NASA Lunar Terrain Visualization in Unreal Engine 5

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NASA Artemis Mission

“With Artemis missions, NASA will land the first woman and first person of color on the Moon, using innovative technologies to explore more of the lunar surface than ever before. We will collaborate with commercial and international partners and establish the first long-term presence on the Moon. Then, we will use what we learn on and around the Moon to take the next giant leap: sending the first astronauts to Mars.”

https://www.nasa.gov/specials/artemis/

Presentation Overview

- Purpose:
  - Provide information detailing how NASA utilizes Unreal Engine 5 to generate and visualize accurate lunar terrain.

- This presentation is:
  - ❑ Decisional
  - ❑ Directional
  - ✓ Informational
  - ❑ Action Item Closure / Status (Provide action number)

- Topics:
  - Modeling and Simulation for Engineering
  - Lunar Terrain Generation
    - Landscapes
    - Nanite Meshes
    - Clip Maps
  - Lunar Environment Modeling

Modeling and Simulation for Engineering and Exploration

- Our primary concern is that our simulations are sufficiently accurate for the purposes for which they were built.

- All simulations are approximations, and allowable uncertainty is dictated by intended use.

- Balancing fidelity with cost is a never-ending challenge.

- Our visualization and simulation tools are used:

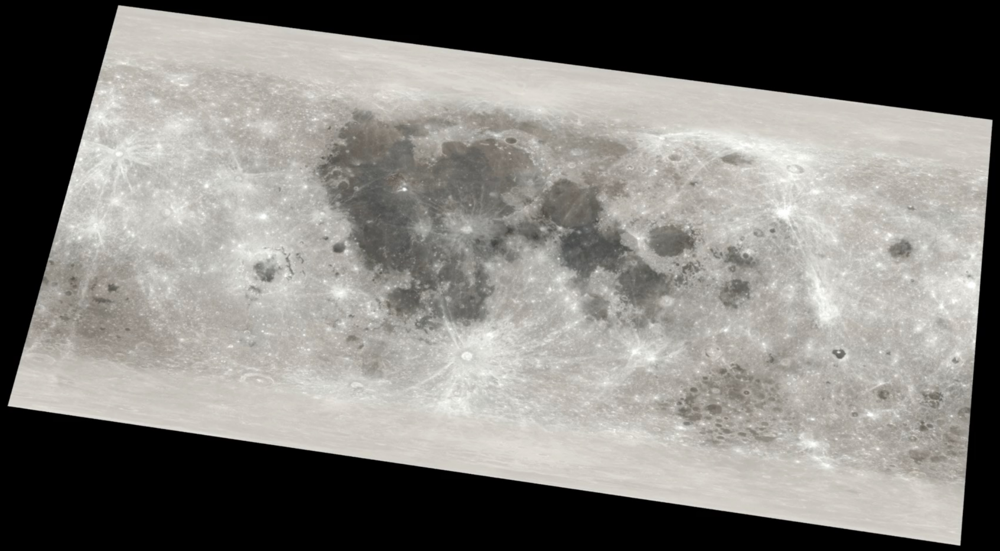
    - to enhance the design of new vehicles where concepts are virtually “flown” in a simulator and evaluated for safety, efficiency, operability, etc.

    - to plan missions involving already-built vehicles, like ISS, by helping mission planners to ensure success while minimizing risk.

    - to train astronauts as they prepare for flight by immersing them in a flight-like environment to enhance skills and prepare them for all potential contingencies.

Why Model the Lunar Surface?

- Support analysis and provide context for lander approach trajectories
- Provide insight to terrain and lighting conditions for mission planning and surface operations
- Generate a representative mission environment for astronaut training
- Additional system analysis for communication, occultation, solar energy and heat generation, etc.
- Develop optimized rover traversals with constraints such as energetics, lighting, and communication line-of-sight

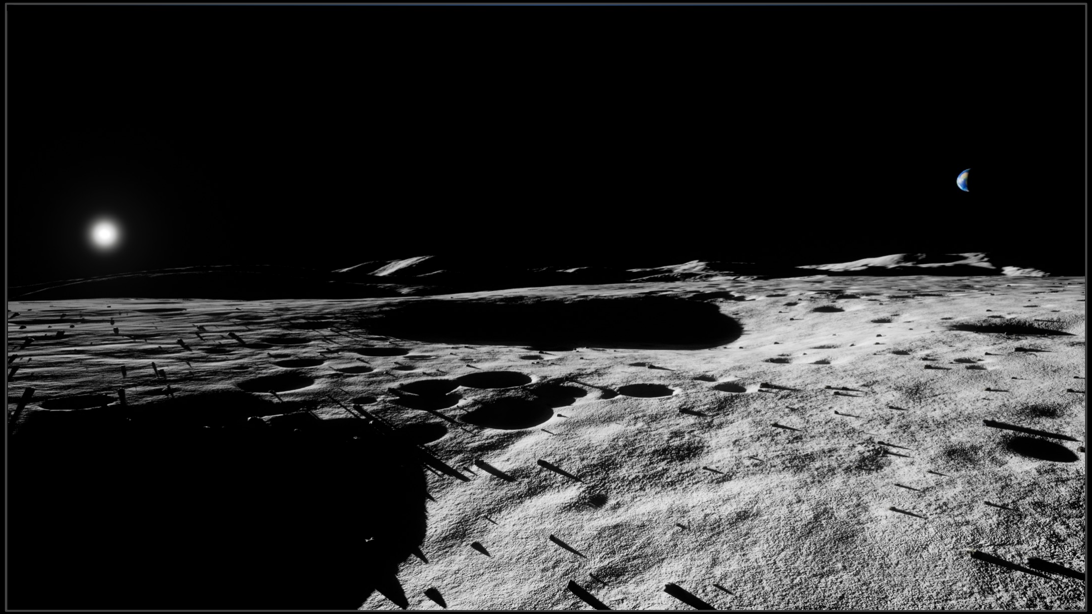


Engineering Driven Design

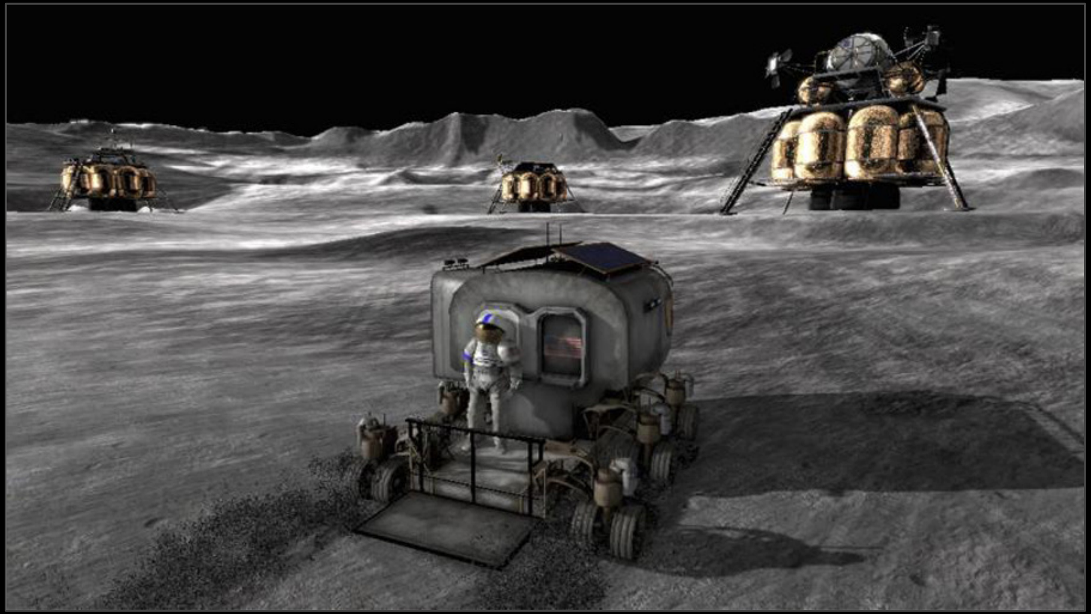
Apollo 17 Image

UE5 Recreation

Accuracy versus Artistry



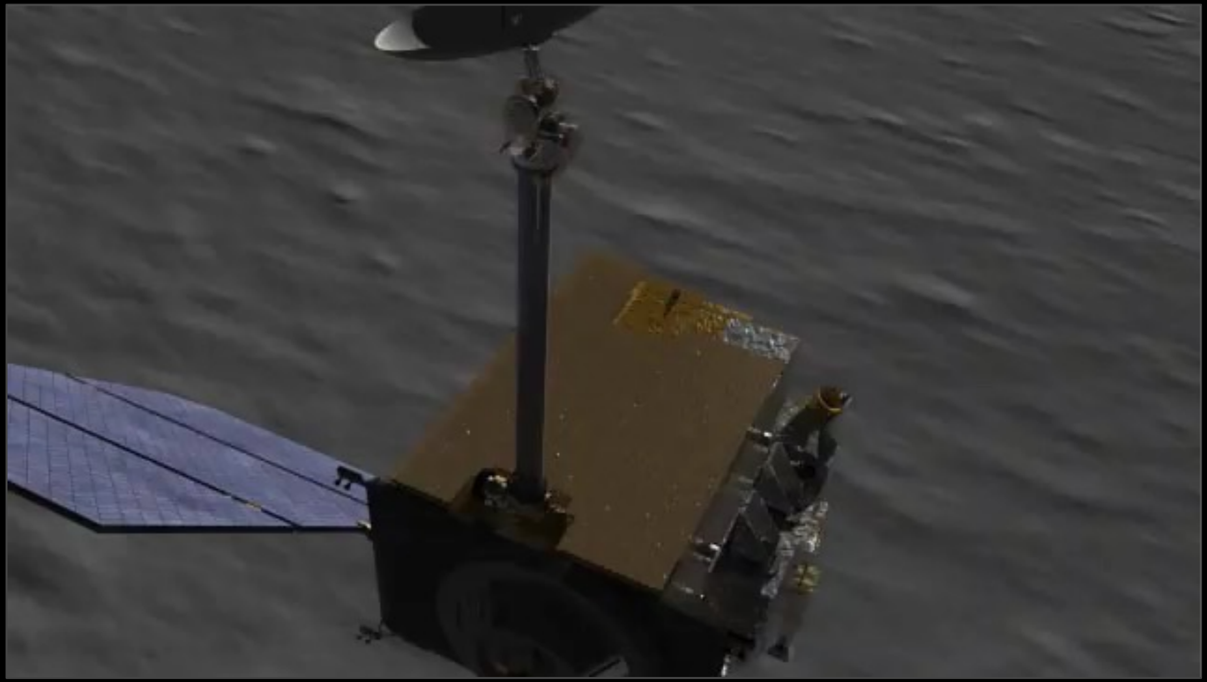
Terrain Generated with LRO Data



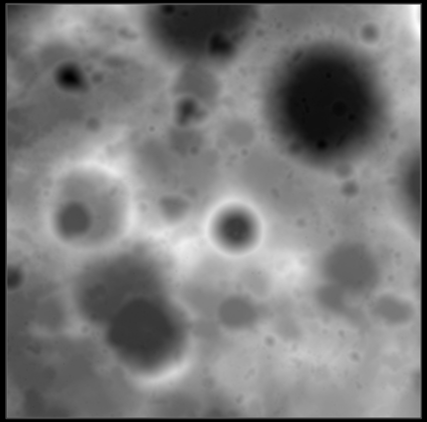
NASA Video Game Moonbase Alpha

Utilizing Terrain Data

- Generating terrain to reflect realistic lunar conditions with data collected from the Lunar Reconnaissance Orbiter (LRO)
- Utilize Digital Elevation Models (DEMs) and the Geospatial Data Abstraction Library (GDAL) to create game engine consumable heightmap data
- DEMs are generally in a .TIFF file format, containing coordinates and corresponding elevations



Video Source: NASA/Goddard Space Flight Center Conceptual Image Lab



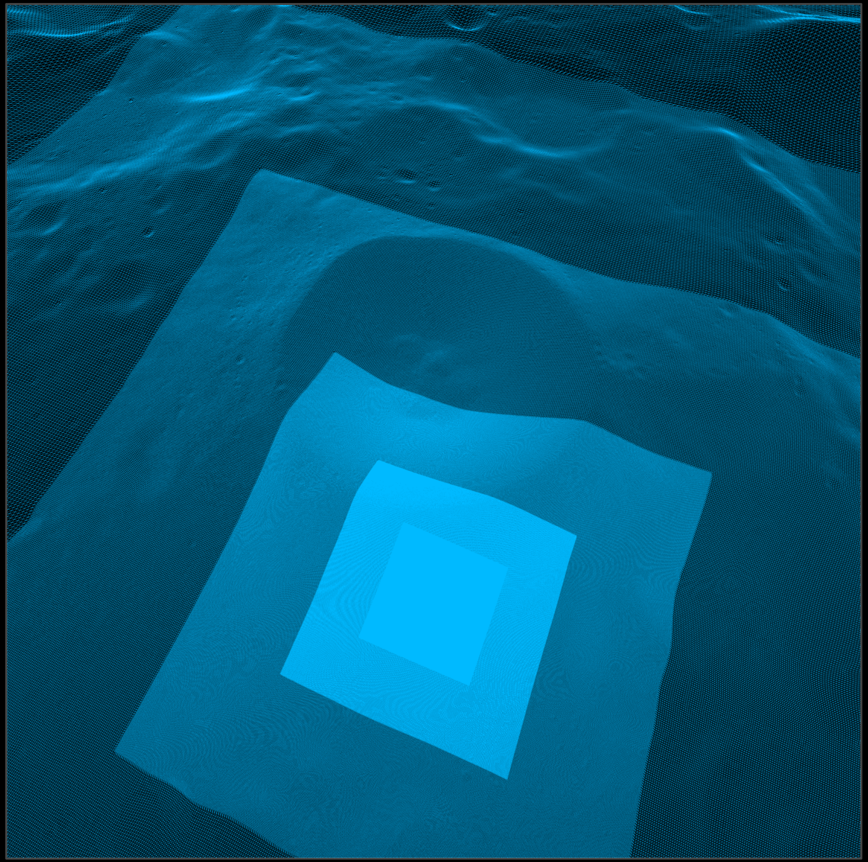
Lunar South Pole DEM

NASA Lunar Terrain

Lunar Terrain Generation

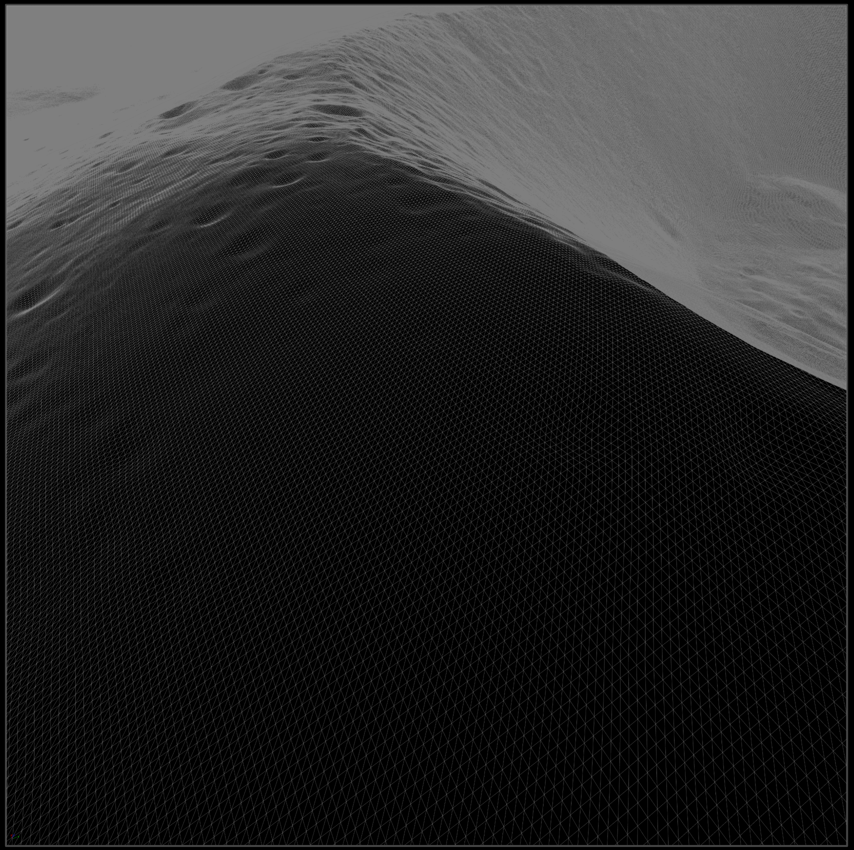
Lunar Terrain Generation

- Landscapes
- Nanite Meshes
- Clip Maps



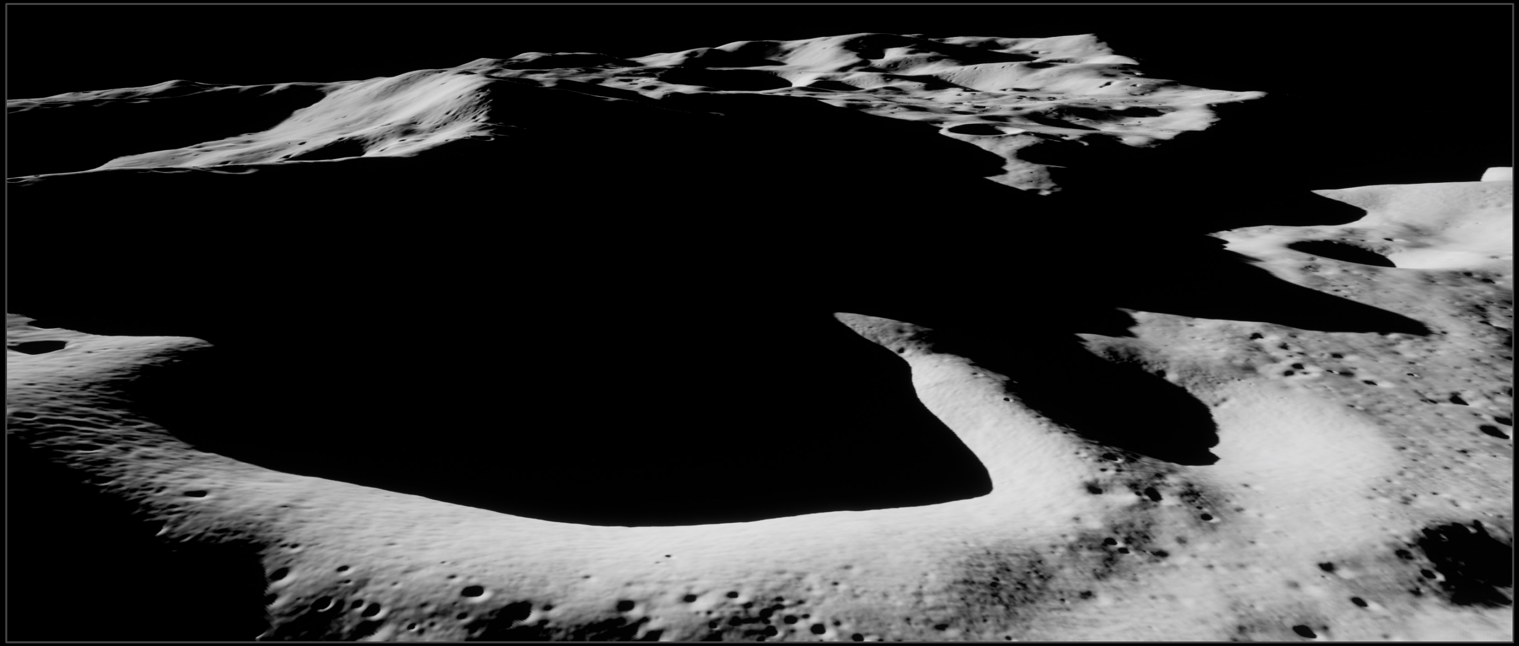
Landscape Lunar Terrain

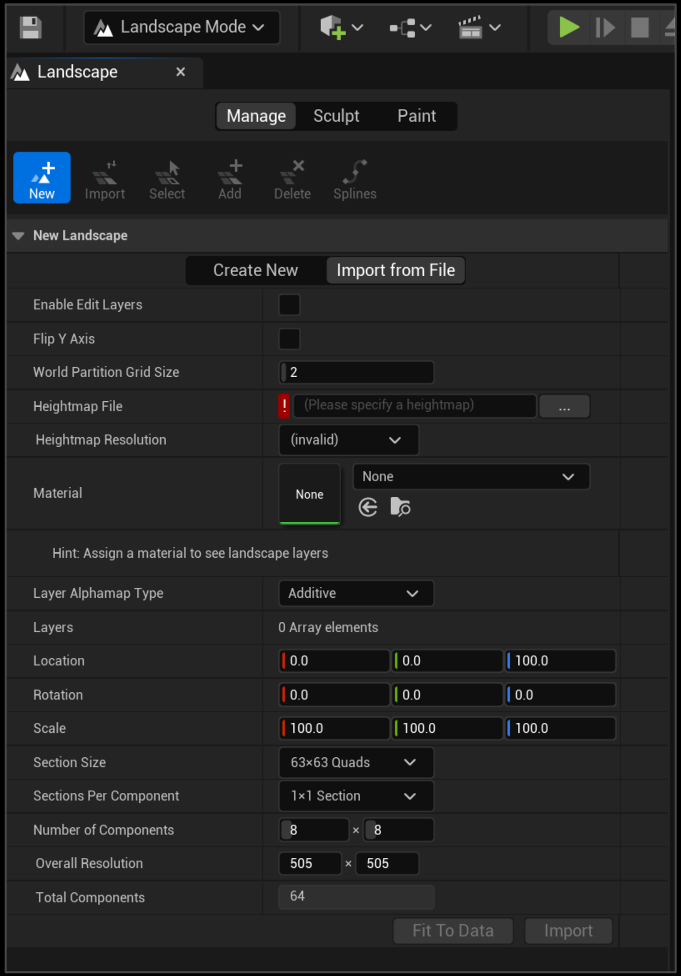
Method: Use GDAL to convert DEM file to a PNG and import directly into level using UE5 Landscape Mode



Importing Lunar Terrain as a Landscape

1. Convert TIFF to PNG using GDAL or similar tool
2. Enter landscape mode, select “Import from File”, and configure settings
3. Calculate xy-scale from pixel width
4. Calculate z-scale as: (minimum_elevation + maximum_elevation) * 100 / 512
5. Select “Import” to generate the landscape





Landscape Lunar Terrain Benefits

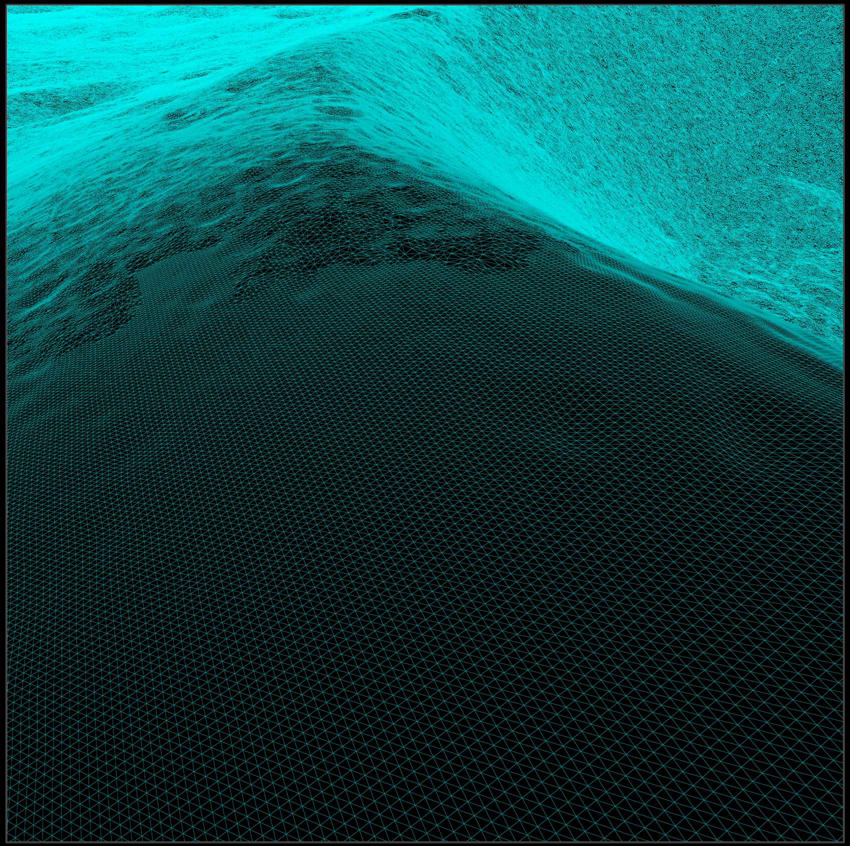
- Streaming Proxies/World Partition
- Landscape Editing Tools
- Constant Improvements
- Built-in collisions
- Easy-to-use and incorporate in additional projects
- Requires no additional plugins

Landscape Lunar Terrain Lessons Learned

- Int16 heights
- Difficult to add accurate lunar curvature
- No native TIFF import
- Limit to individual import size
- Memory/performance limitations

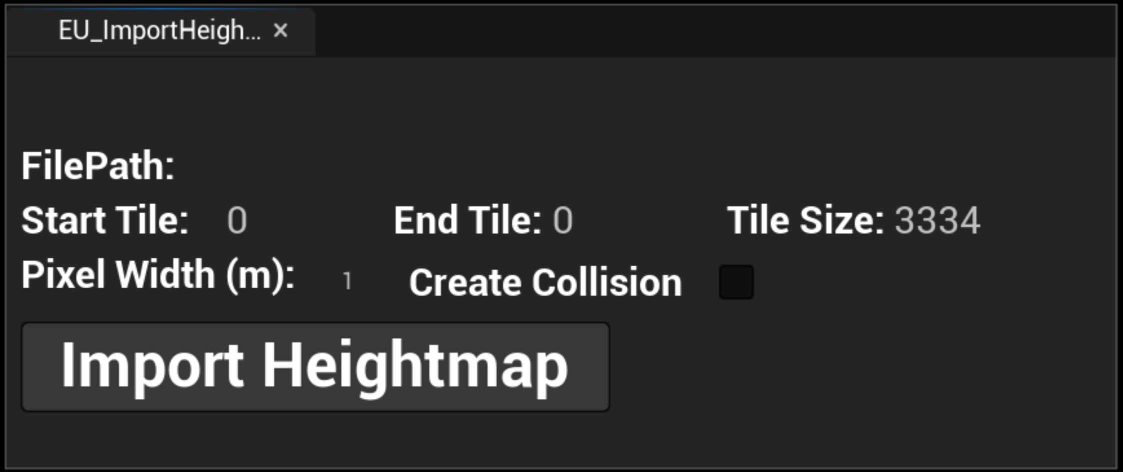
Nanite Mesh Lunar Terrain

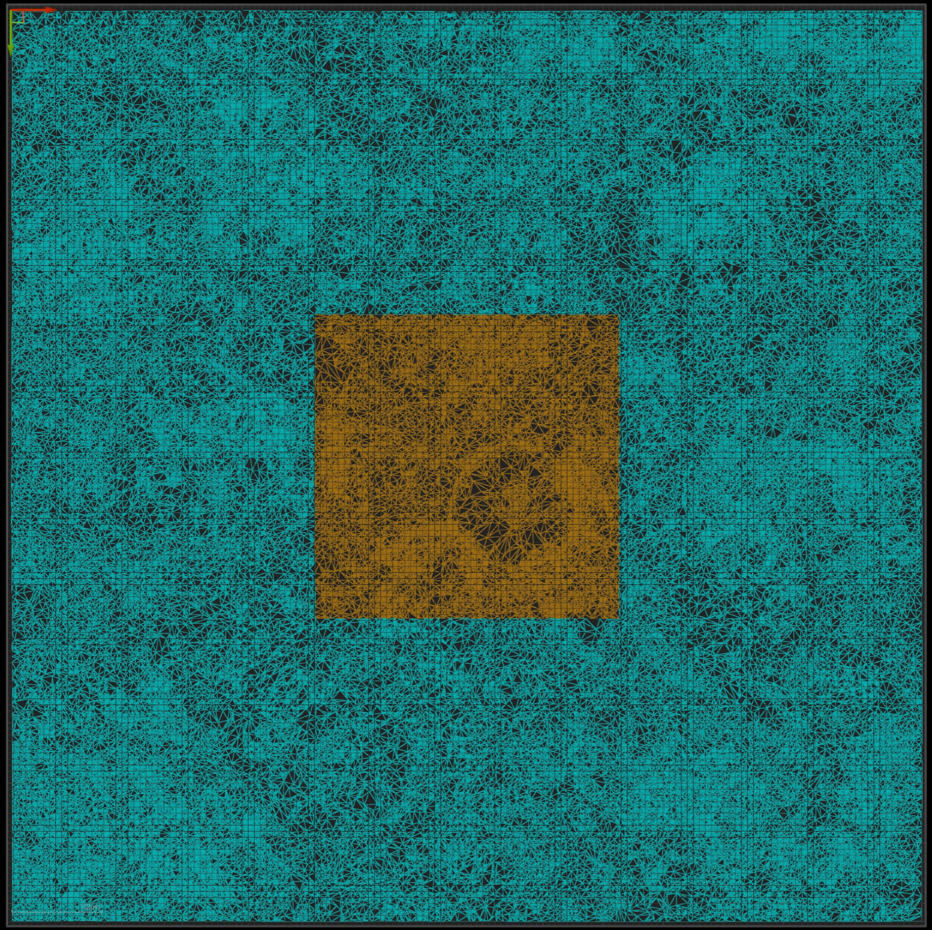
Method: Import DEMs directly one at a time with custom in-engine Heightmap Importer Tool. Tiles selected DEMs and builds static meshes from the data with Nanite enabled



Nanite Mesh Lunar Terrain: Details

- In-engine capability requires only a Nanite capable UE5 project with the UnrealGDAL plugin and a custom heightmap importer editor utility
- Imported DEMs are tiled to limit memory usage
- Generating Static Mesh for DEMs ranging from 300 mb to 6 GB utilizes increasing amounts of disk space and time





300 mb Float32 DEM Results in 9 Nanite Mesh Titles

Nanite Creates New Possibilities for Open Worlds

- Virtual Shadow Maps remain visibly accurate as distance to mesh increases

- No visible modifications to terrain as mesh updates

- Allows for increased performance with scalable vertex counts

Nanite Mesh Lunar Terrain Benefits

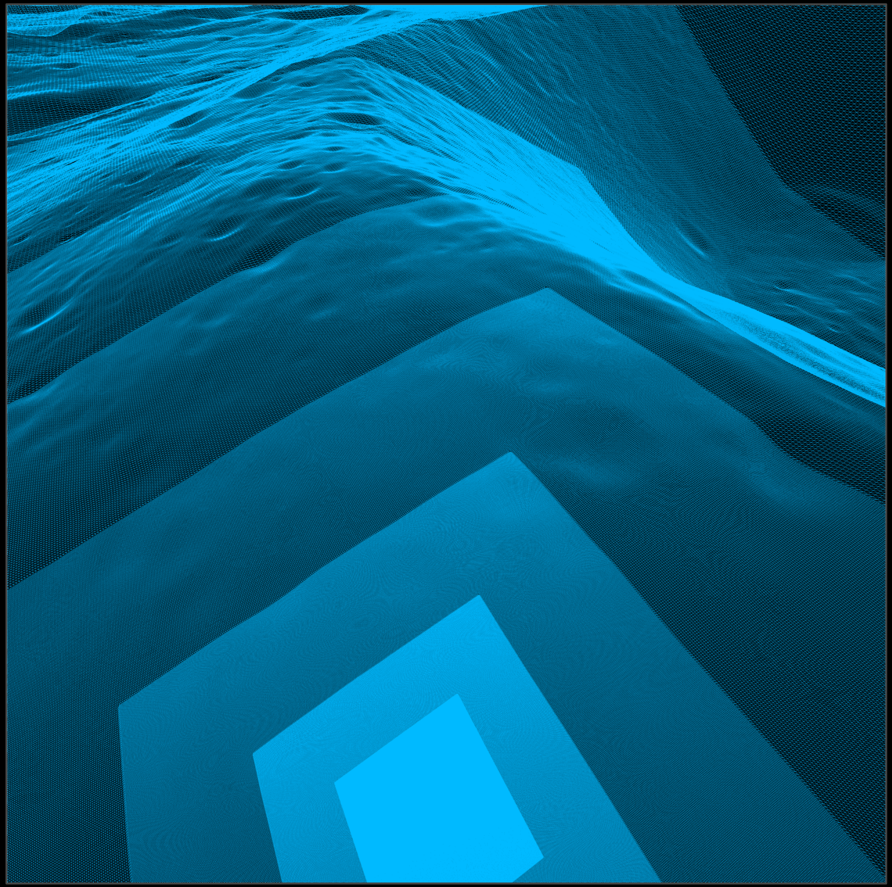
- Performant
- Double precision
- Generated directly from DEM
- Lunar curvature
- Easy to use once generated
- Optimized with Virtual Shadow Maps

Nanite Mesh Lunar Terrain Lessons Learned

- Generation process takes a long time (1 hr – 1 day)
- Limited platform support currently
- Virtual memory utilization increases hardware requirements
- Level loading takes approximately 5 minutes for scene with full terrain imported and no level streaming
- Difficult to accurately modify the mesh to fix issues like mesh seams

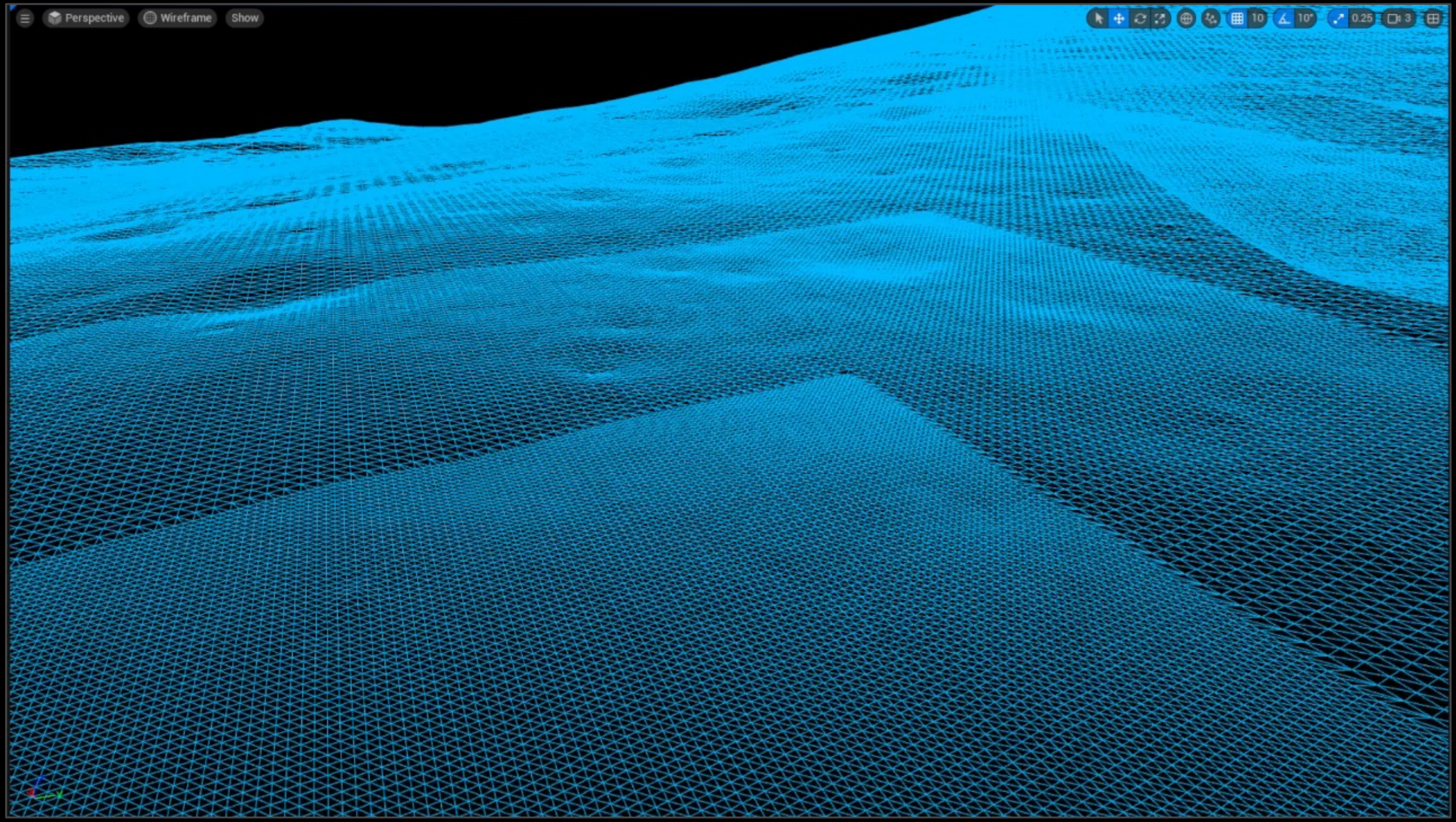
Clip Map Lunar Terrain

Method: During runtime DEMs are imported and continuously supply the clip map with data



Clip Map Lunar Terrain: Details

- Uses: Runtime Mesh Components, Procedural Mesh Components, and UnrealGDAL
- Level count, grid width, and starting resolution can be modified in the editor
- During runtime, these settings can be configured with graphics presets
- Lowest level of the grid will continuously follow the viewport's position

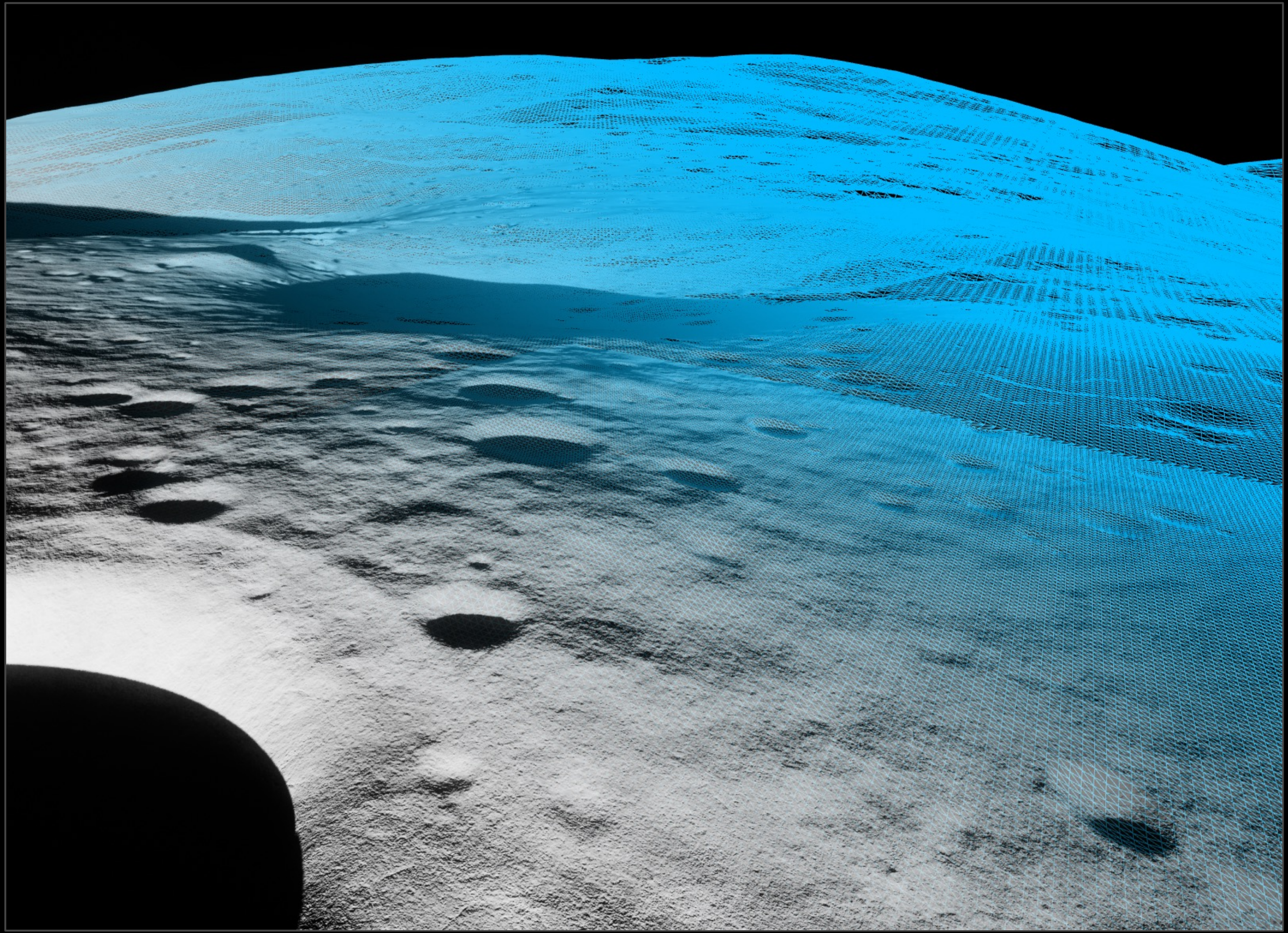


Clip Map Lunar Terrain: Details

- Any number of DEMs can be imported, limited only by the memory required to load the large .TIFF files
- The highest resolution DEM will take precedence over lower with overlapping coordinates
- Collisions provided by forcefully adjusting Actor height when near heightmap data or with localized procedural mesh components

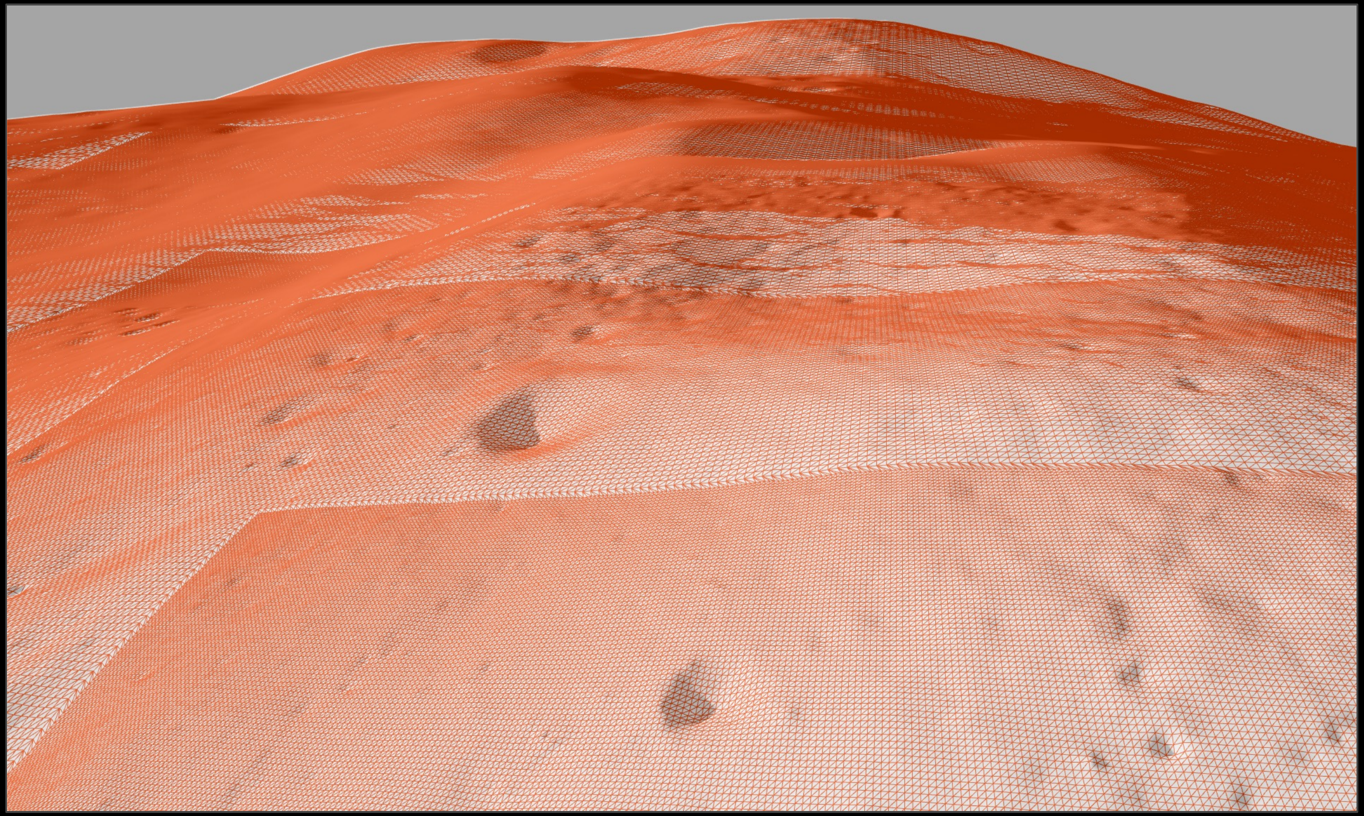
Clip Map Lunar Terrain: Details

- When the vertex grid doesn't exactly align with the DEM grid, we interpolate the height with the 4 nearest points in the DEM to get the height for the vertex
- Normals are calculated using slopes obtained by sampling nearby points on the heightmap
- When the camera is moving, the mesh updates at a rate designed to lower the number of new vertex positions, which also lowers the number of visual artifacts
- The mesh update happens on a separate thread, but moving the camera too fast results in the high-resolution area falling behind



Clip Map Lunar Terrain Benefits

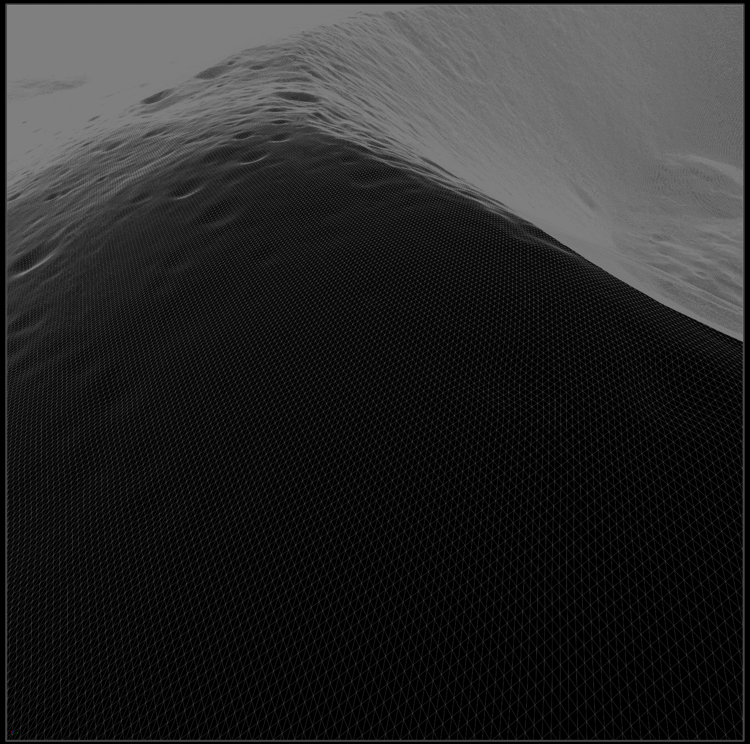
- Generated directly from DEM
- Easy to modify accurately
- Scalable
- Memory efficient
- Lunar curvature
- Double precision
- Multiple platform support
- Performant



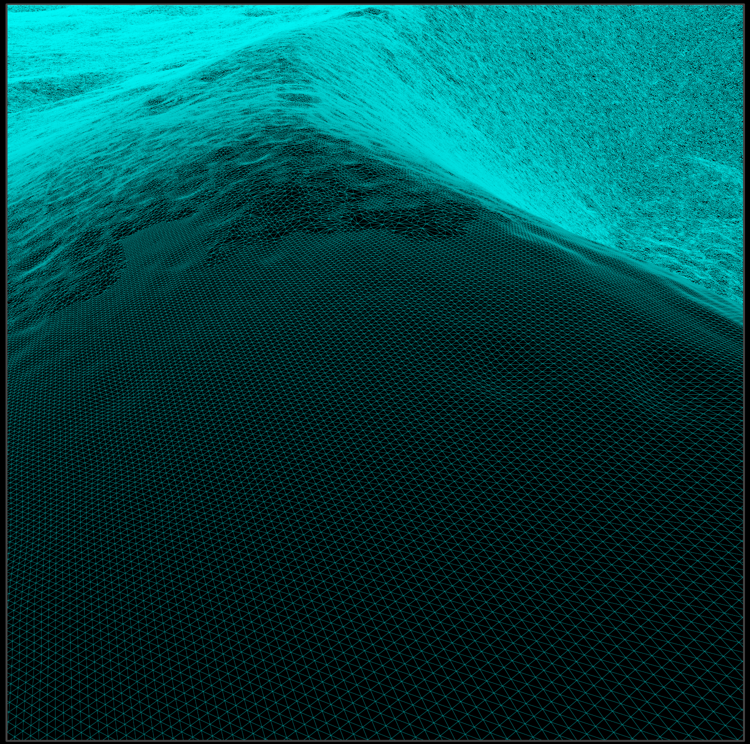
Clip Map Lunar Terrain Lessons Learned

- Fast camera speeds can display artifacts as the terrain updates
- Shadows may not be fully formed when using low level counts
- High resolution DEMs visibly update when transitioning levels

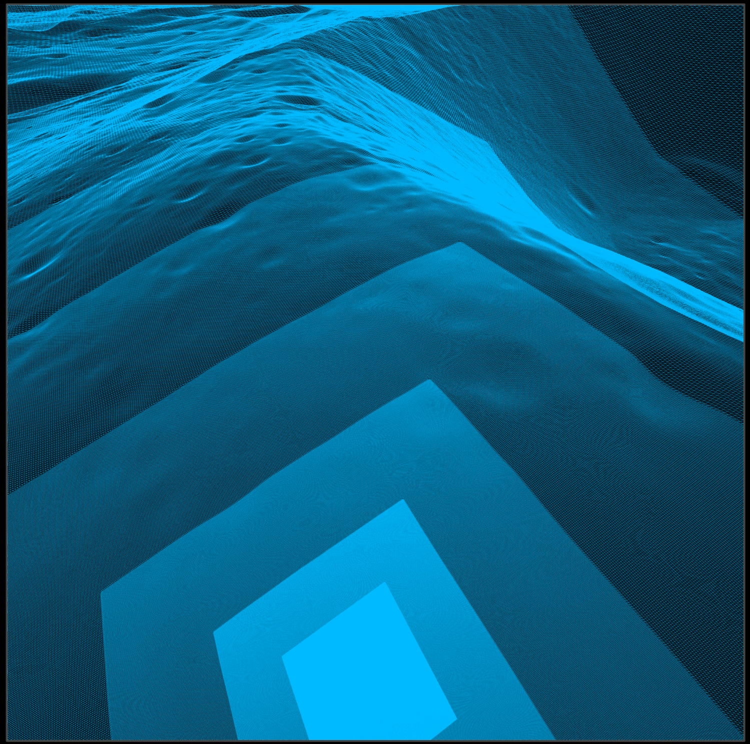
Drastically Different Wireframes



Landscapes



Nanite Mesh



Clip Maps

Minimal Differences In Visuals

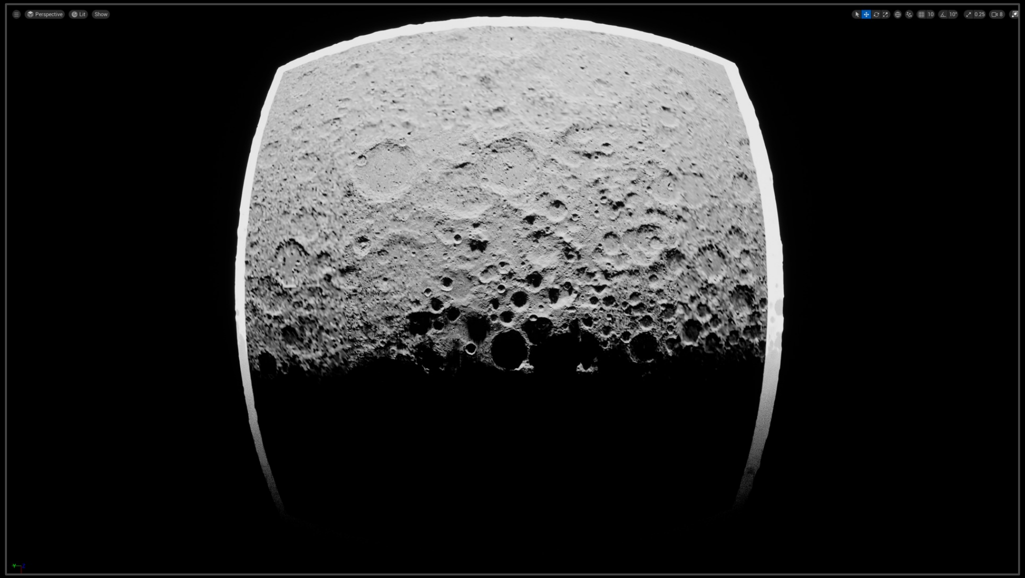
Landscapes

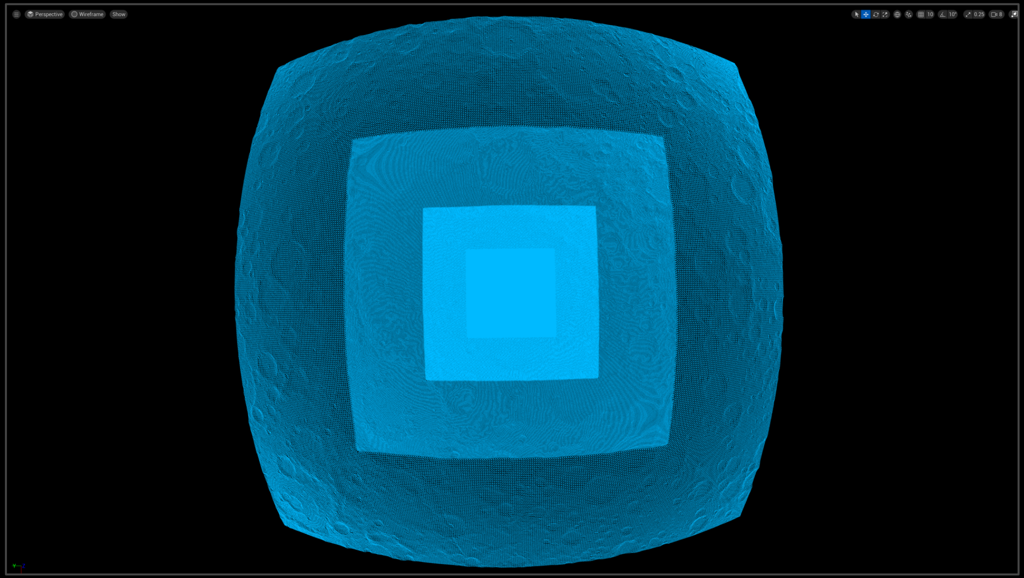
Nanite Mesh

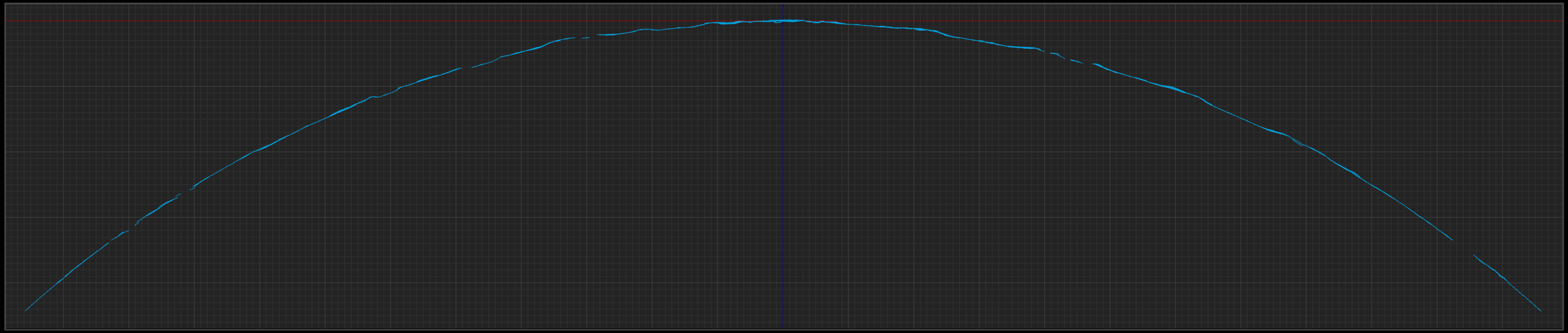
Clip Maps

Lunar Environment Modeling

Lunar Curvature/Scale

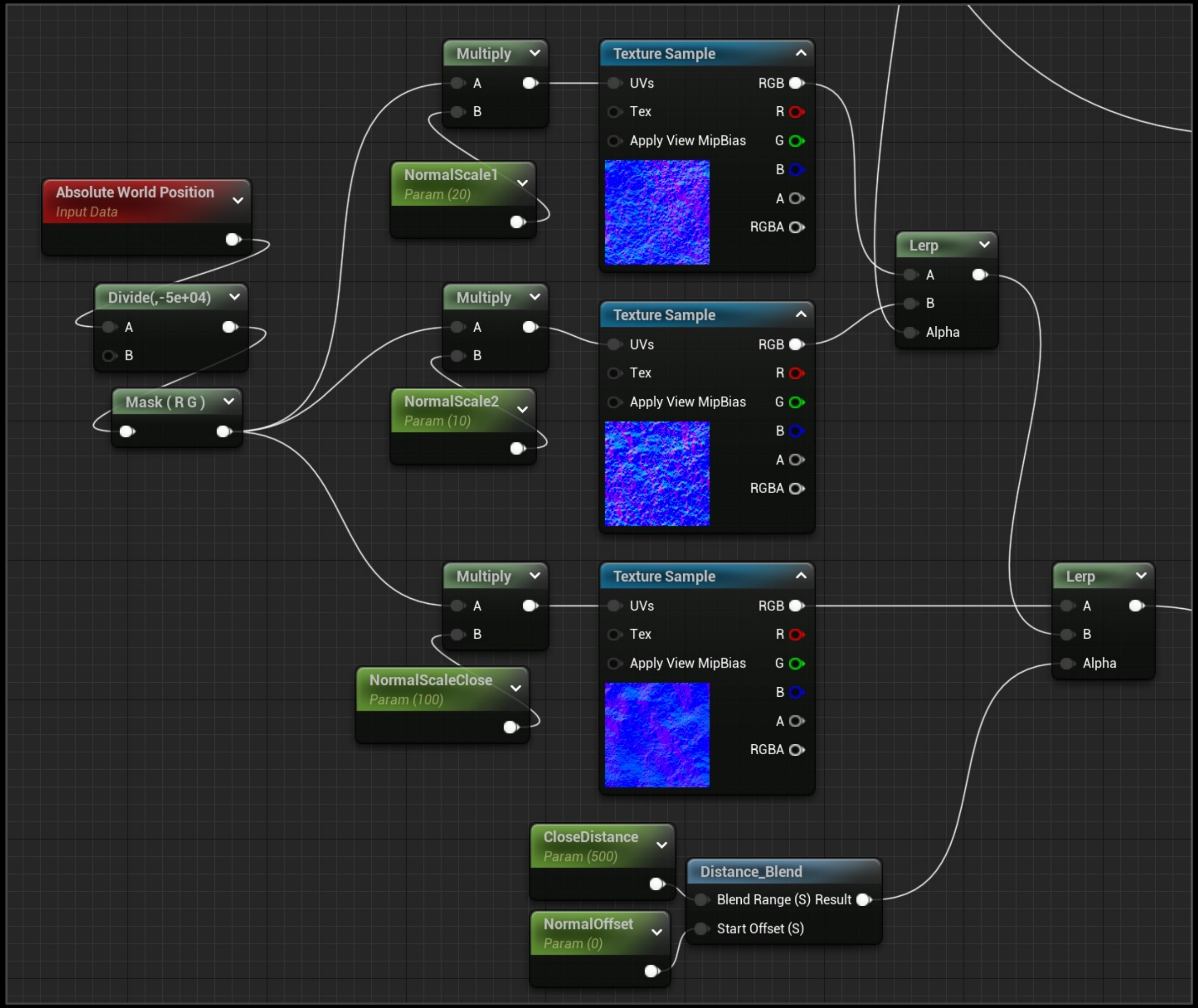




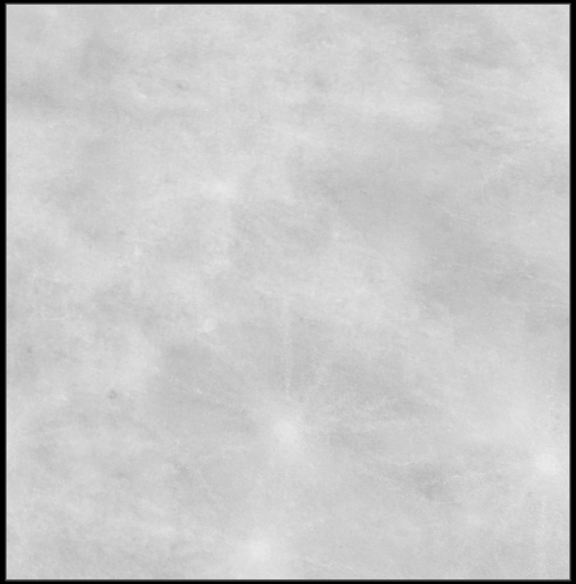


Lunar Surface Texture

- Absolute World Coordinates rather than UVs
- Support Height range from 1 m to 5 km
- Difficult to model realistic small surface particles
- Minimize effect of nearly parallel light angles
- Future work to add additional detail and allow deformation



Lunar Surface Texture



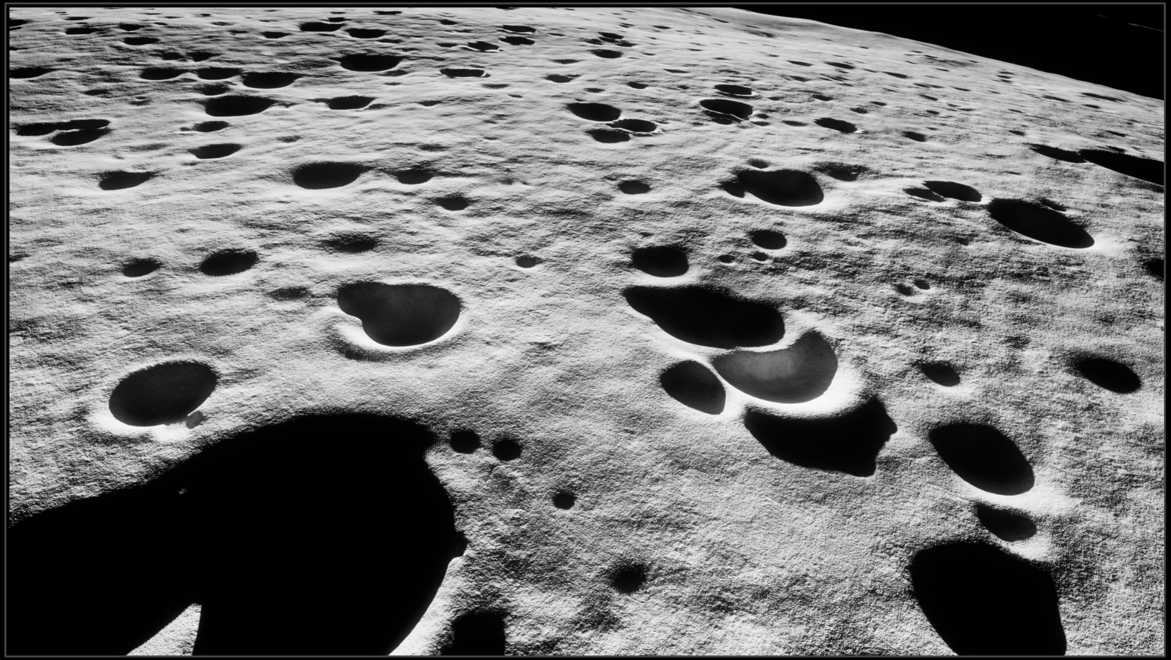
Unlit

< 5 m

> 5 m

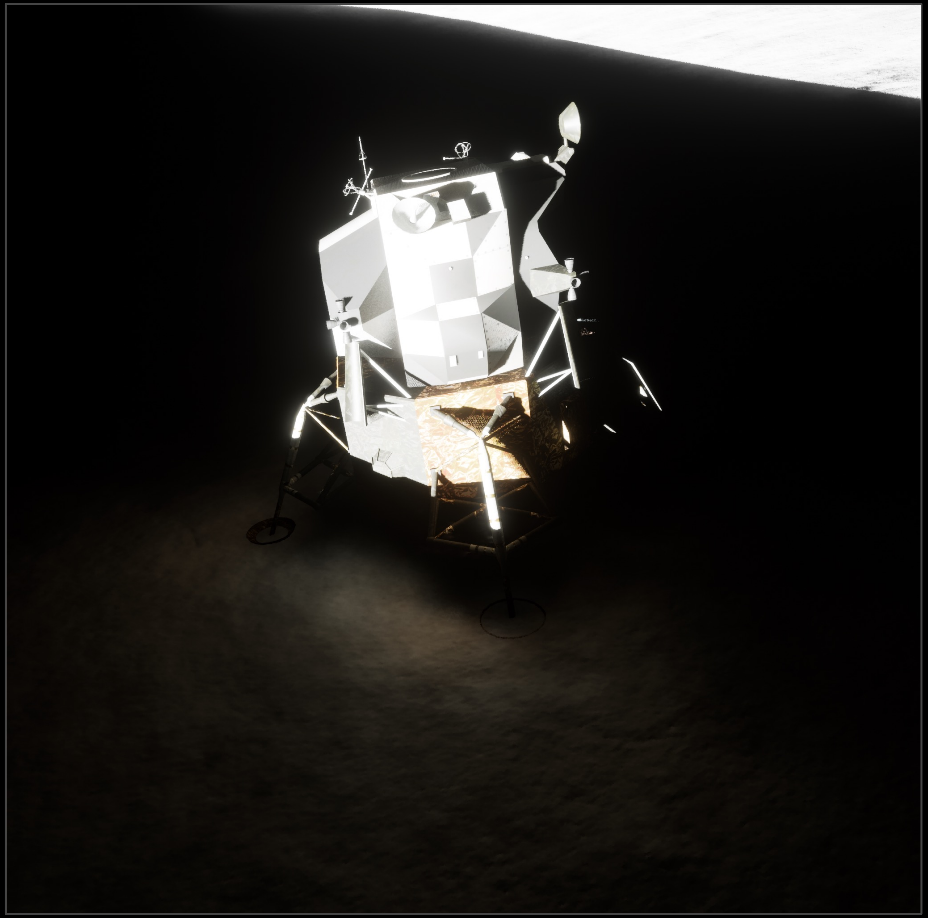
Rocks and Craters

- Statistically distributed and representatively placed for the regions of interest
- Apollo era scanned rock samples
- Nanite enabled meshes
- Craters provide sub-pixel detail to supplement and enhance 5 mpp resolution data up to 20 cmpp



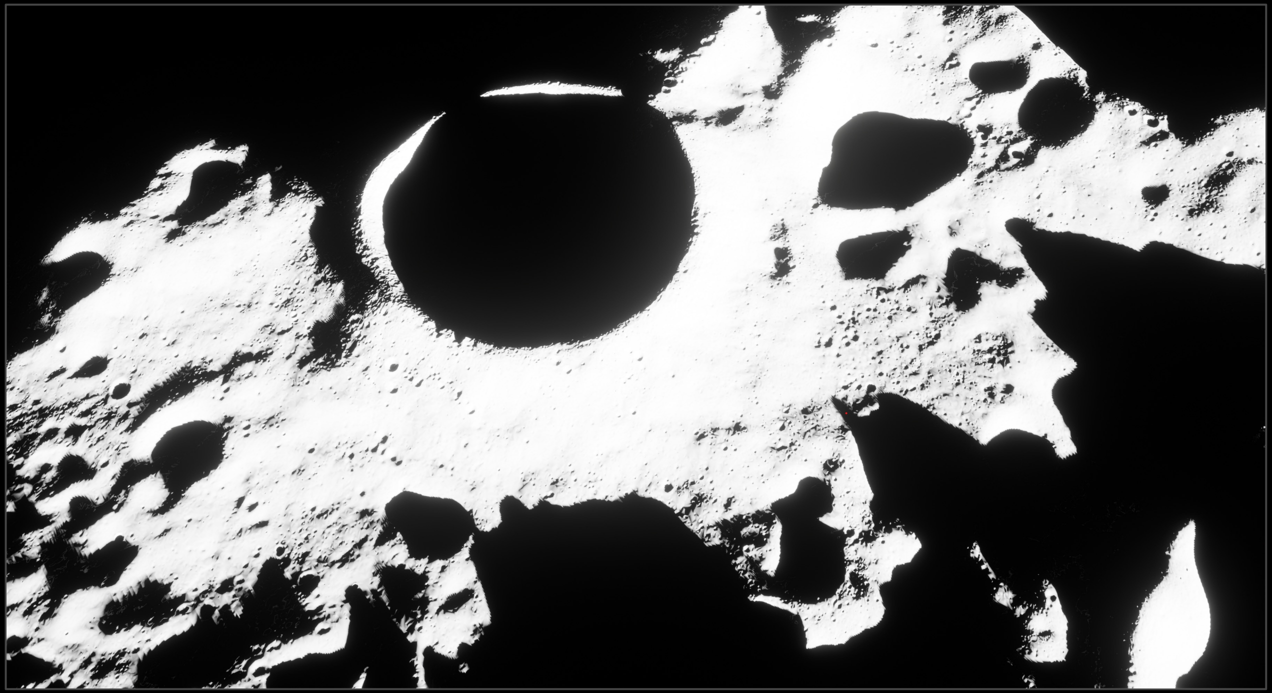
Lumen

- Provides bounce lighting increasing crater visibility when light is reflected from objects like spacesuits and regolith
- Helps illustrate crater depth and the impact of the sun's intensity without an atmosphere to hinder it
- Bounce lighting approximations using global distance fields over large areas of terrain increase realism of light and shadow visualization around habitat areas



Virtual Shadow Maps

- Provide extreme shadow rendering distances with minimal accuracy reduction
- Proficiency with dynamic directional lights lets us model moving lunar sunlight over hundreds of kilometers of terrain with little performance impact
- Enabling Nanite and VSMs on small objects such as rocks allows for increasing scale



Double Precision

- Allows for SPICE integration for placement of planetary bodies at real-world positions relative to the observer and rendered at actual scale
  - SPICE is the NASA-JPL ephemeris toolkit for spacecraft and planetary bodies
- Able to replicate predicted lighting conditions based off the sun and earth positions
- Can position spacecraft in actual relative positions to lunar center
- Terrain generated to accurately reflect source data

Additional Benefits of Unreal

- Multiple infinite light sources
- World Partitioning
- Nanite
- nDisplay
- Pixel Streaming

Summary

- Modeling and Simulation for Engineering
  - Designing for engineering accuracy by utilizing LRO terrain data
- Lunar Terrain Generation
  - Landscapes
    - Easy-to-use and add to new projects
    - Landscape Editing Tools
    - Constant Improvements
  - Nanite Meshes
    - Performant
    - Double precision
    - Generated directly from DEM
  - Clip Maps
    - Generated directly from DEM
    - Scalable
    - Multiple platform support
- Lunar Environment Modeling
  - Adding details with curvature, texture, and rocks/craters
  - Benefits of Lumen, double precision, Virtual Shadow Maps

Images/Videos Credit: NASA

Questions