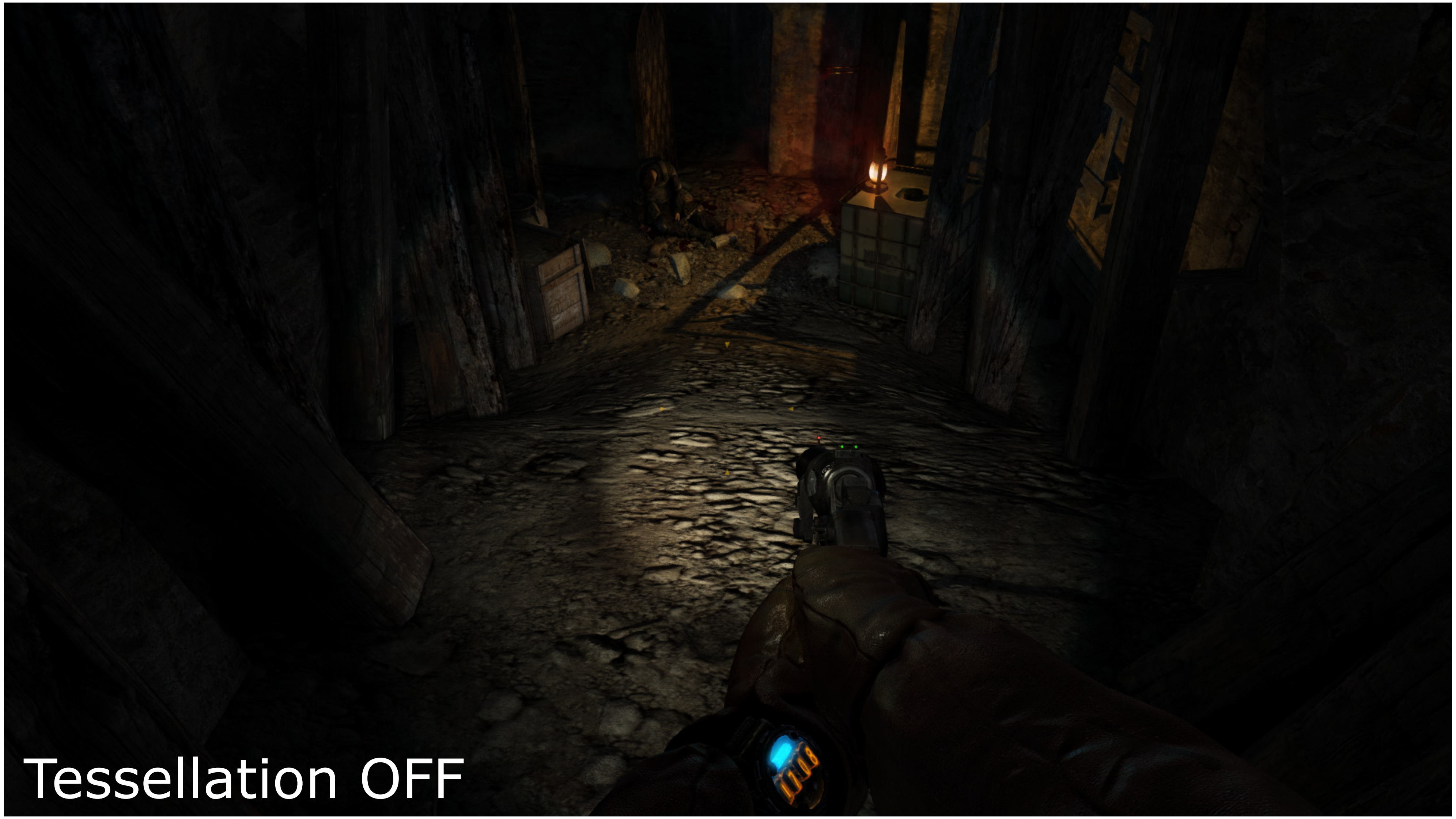
Tessellation OFF

Metro: Last Light



Tessellation ON

Metro: Last Light



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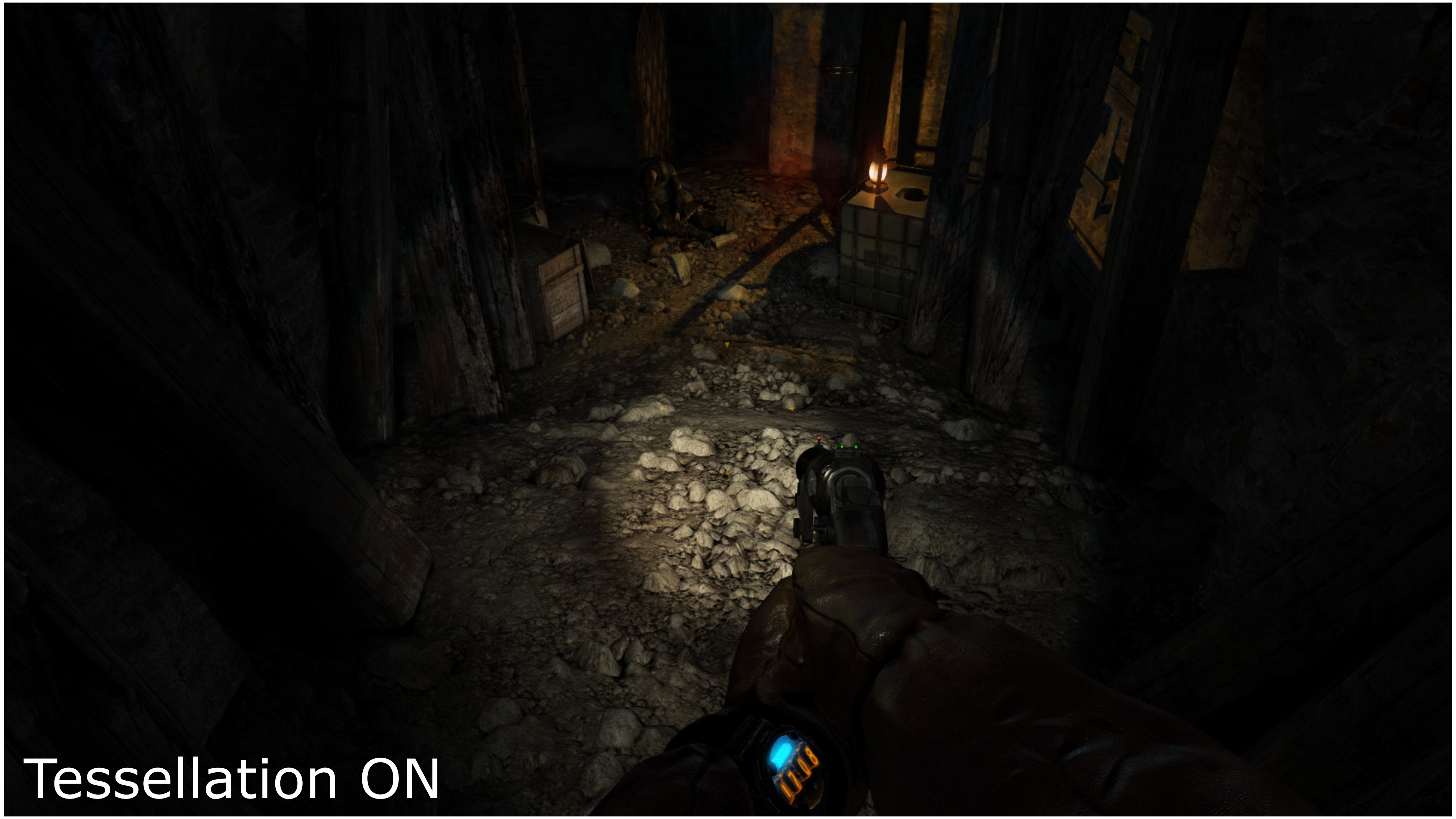
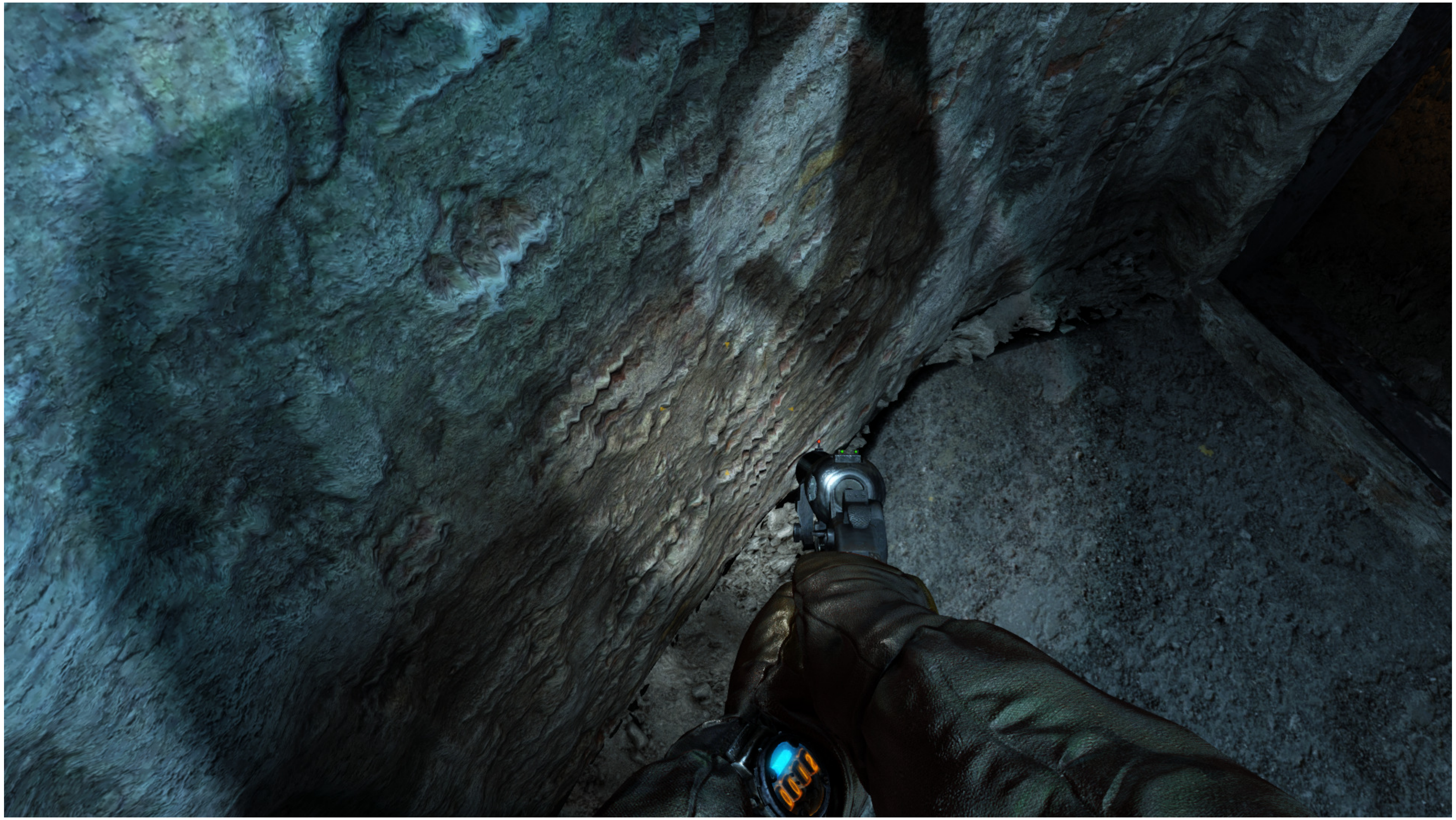


Under-tessellation is bad

- Super-static objects are often modelled with large triangles
- Level of detail required to represent displacement can exceed DirectX tessellation factor limit

Under-tessellation is bad



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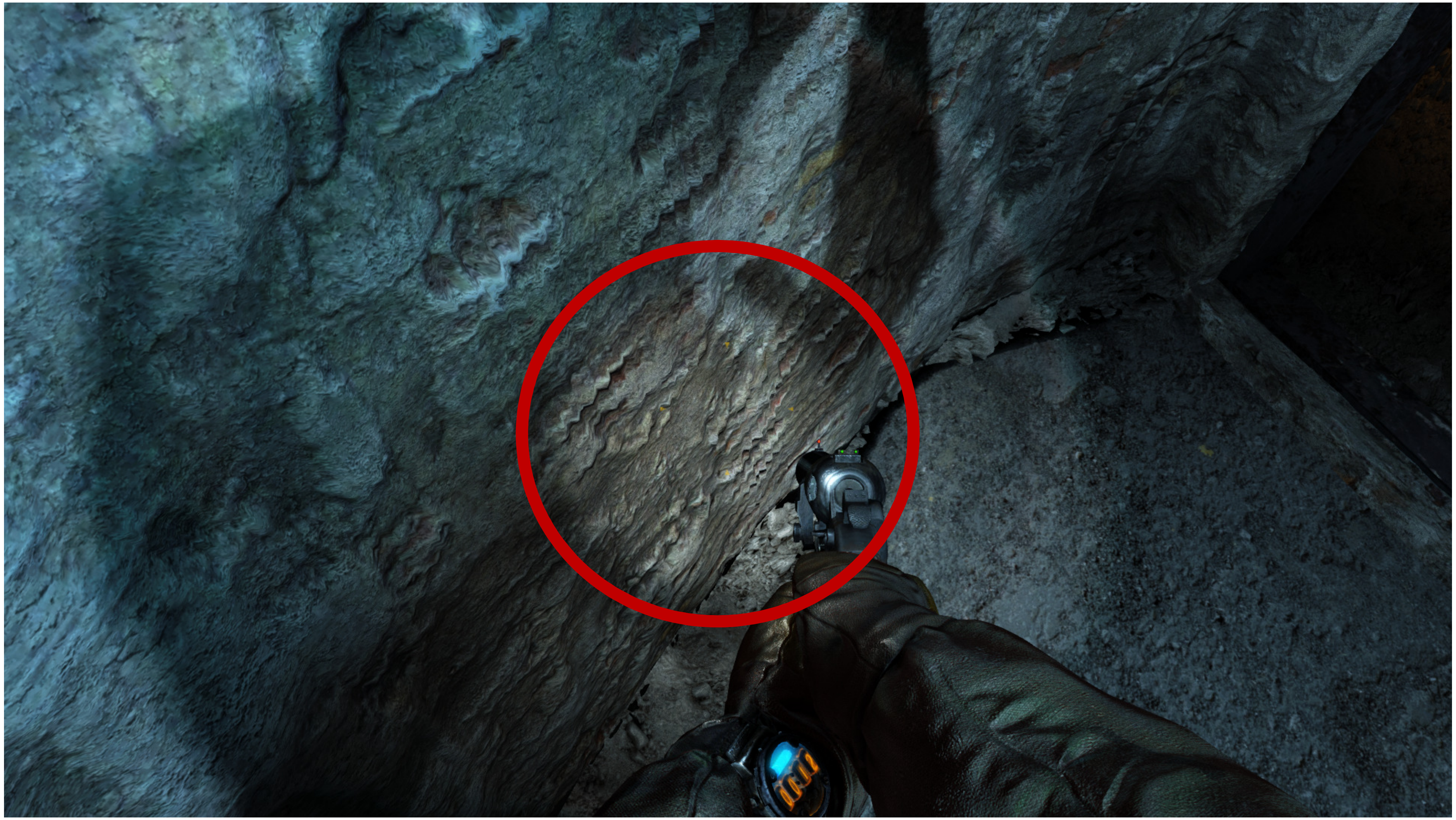

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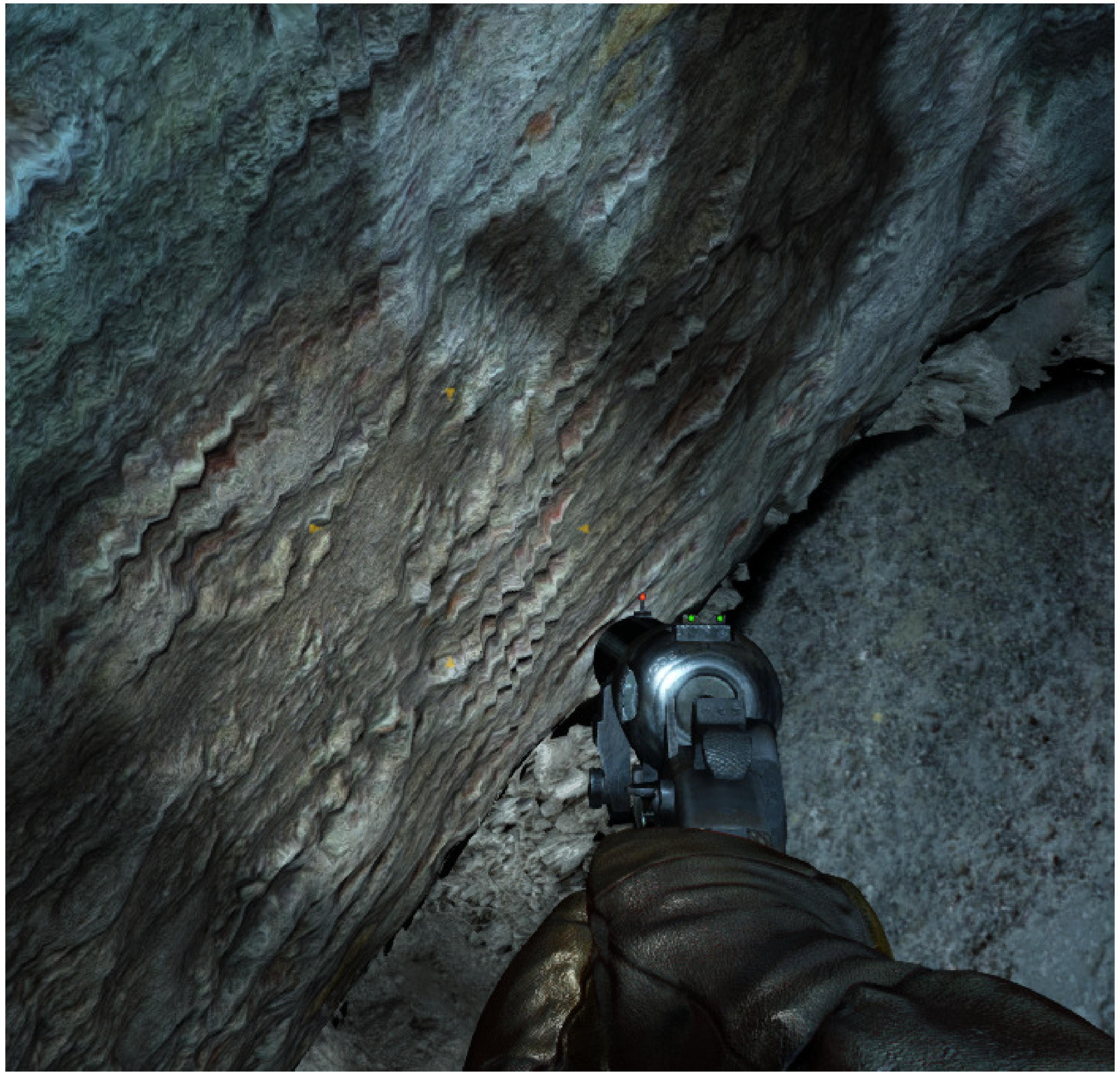
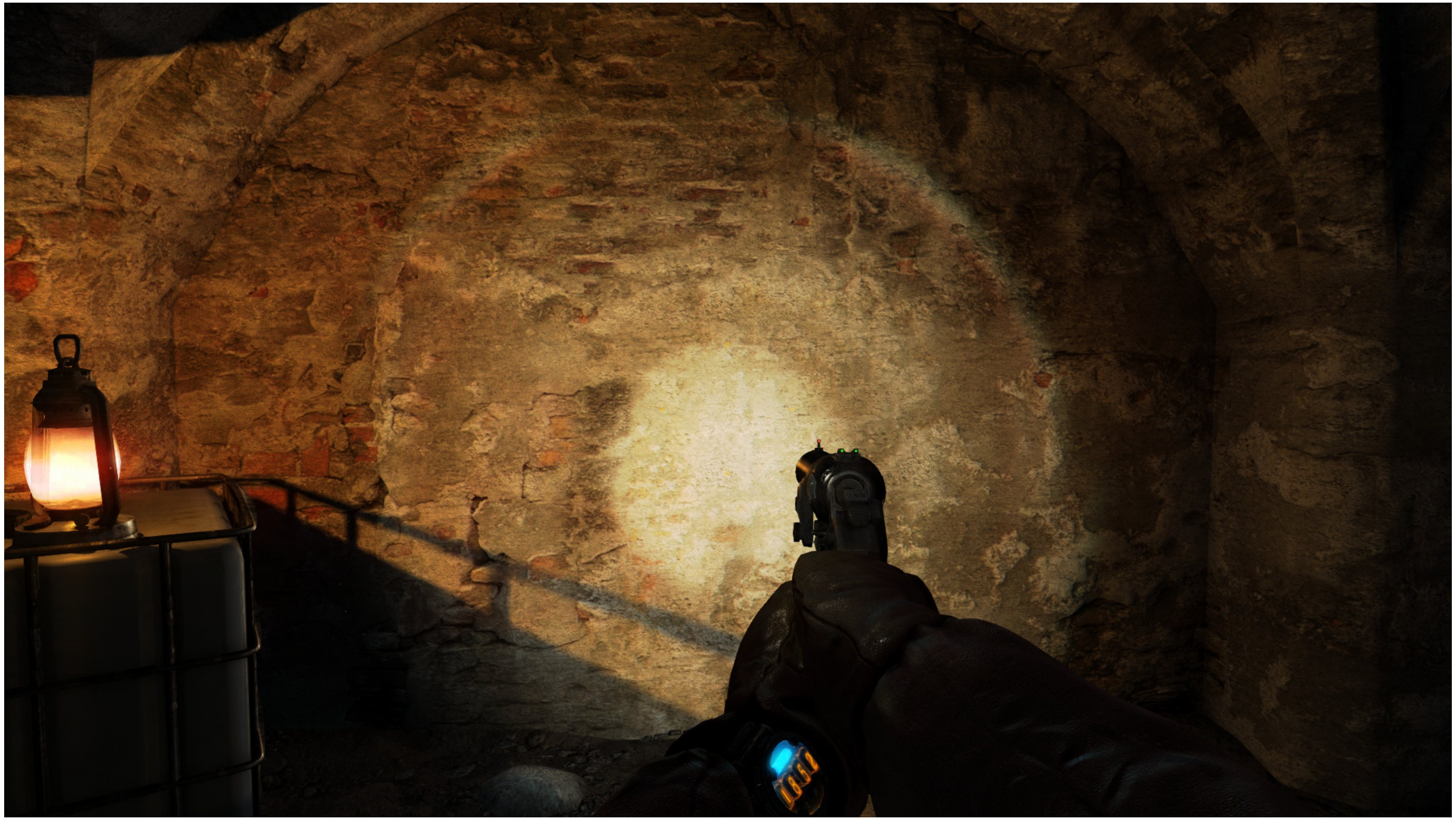


Virtual dicing

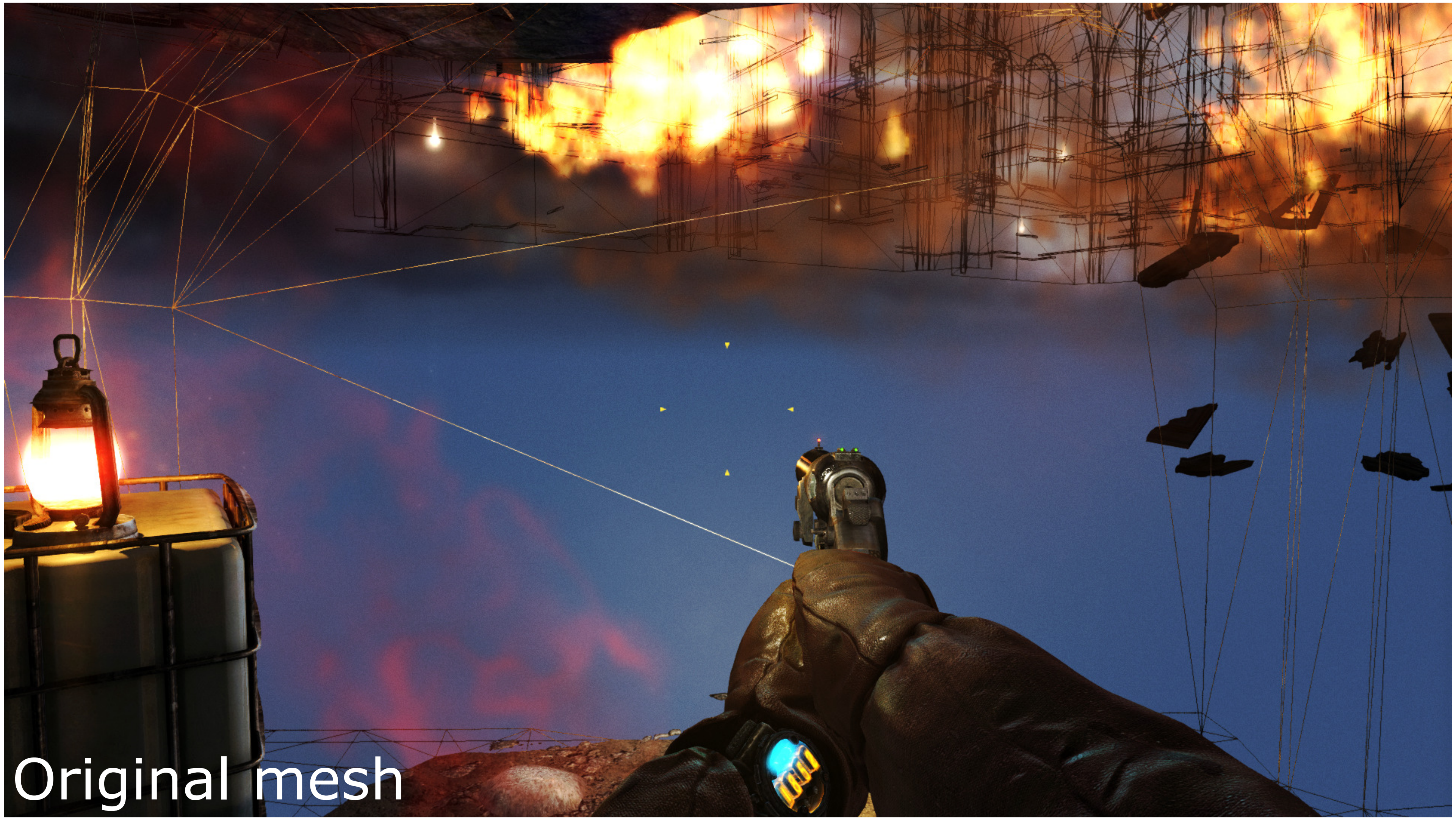
- Virtual dicing subdivides big triangles into smaller ones on-the-fly

- This can also be done offline

Virtual dicing in Metro: Last Light

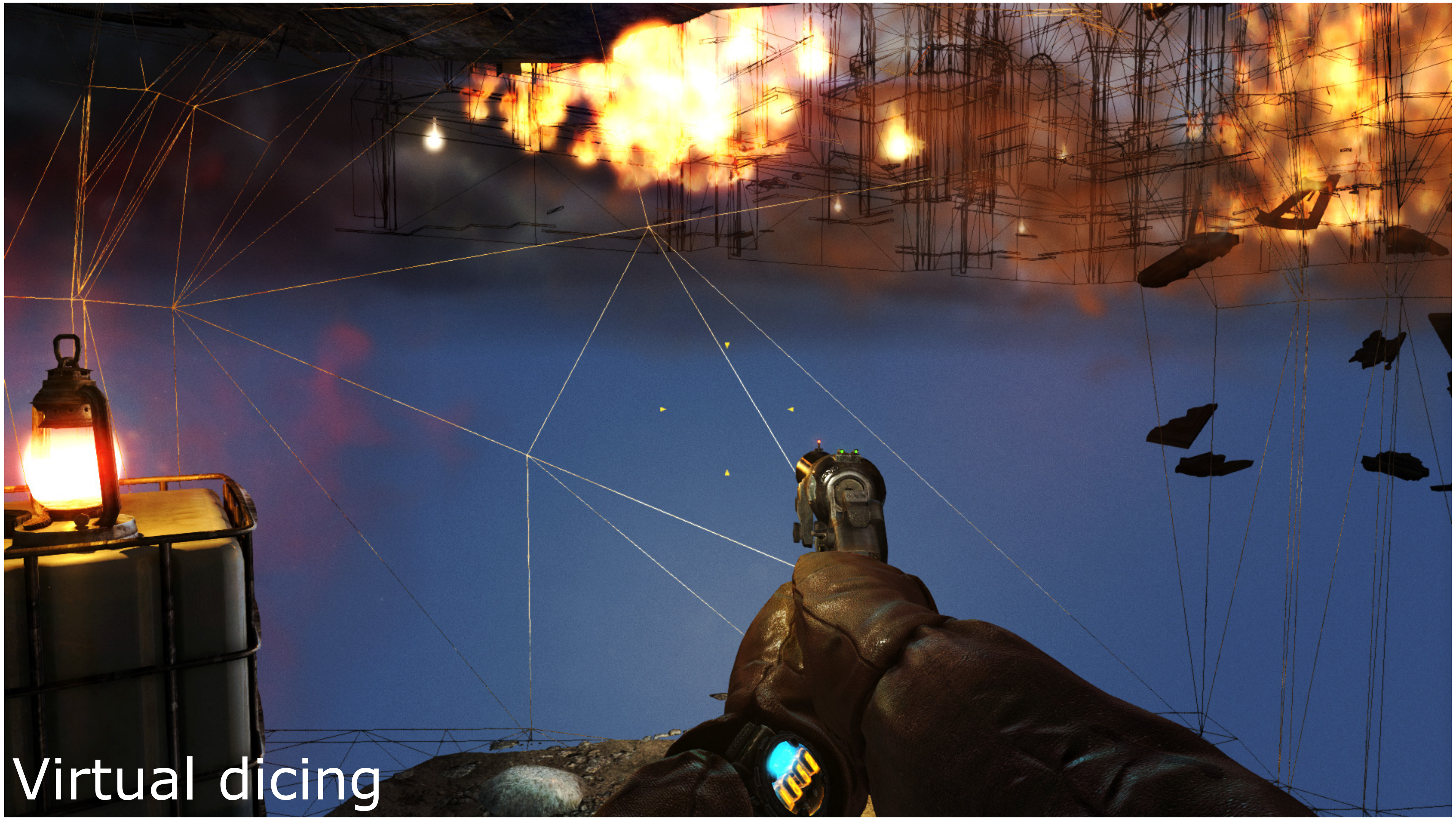


Virtual dicing in Metro: Last Light



Original mesh

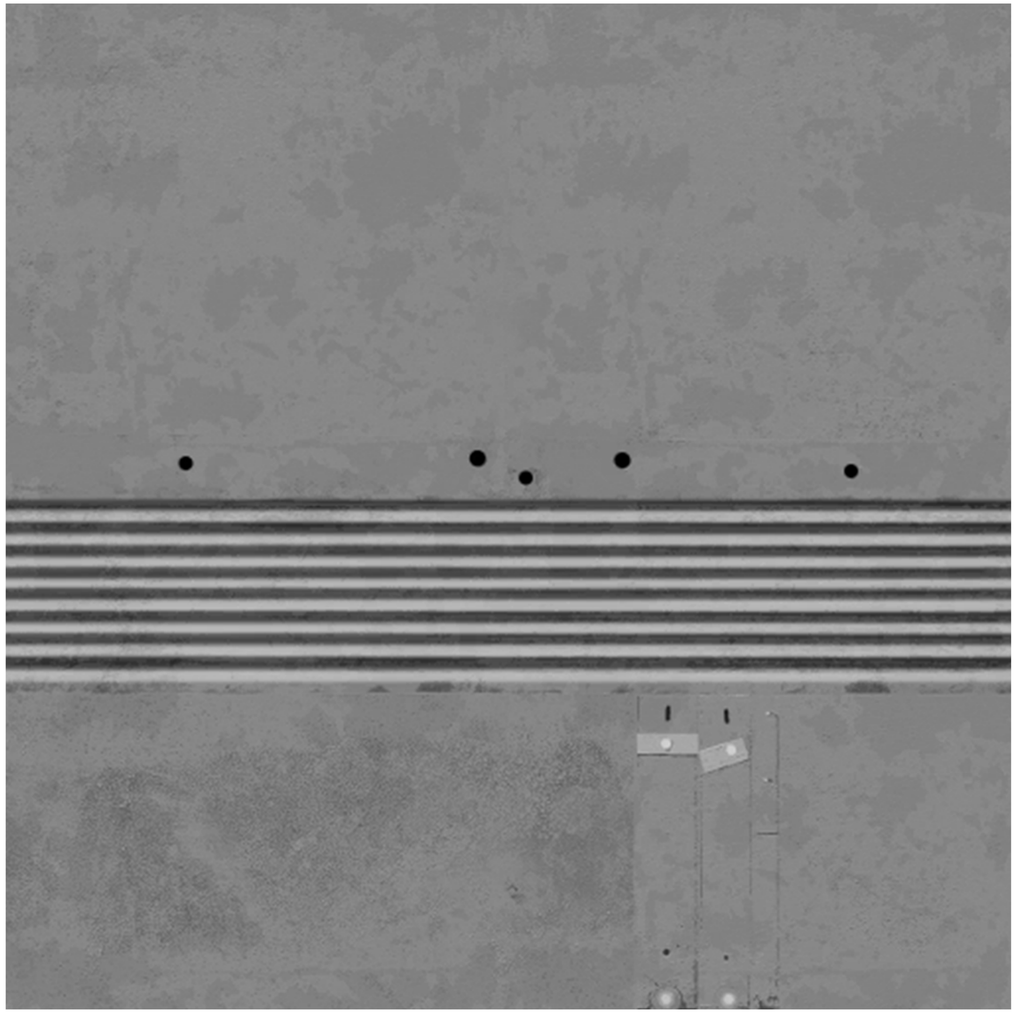
Virtual dicing in Metro: Last Light



Virtual dicing

Over-tessellating is wasteful

- Some areas on displacement maps don’t require high tessellation factors



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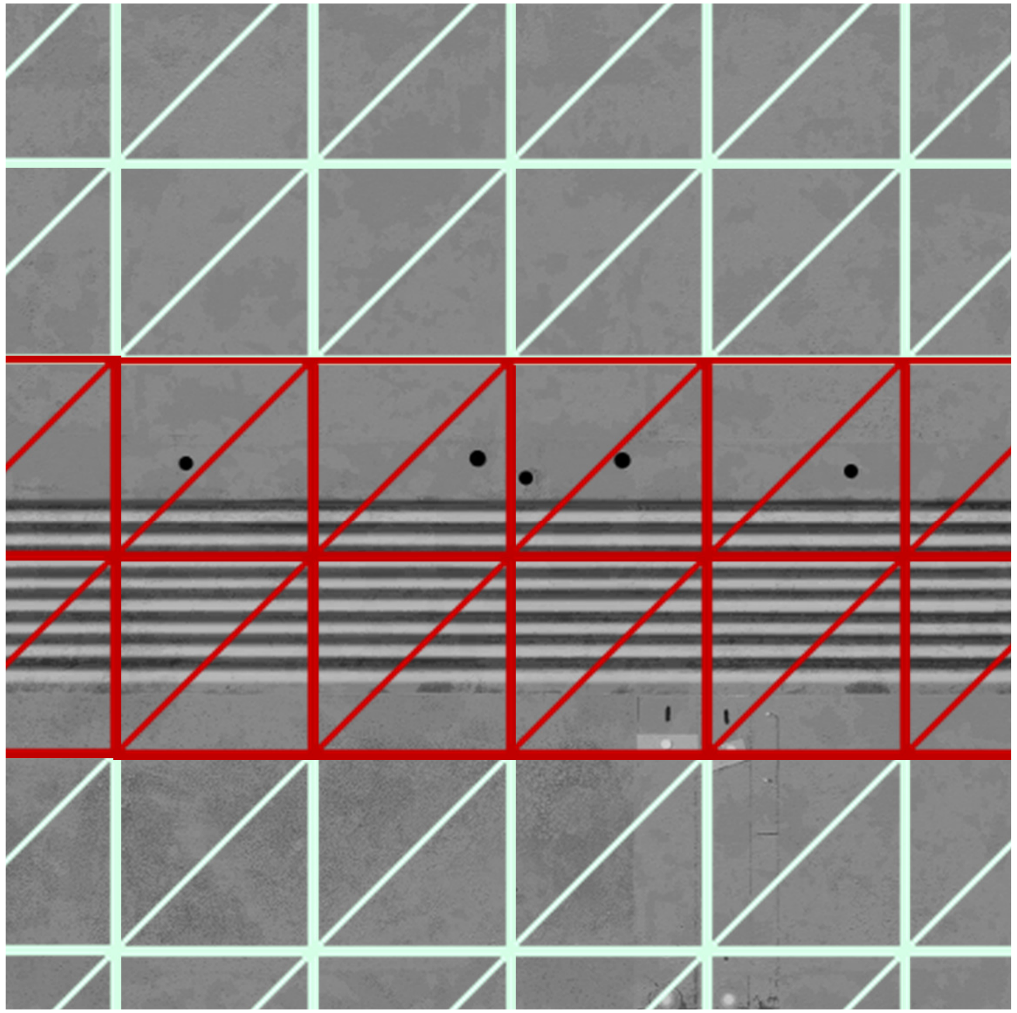

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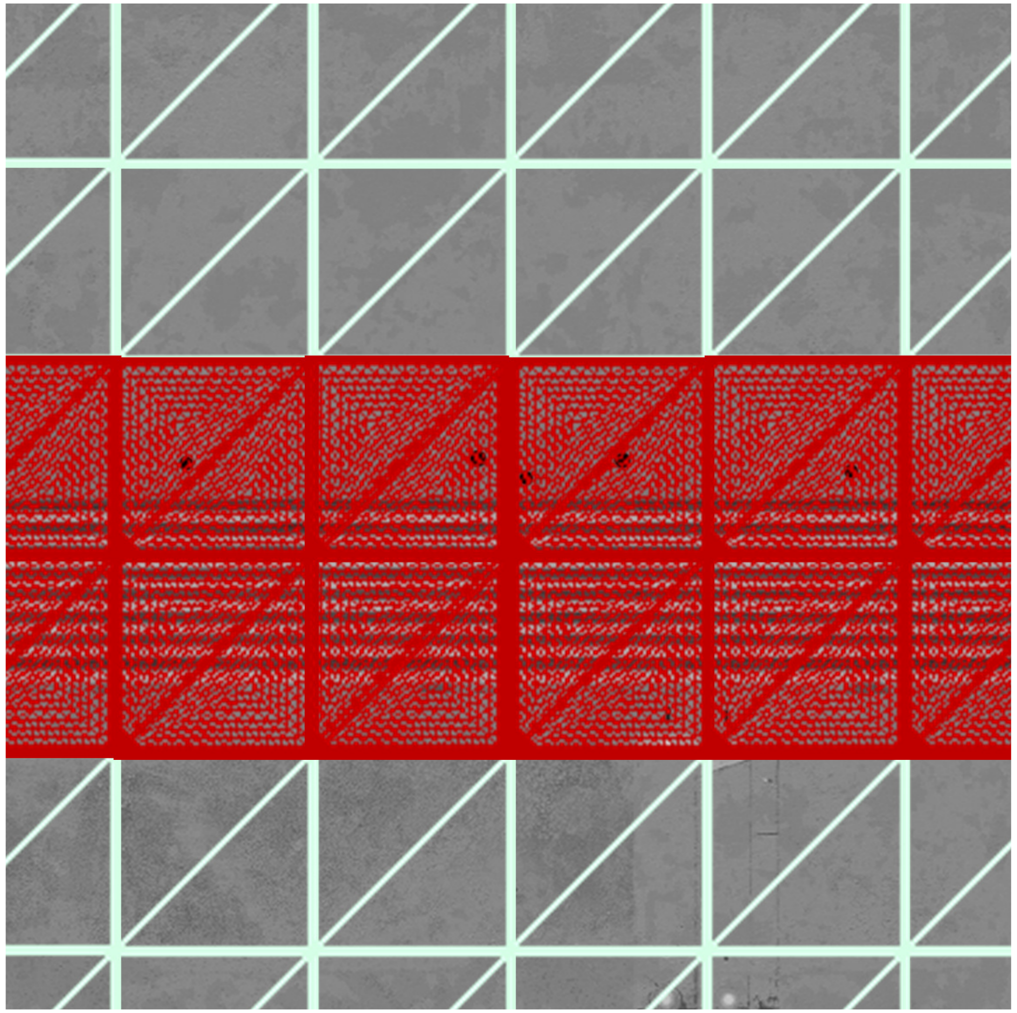

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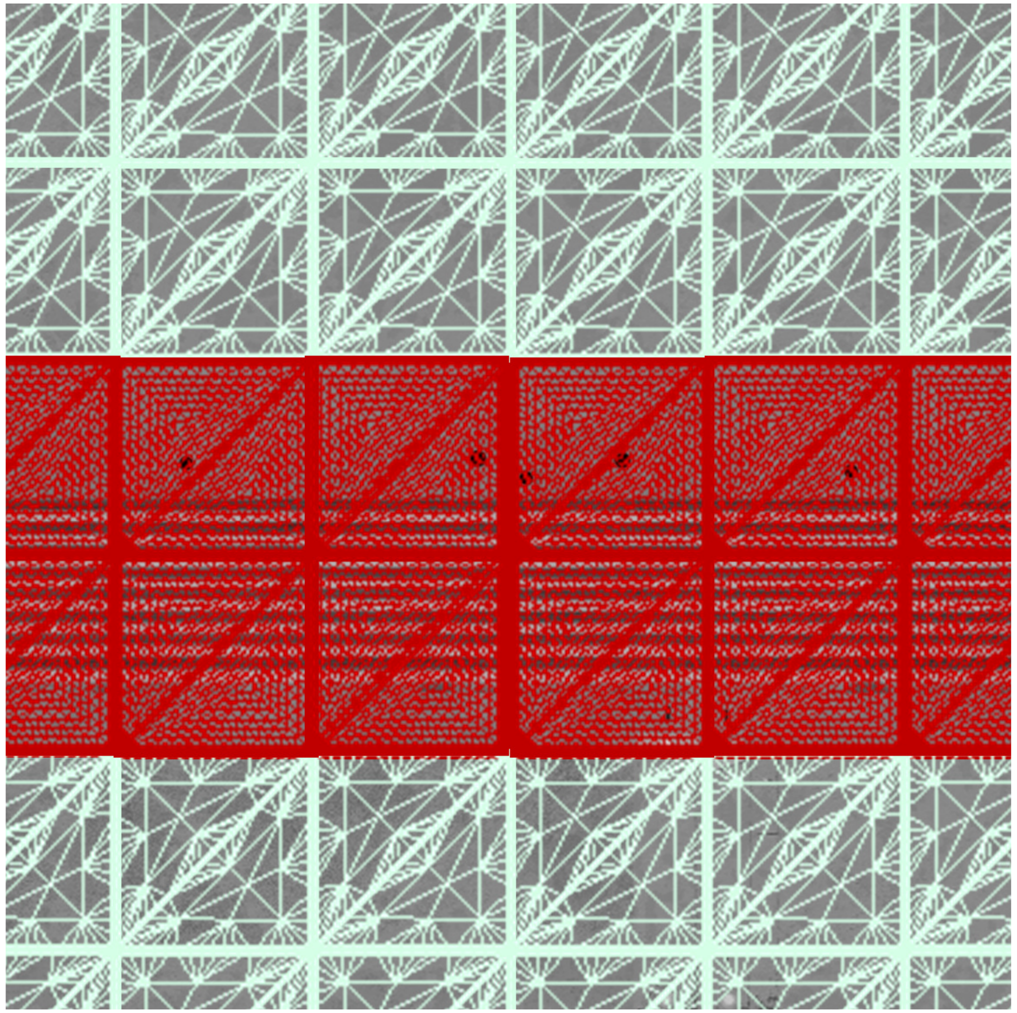
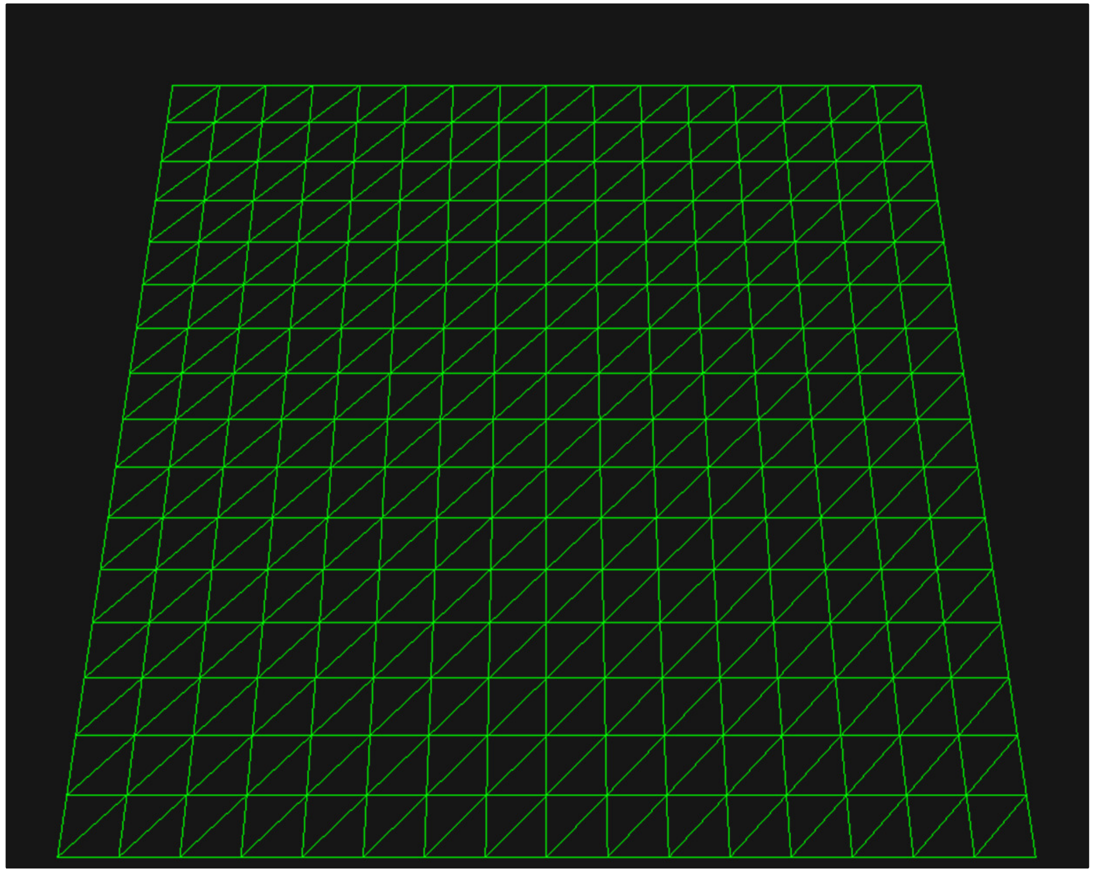


Use adaptive tessellation

- Analyze the displacement map covered by the triangle
- Adjust the inside tessellation factor accordingly

Adaptive tessellation in detail

- Use a simple quad mesh as an example



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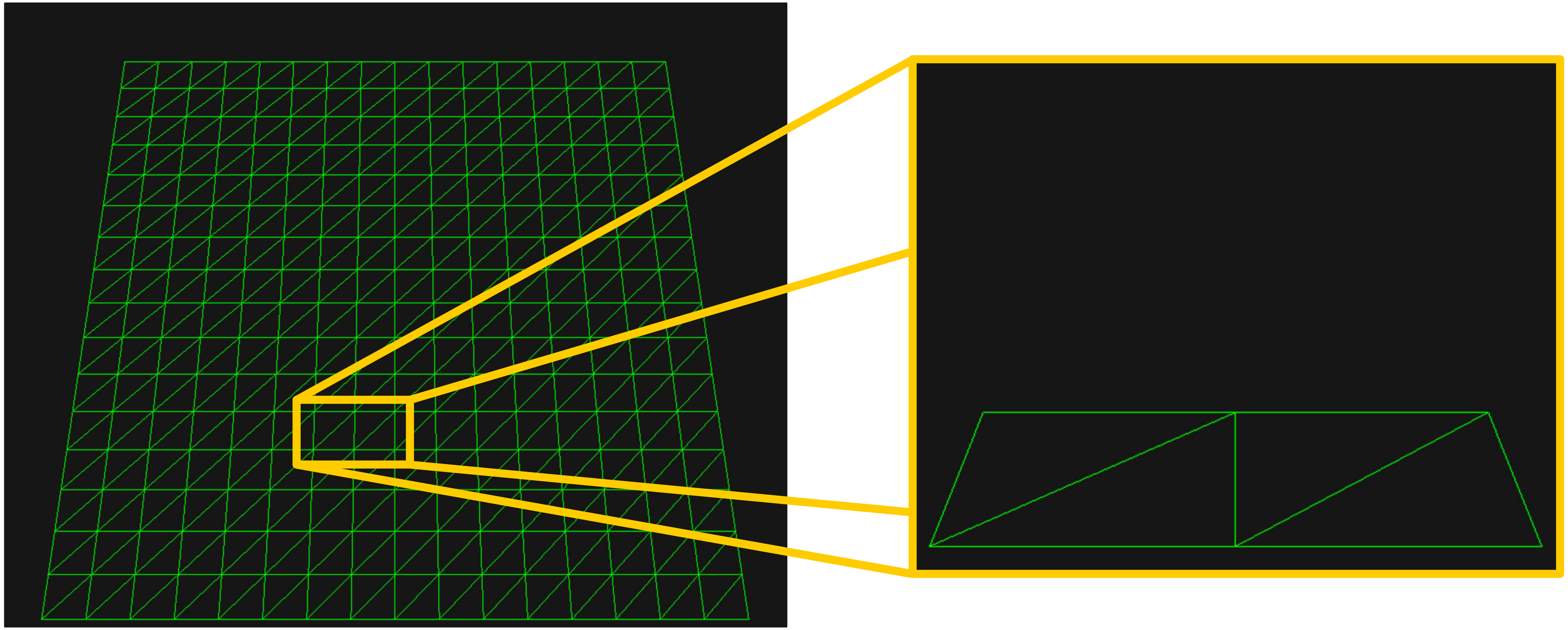
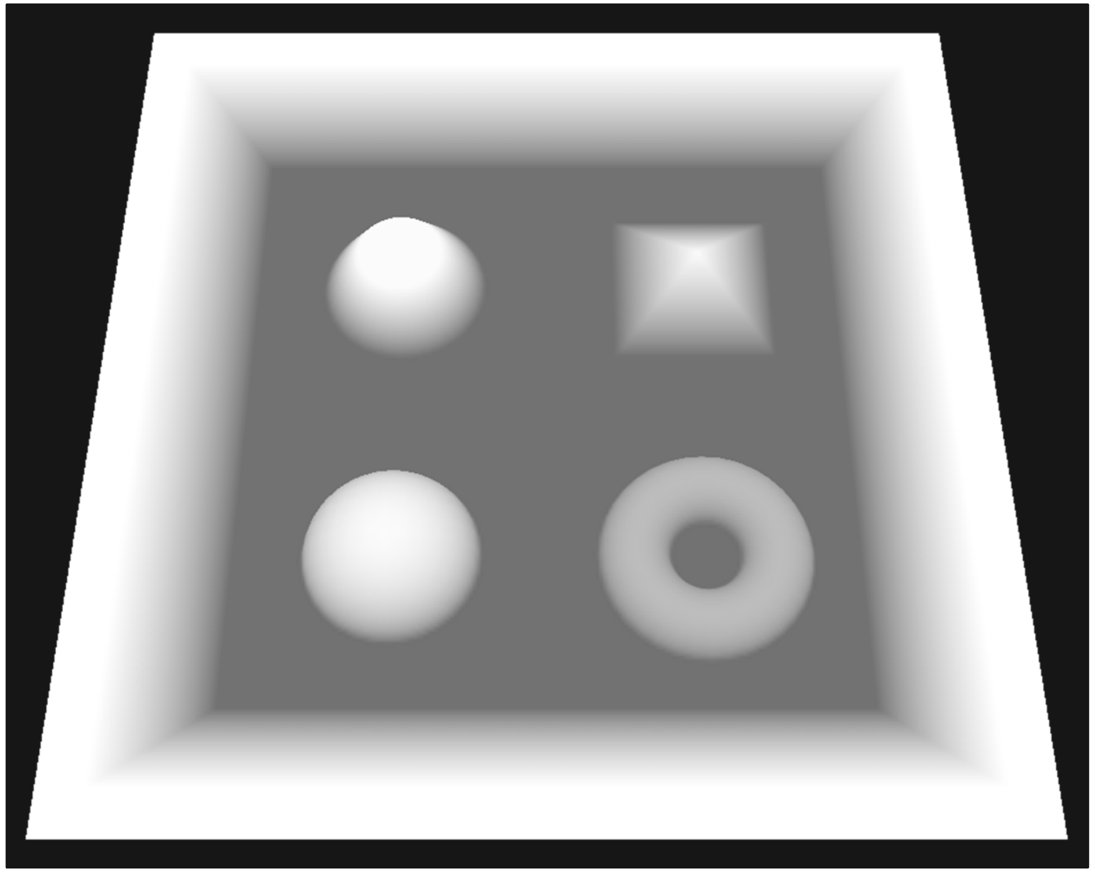


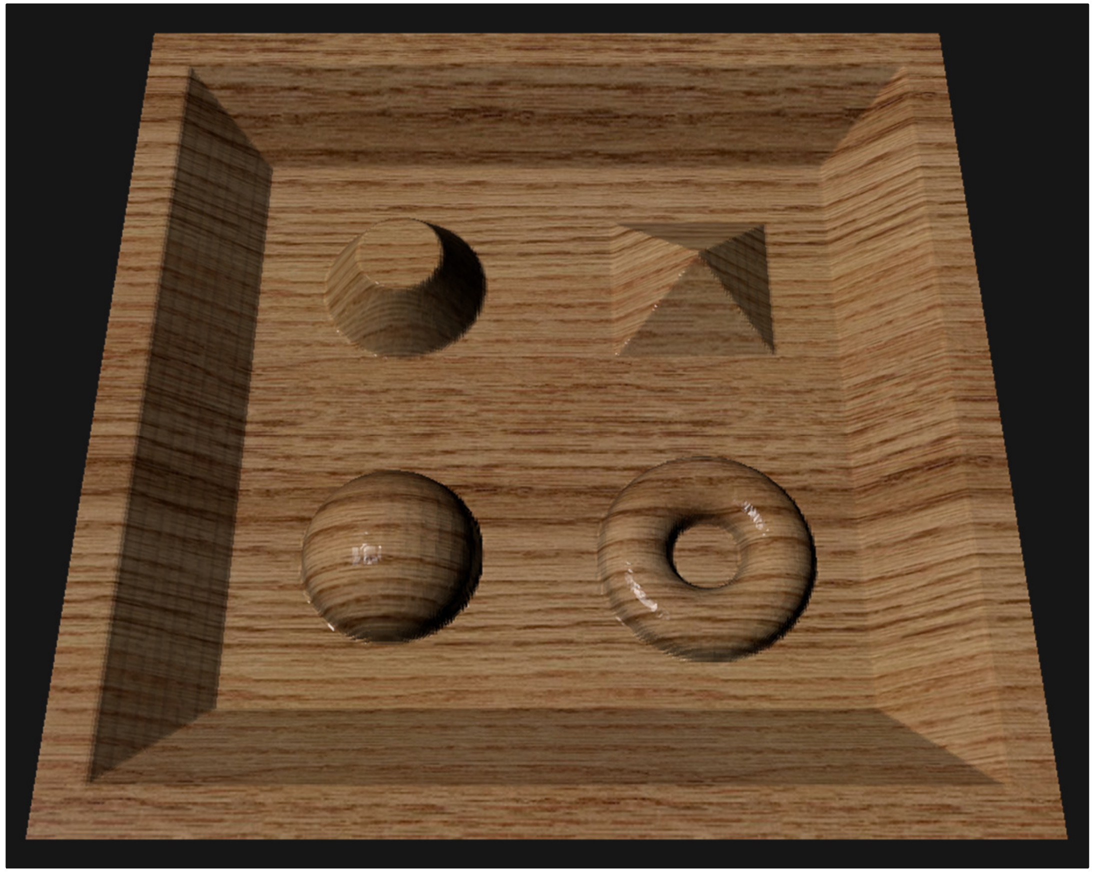
Adaptive tessellation in detail

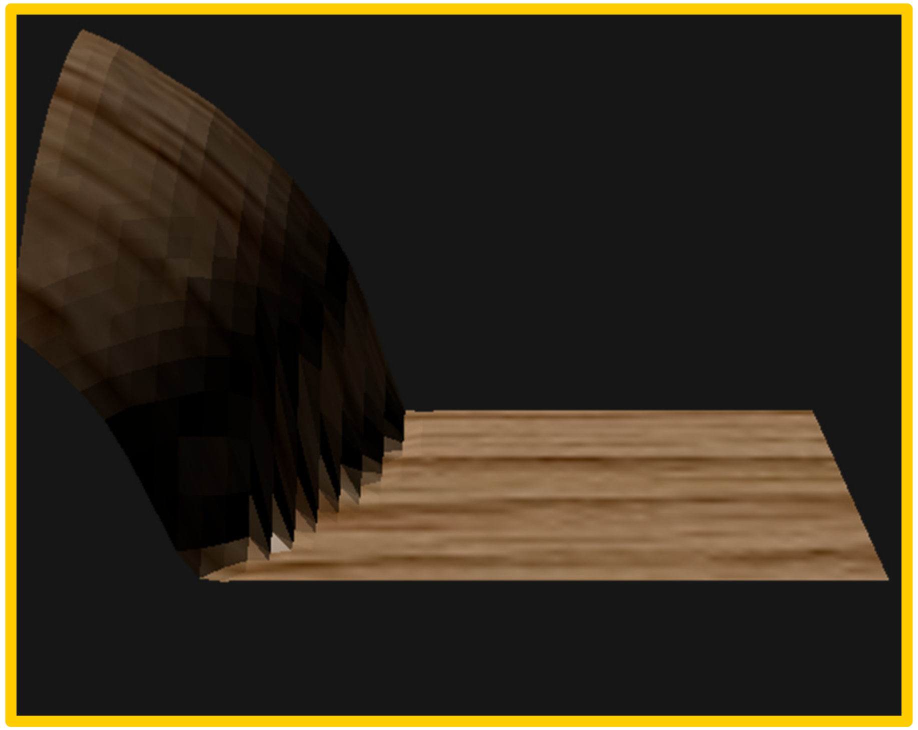
- Add displacement map



Adaptive tessellation in detail

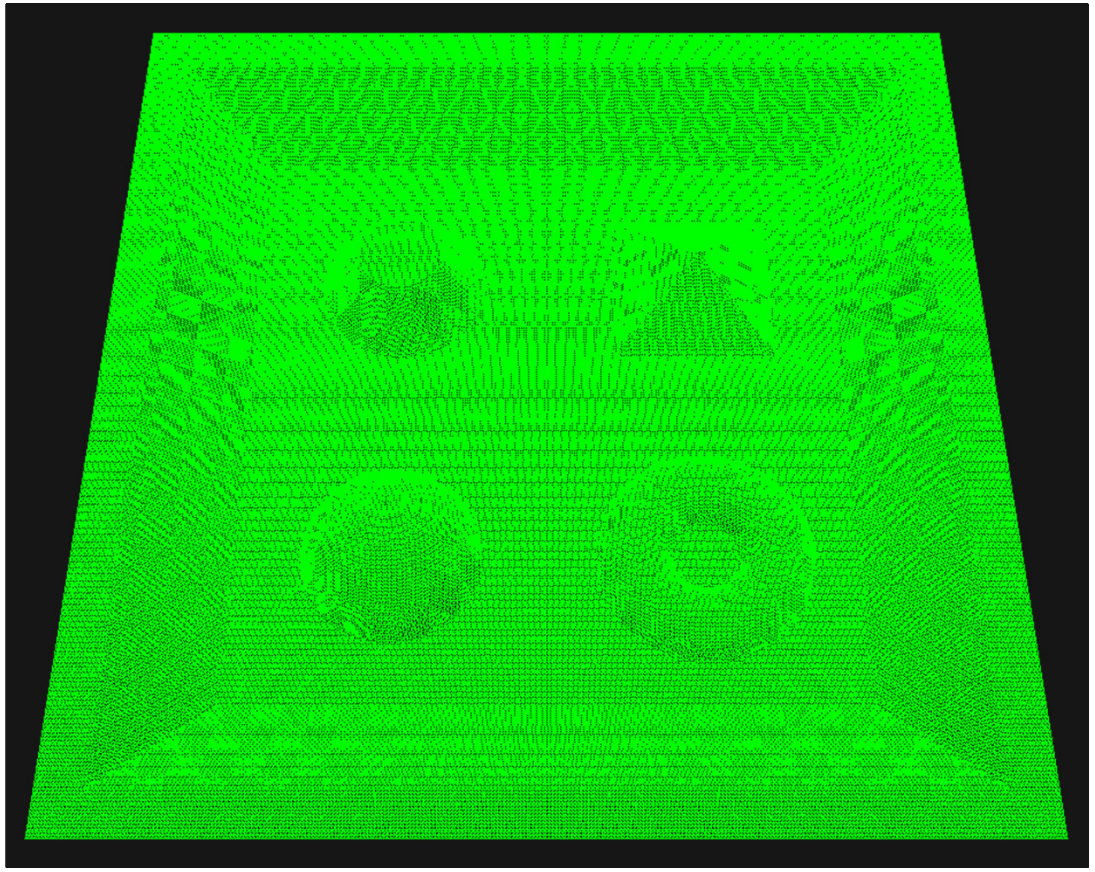
- Smooth shapes require high expansion

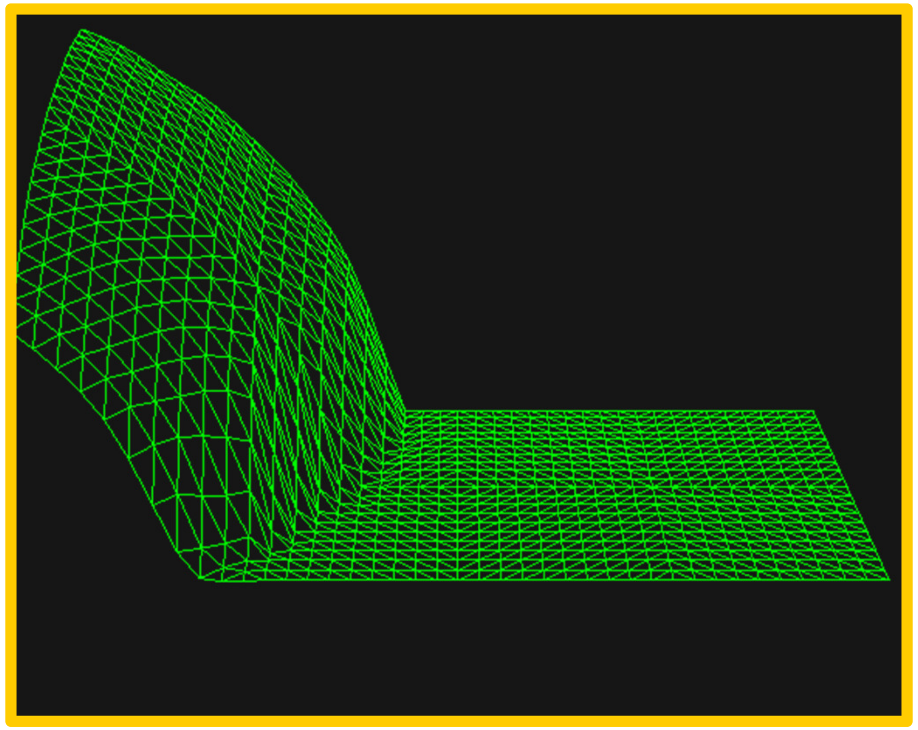




Adaptive tessellation in detail

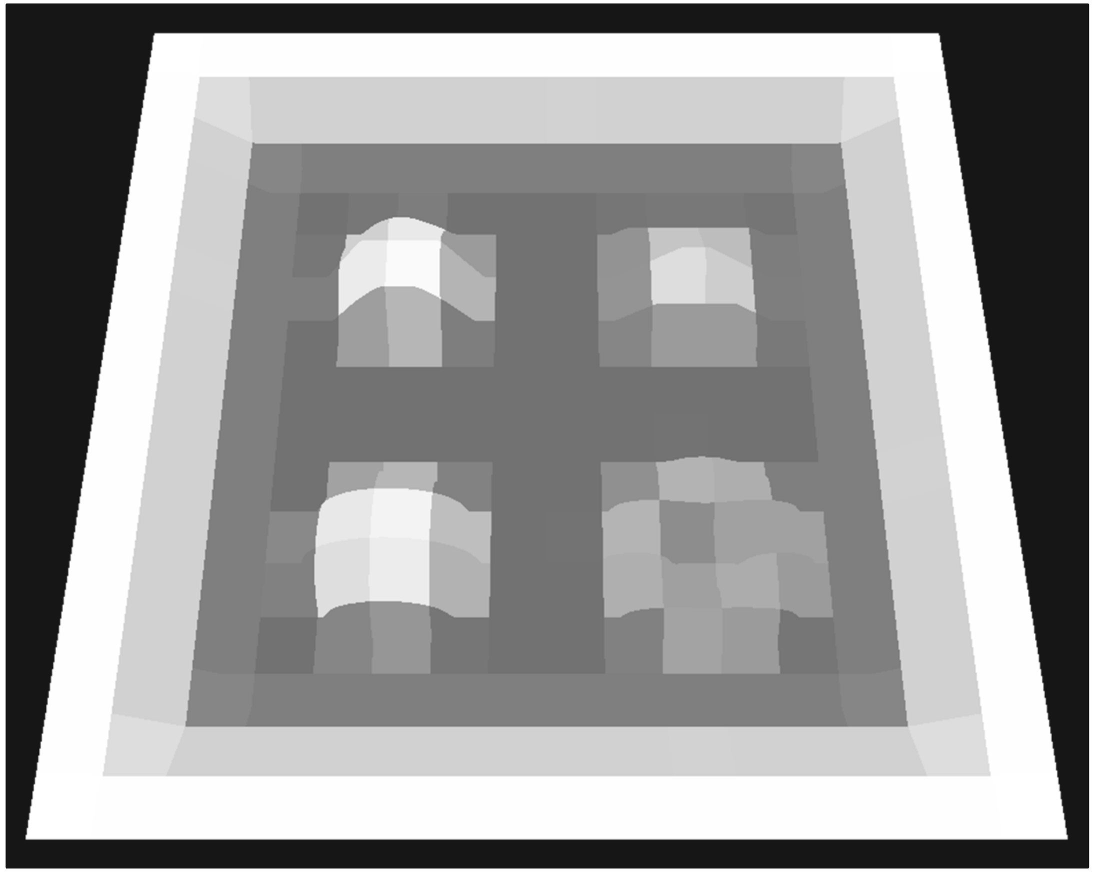
- Flat areas can use lower expansion

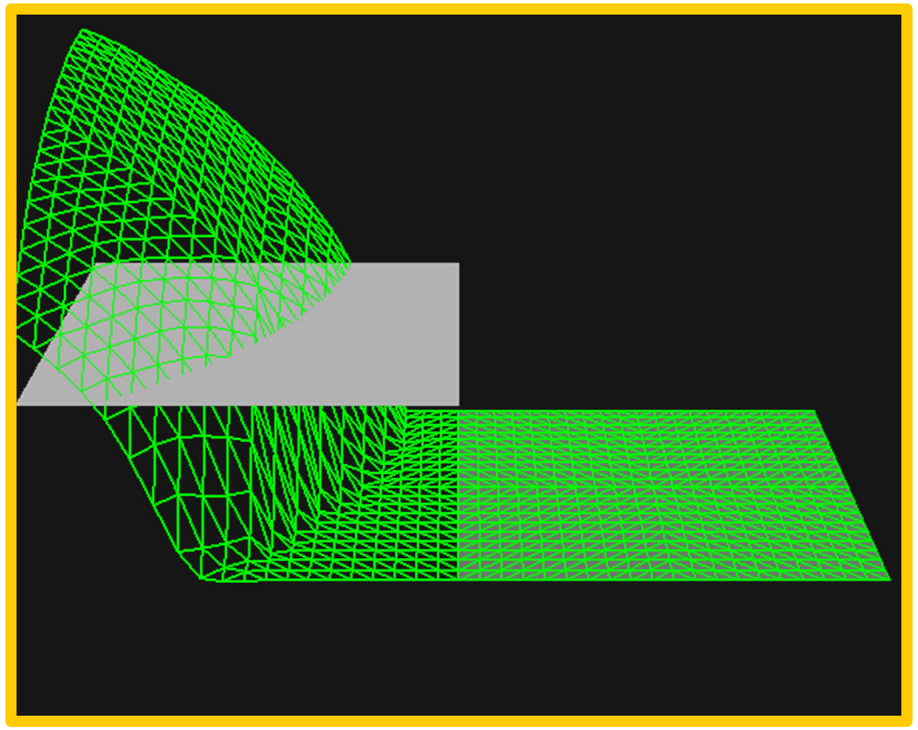




Adaptive tessellation in detail

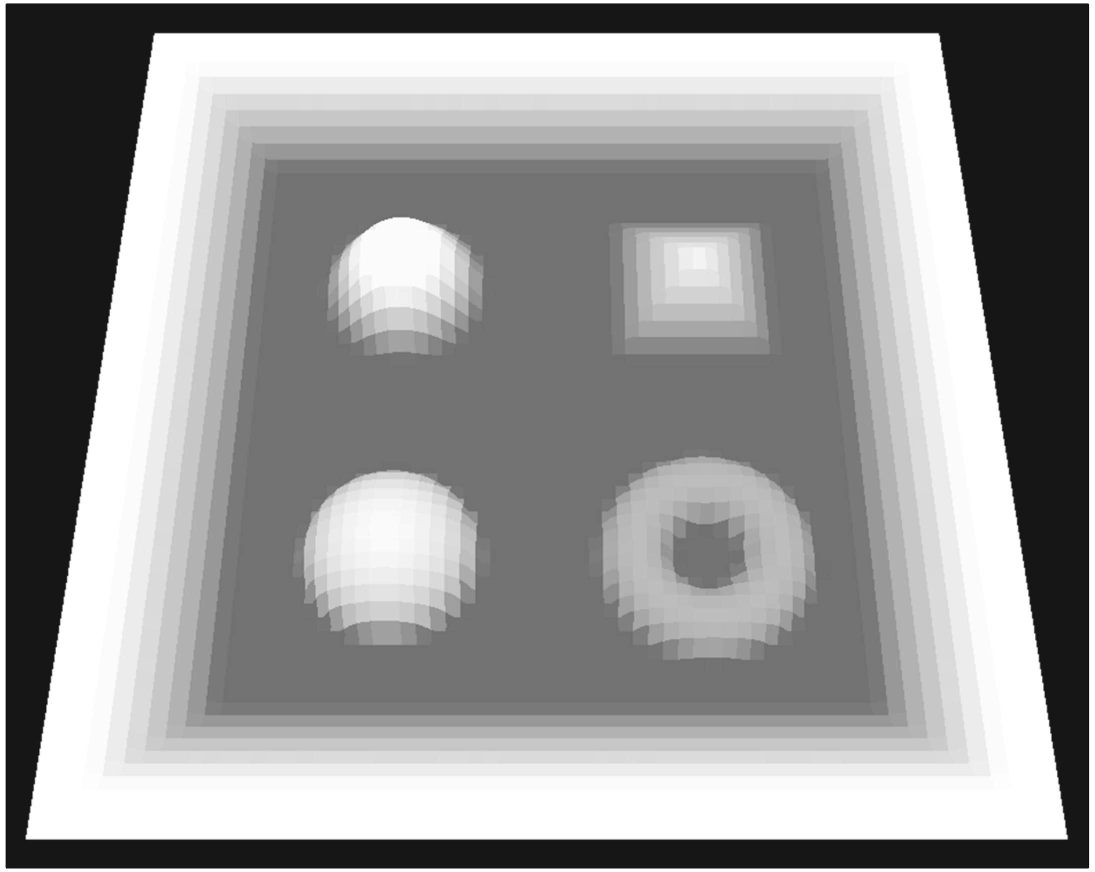
- Take the average from coarse mip-level

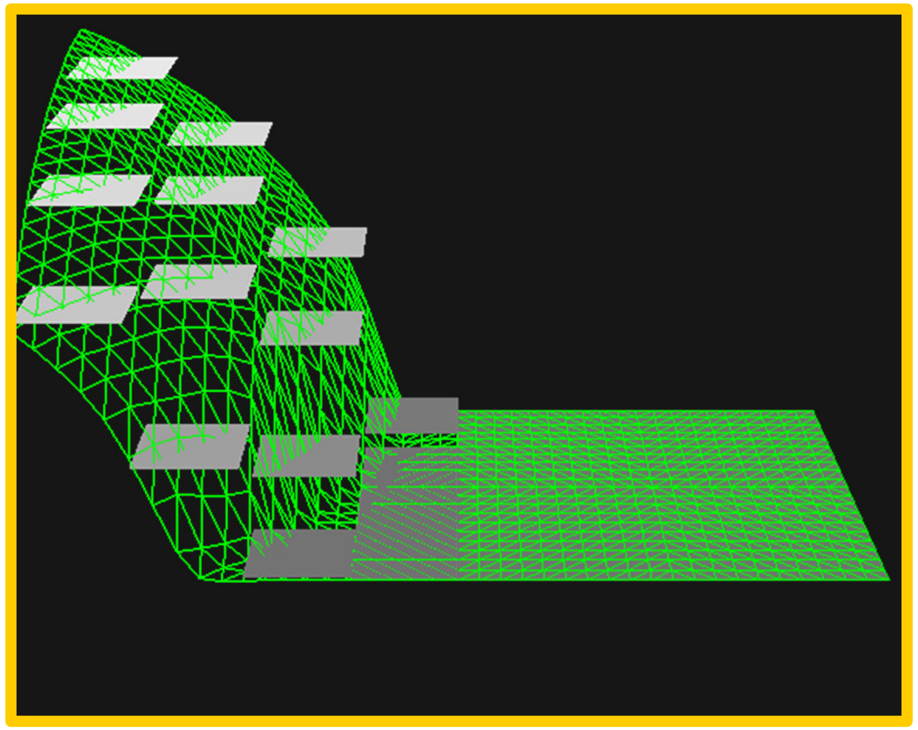




Adaptive tessellation in detail

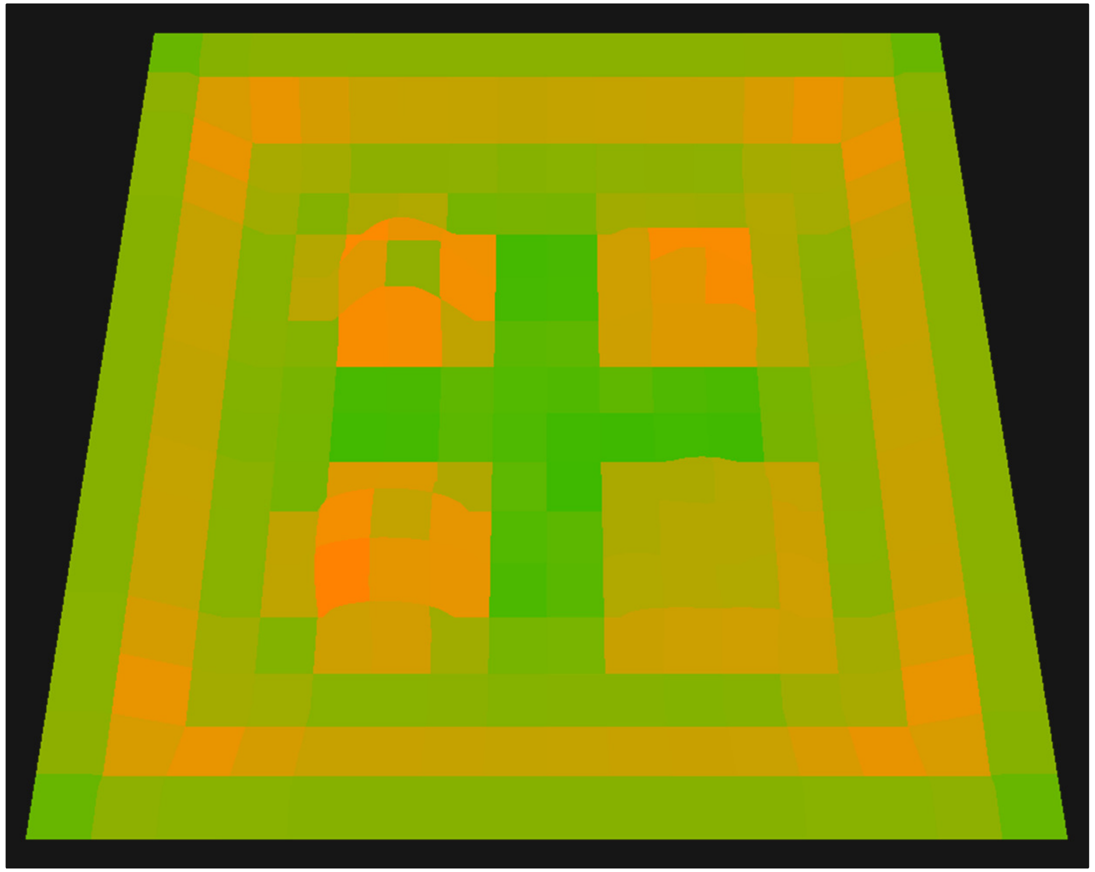
- Use finer mip-level to calculate variance

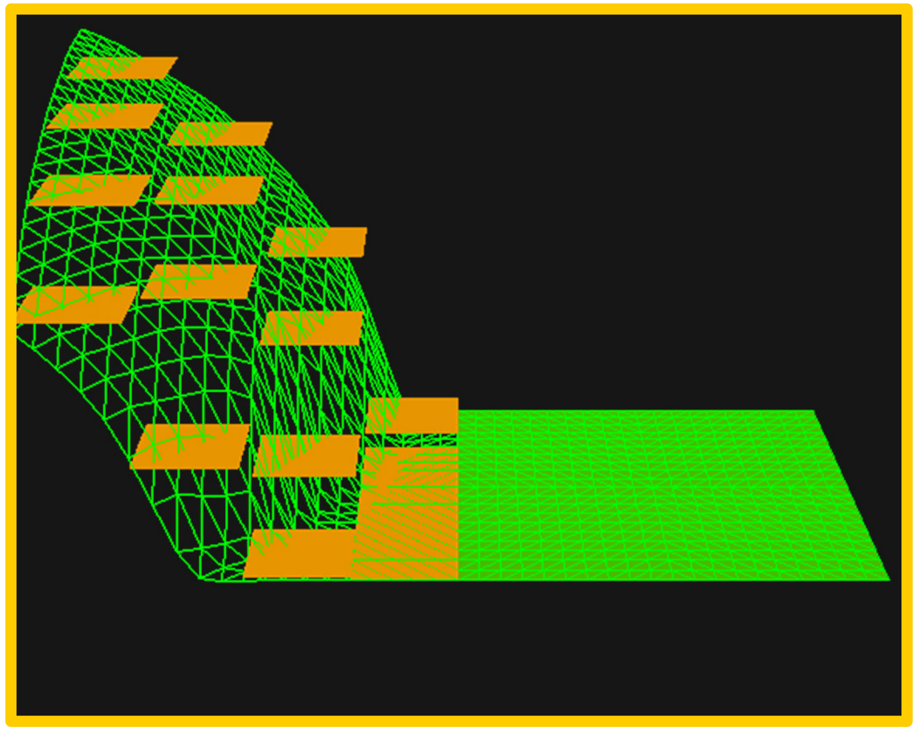




Adaptive tessellation in detail

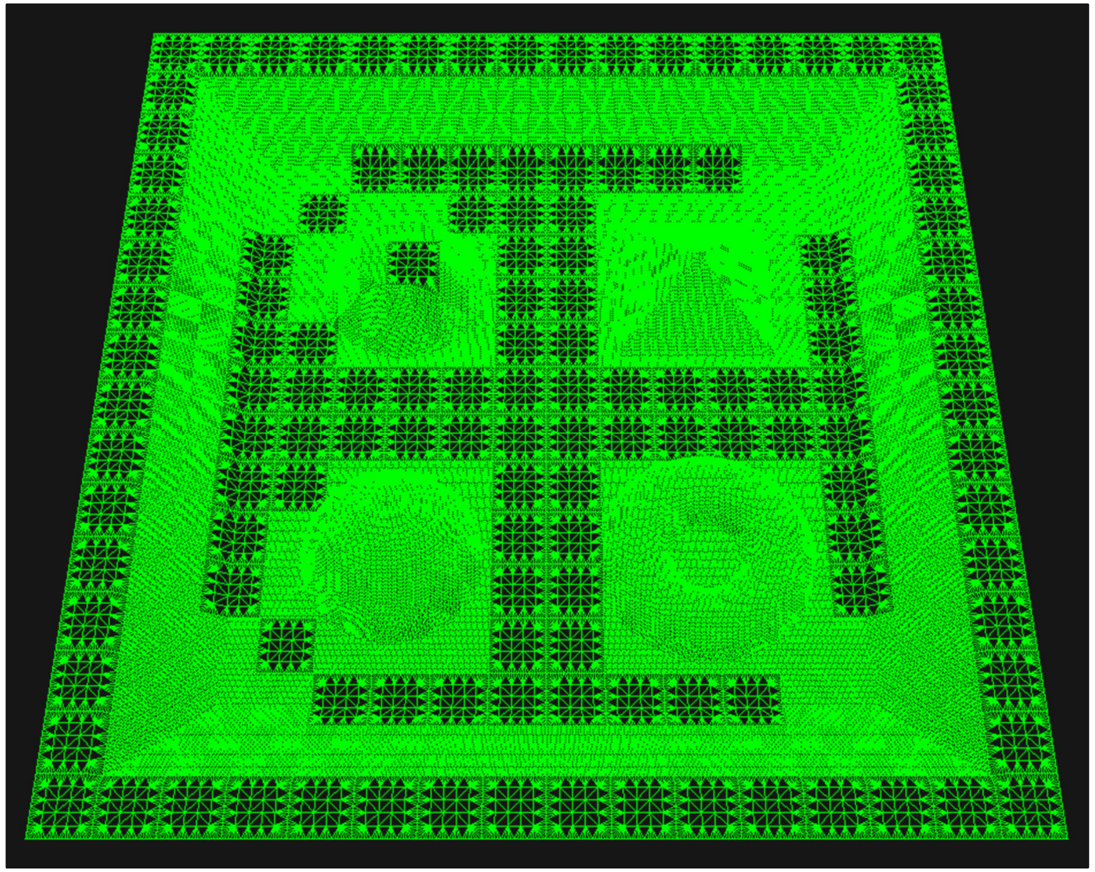
- Calculate the metric based on variance

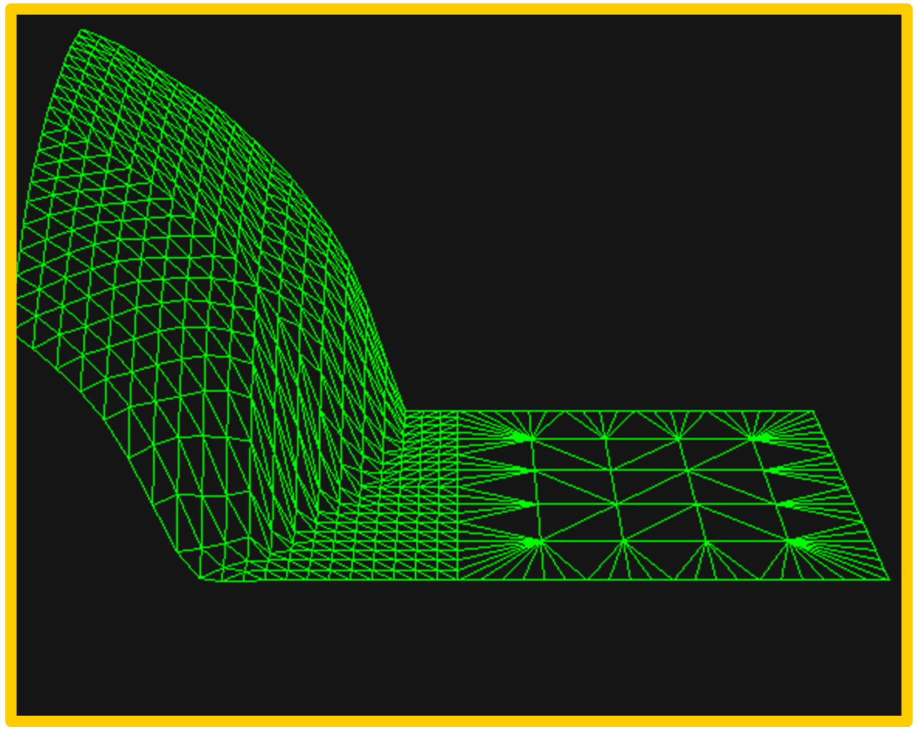




Adaptive tessellation in detail

- Use threshold to control tessellation factors





DEMO

- Metro: Last Light

Performance and conclusions

- Metro: Last Light, Undercity level, 1920x1200, Very High, SSAA OFF

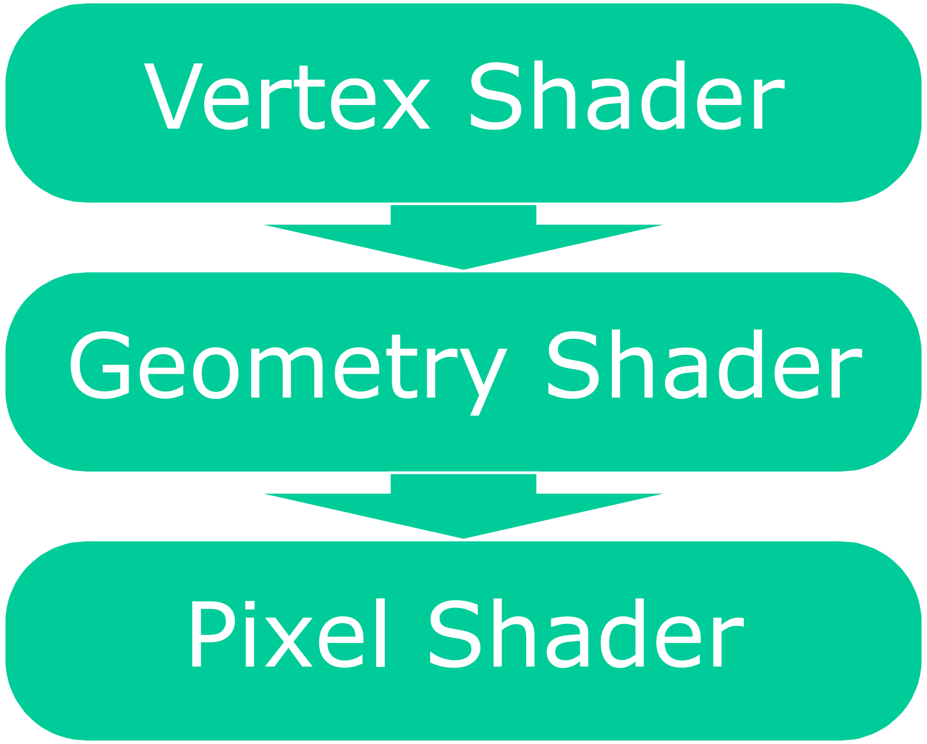
FPS	Adaptive OFF	**Adaptive ON**	Gain
GTX 750Ti	17.2	**31.1**	**2X**
GTX 760	27.8	**47.2**	**2X**
GTX 770	35.1	**60.7**	**2X**
R7 260X	16.2	**29.4**	**2X**
R9 270X	13.9	**41.6**	**3X**
R9 280X	14.9	**57.7**	**4X**

Performance and conclusions

- Adaptive tessellation doubles performance on tessellation-heavy levels in Metro: Last Light
- Don’t be afraid to tessellate densely where needed
- But use your triangles efficiently!

Another meaning of tessellation

- Before DX11, we could only perform calculations at vertex, geometry or pixel rates


Vertex Shader

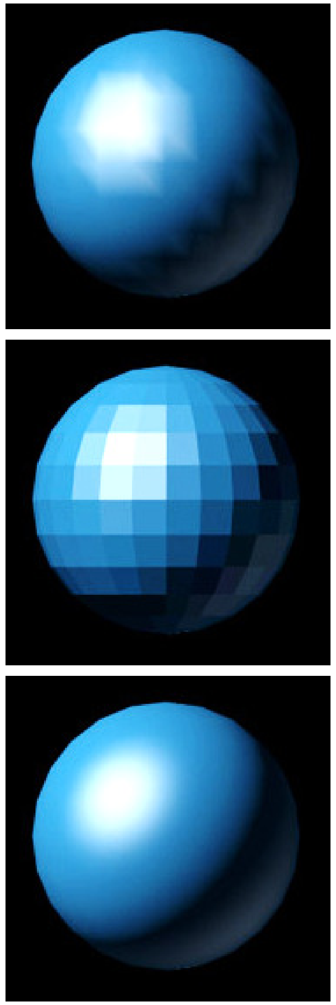
Geometry Shader

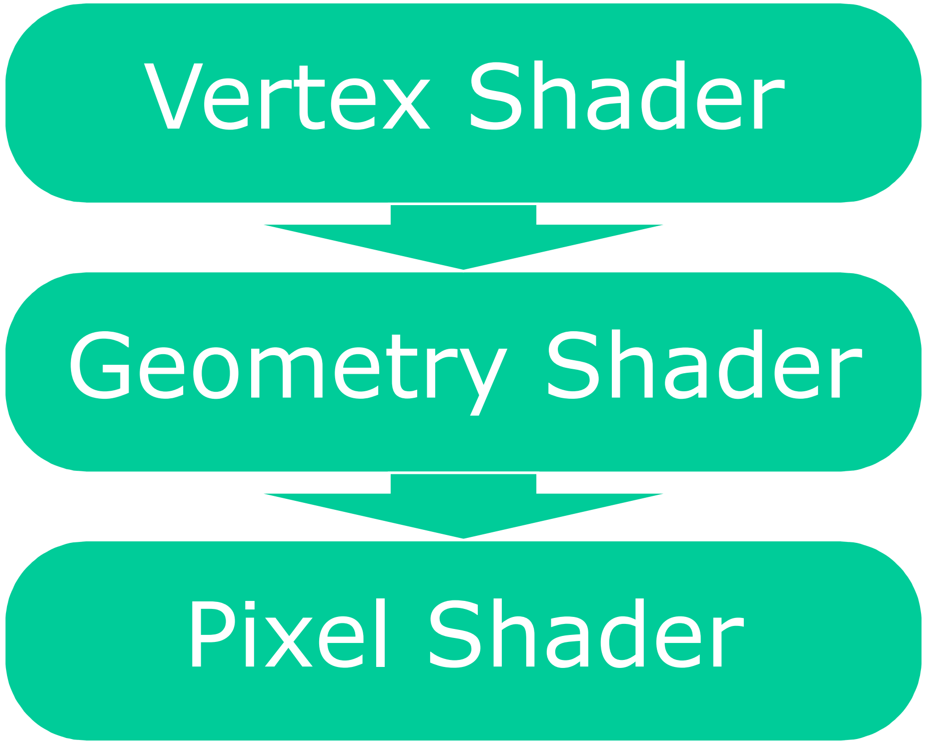
Pixel Shader

Another meaning of tessellation

Same Blinn-Phong shading done at different rates:

- Gouraud
- Flat
- Phong





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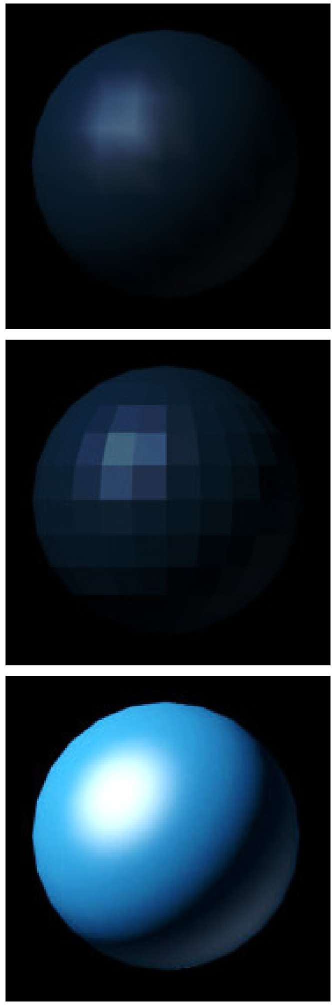
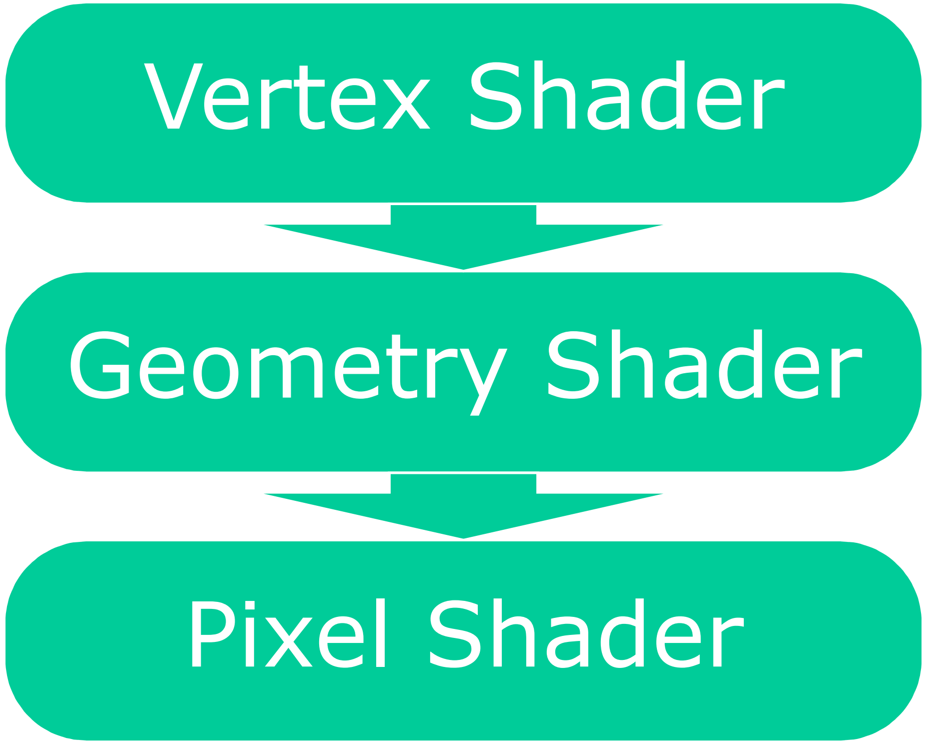
Only Phong looks nice

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Another meaning of tessellation

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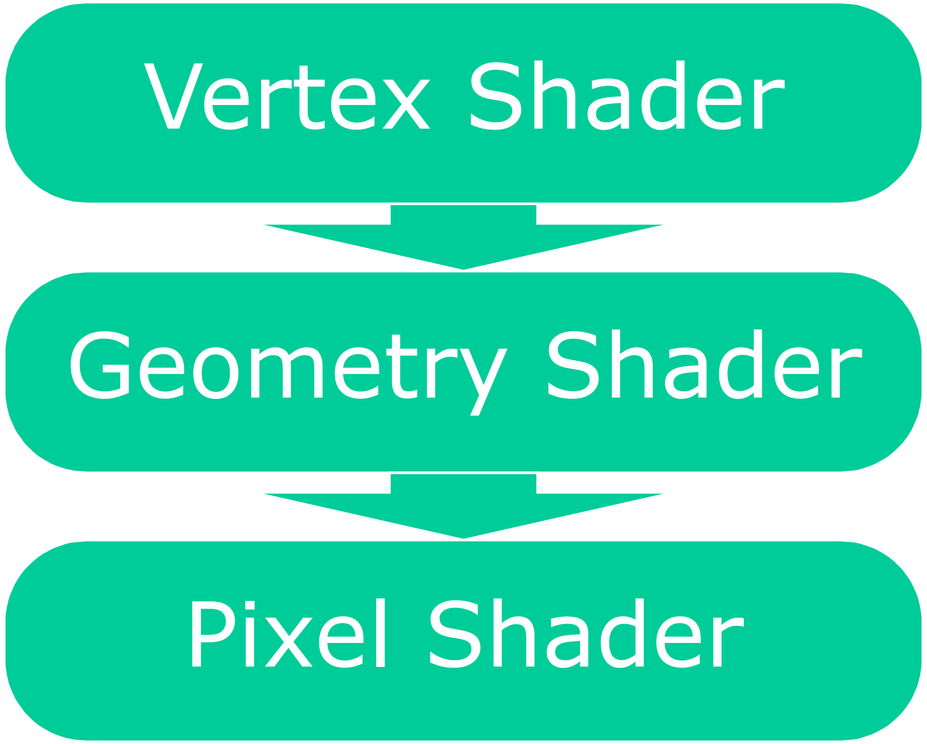
- Vertex or geometry rate is too low
- For some effects, pixel rate is too high



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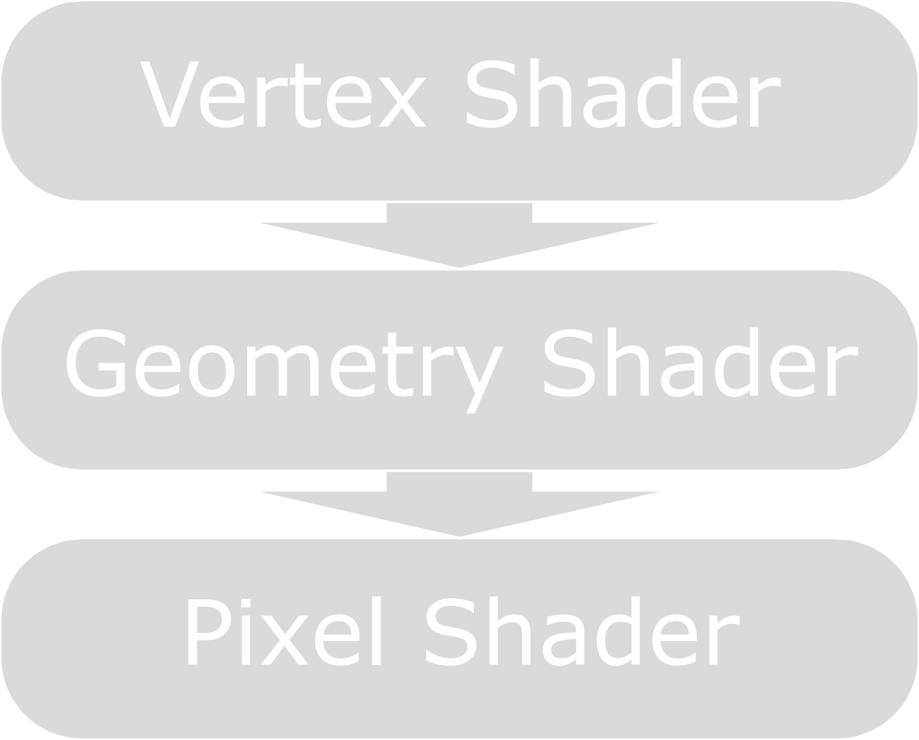
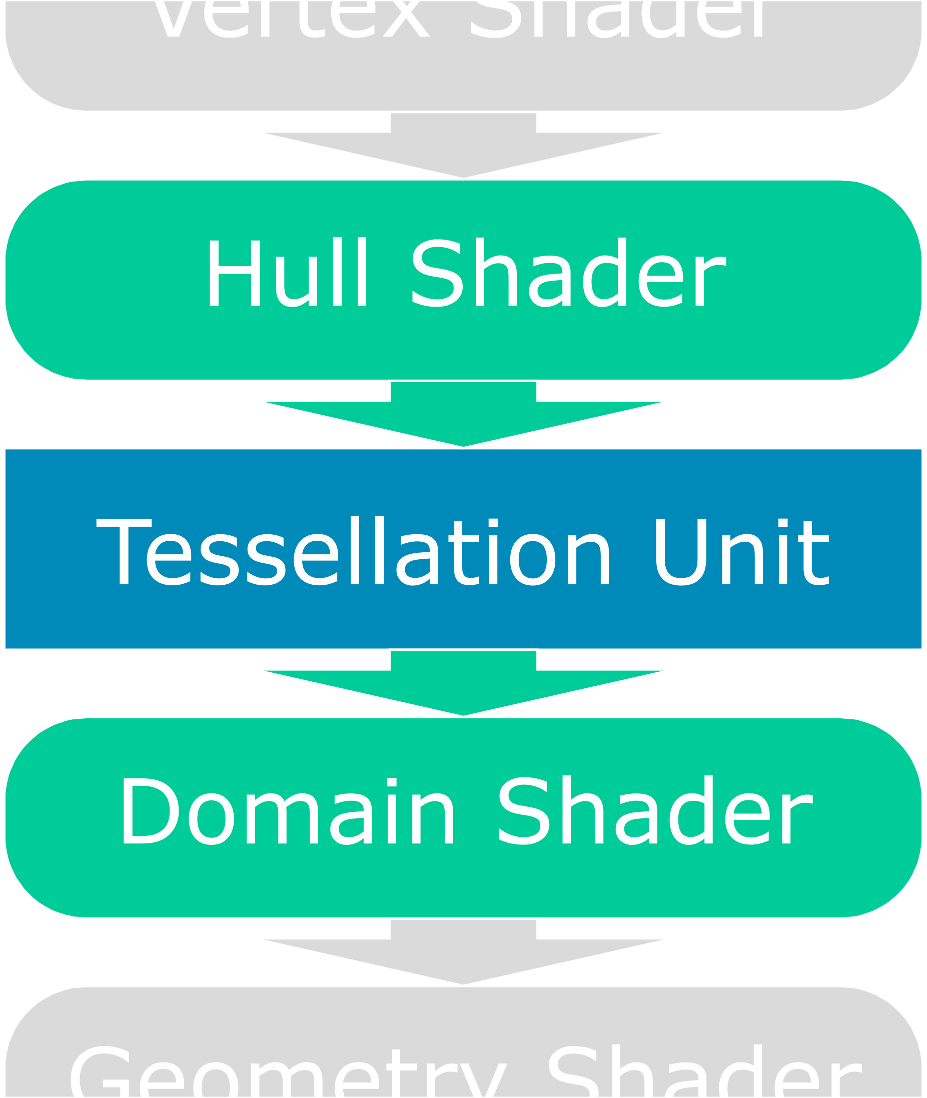


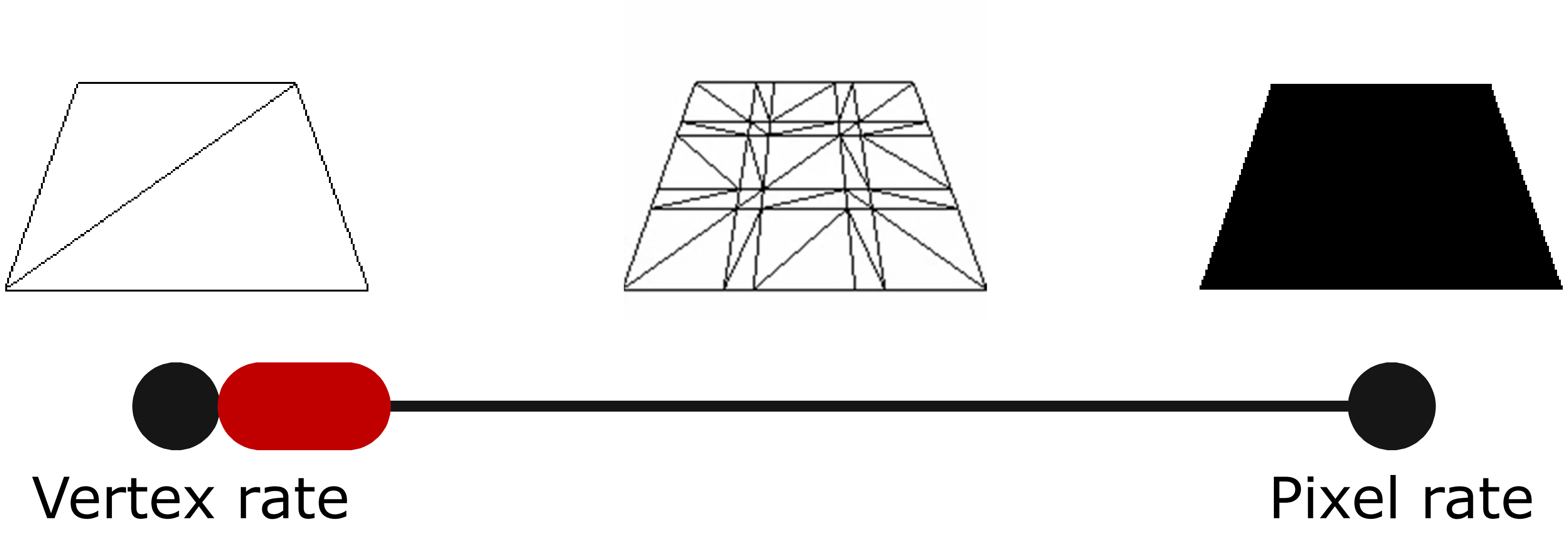
Another meaning of tessellation

- Tessellation is a stage with adjustable shading rate



Adjustable shading rate

- Hull shader is a “slider” that allows to adjust shading rate
- Domain shader does the actual shading

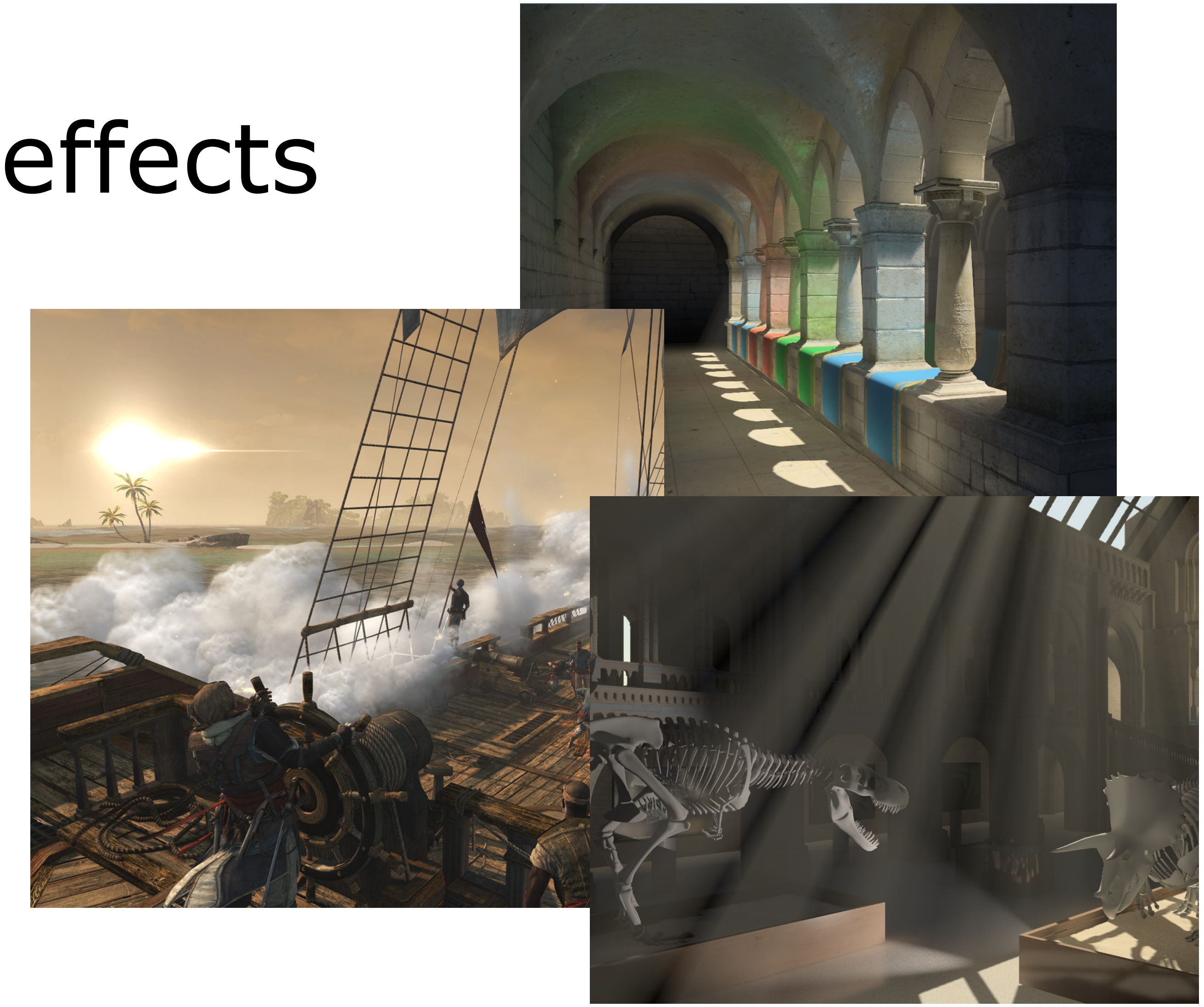


Adjustable shading rate

- Similar to Reyes pipeline
  - Shading is done in object space
  - Sampling (rasterization) is only used to interpolate results

Which effects can benefit from it?

- Computation-heavy effects with low frequency
  - Particle shadows
  - Volumetric effects
  - Global illumination
  - …



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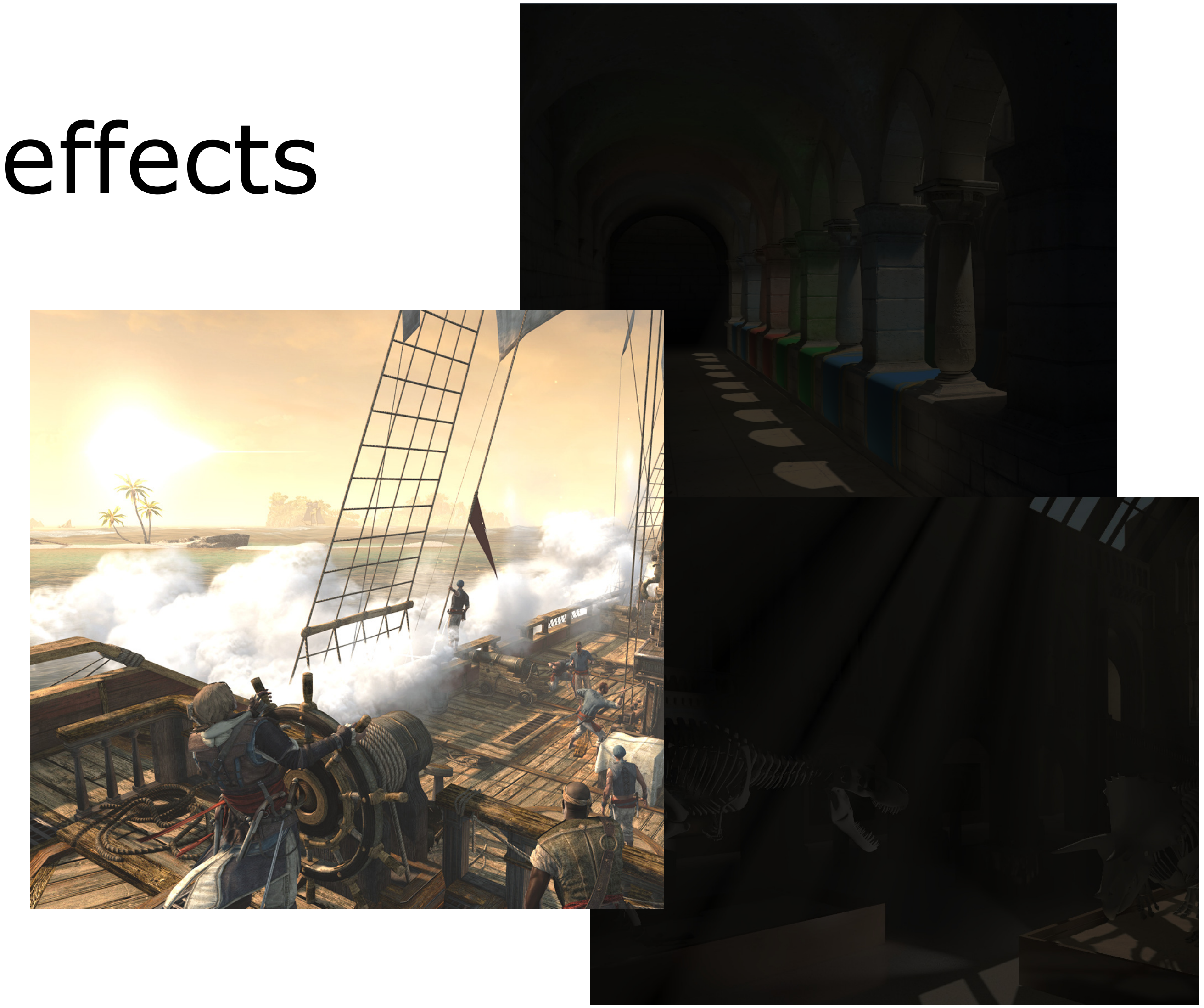
  - **Particle shadows**
  - Volumetric effects
  - Global illumination
  - …



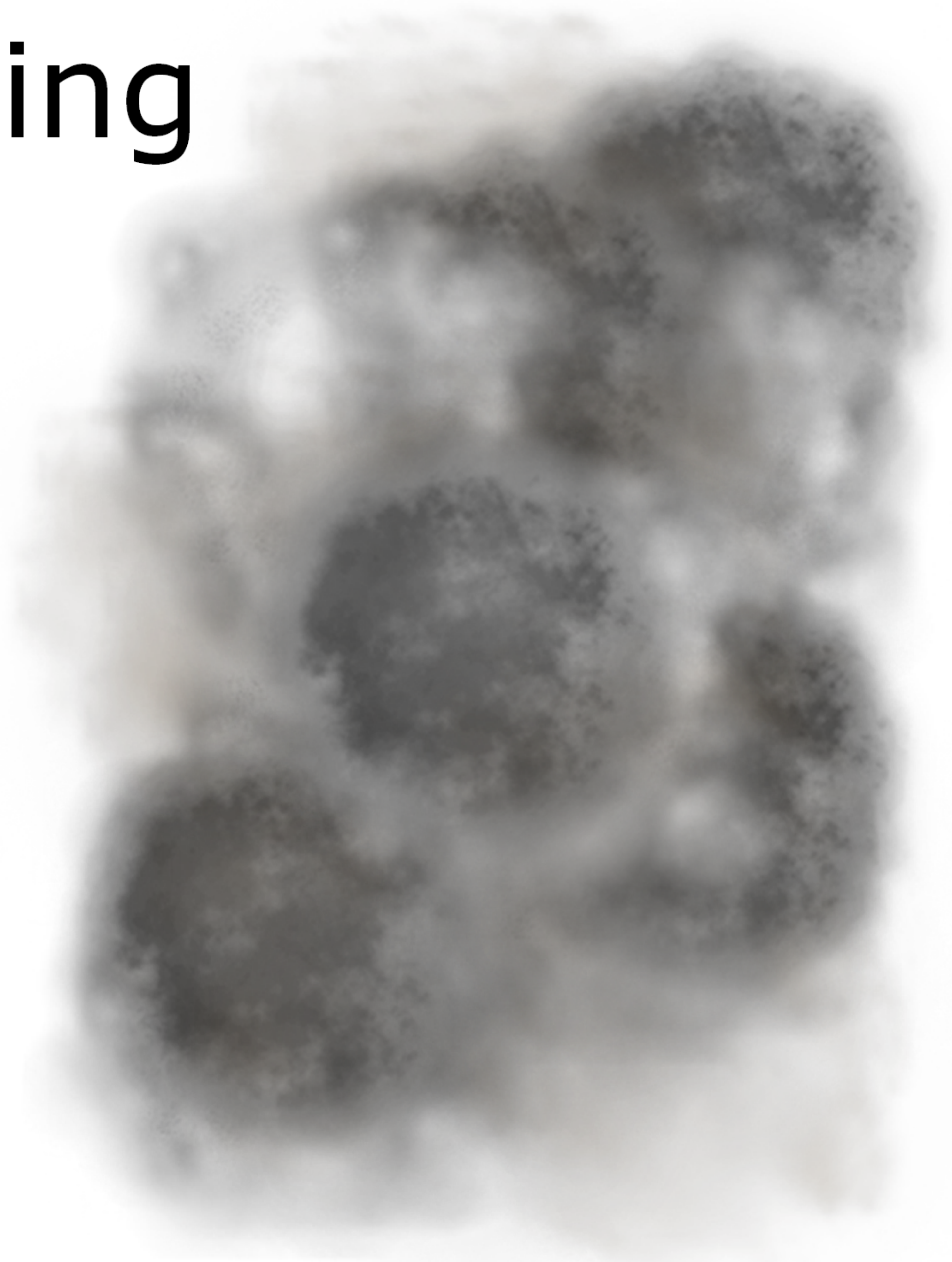
AC4BF screenshot was made by Andrew Iain Burnes and published at GeForce.com

Particle Shadow Mapping

- Calculate shadow from a particle system
- Calculate particle system self-shadowing

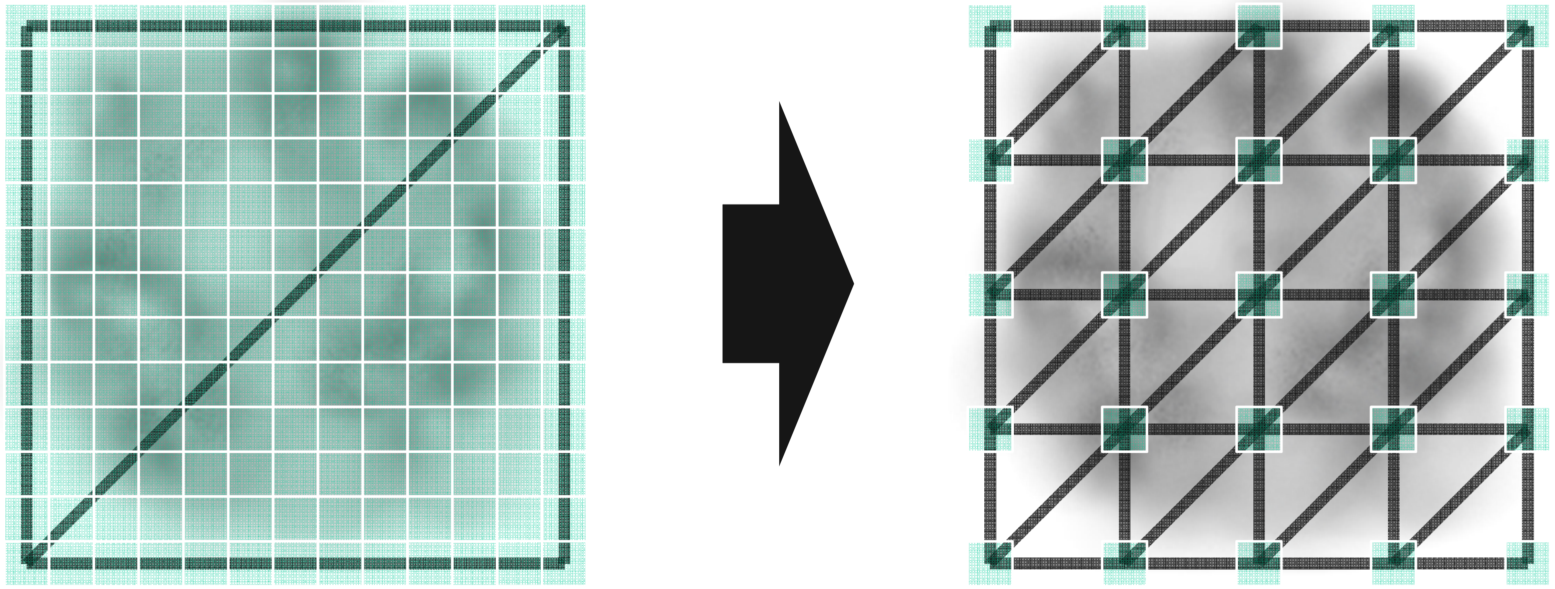
Particle Shadow Mapping

- Particle systems contain thousands of particles
- Shadowing has to be calculated for every pixel of every particle
- **Or maybe not?**



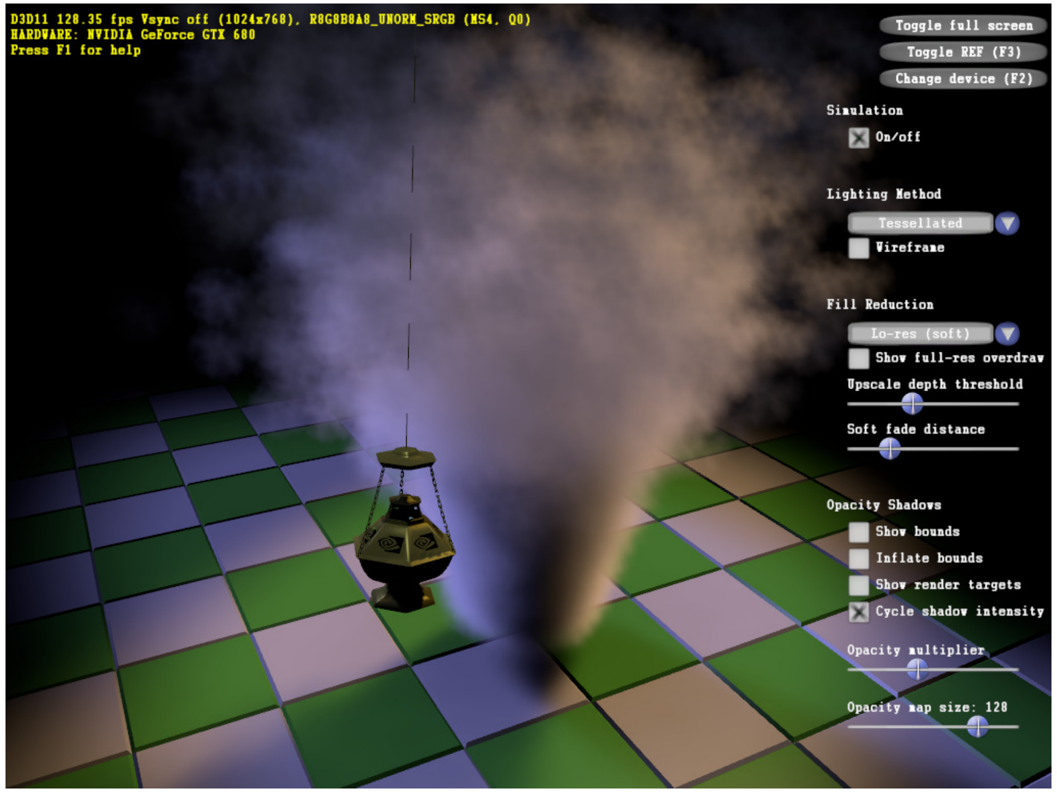
Particle Shadow Mapping

- Let’s calculate it in DS!
- Tessellate the particle sprites
- Use HS to determine shading rate



Fourier Opacity Mapping

- A sample by Jon Jansen and Louis Bavoil



```
D3D11 128.35 fps Vsync off (1024x768), R8G8B8A8_UNORM_SRGB (MS4, Q0)
HARDWARE: NVIDIA GeForce GTX 680
Press F1 for help
```

Simulation

☒ On/off

Lighting Method

Tessellated

□ Wireframe

Fill Reduction

Lo-res (soft)

□ Show full-res overdraw

Upscale depth threshold

Soft fade distance

Opacity Shadows

□ Show bounds

□ Inflate bounds

□ Show render targets

☒ Cycle shadow intensity

Opacity multiplier

Opacity map size: 128

https://developer.nvidia.com/sites/default/files/akamai/gamedev/files/sdk/11/OpacityMappingSDKWhitePaper.pdf

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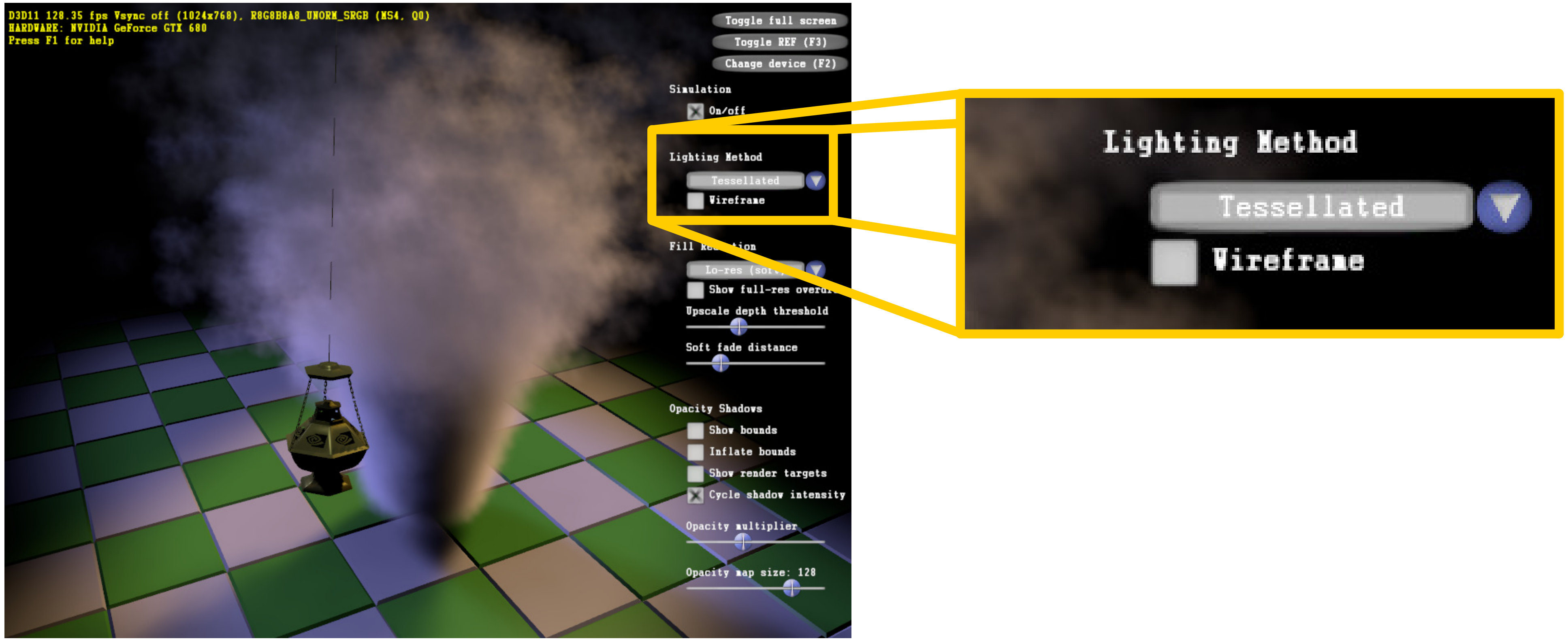

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Opacity multiplier

Opacity map size: 128

https://developer.nvidia.com/sites/default/files/akamai/gamedev/files/sdk/11/OpacityMappingSDKWhitePaper.pdf

DEMO

- Fourier Opacity Mapping sample

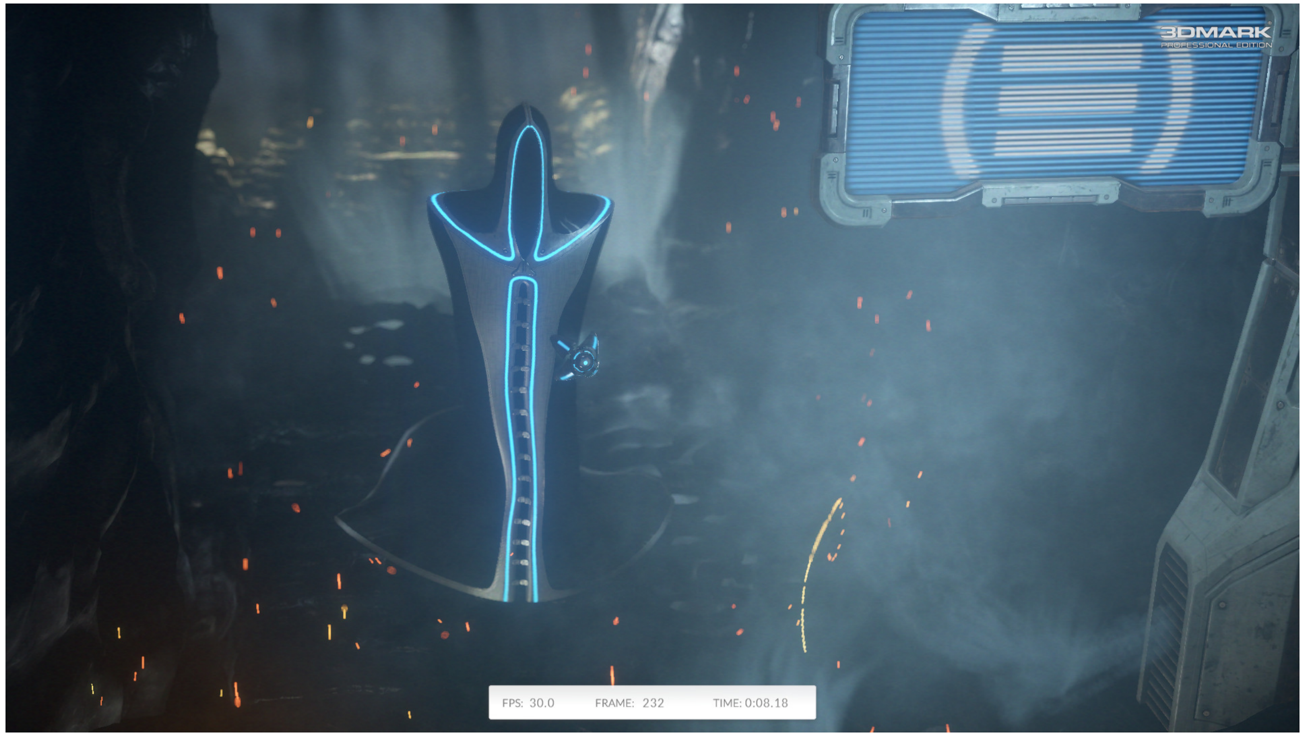
Performance

- Fourier Opacity Mapping sample, 1920x1200

FPS	Per-Pixel	**Tessellated**	Gain
GTX 750Ti	17.2	**68.7**	**4X**
GTX 760	34.2	**118.7**	**3.5X**
GTX 770	48.2	**155.2**	**2x**
R7 260X	15.1	**65.3**	**4X**
R9 270X	21.9	**85.3**	**4X**
R9 280X	32.8	**100.5**	**3X**

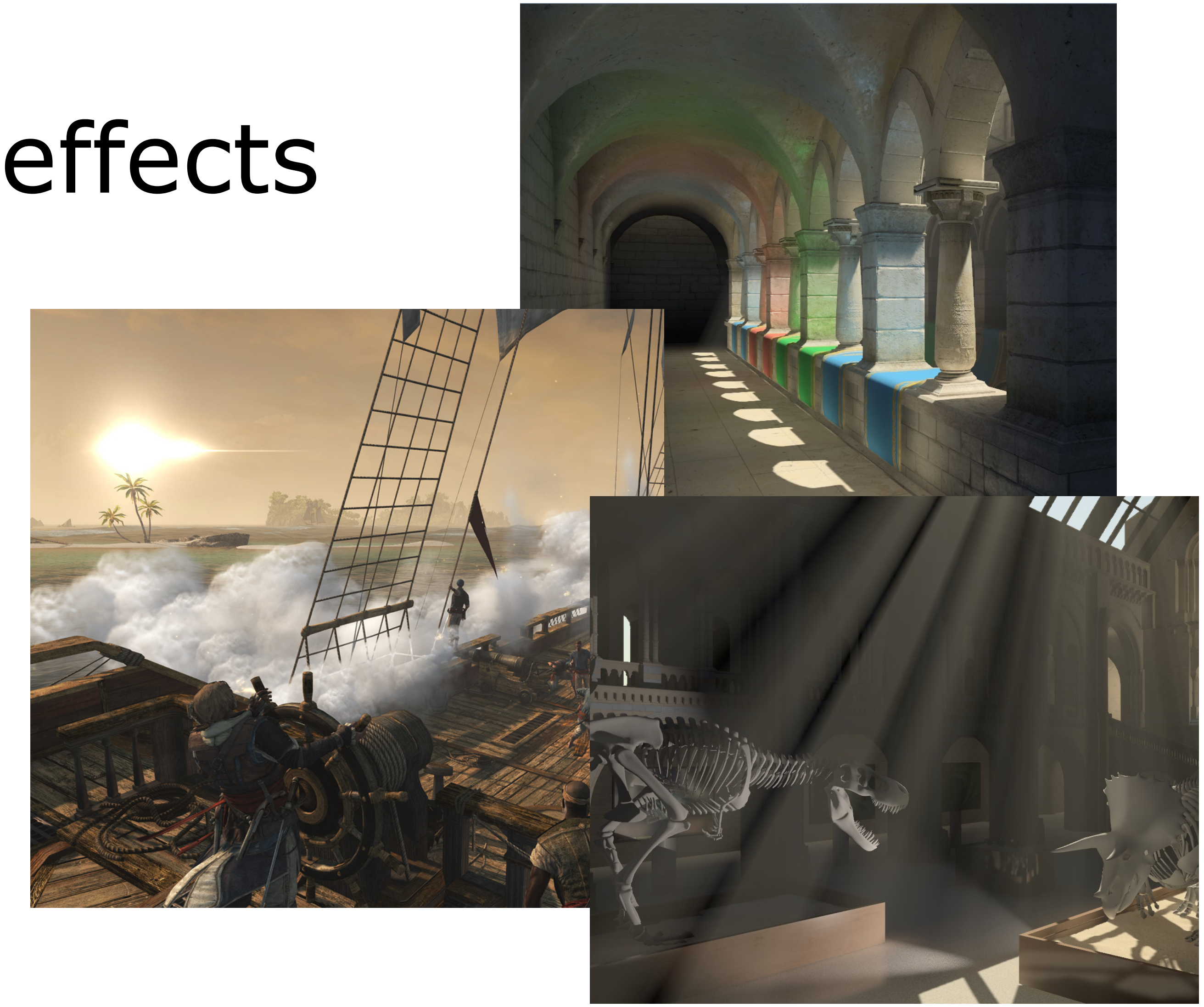
Particle Irradiance in 3DMark

- This approach was successfully used in 3DMark for Windows 8



Which effects can benefit from it?

- Computation-heavy effects with low frequency
  - Particle shadows
  - Volumetric effects
  - Global illumination
  - …



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- Computation-heavy effects with low frequency
  - Particle shadows
  - **Volumetric effects**
  - Global illumination
  - …

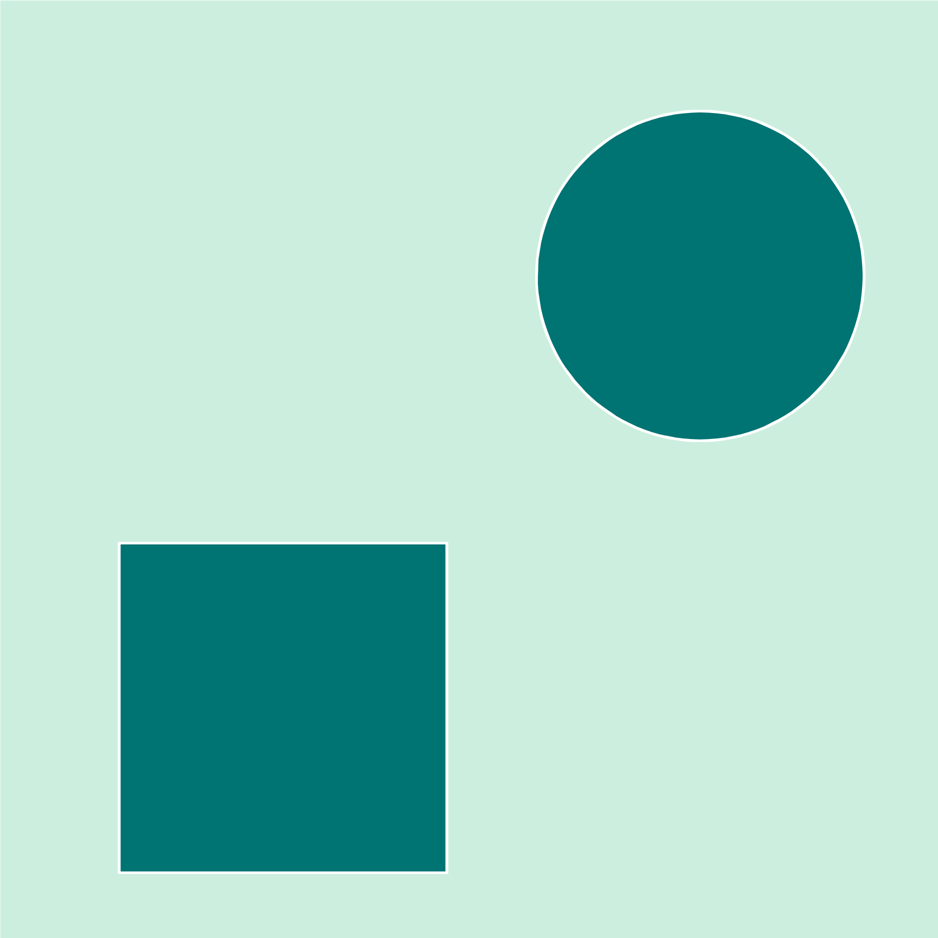
Godrays screenshot was taken from a sample by Alexey Panteleev

Volumetric effects

- Typically use ray-marching to integrate over the medium inside the volume

Godrays

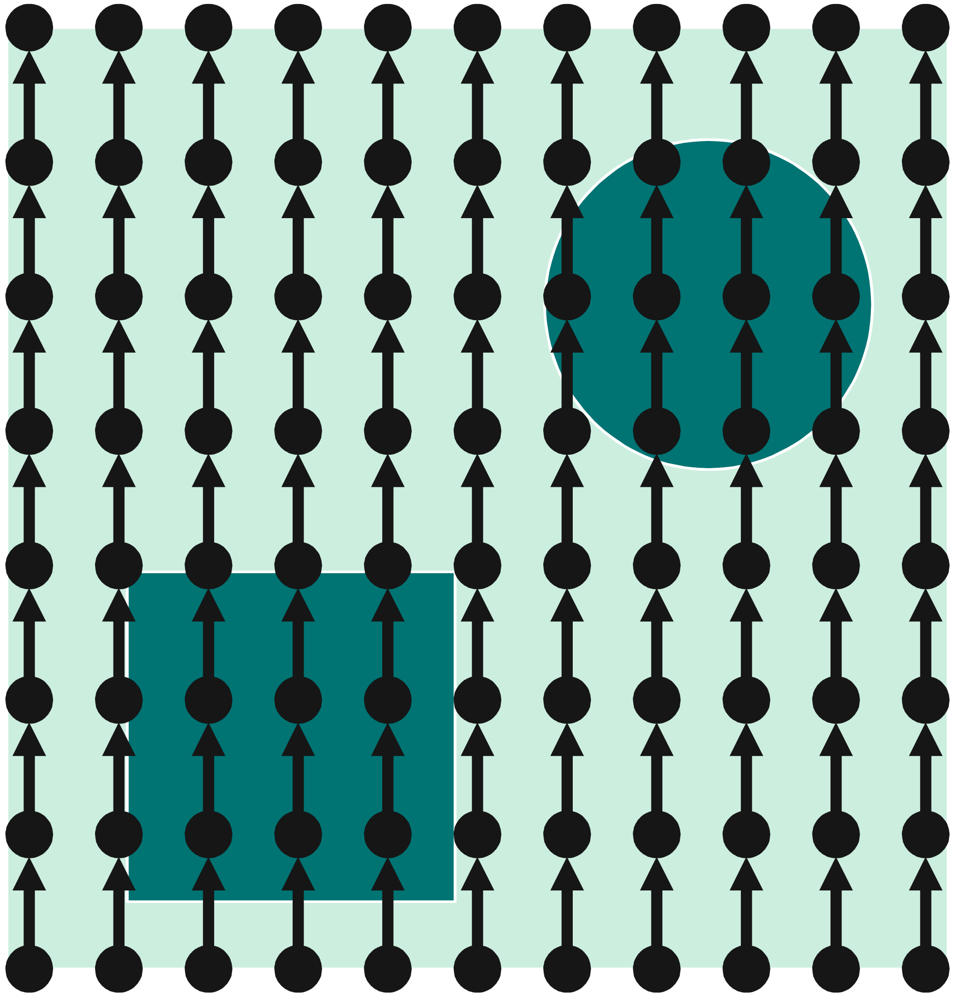
- We have a medium and objects that occlude it from the light
- Occluders are typically represented as rendered into shadowmap



Godrays

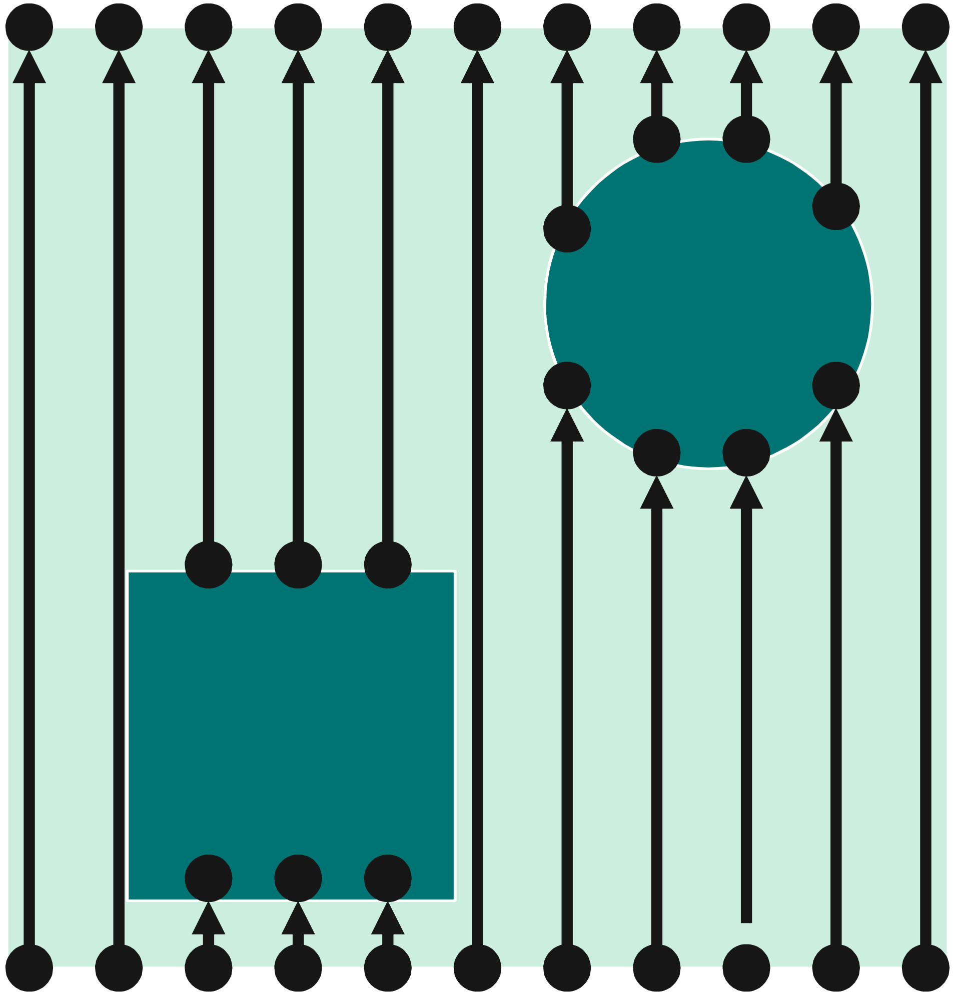
At each ray-marching step

- Medium transmittance is calculated
- Shadowmap is fetched



Godrays

- We don’t need to do that many ray-marching steps if the medium is uniform
- We need to know the contents of the volume



Godrays

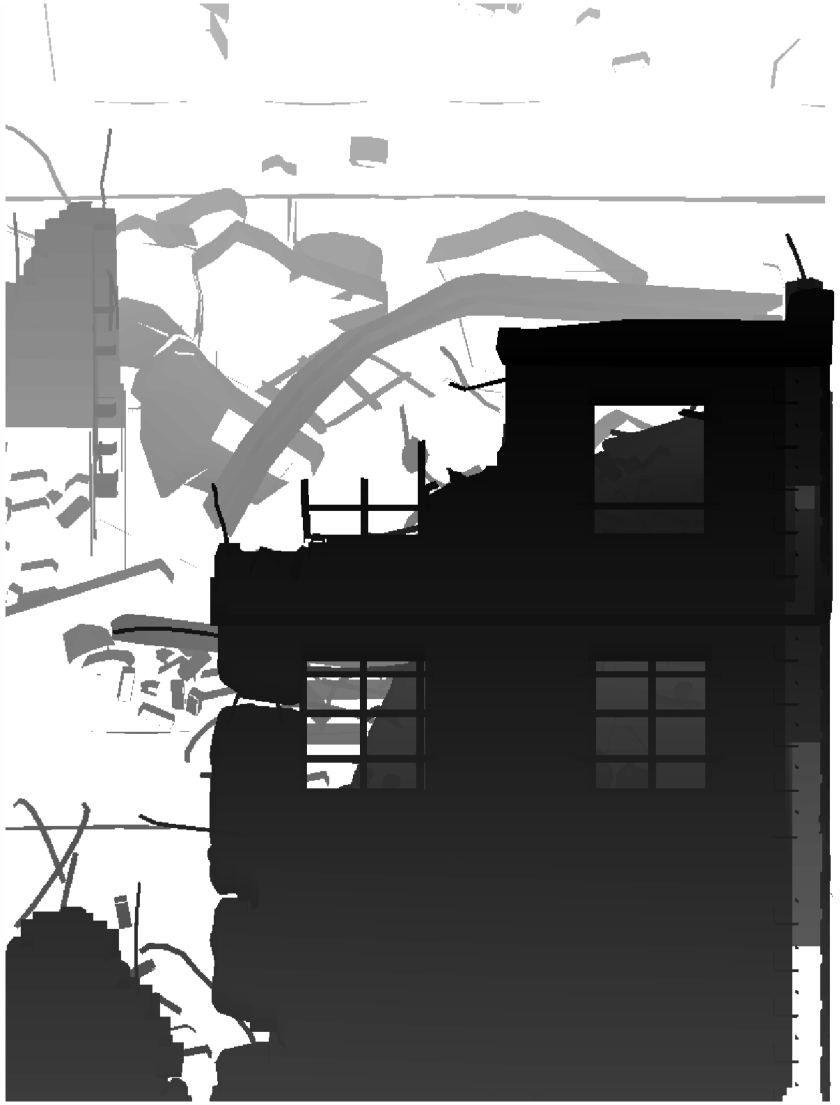
- Instead of rendering the volume, let's render the actual geometry of godrays!

Tessellated godrays

- Scene

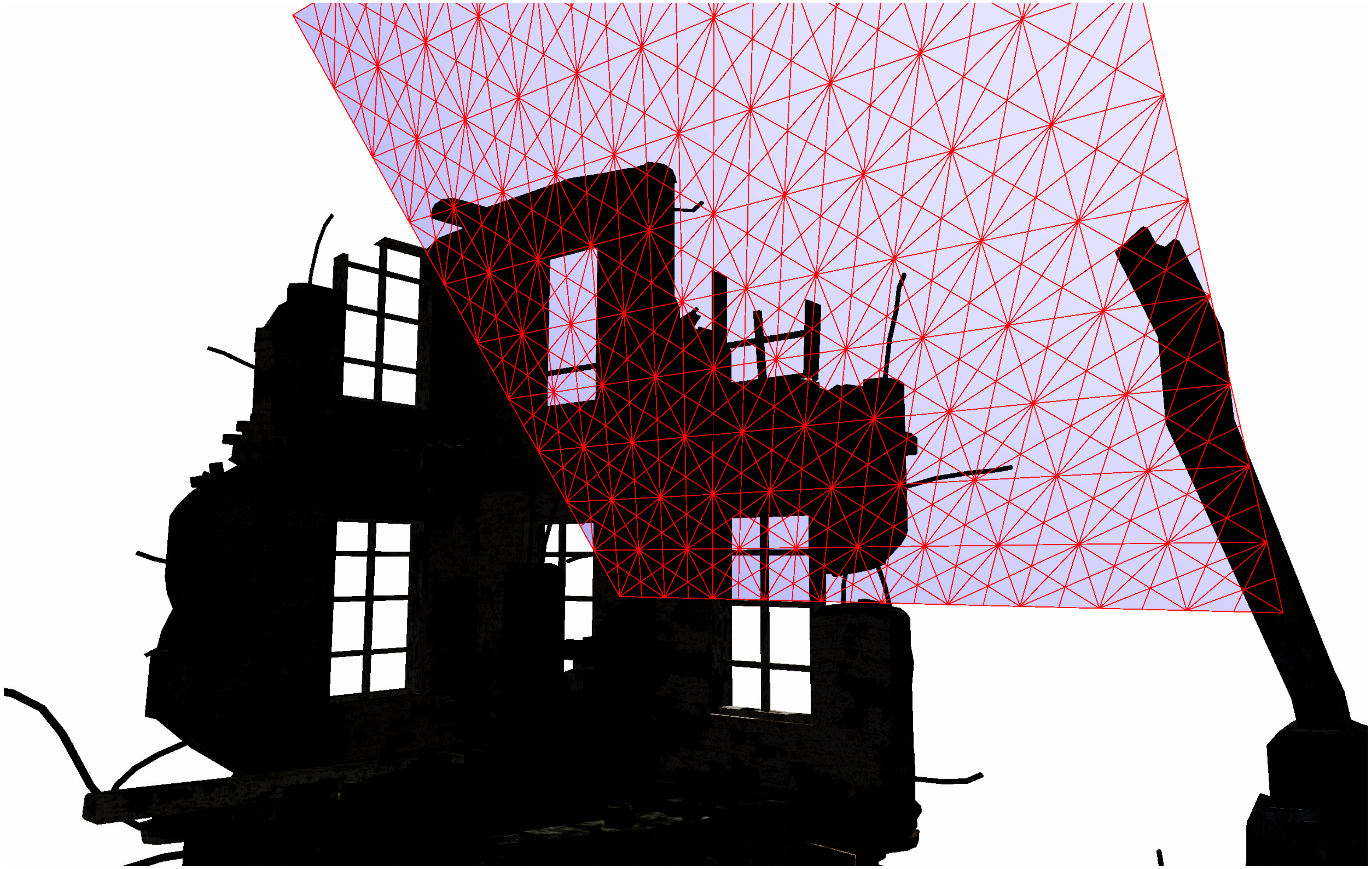
Tessellated godrays

- Shadowmap



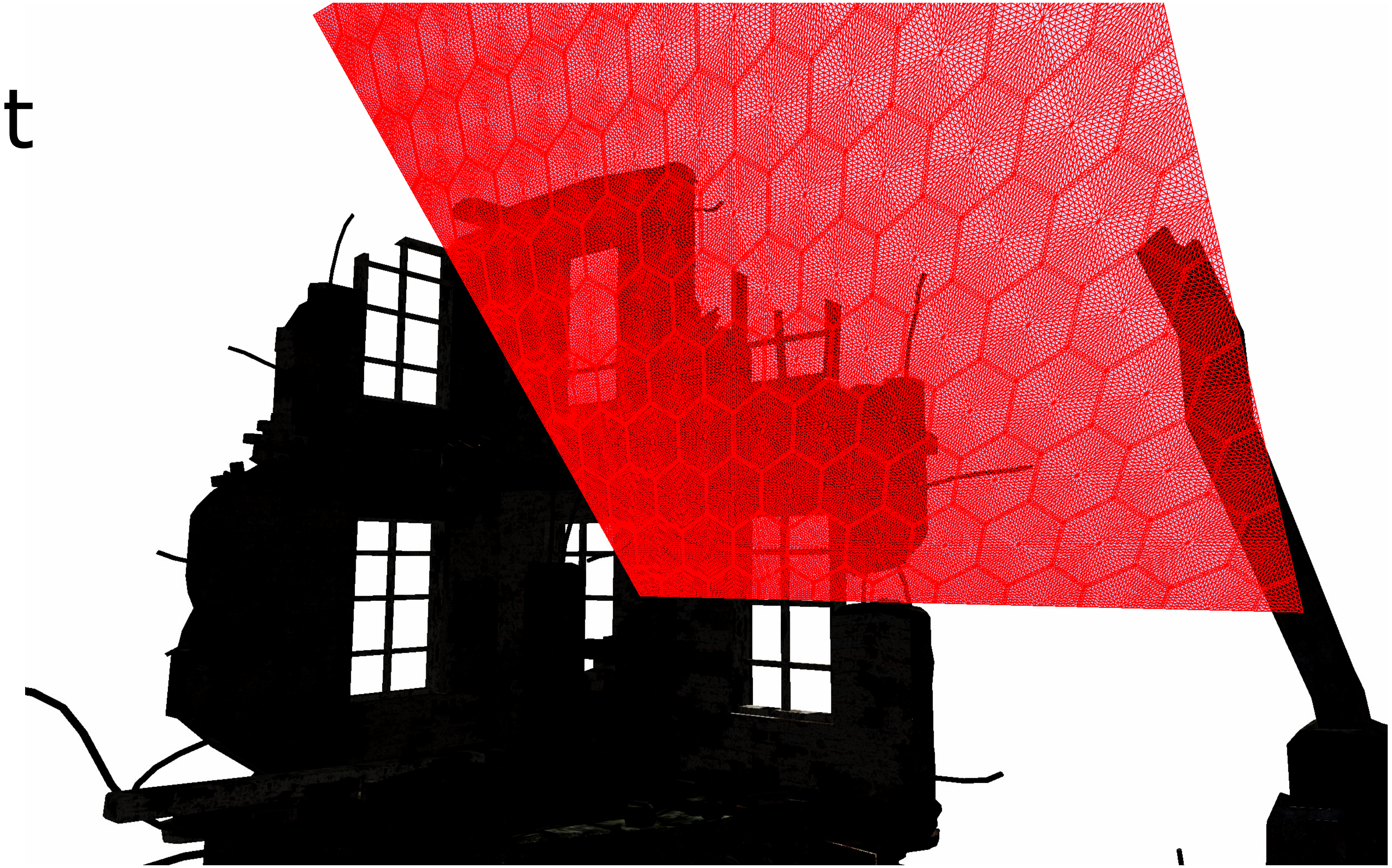
Tessellated godrays

- Render grid



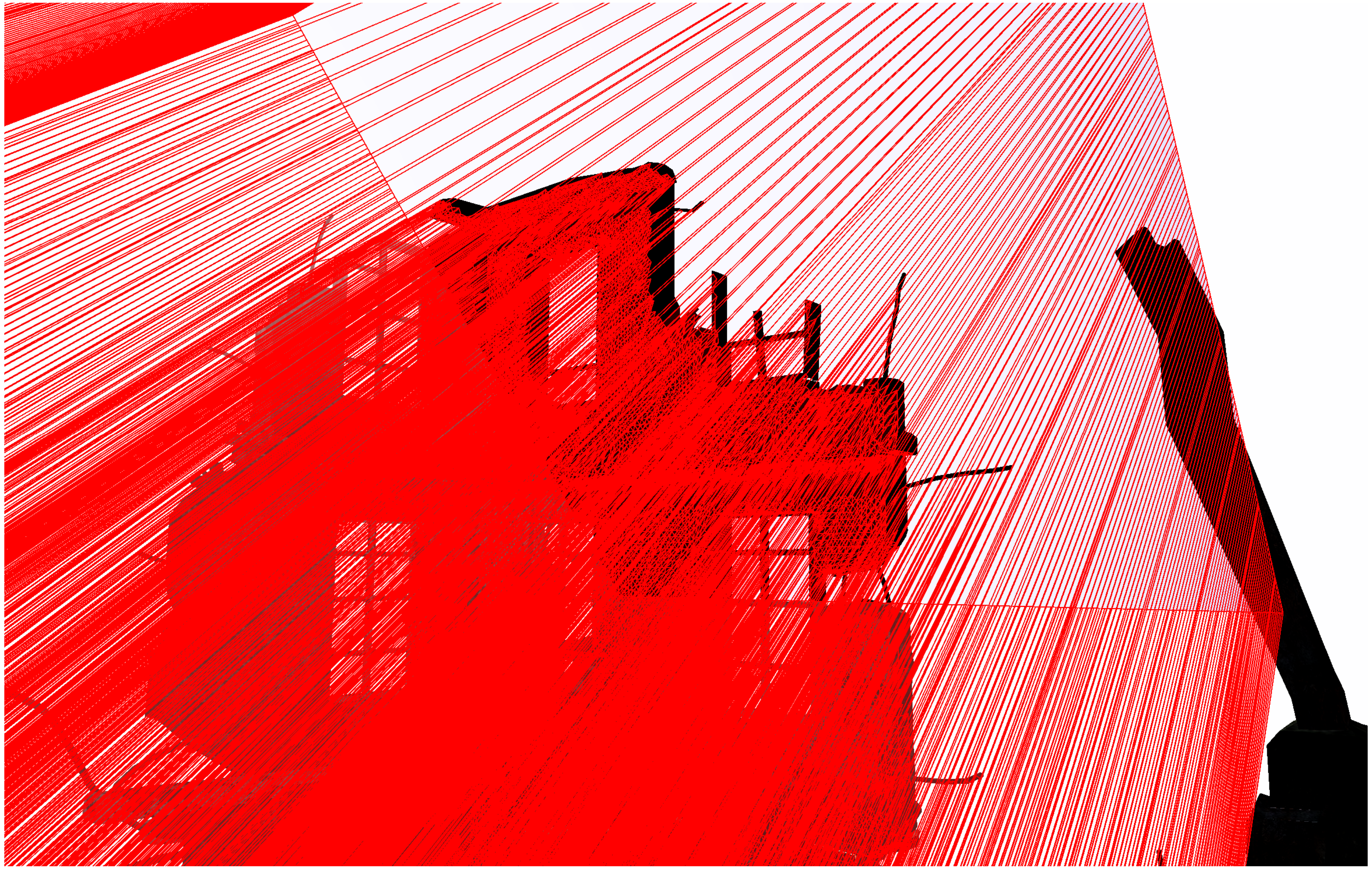
Tessellated godrays

- Tessellate it



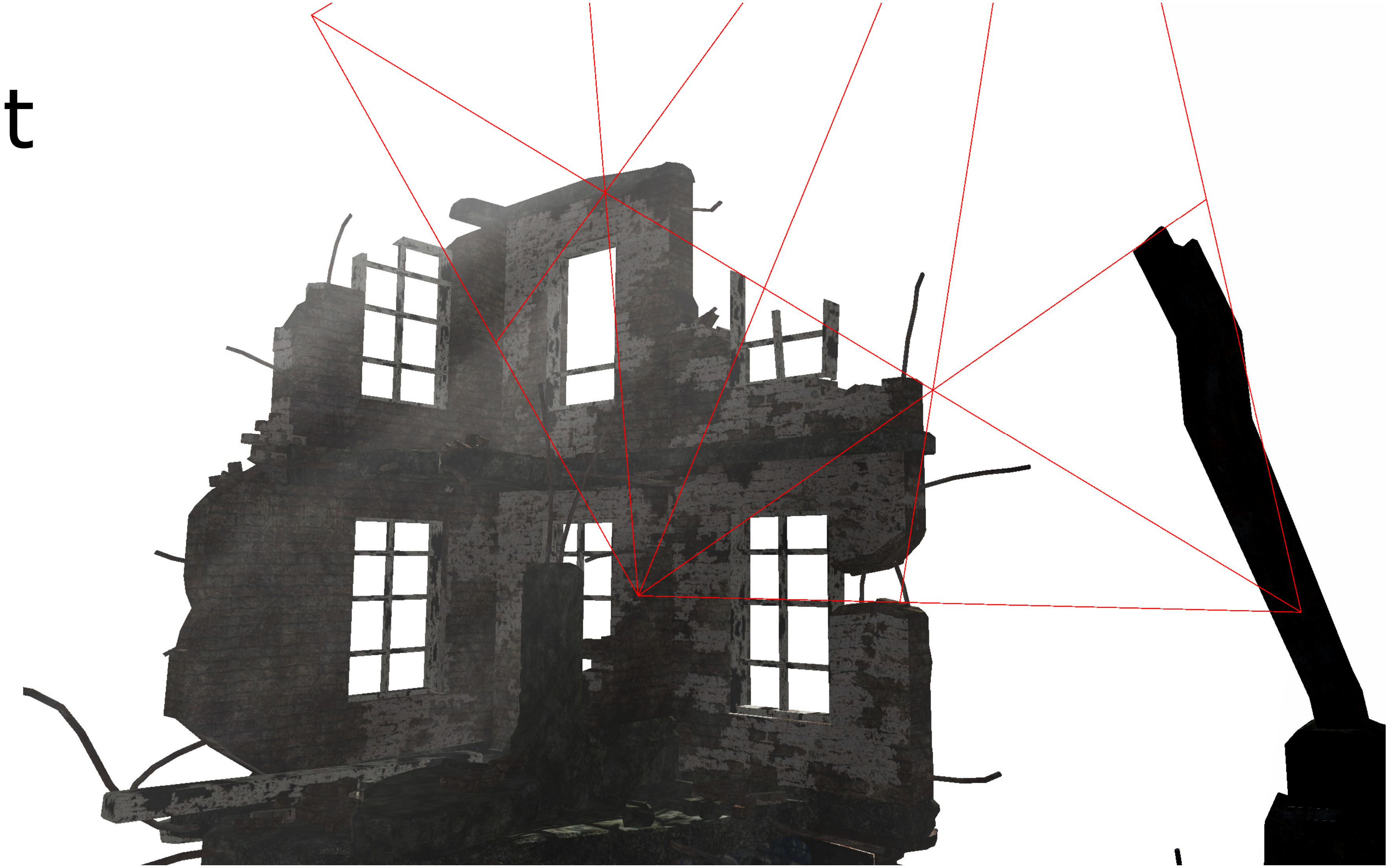
Tessellated godrays

- Fetch from shadowmap and offset vertices



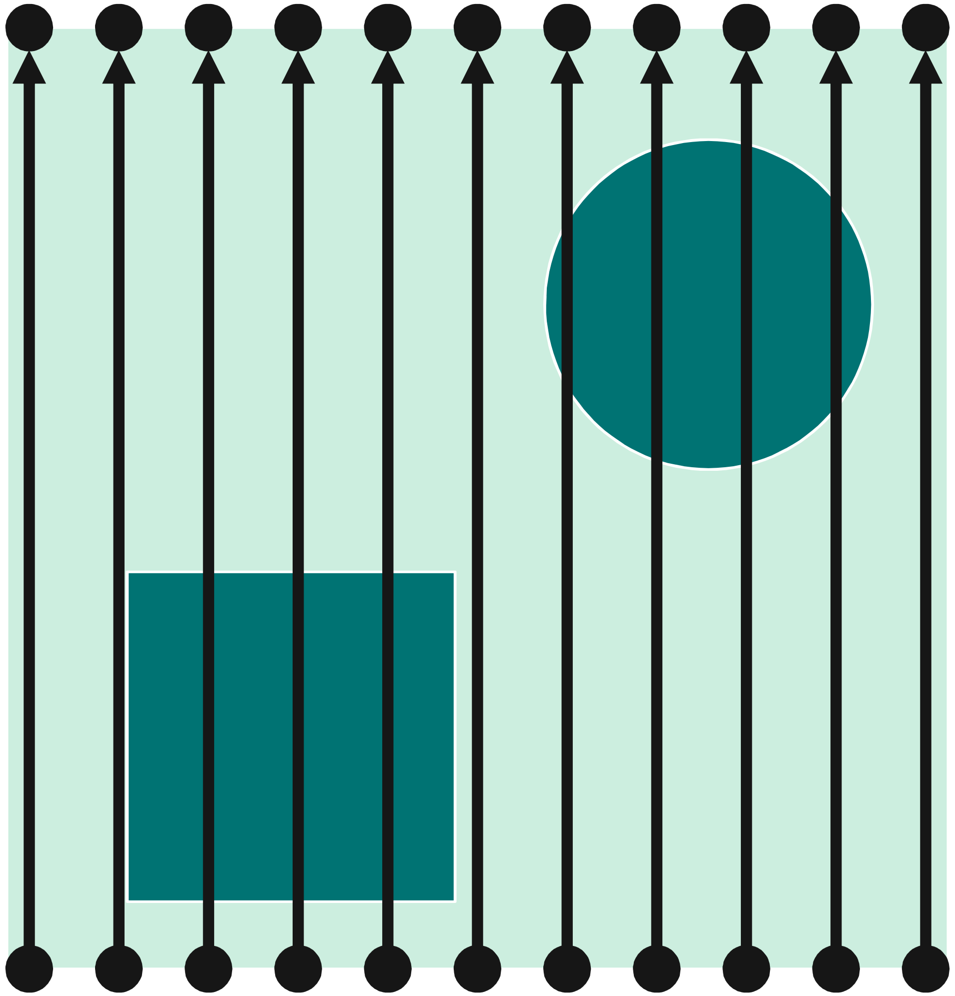
Tessellated godrays

- Don’t forget the cap



Tessellated godrays

- Integrate with positive sign for backfaces
- Integrate with negative sign for frontfaces



Tessellated godrays

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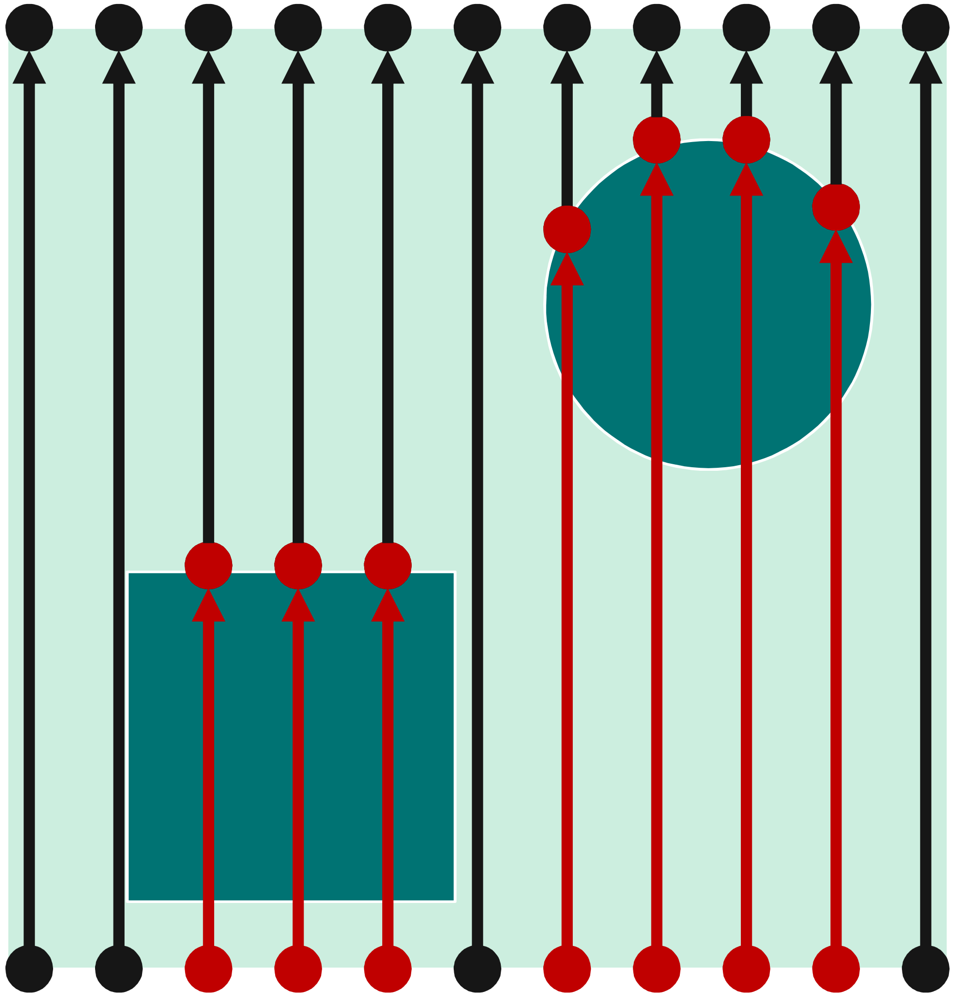

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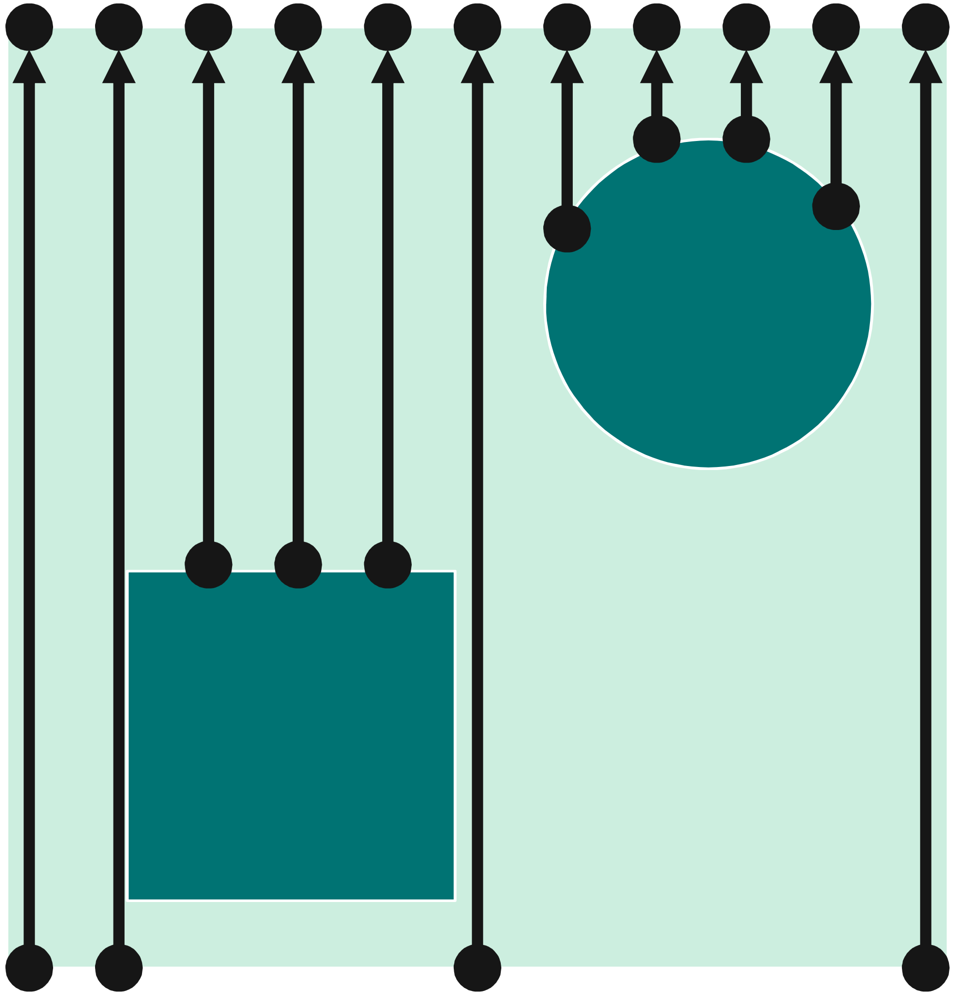

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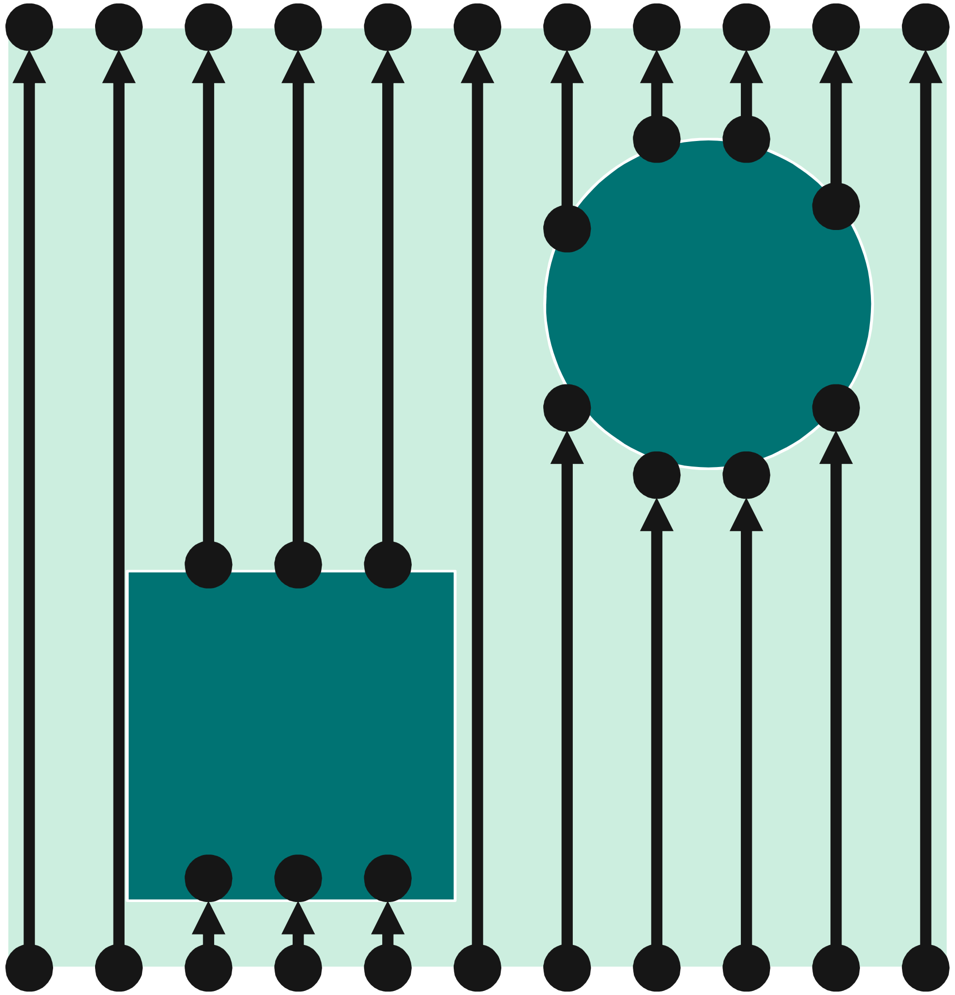
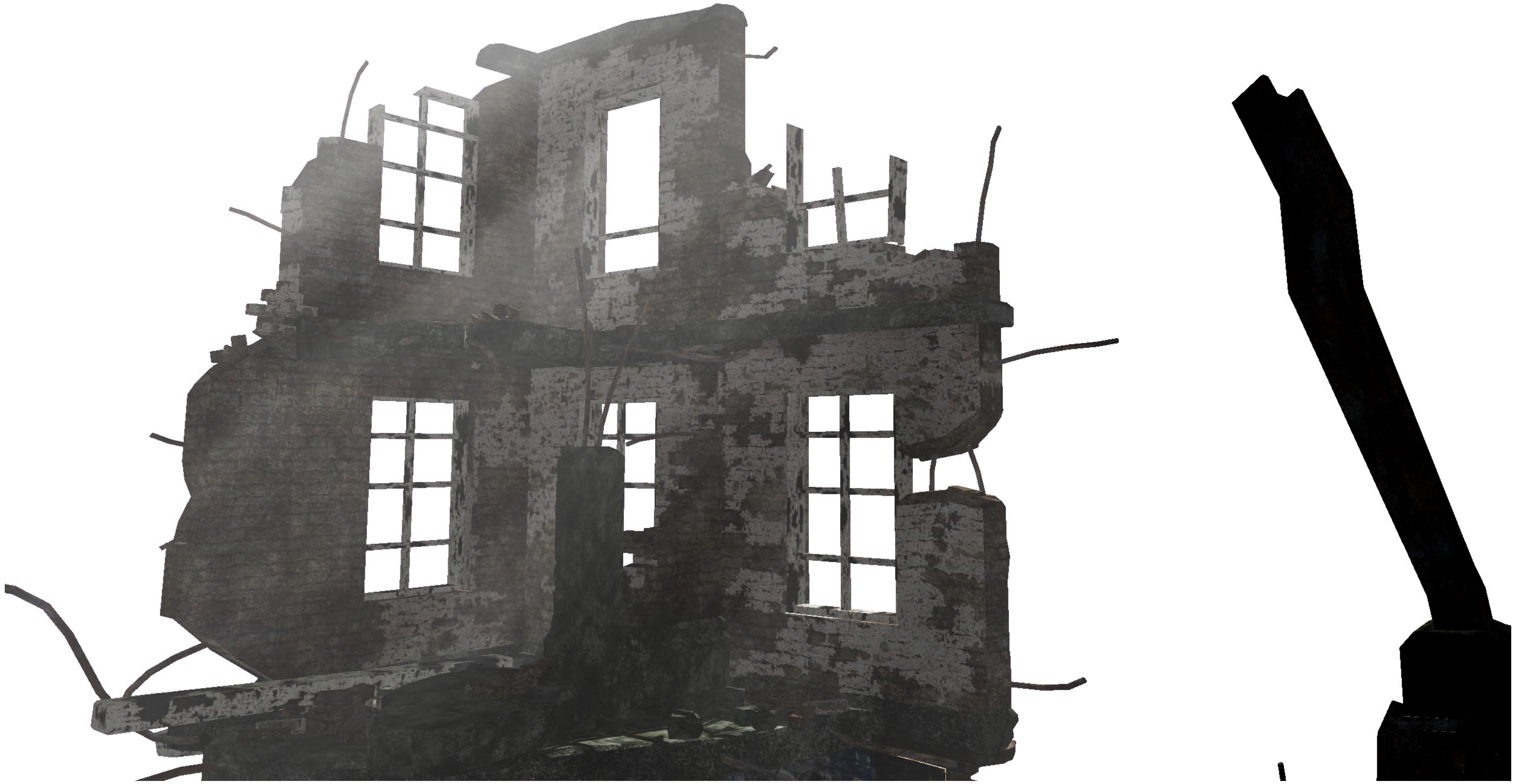


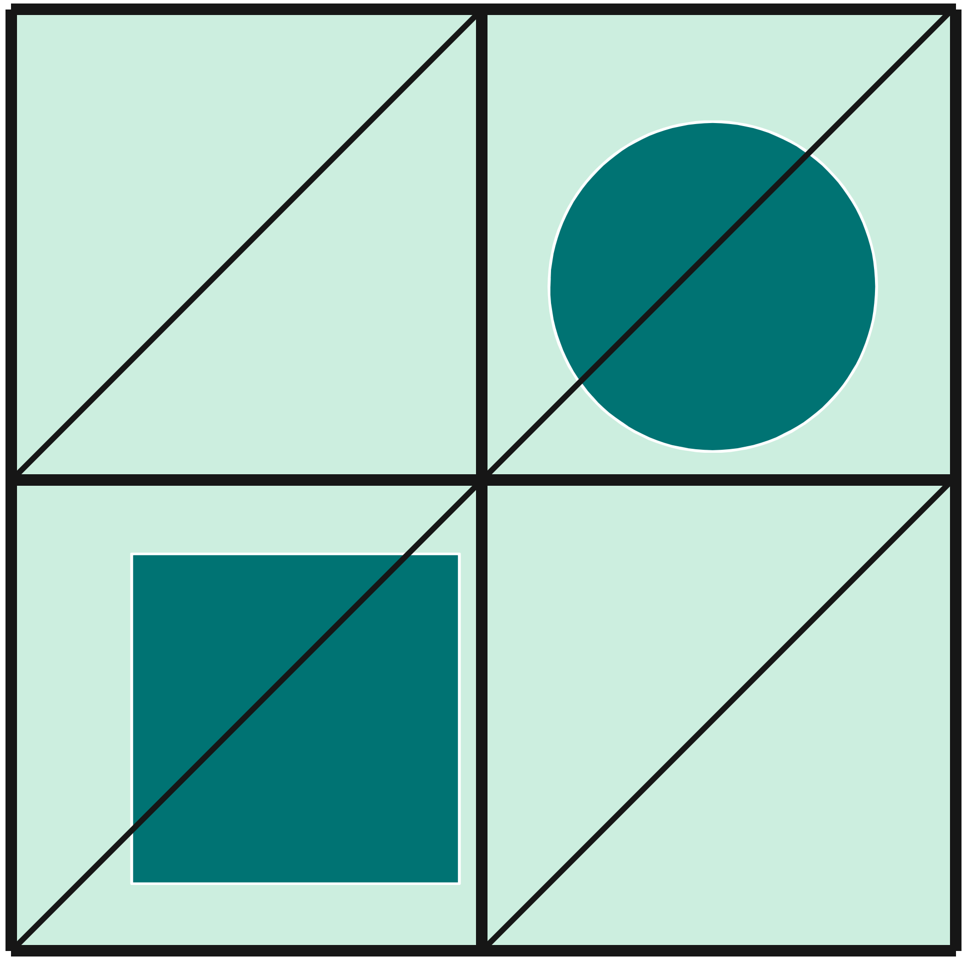
Tessellated godrays

- Result



Why use tessellation?

- Tessellation allows making grid resolution adaptive



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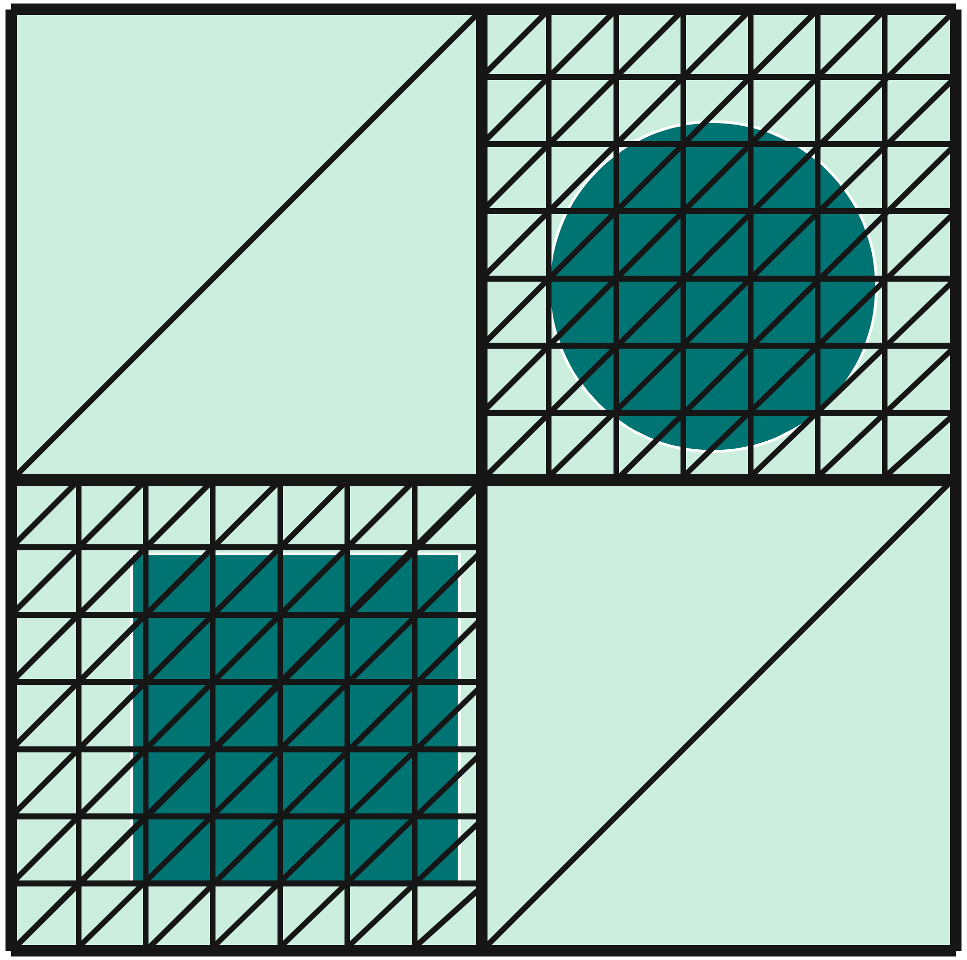
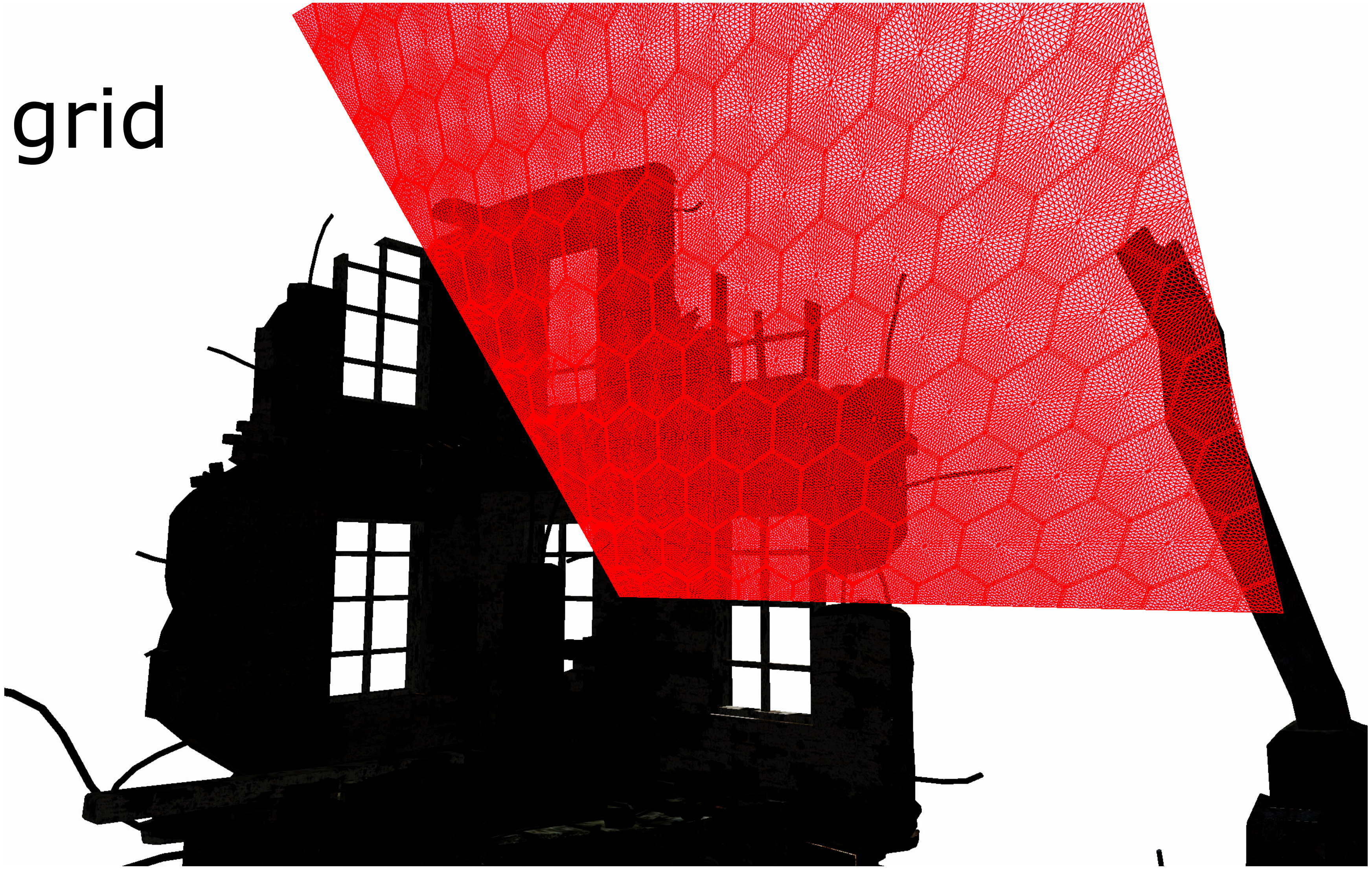


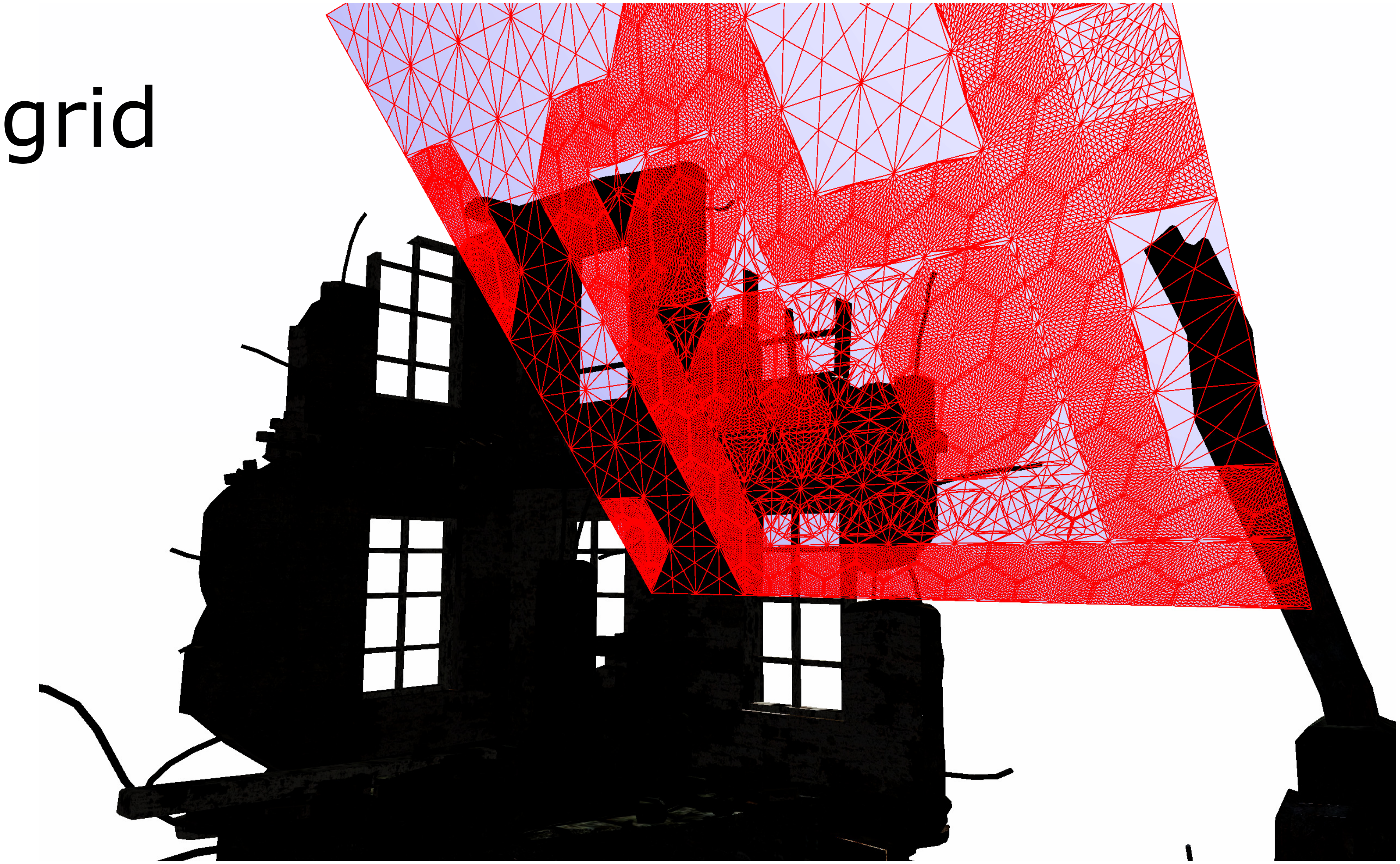
Adaptive tessellation

- Tessellated grid



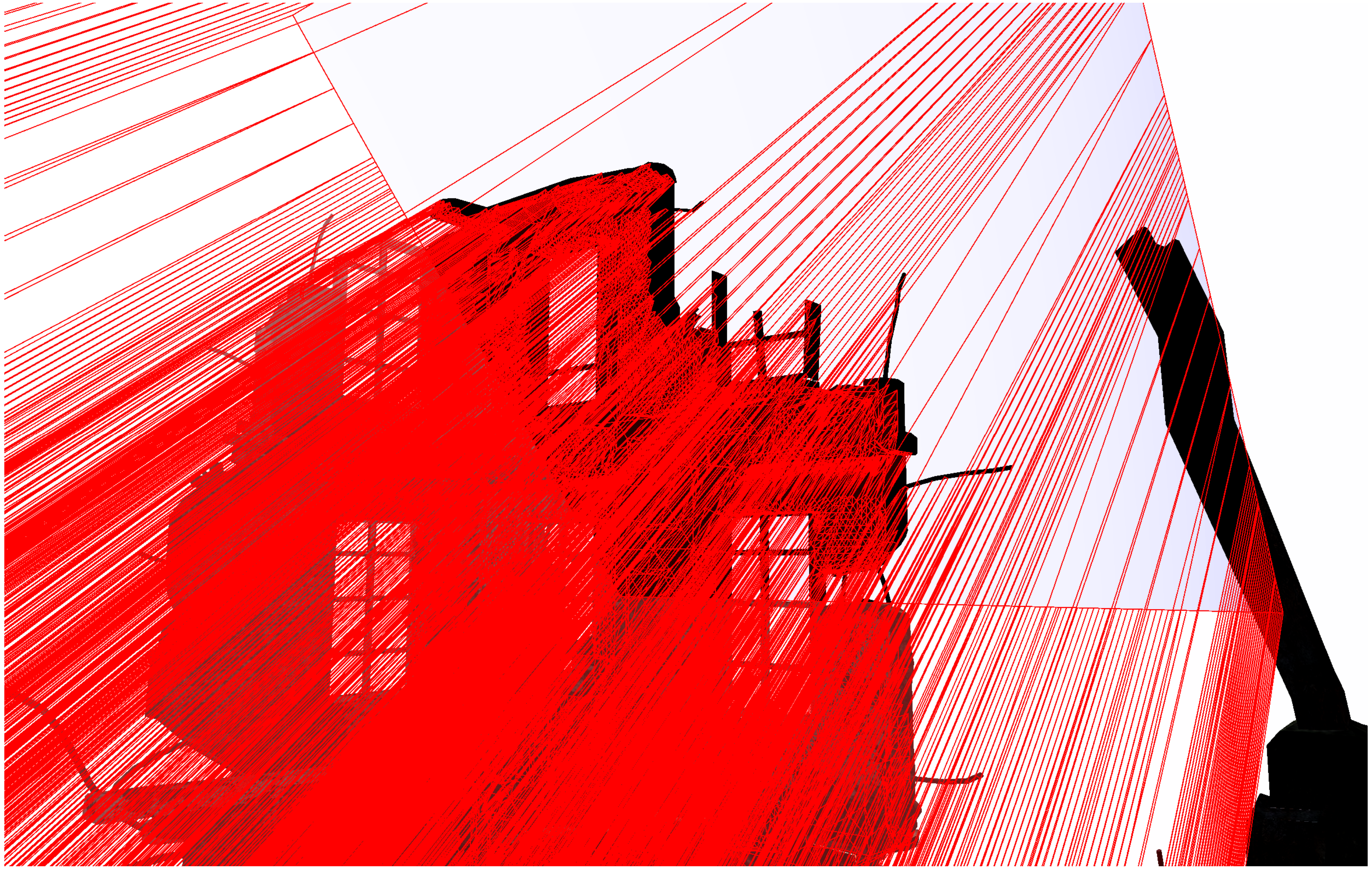
Adaptive tessellation

- Optimized grid



Adaptive tessellation

- Geometry of godrays



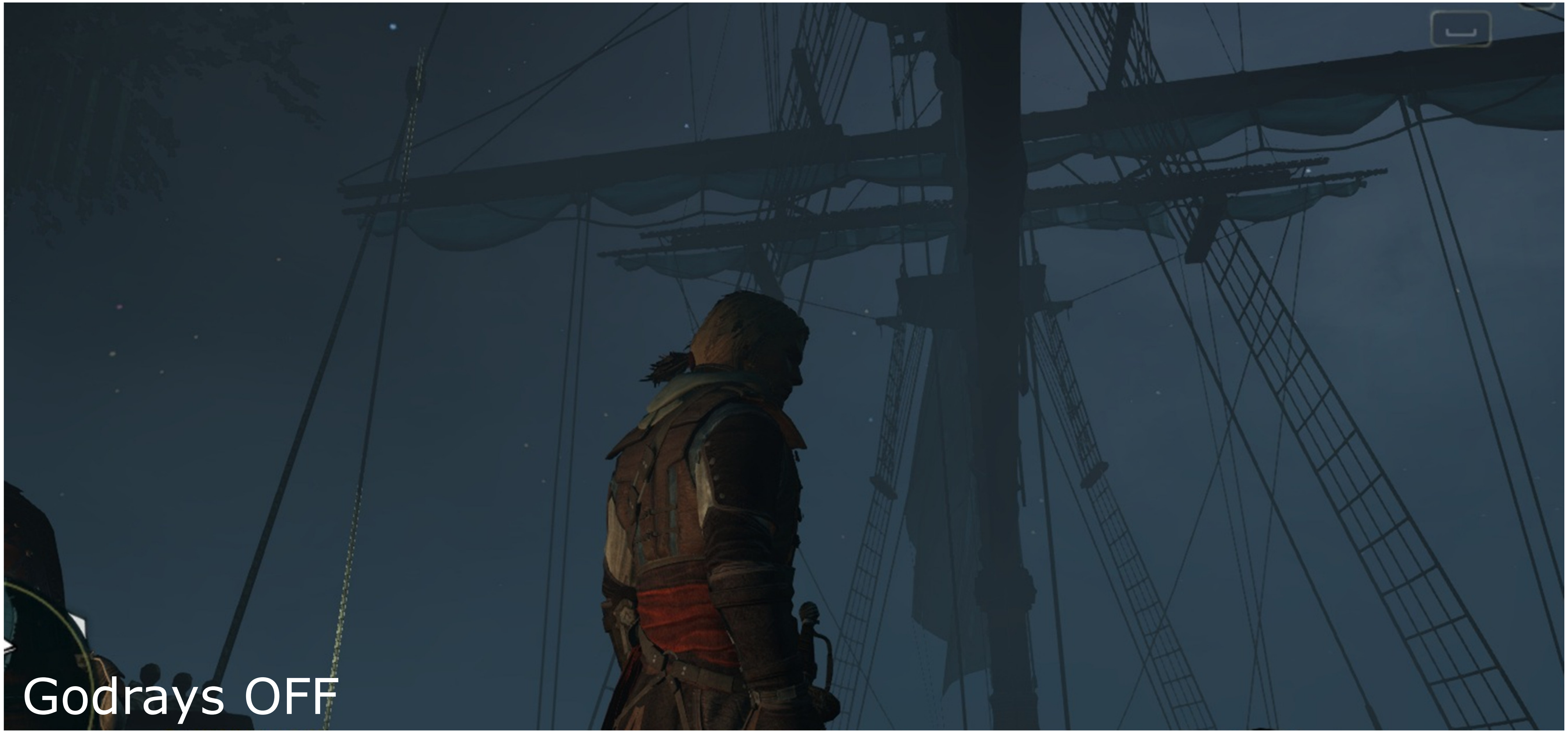
Advantages

- Up to **4X** performance improvement
- No banding, no aliasing
- Ability to represent small details

Assassin’s Creed IV Black Flag

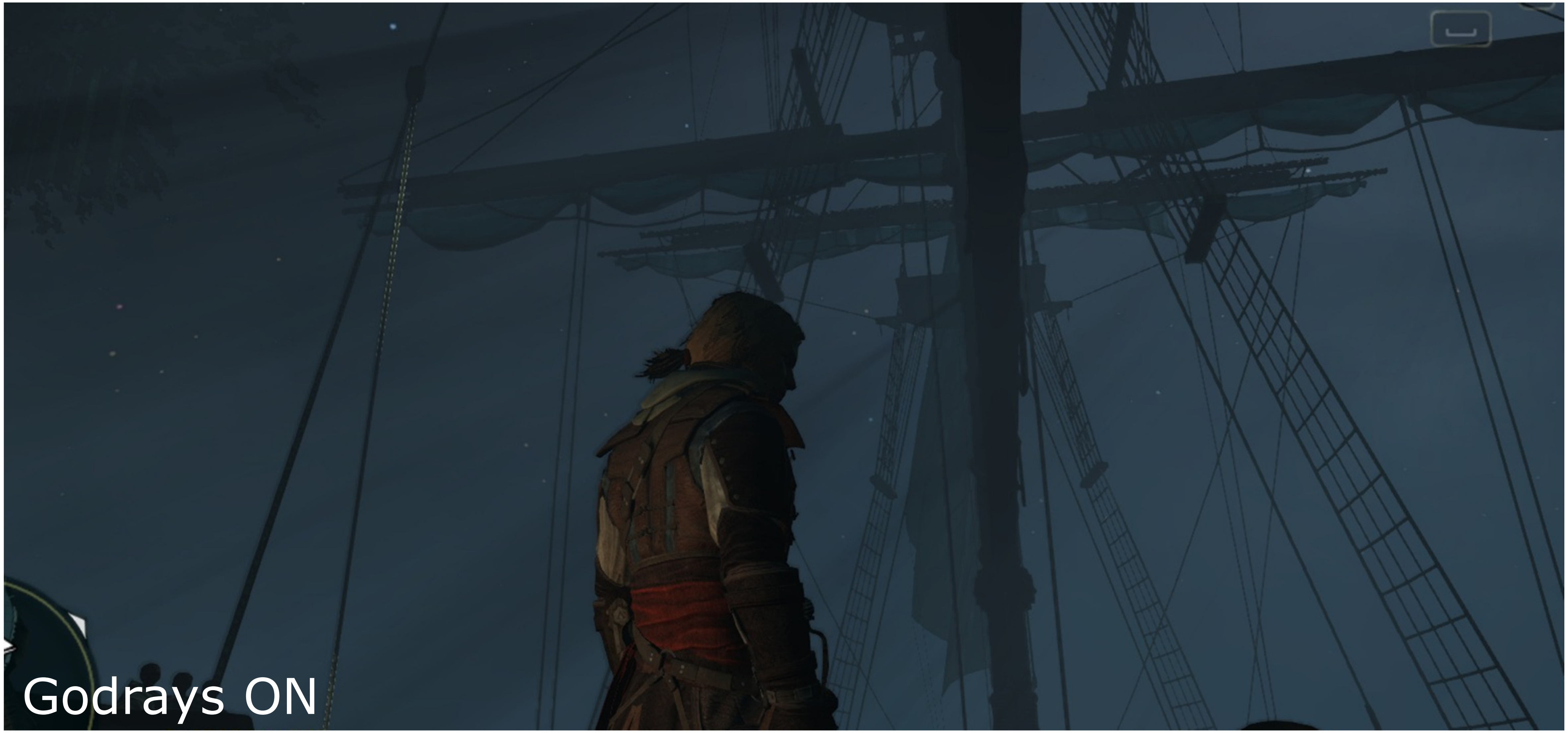
- We integrated tessellation-based godrays into Assassin’s Creed IV Black Flag
- A joint project of Ubisoft Kiev and NVIDIA

Assassin’s Creed IV Black Flag



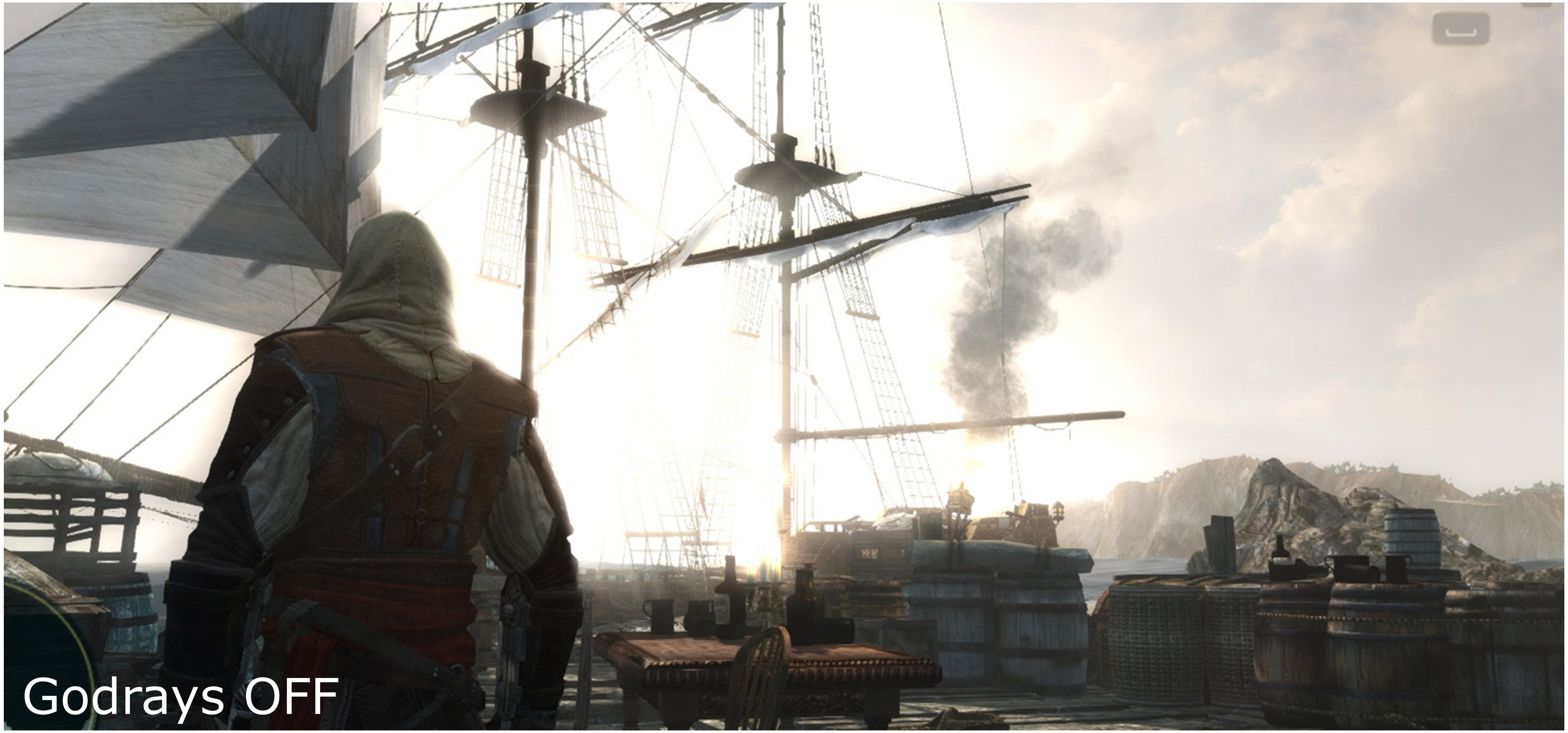
Godrays OFF

Assassin’s Creed IV Black Flag



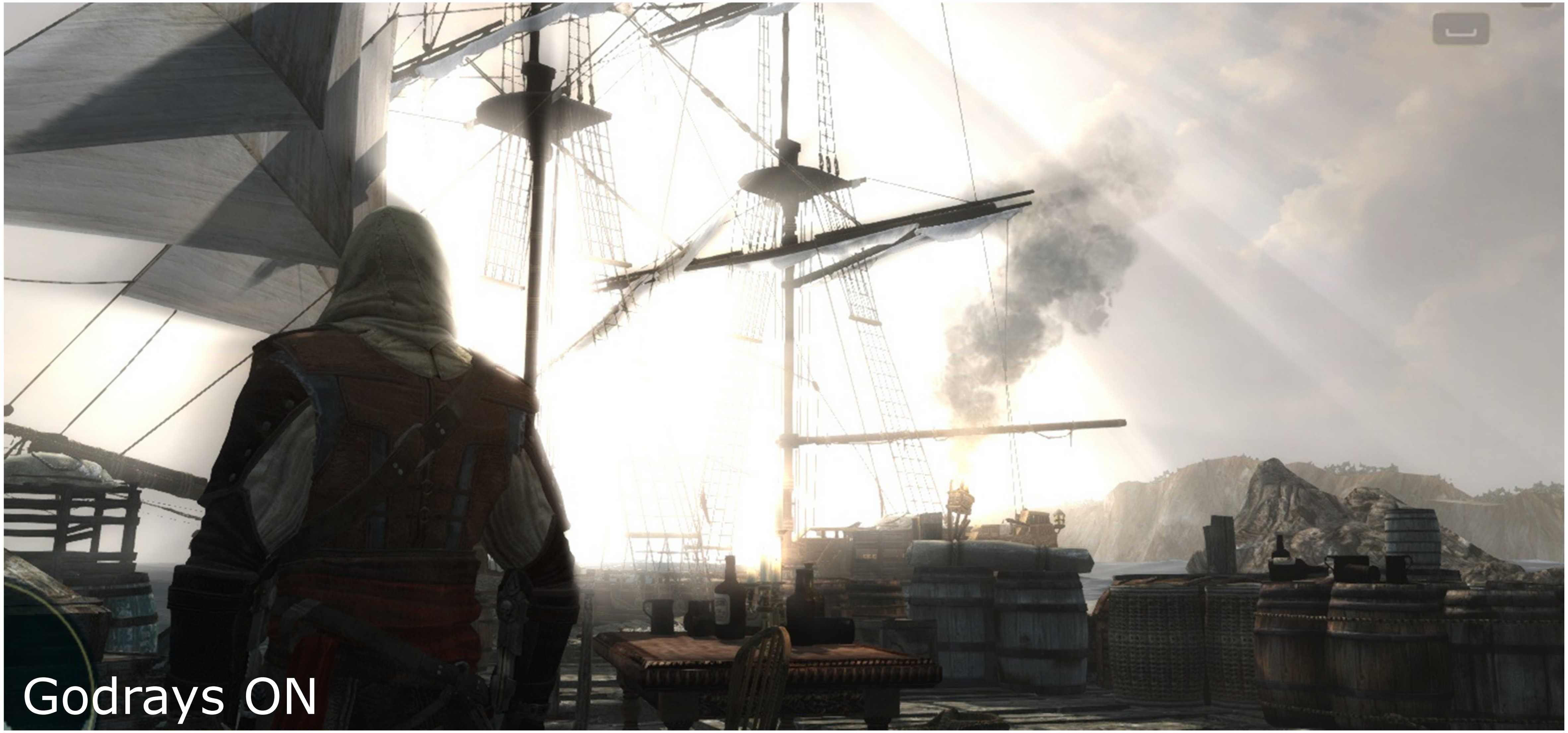
Godrays ON

Assassin’s Creed IV Black Flag

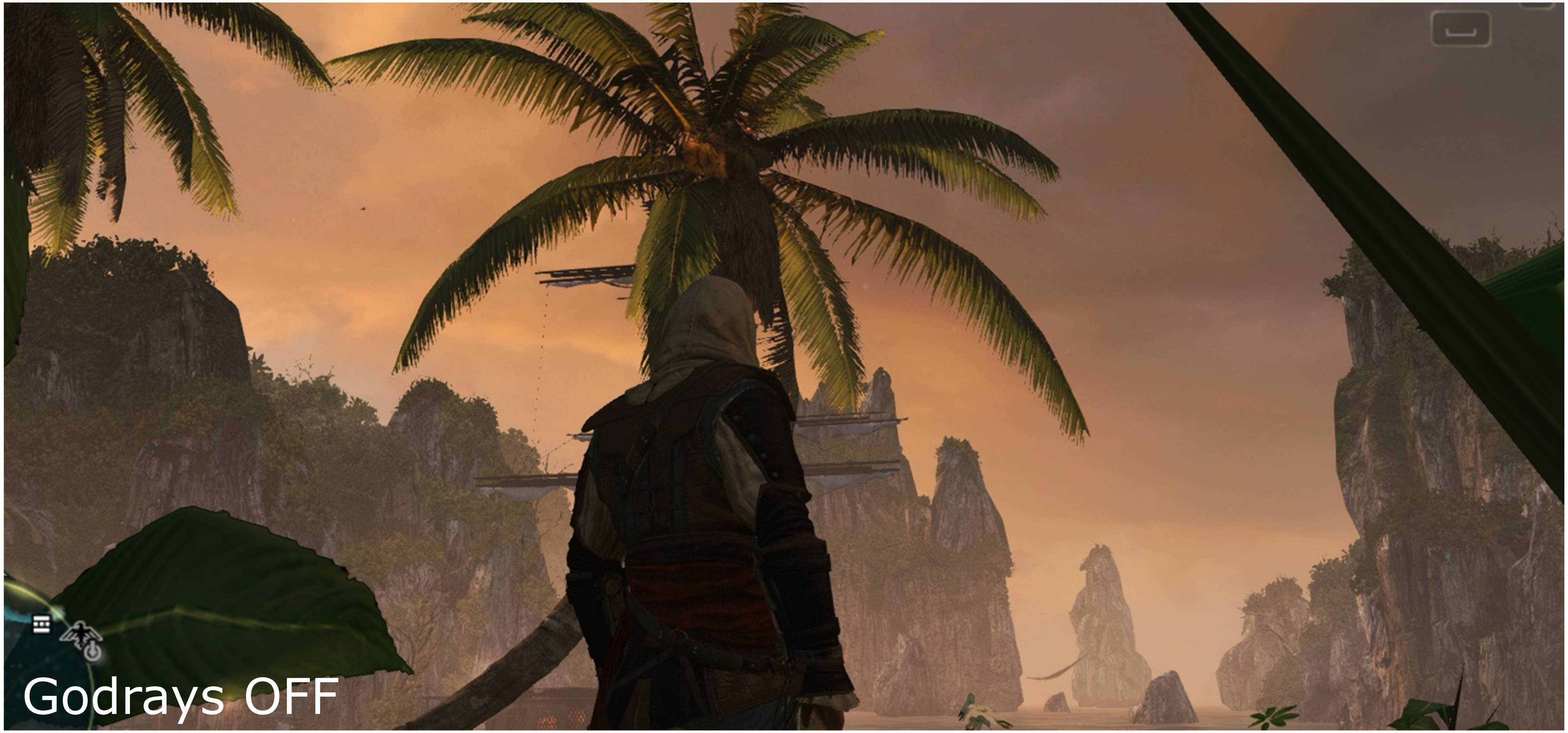


Godrays OFF

Assassin’s Creed IV Black Flag

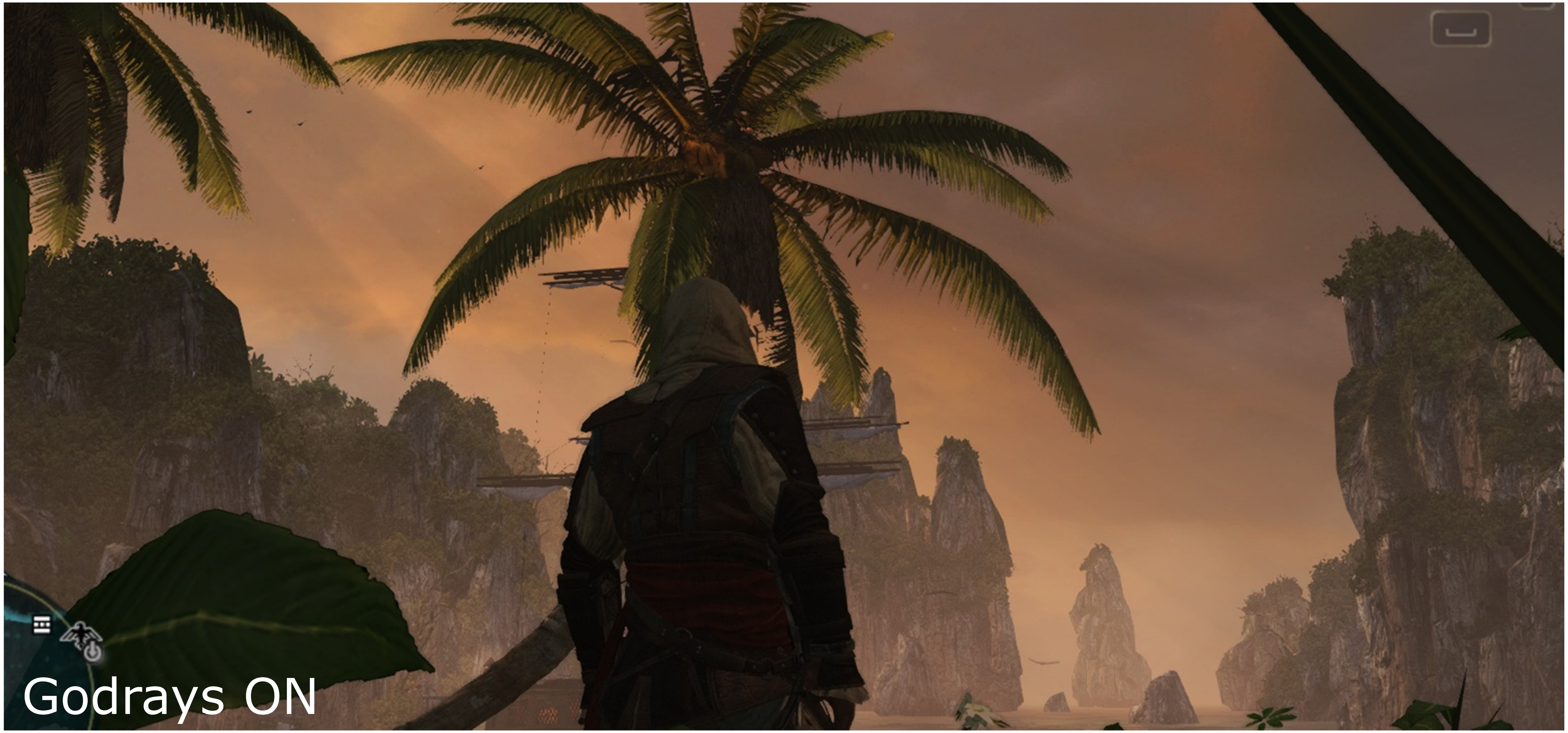


Assassin’s Creed IV Black Flag

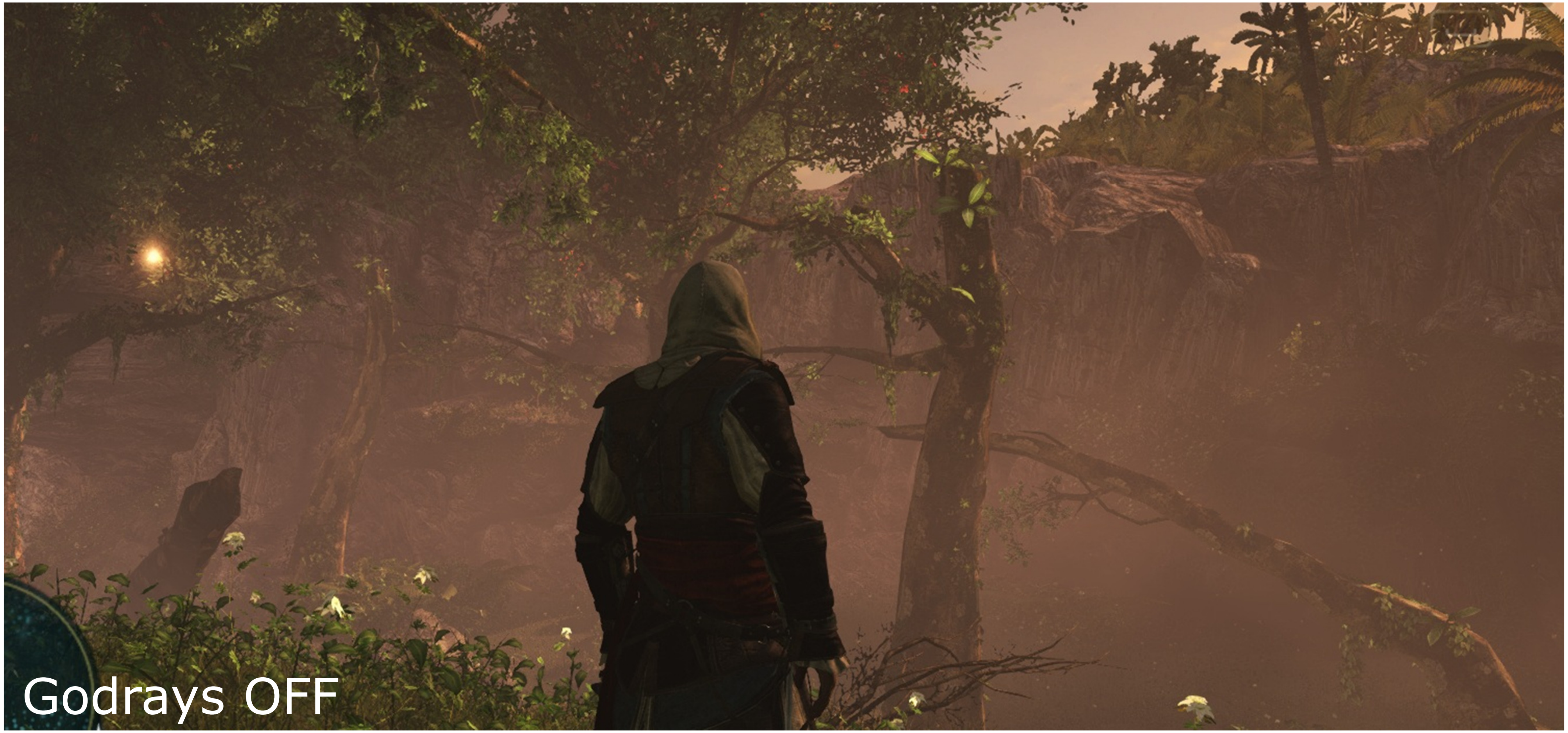


Godrays OFF

Assassin’s Creed IV Black Flag

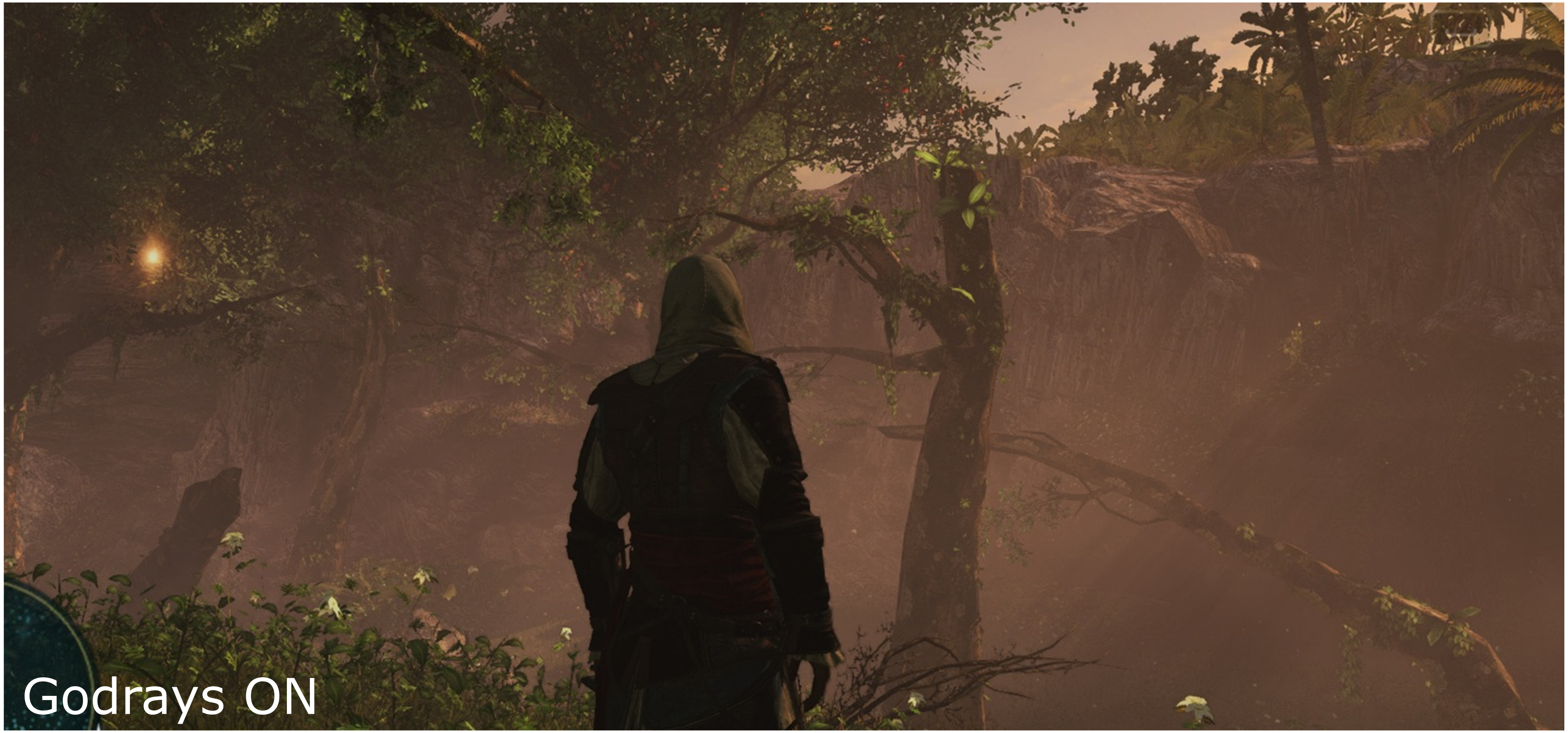


Assassin’s Creed IV Black Flag



Godrays OFF

Assassin’s Creed IV Black Flag



Which effects can benefit from it?

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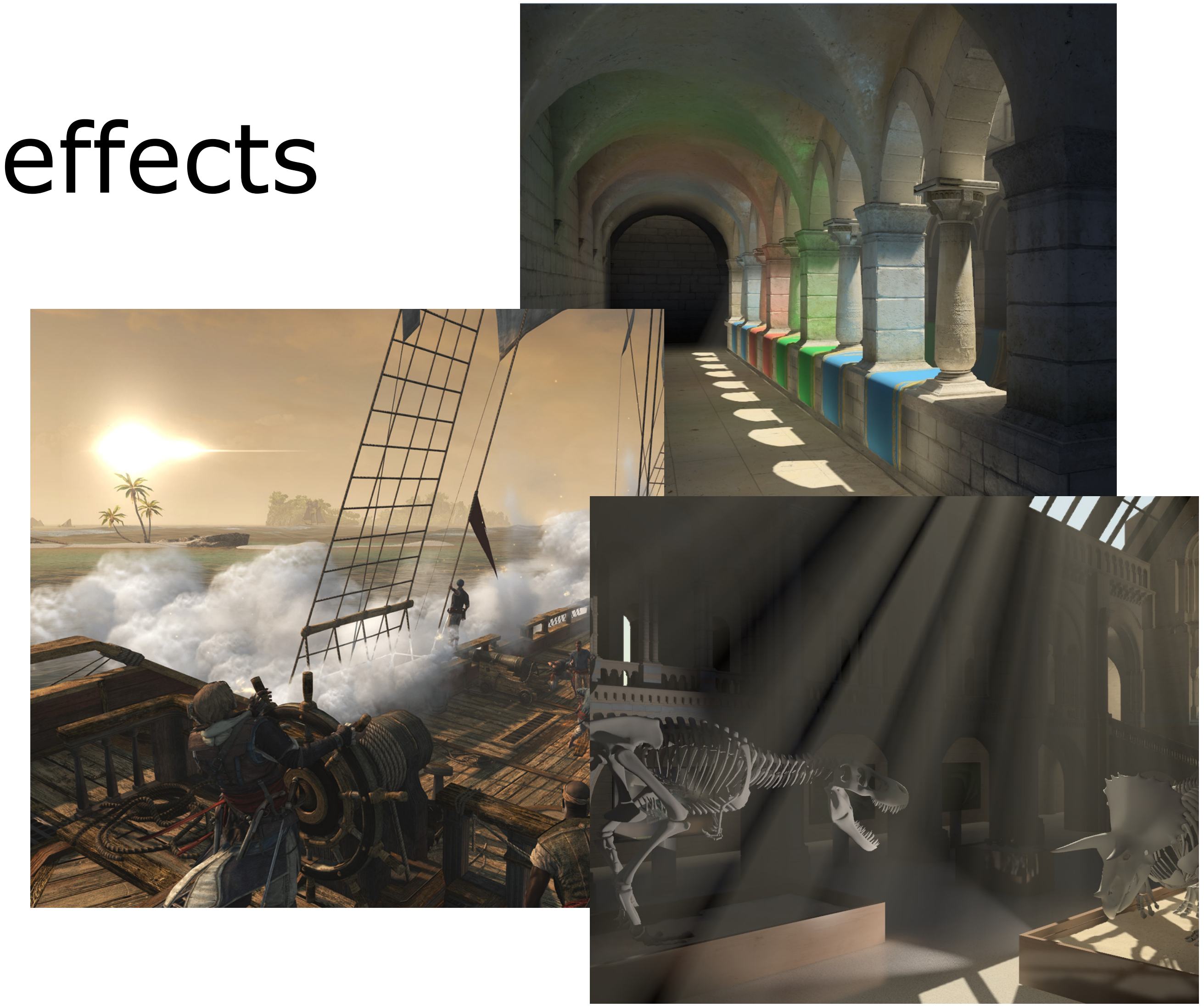
  - Global illumination
  - …



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  - …

AC4BF screenshot was made by Andrew Iain Burnes and published at GeForce.com

Tips and Tricks

- Adding tessellation to your game is not that straightforward
- These corner-cases require attention:
  - Tessellation vs. Depth Pre-Pass
  - Tessellation vs. Shadowmapping
  - Tessellation vs. Decals

Tips and Tricks

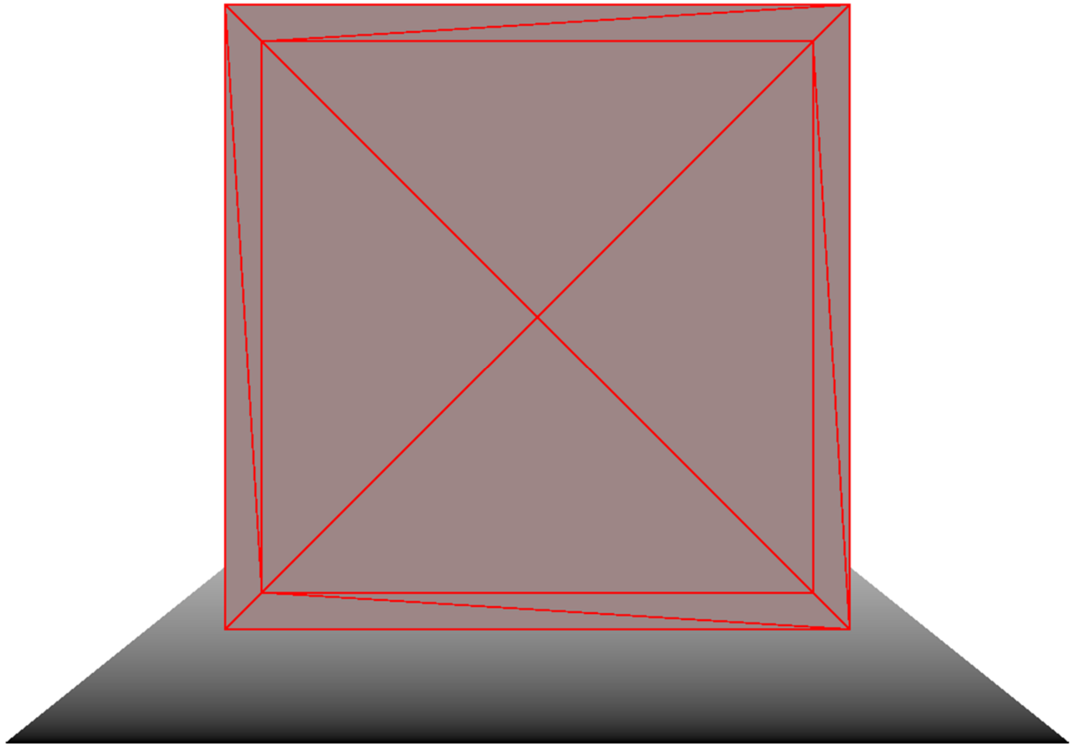
- Tessellation vs. Depth Pre-Pass
- Tessellation vs. Shadowmapping
- Tessellation vs. Decals

Tips and Tricks

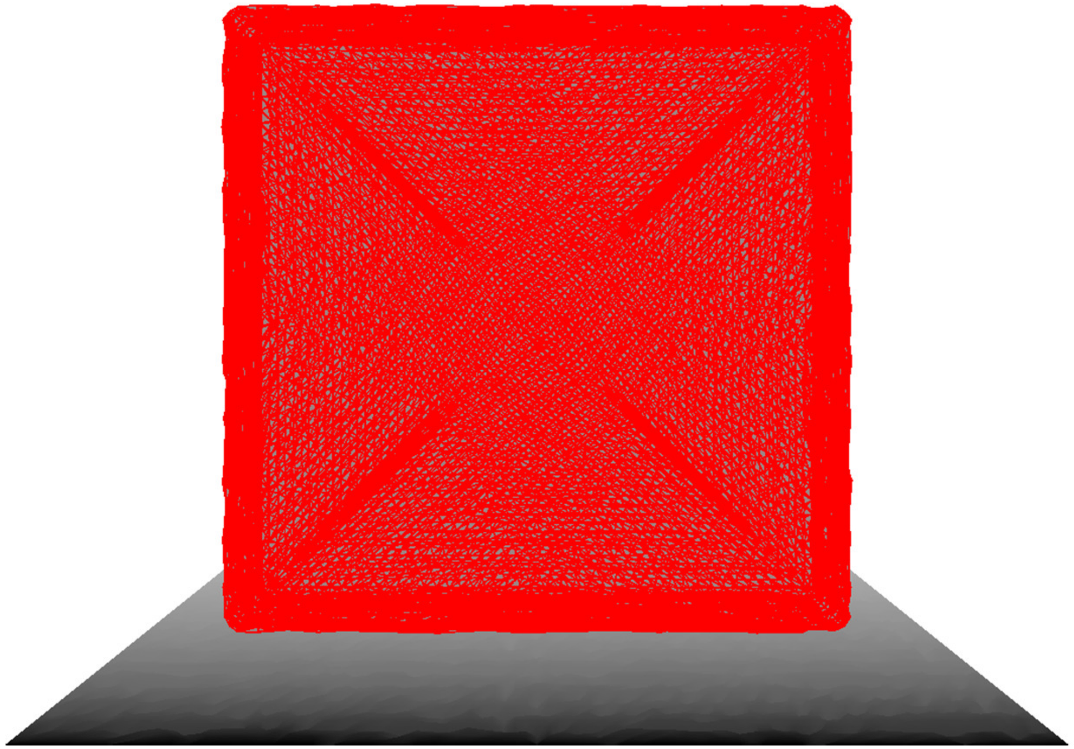
- **Tessellation vs. Depth Pre-Pass**
- Tessellation vs. Shadowmapping
- Tessellation vs. Decals

Tessellation vs. Depth pre-pass

- Tessellating during depth pre-pass can kill the performance benefits of depth pre-pass



vs.



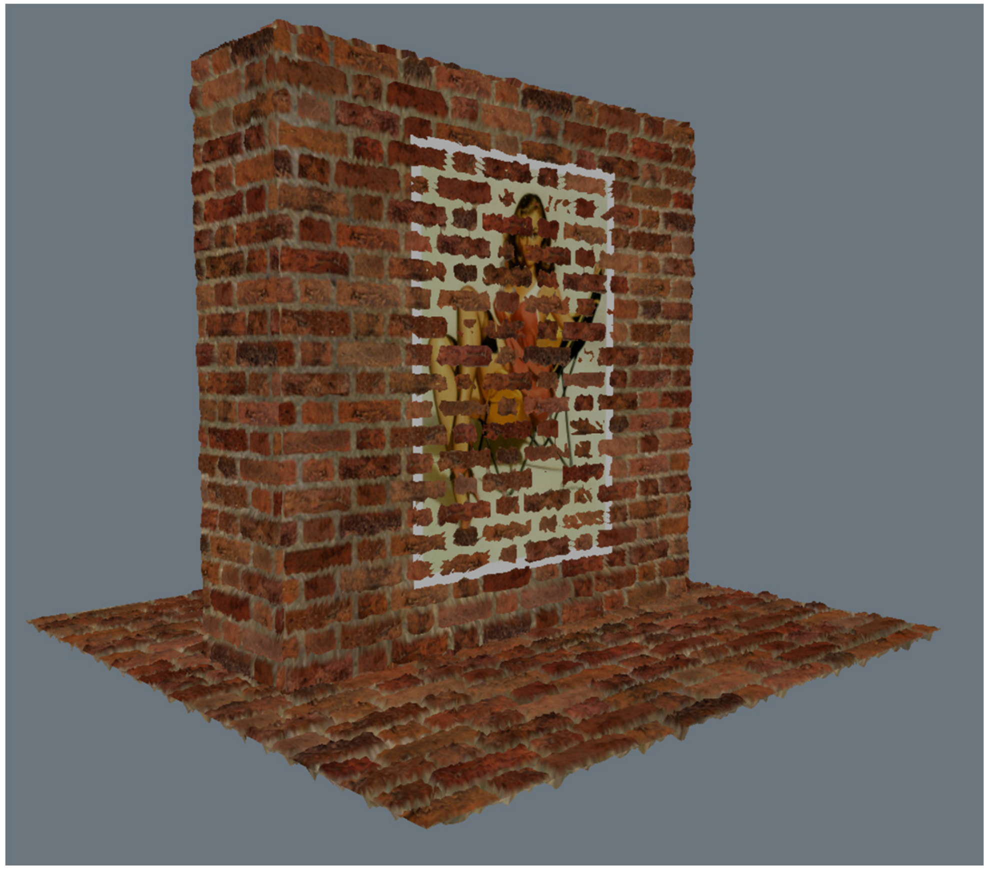
Tessellation vs. Depth pre-pass

- Turn depth pre-pass off

  or
- Don’t use tessellation in depth pre-pass
  - Use always positive tessellation
  - Configure depth test properly

Tessellation vs. Depth pre-pass

- Not tessellating in depth pre-pass



Tessellation vs. Depth pre-pass

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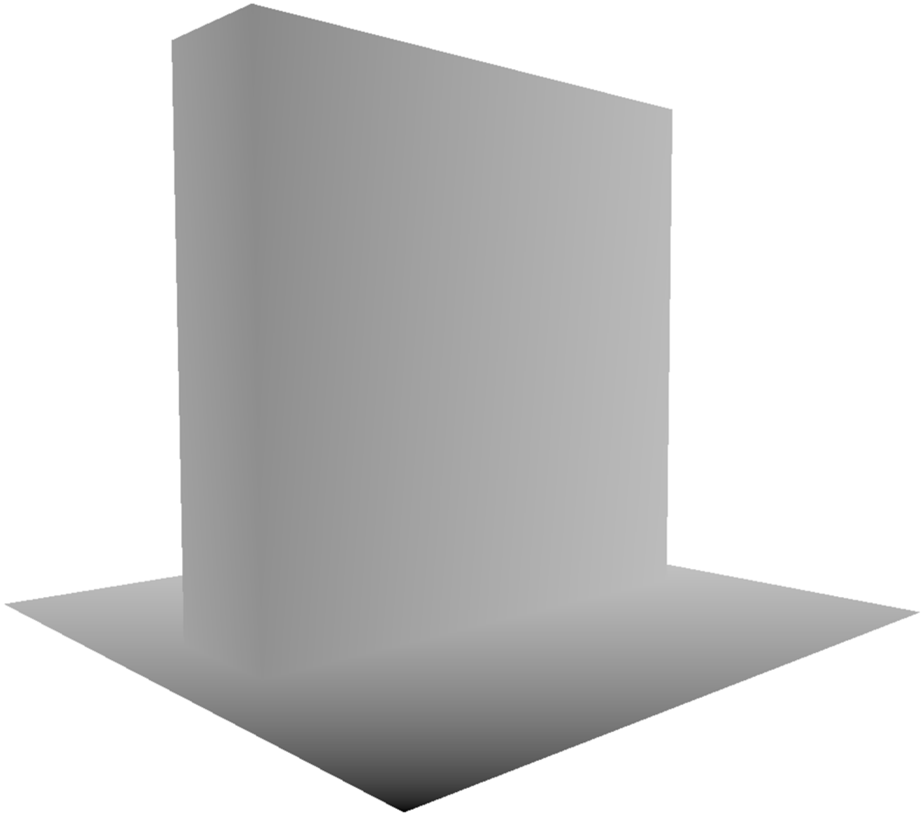

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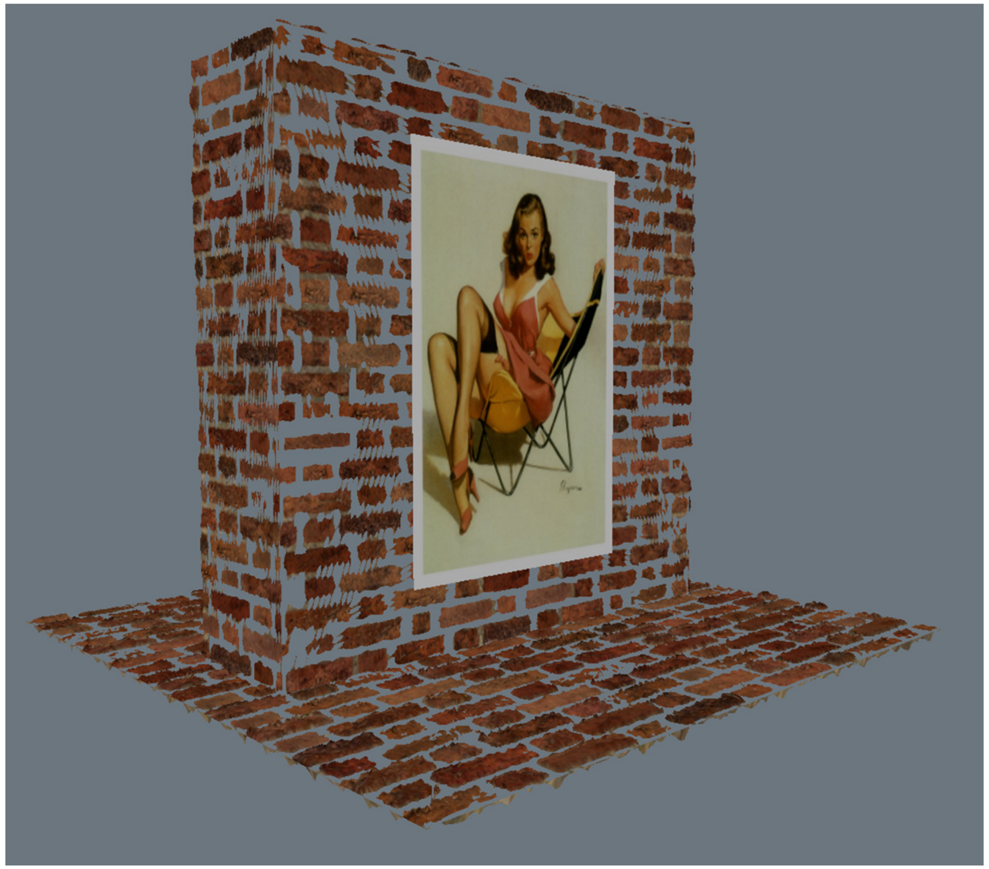


Tessellation vs. Depth pre-pass

- Use always-positive displacement

Tips and Tricks

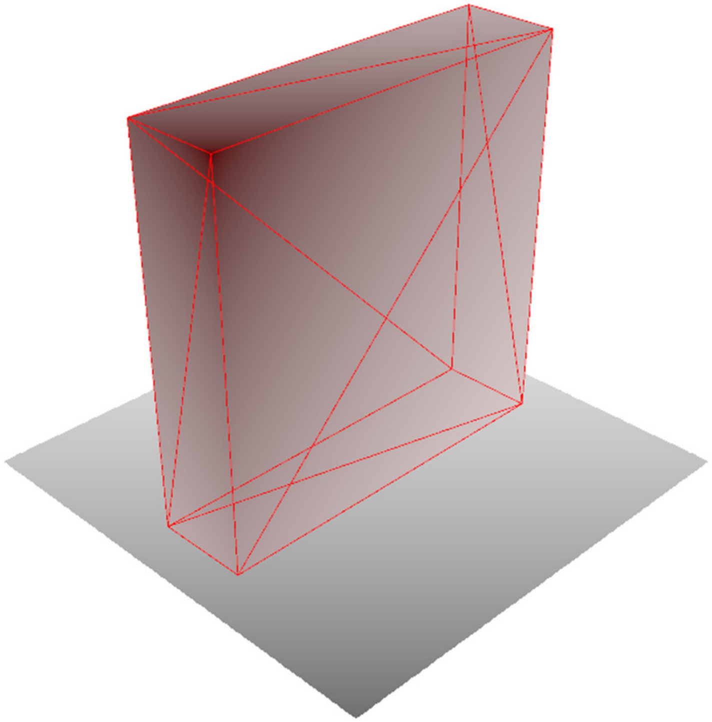
- Tessellation vs. Depth Pre-Pass
- Tessellation vs. Shadowmapping
- Tessellation vs. Decals

Tips and Tricks

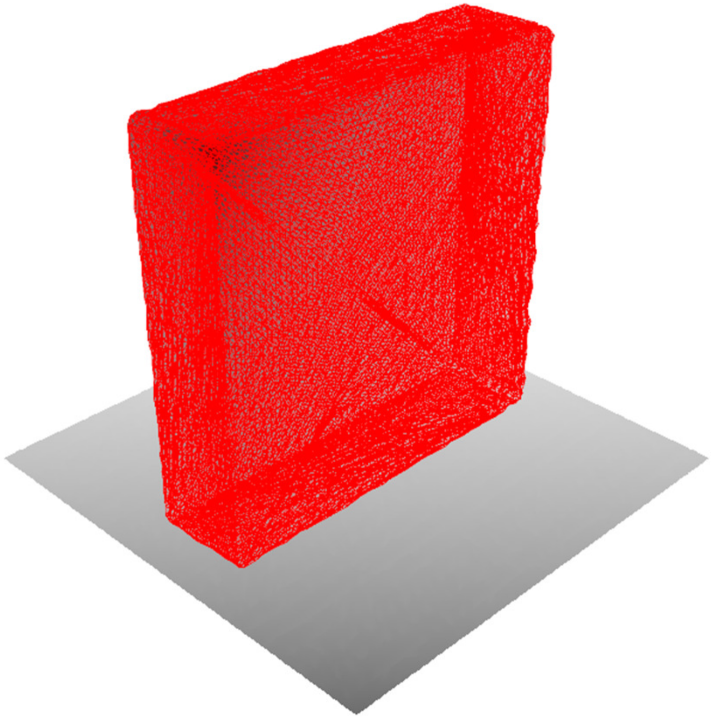
- Tessellation vs. Depth Pre-Pass
- **Tessellation vs. Shadowmapping**
- Tessellation vs. Decals

Tessellation vs. Shadowmapping

- Tessellating while rendering to shadowmap can kill performance

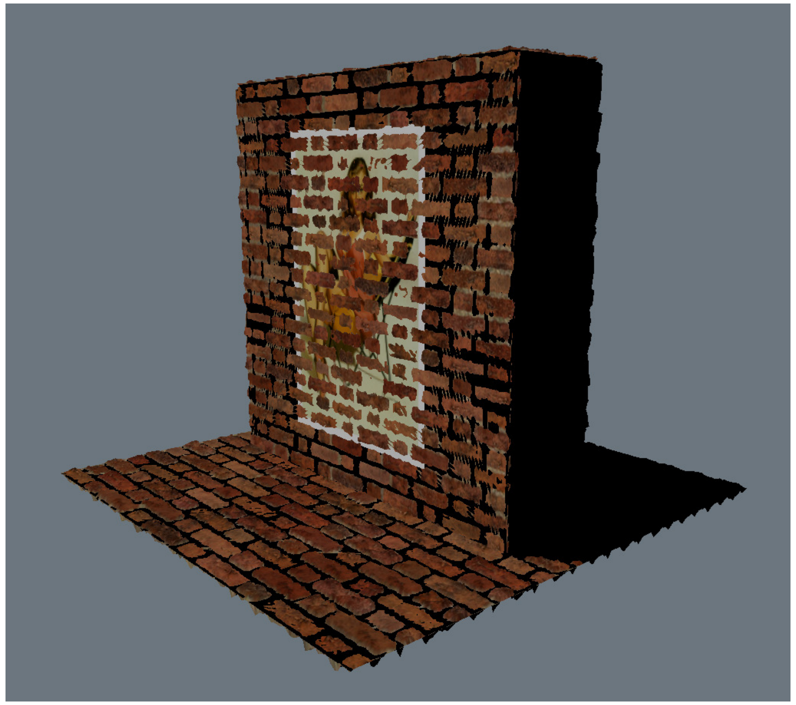


vs.



Tessellation vs. Shadowmapping

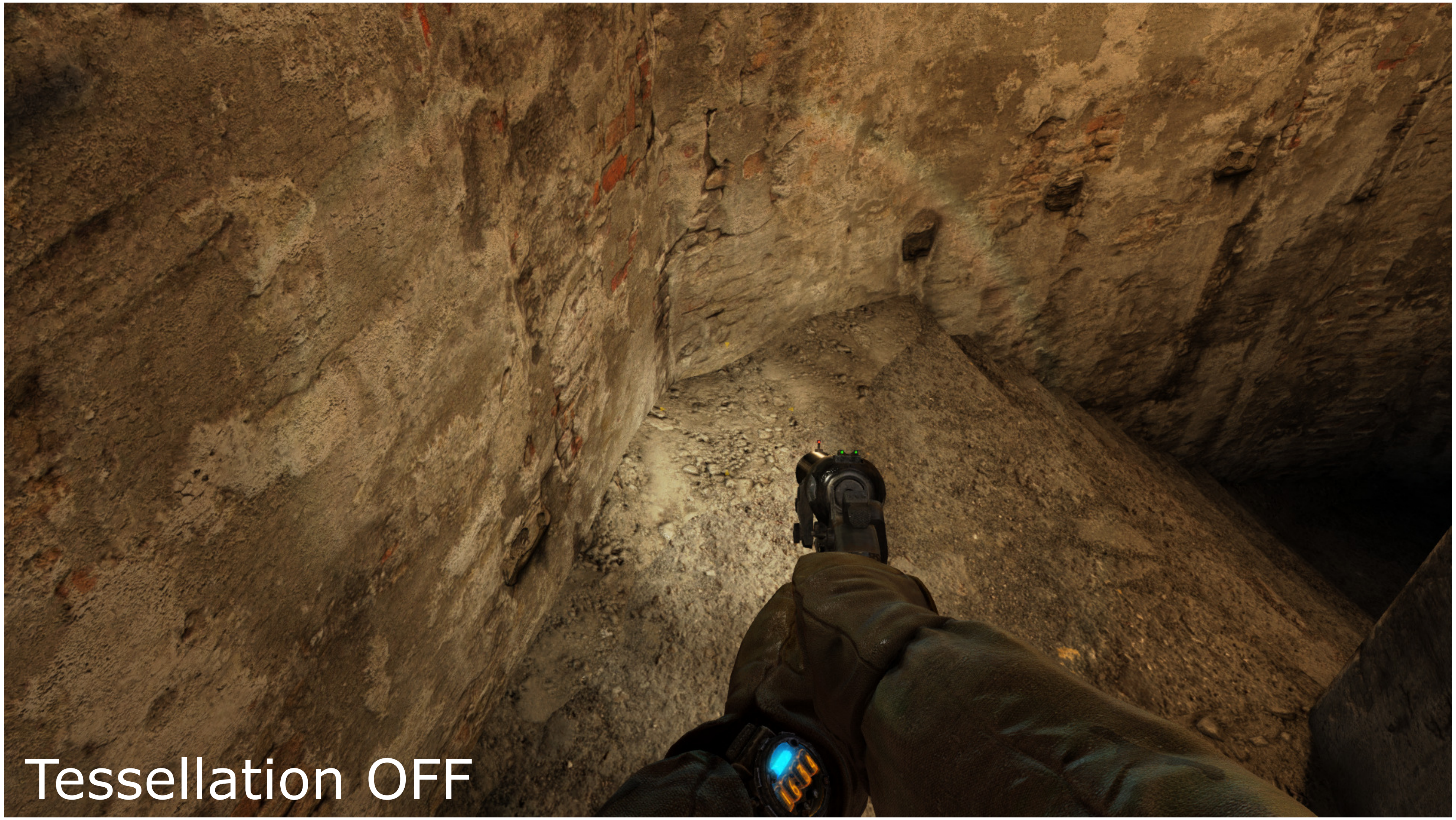
- Turning tessellation off in shadowmaps can introduce artifacts



Tessellation vs. Shadowmapping

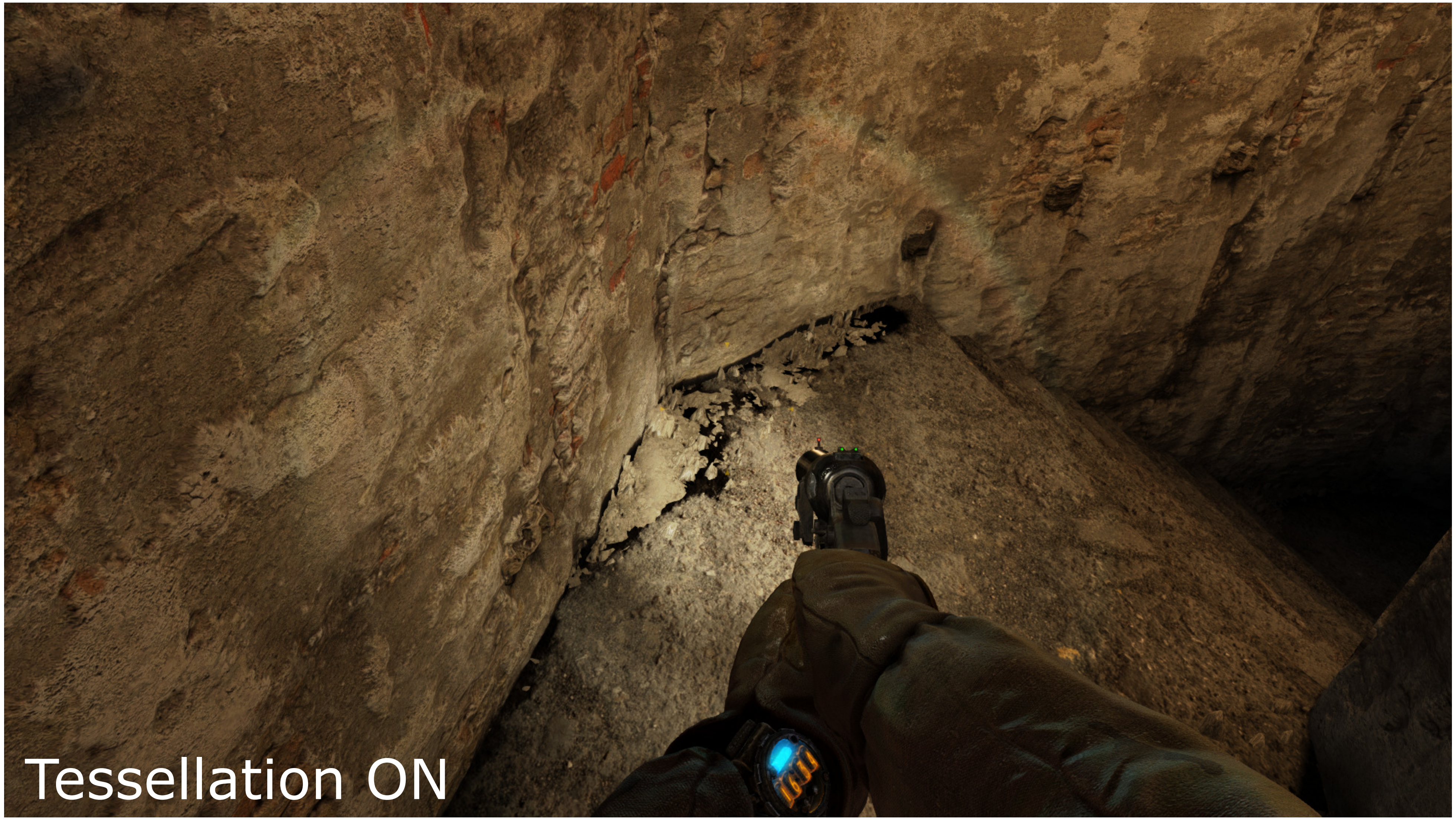
- We decided to turn tessellation **off** in shadowmaps in Metro: Last Light
- This introduced artifacts that artists had to fix by tuning the content

Metro: Last Light

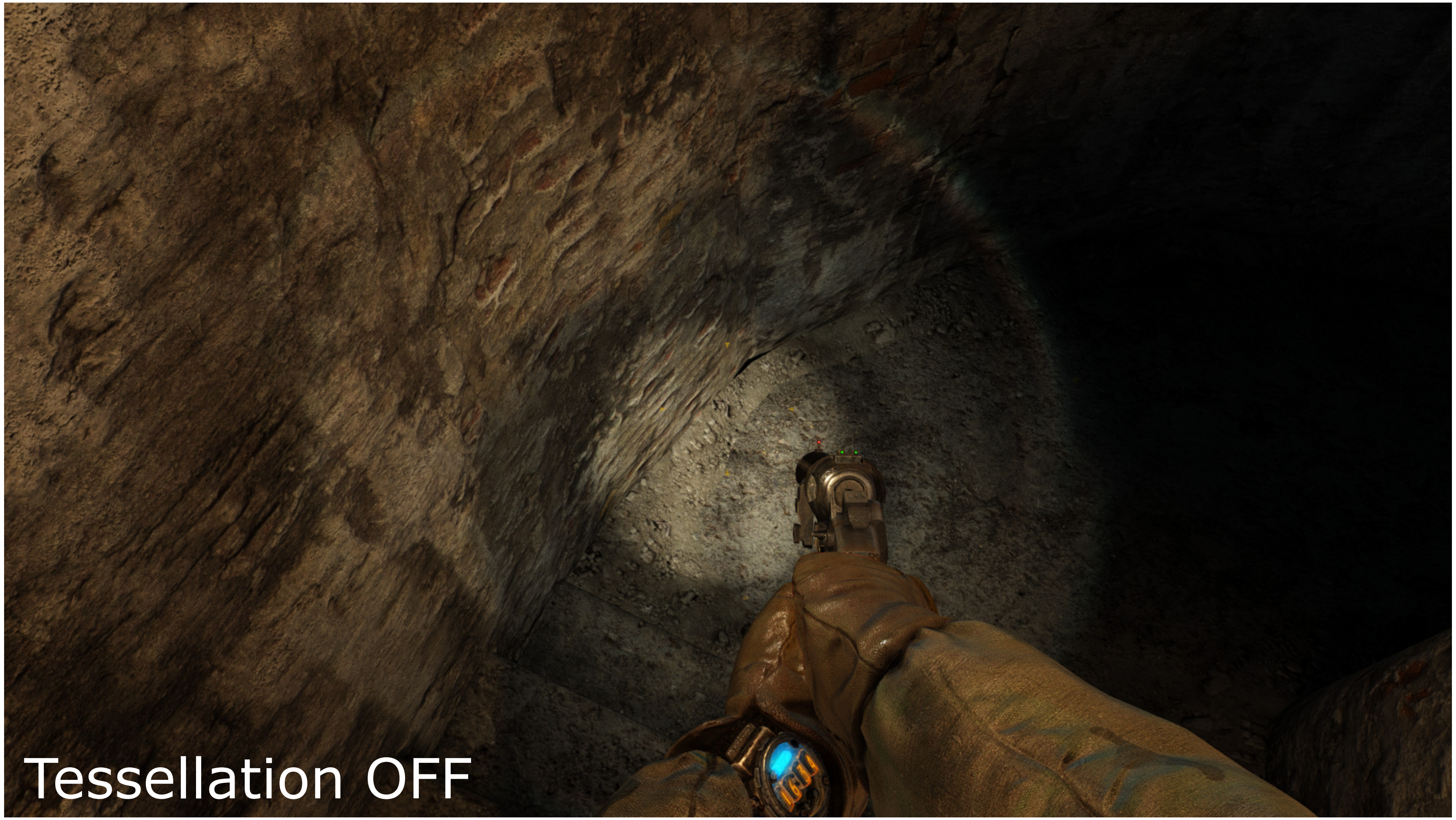


Tessellation OFF

Metro: Last Light

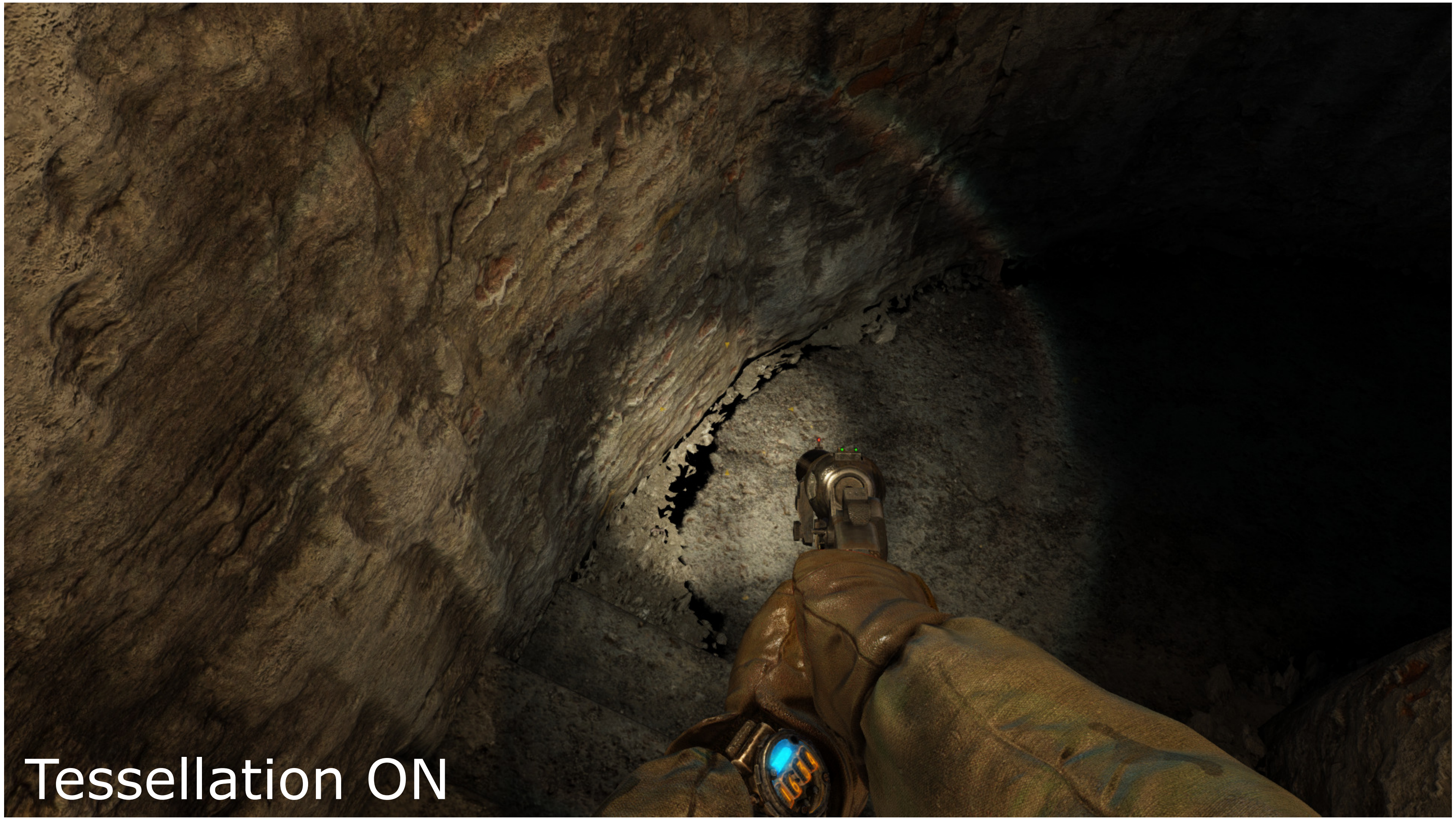


Metro: Last Light



Tessellation OFF

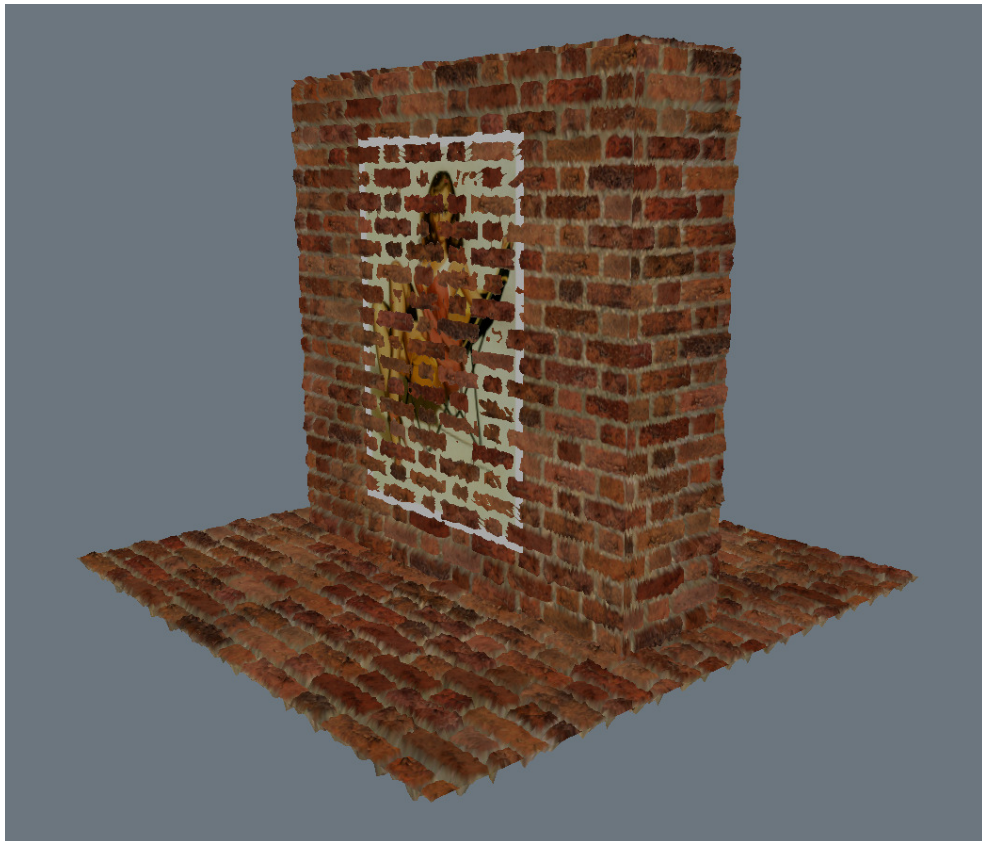
Metro: Last Light



Tessellation ON

Tessellation vs. Shadowmapping

- Use always-positive displacement



Tessellation vs. Shadowmapping

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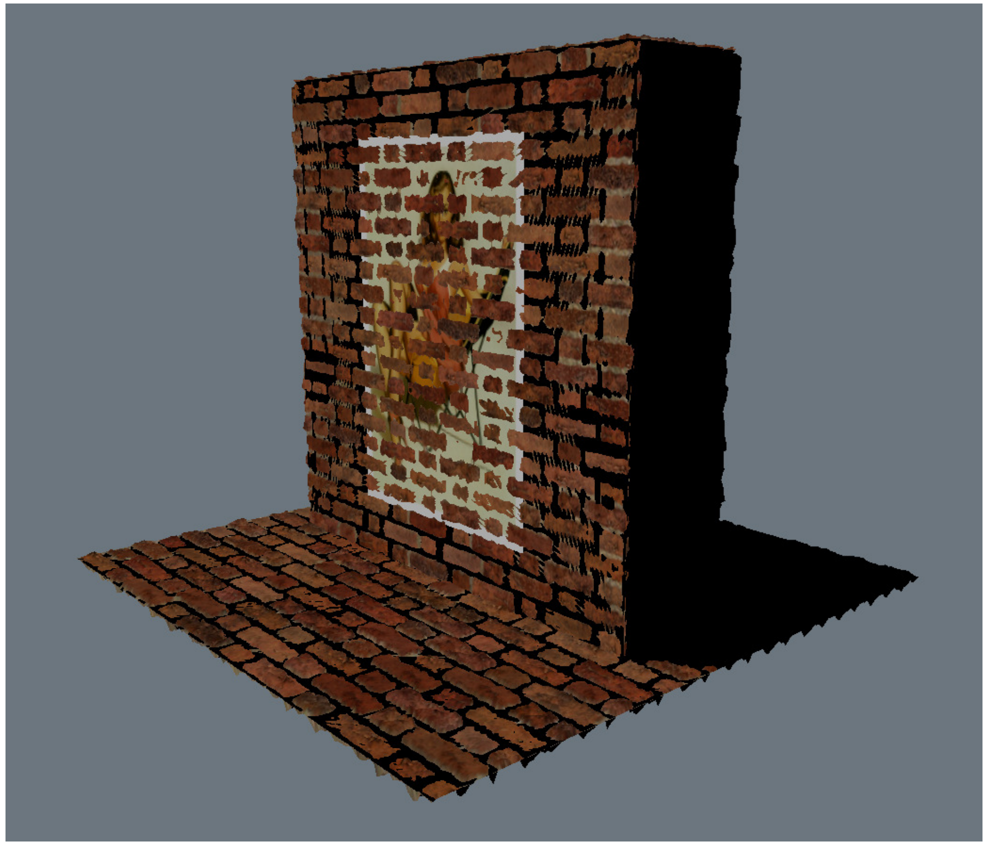

Tessellation vs. Shadowmapping

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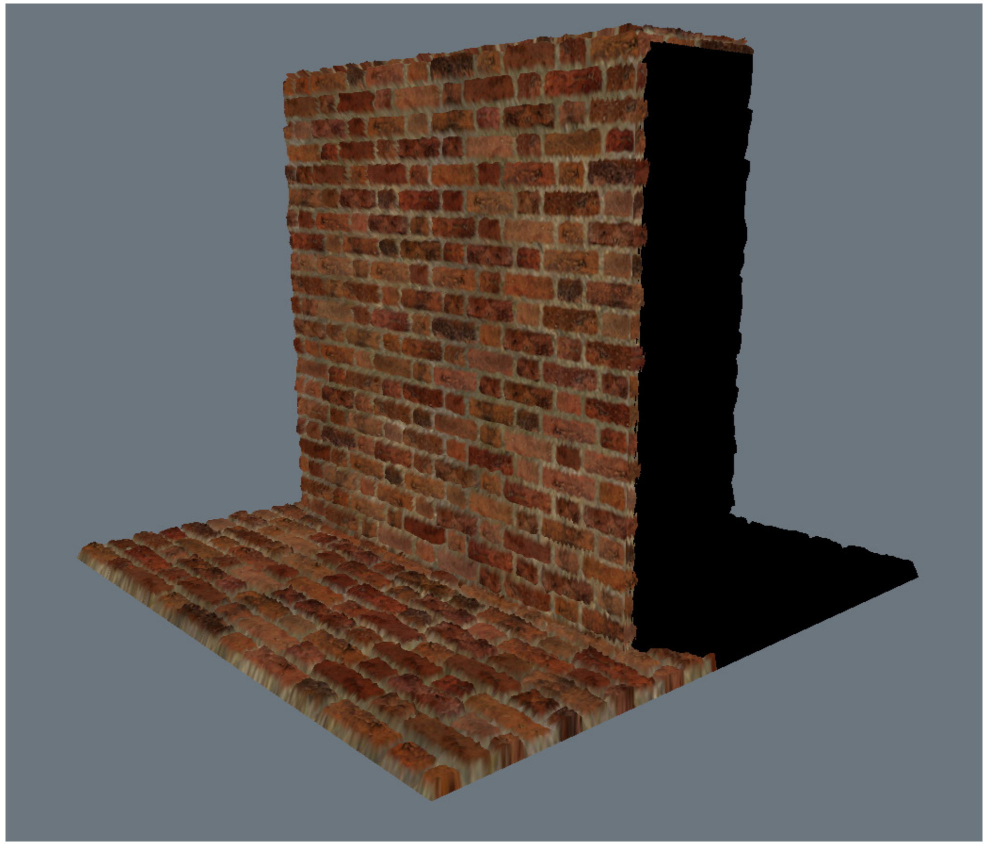
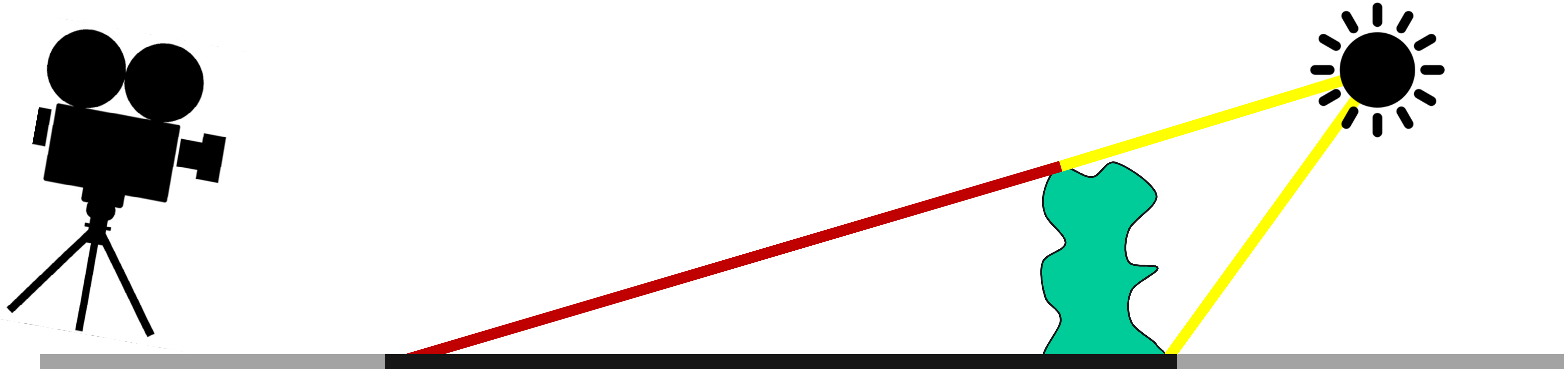


Tessellation vs. Shadowmapping

- If performance is not a problem, what tessellation factor to choose for shadowmap?
  - The same as was used for main screen rendering or
  - Calculated relative to shadowmap camera

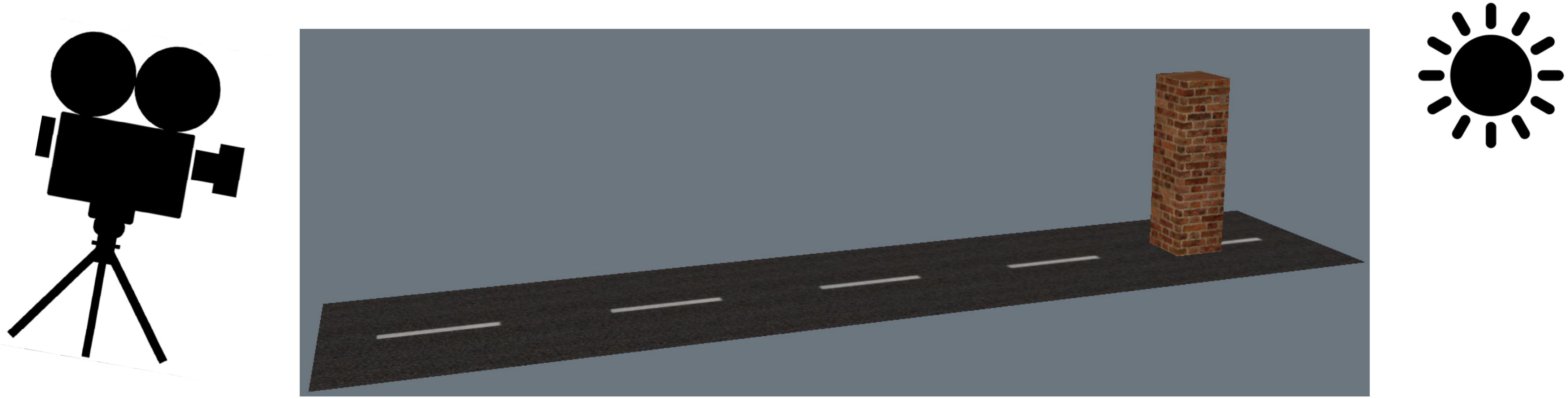
Tessellation vs. Shadowmapping

- Problem of camera and light opposing each other



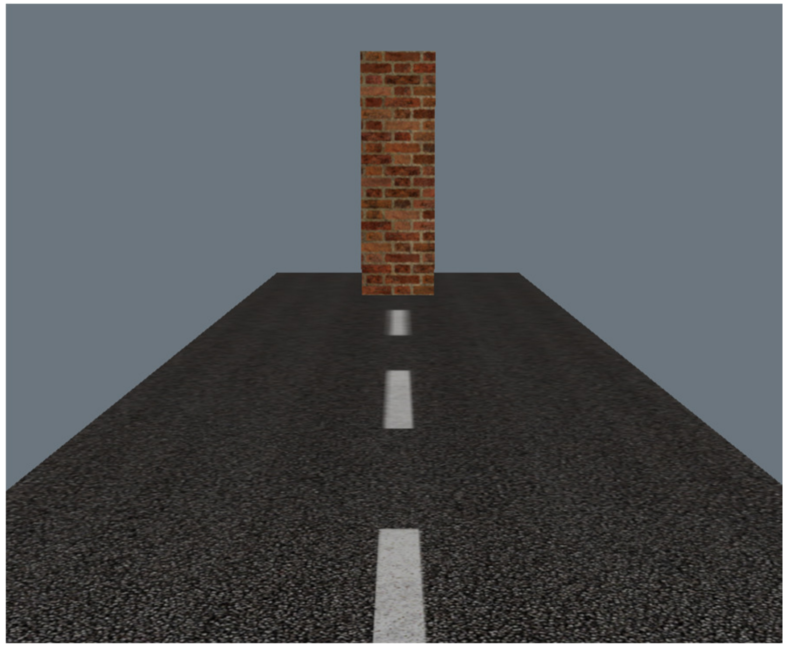
Tessellation vs. Shadowmapping

- Problem of camera and light opposing each other

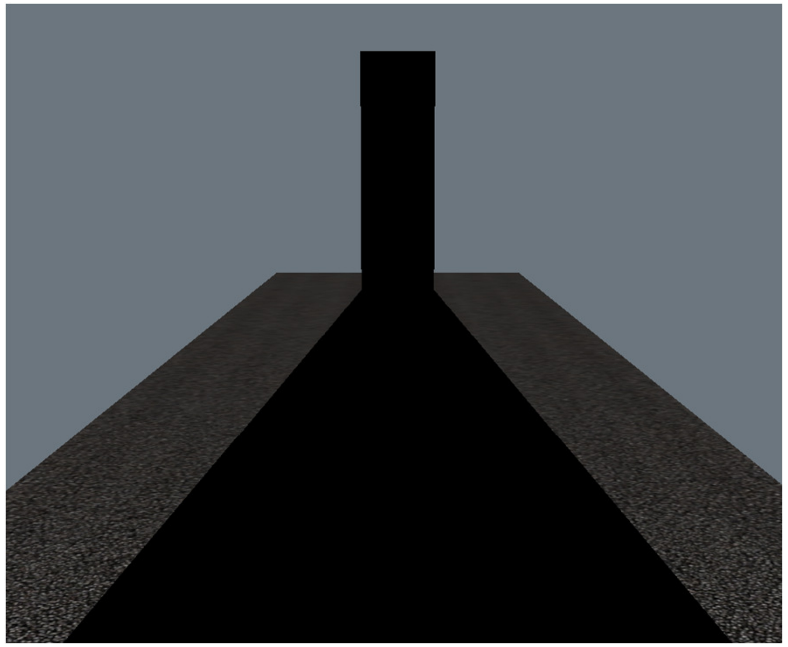


Tessellation vs. Shadowmapping

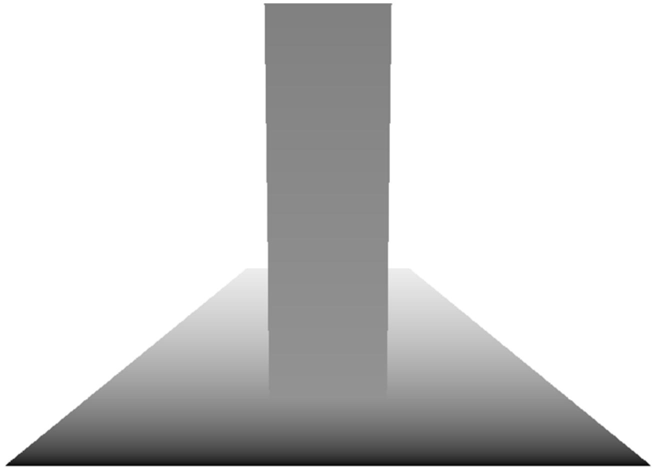
- Camera and light oppose each other



Camera view, no shadows



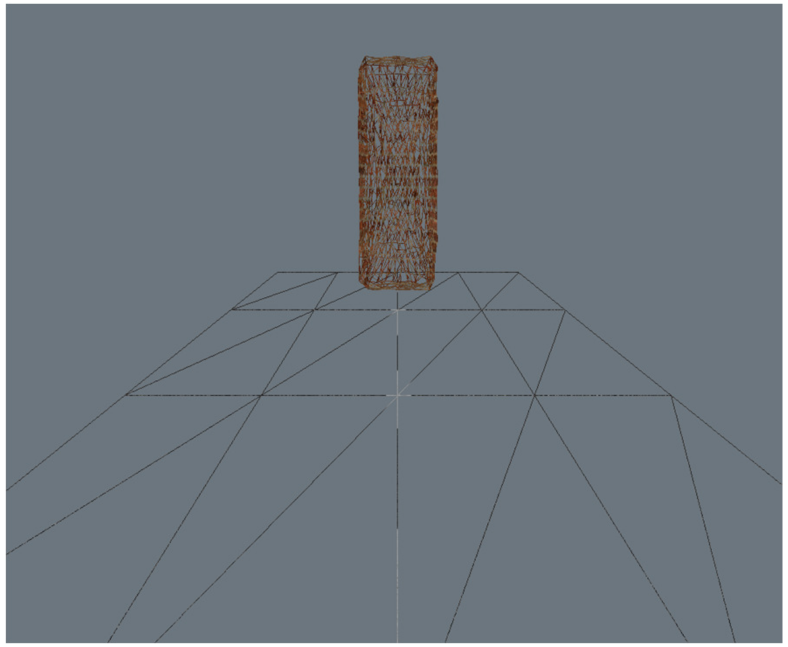
Camera view, shadows enabled



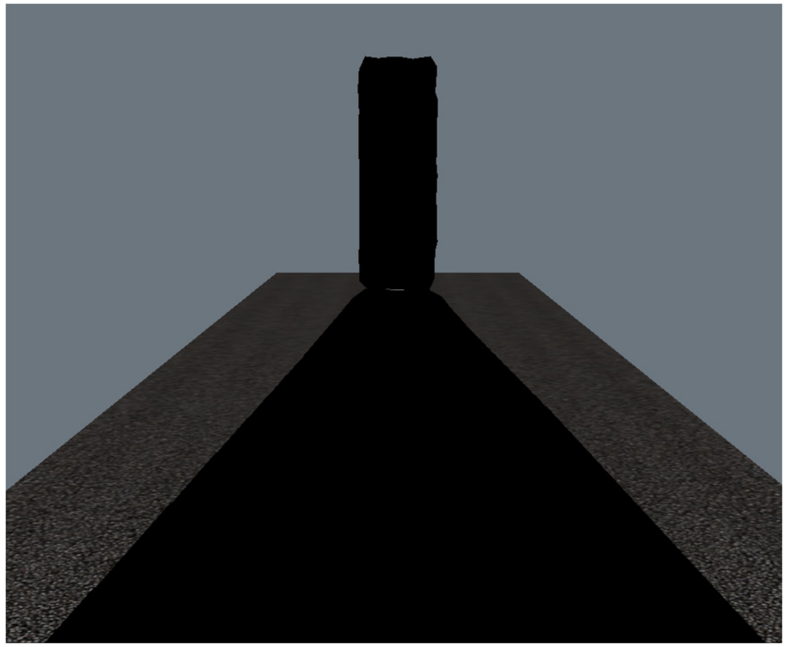
Shadowmap view

Tessellation vs. Shadowmapping

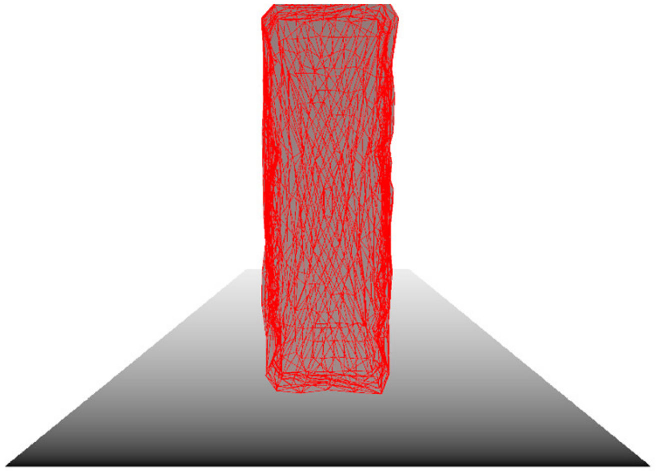
- Using main camera tessellation factor



Camera view, no shadows, wireframe



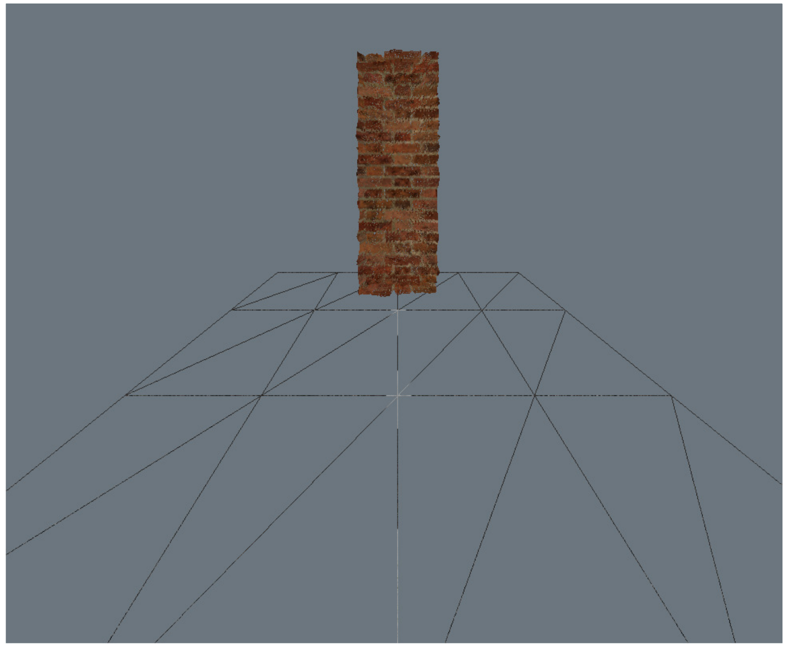
Camera view, shadows enabled



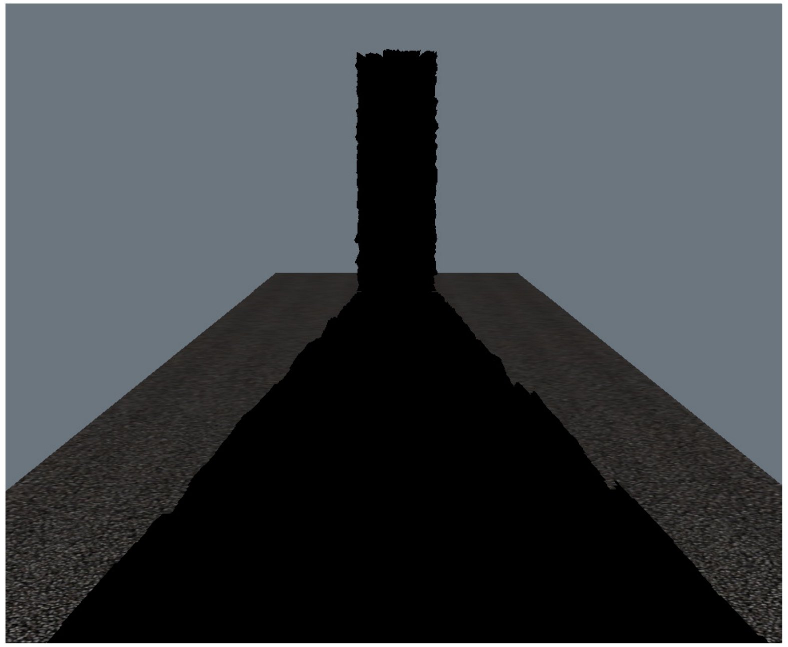
Shadowmap view

Tessellation vs. Shadowmapping

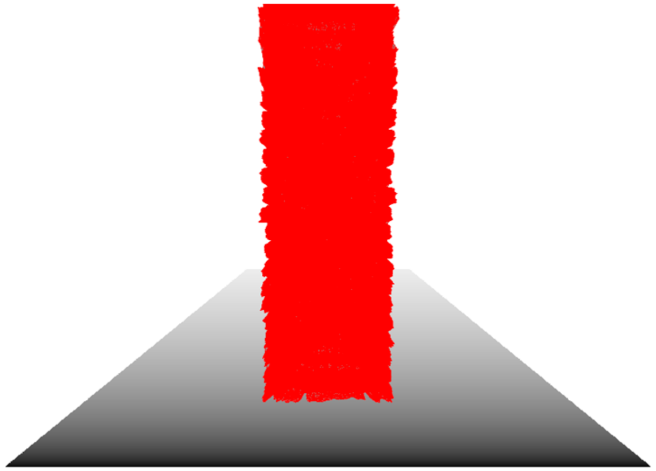
- Using shadowmap tessellation factor



Camera view, no shadows, wireframe



Camera view, shadows enabled



Shadowmap view

Tessellation vs. Shadowmapping

- Choose the maximum tessellation factor from the main screen factor and shadowmap factor
- Make sure to not generate sub-pixel triangles

Tips and Tricks

- Tessellation vs. Depth Pre-Pass
- Tessellation vs. Shadowmapping
- Tessellation vs. Decals

Tips and Tricks

- Tessellation vs. Depth Pre-Pass
- Tessellation vs. Shadowmapping
- **Tessellation vs. Decals**

Tessellation vs. Decals

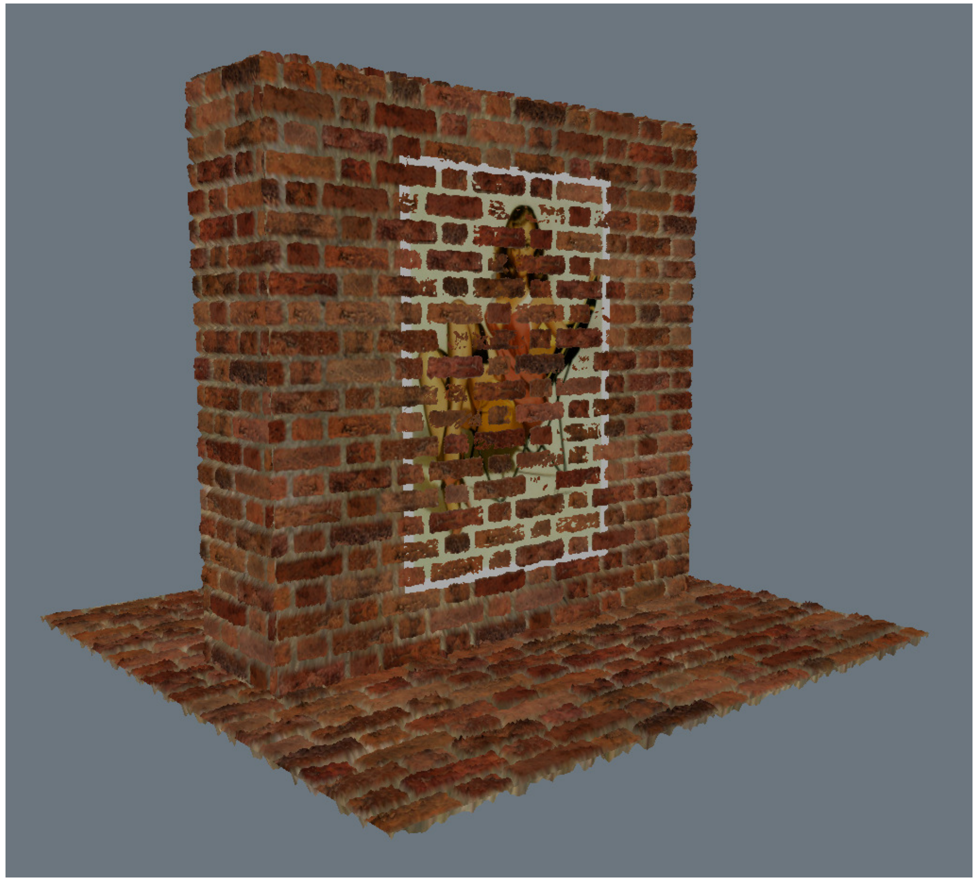
- Tessellated geometry can penetrate through decals
- We had this problem during the development of Metro: Last Light
- Artists had to fix it by tuning the content

Tessellation vs. Decals

- Use always-negative displacement

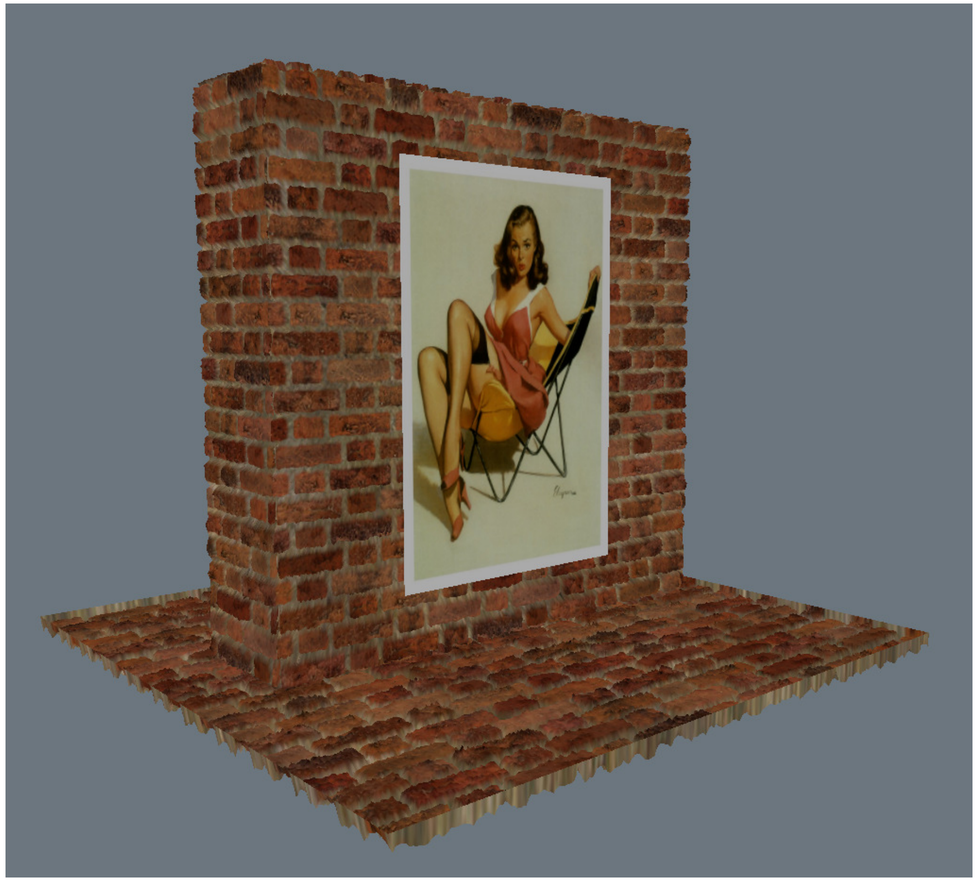
Tessellation vs. Decals

- Use always-negative displacement

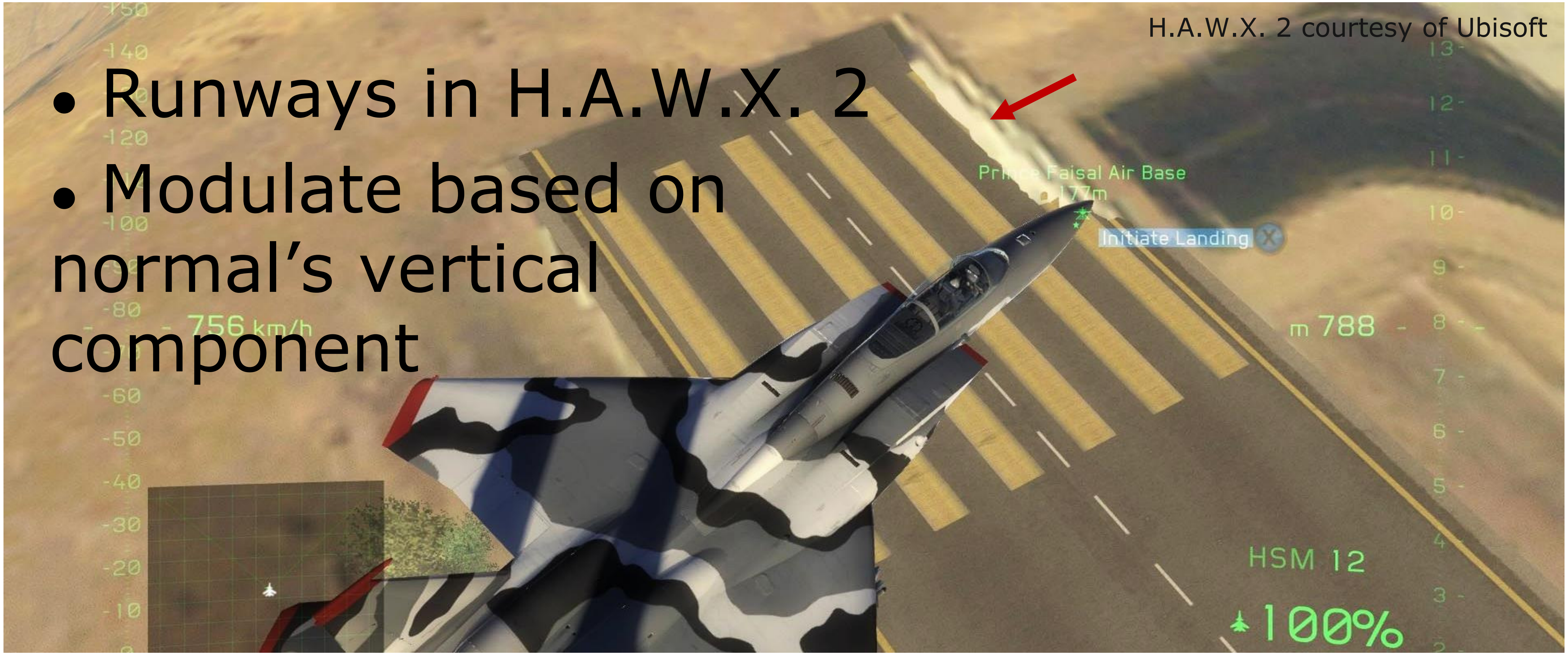


Tessellation vs. Decals

- Use always-negative displacement



Tessellation vs. Decals



H.A.W.X. 2 courtesy of Ubisoft

- Runways in H.A.W.X. 2
- Modulate based on normal’s vertical component

Tessellation vs. Decals

- Use “screen space decals” technique
- Pope Kim, Screen Space Decals in Warhammer 40,000: Space Marine, Siggraph 2012

Conclusions

- Tessellation can be used to produce spectacular images on all platforms
- Use your triangles wisely!
- The new paradigm of varying shading rate can bring significant speedup to your effects

Conclusions

- When adding tessellation to your title, keep these in mind:
    - Tessellation vs. Depth pre-pass
    - Tessellation vs. Shadowmapping
    - Tessellation vs. Decals

References

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- Albert Cervin, Adaptive Hardware-accelerated Terrain Tessellation, Linkoping University, 2012
- Mattias Widmark, Terrain in Battlefield 3: A Modern, Complete and Scalable System, GDC 2012
- Jon Jansen, Louis Bavoil, Fast Rendering of Opacity-Mapped Particles Using DirectX 11 Tessellation and Mixed Resolutions, Nvidia SDK whitepaper, 2011
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Jani Joki

Juha Sjoholm

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