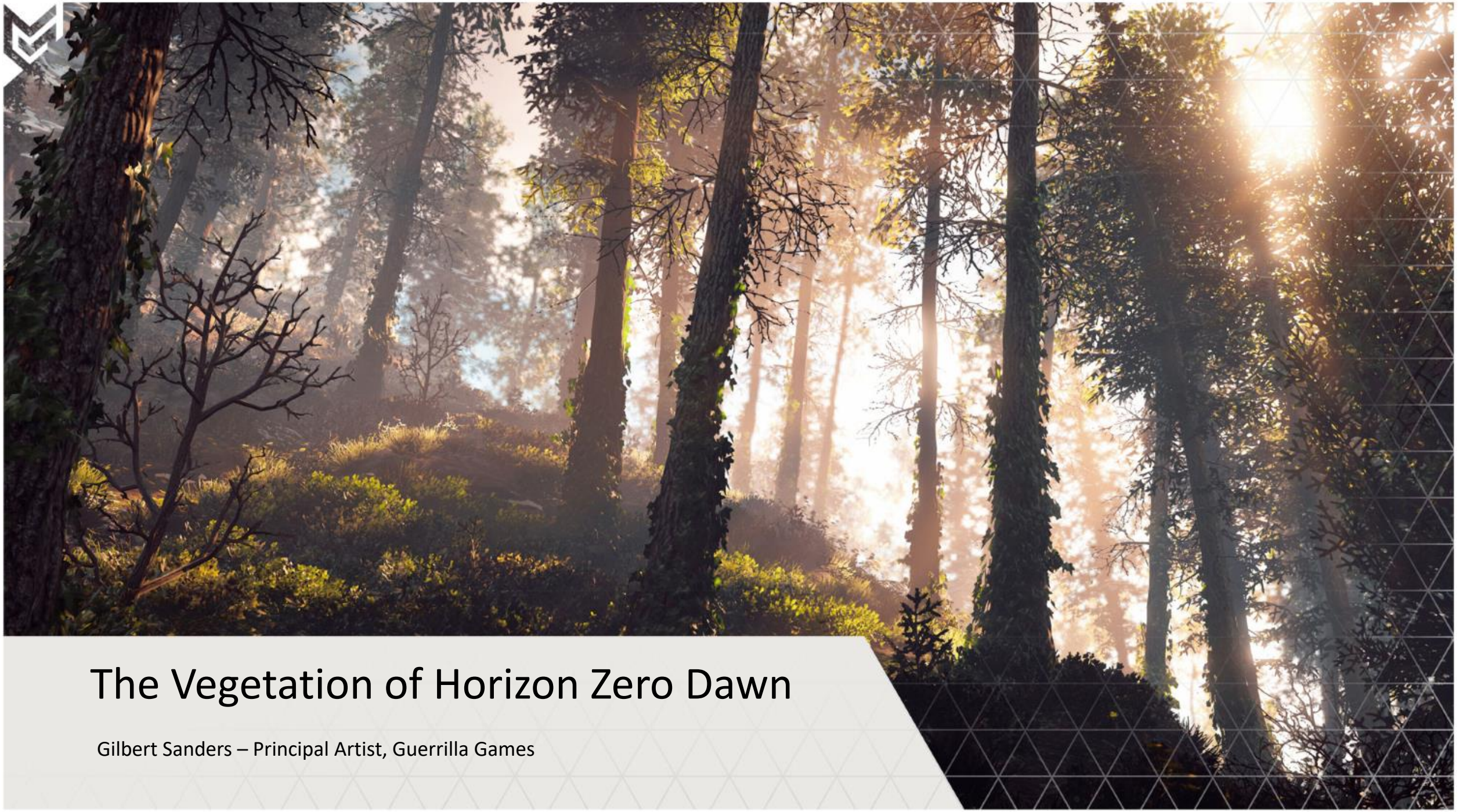
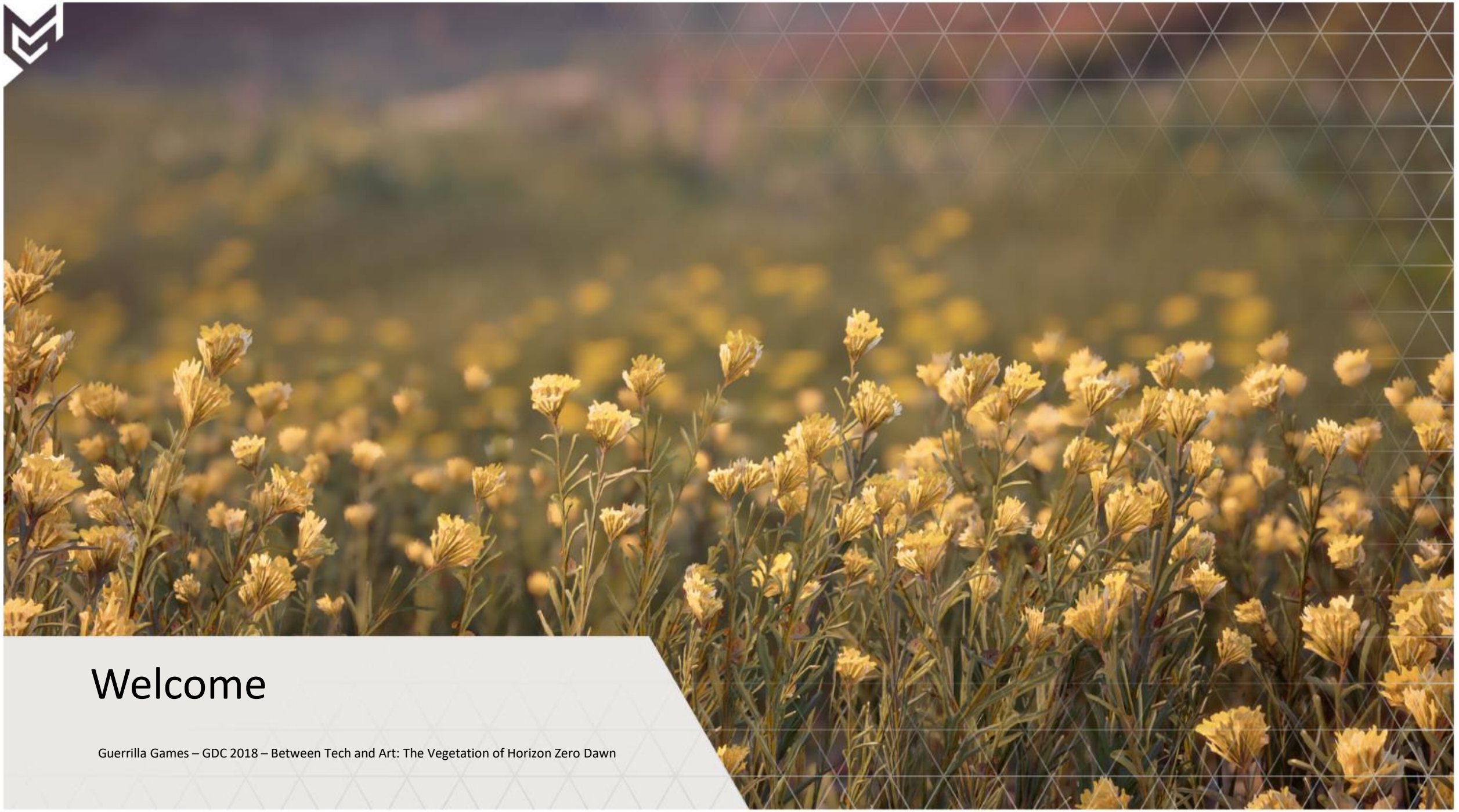


The Vegetation of Horizon Zero Dawn

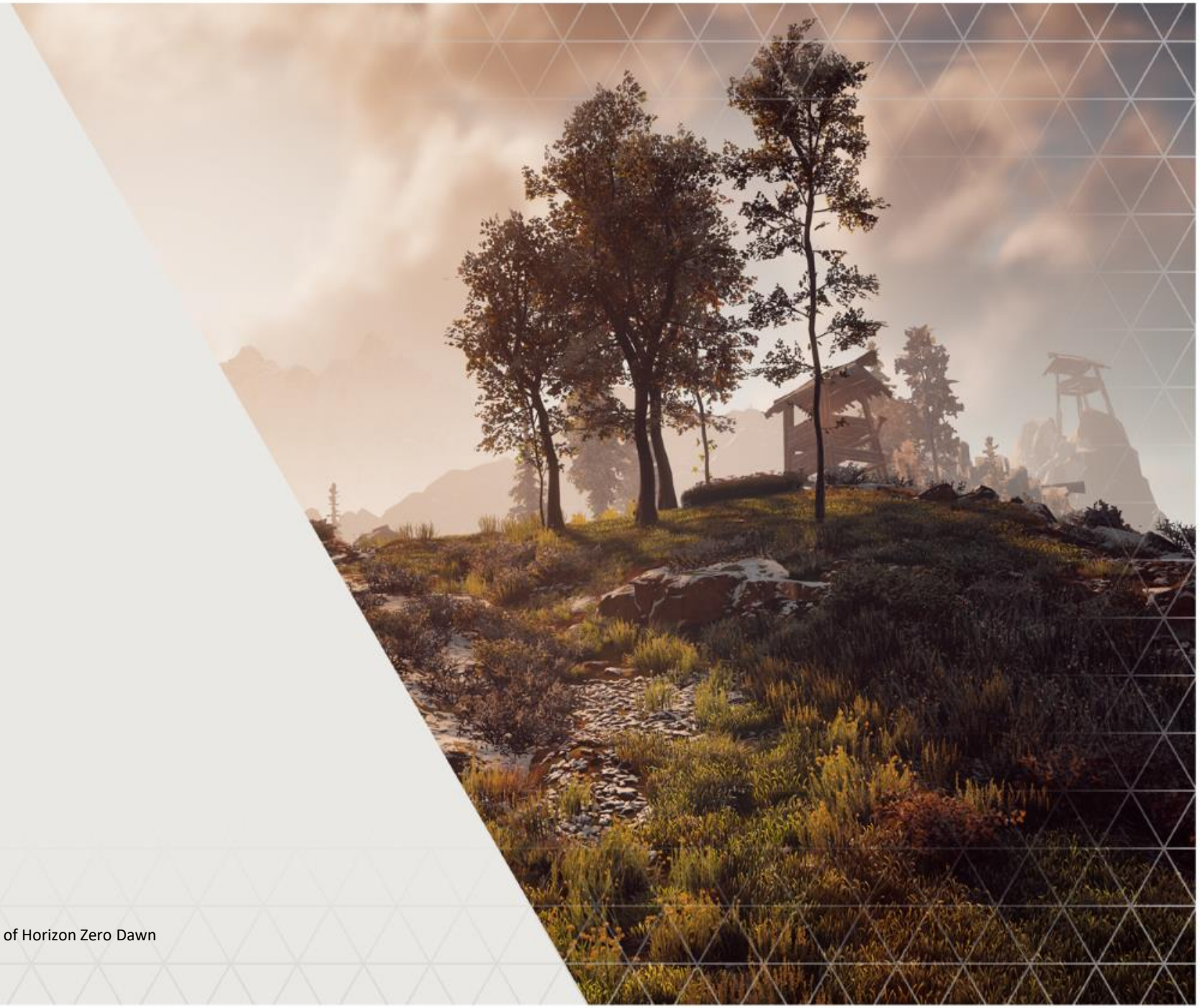
Gilbert Sanders – Principal Artist, Guerrilla Games



Welcome

Topics

- Simulation
- Shading
- Creation
- Shadow Casting
- Summary



Introduction

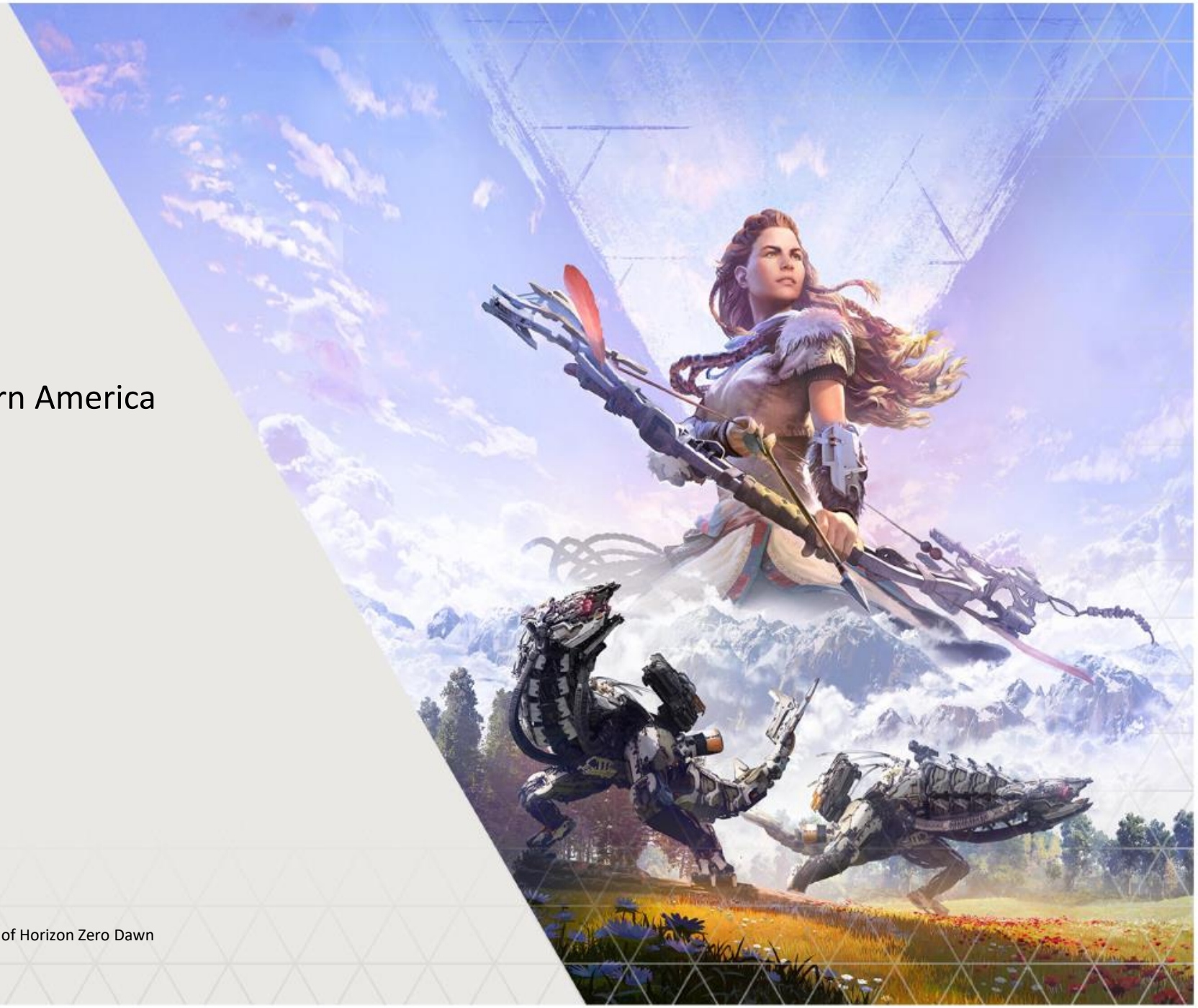
Our Renderer

- Artist Node-Based Shader Editing
  - Our Rendering Engine running in Maya
  - Guerrilla Custom Shader Nodes
- Deferred Shading
- Targeting 30 fps at 1080p / 4K

Introduction

Horizon Zero Dawn

- Open World Action RPG
- Day and Night Cycle
- Post - Post Apocalyptic Northern America
- ‘BBC’ Nature
- Robotic Wildlife



Introduction

Our first steps…

Killzone Shadow Fall:

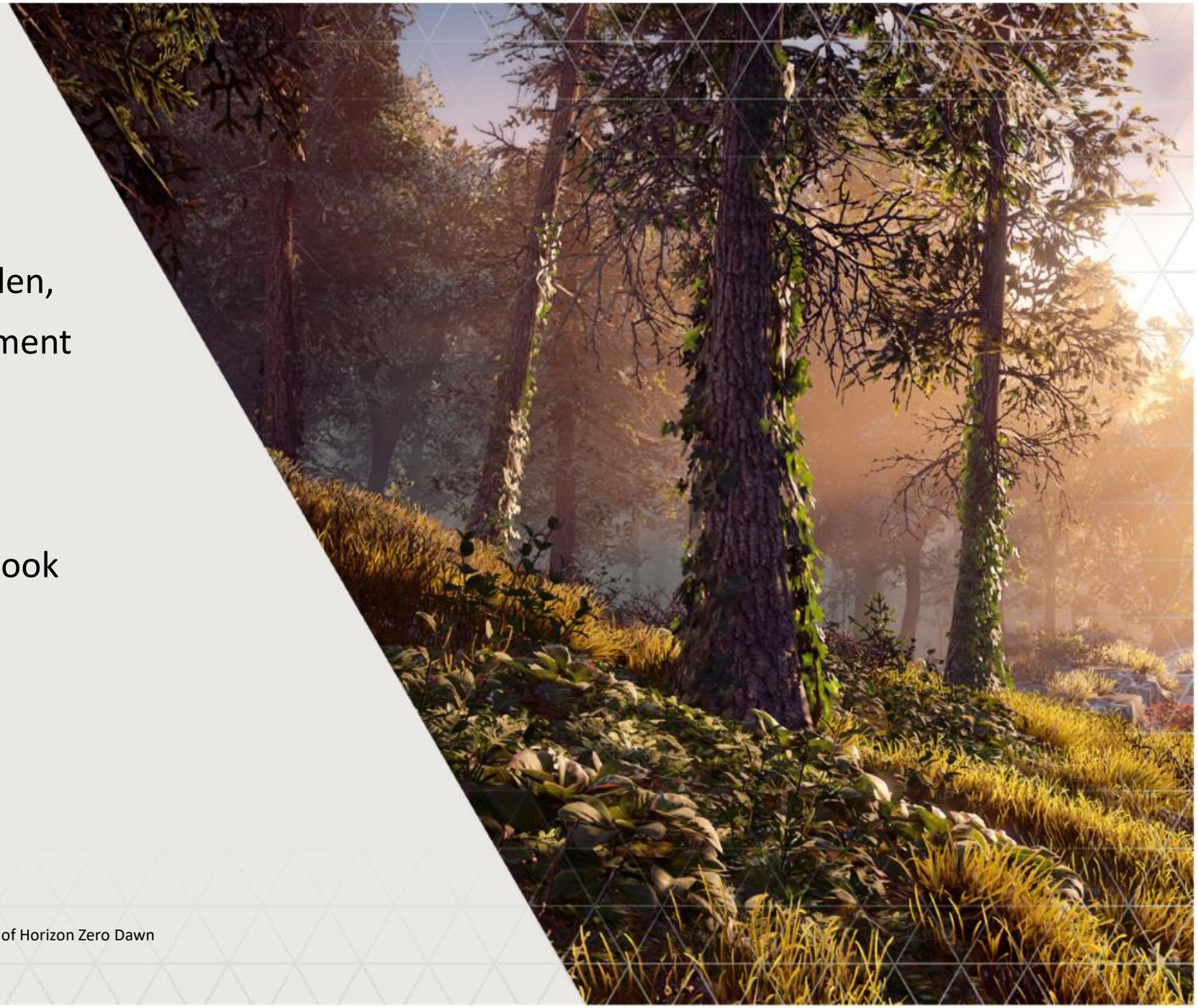
- First Real Test in Production
- Quality and Performance
- Placement System Needed!

Placement System

2017 GDC Talk – Jaap van Muijden,

GPU-Based Procedural Placement in Horizon Zero Dawn

- Quick iterations
- Large variety and Believable look
- Art Directable
  - Data driven
  - Deterministic
  - Locally stable



Simulation

Guerrilla Games – GDC 2018 – Between Tech and Art: The Vegetation of Horizon Zero Dawn

Simulation

Making Foliage Move

All Movement is driven by a Global Wind Force Field

- Compute Shader: around 150 microseconds
- Local Around the Player / Camera
- Baked-in Physical Properties
  - Supports up to 4 Different Categories of Spring Settings


Force fields enabled
Enable turbulence
Enable flow
Show force field vectors
Place vector field at camera
Show force field probes
Move Probes with Player Cam
Move Probes with First Person Cam
Lock Probes
Cycle Forcefield Cascade
Show Near Cascade
Show Mid Cascade
Show Far Cascade
Cycle Forcefield Solver
Show Special Solver
Show Grass Solver
Show Plant Solver
Show Tree Solver
Force Visualization Scale 0.963
Slider Slice 5.00000000
Force Visualization Scale 0.963
Slider Slice 5.00000000
Enable AttractRepelHack
Repel speed multiplier 1.40
ScaleWithSpeed Factor 2.00
Repel speed exp 0.47
Enable directional force

Simulation

Making Foliage Move

Categories of Spring Settings:

- Trees
  - Vegetation_Shader
- Plants
  - Vegetation_Shader
- Grasses
  - Vegetation_Grass_Shader
- Special
  - Sampled by Banners, Tarps, Canvas, etc.

Trees and Plants

Simulation

Vertex Program: Trees

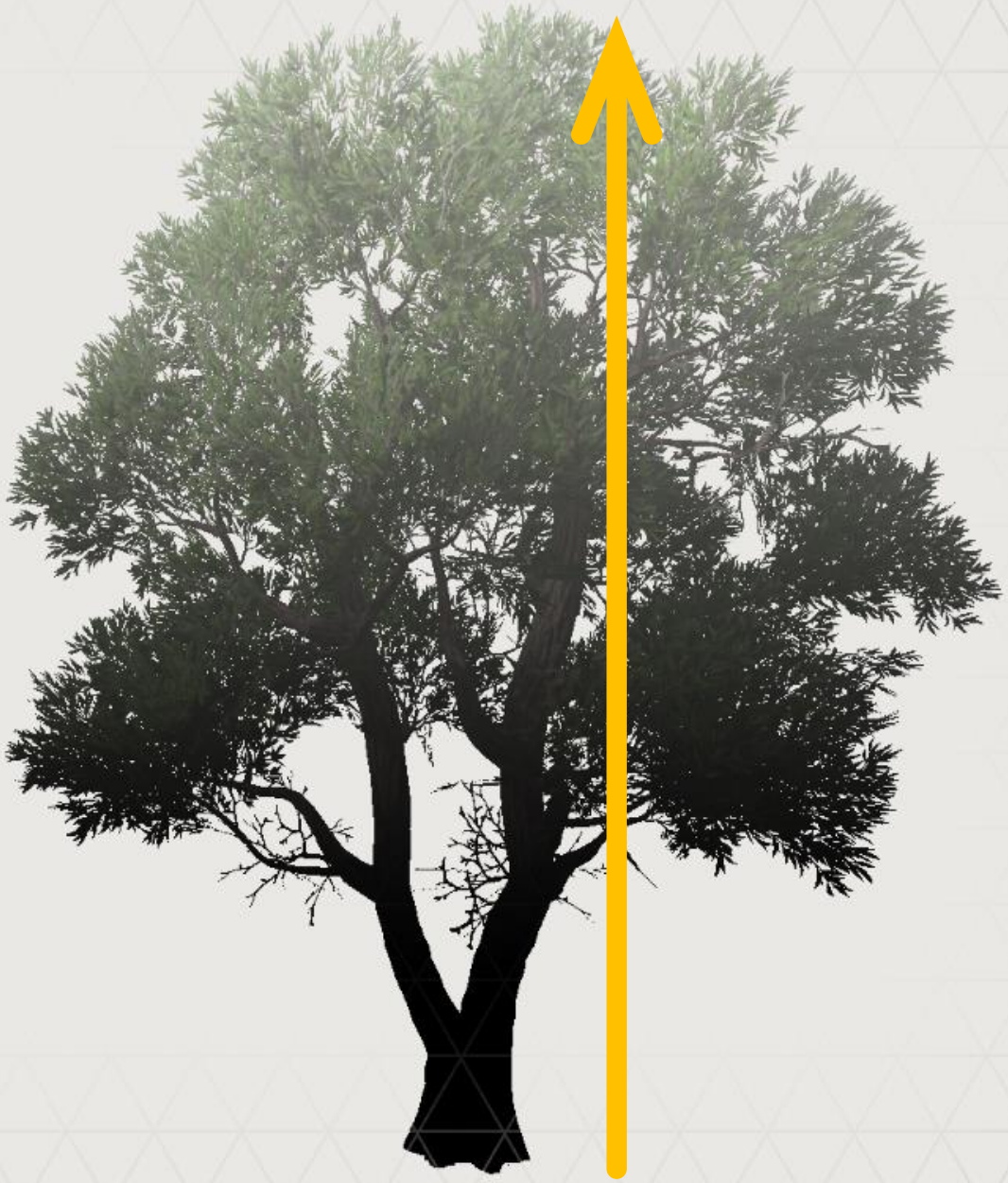
Three Levels of Motion

Simulation

Vertex Program: Trees

Three Levels of Motion:

- Tree Movement (Bend)
  - Height of the Object

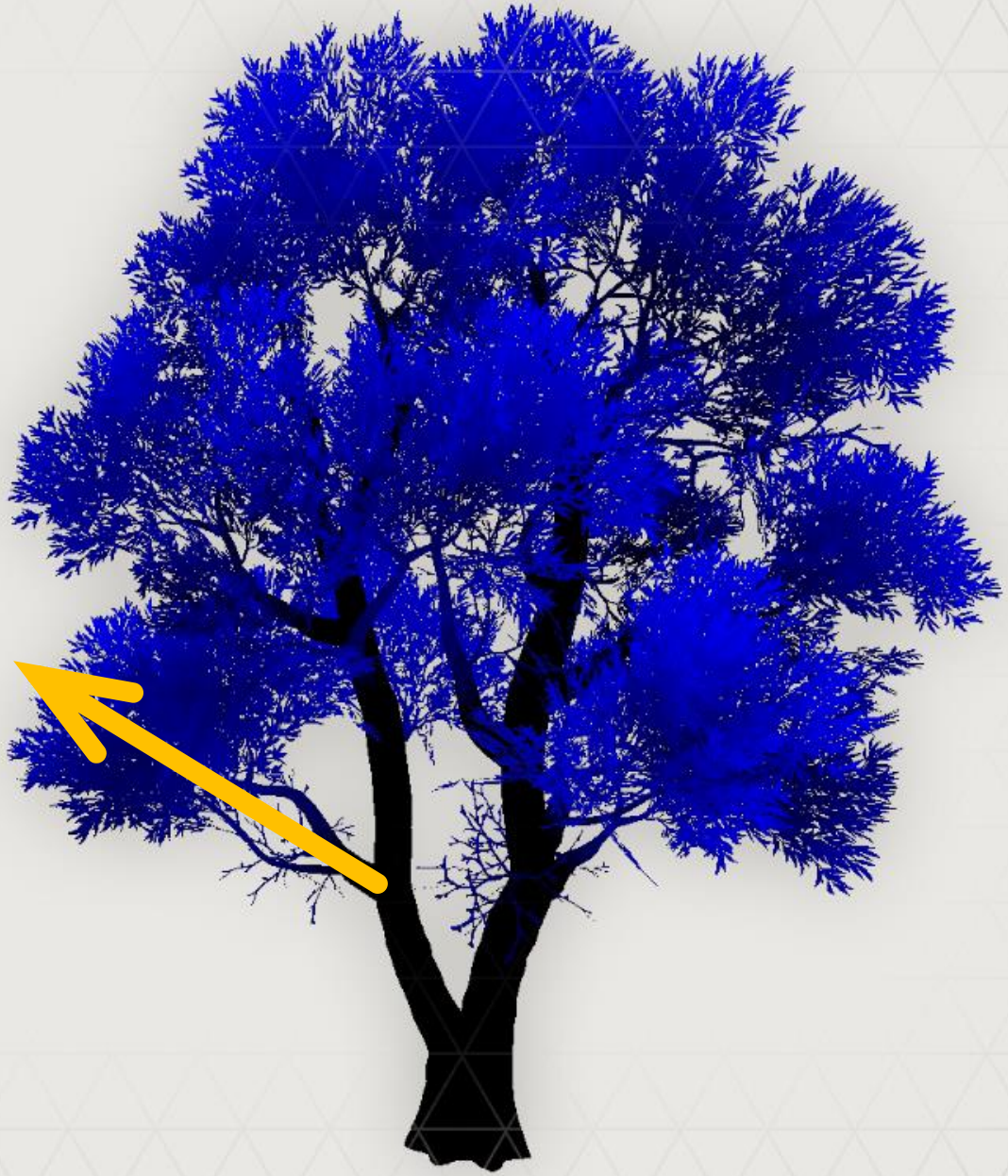


Simulation

Vertex Program: Trees

Three Levels of Motion:

- Tree Movement (Bend)
  - Height of the Object
- Branch Movement
  - Distance to Trunk



Simulation

Vertex Program: Trees

Three Levels of Motion:

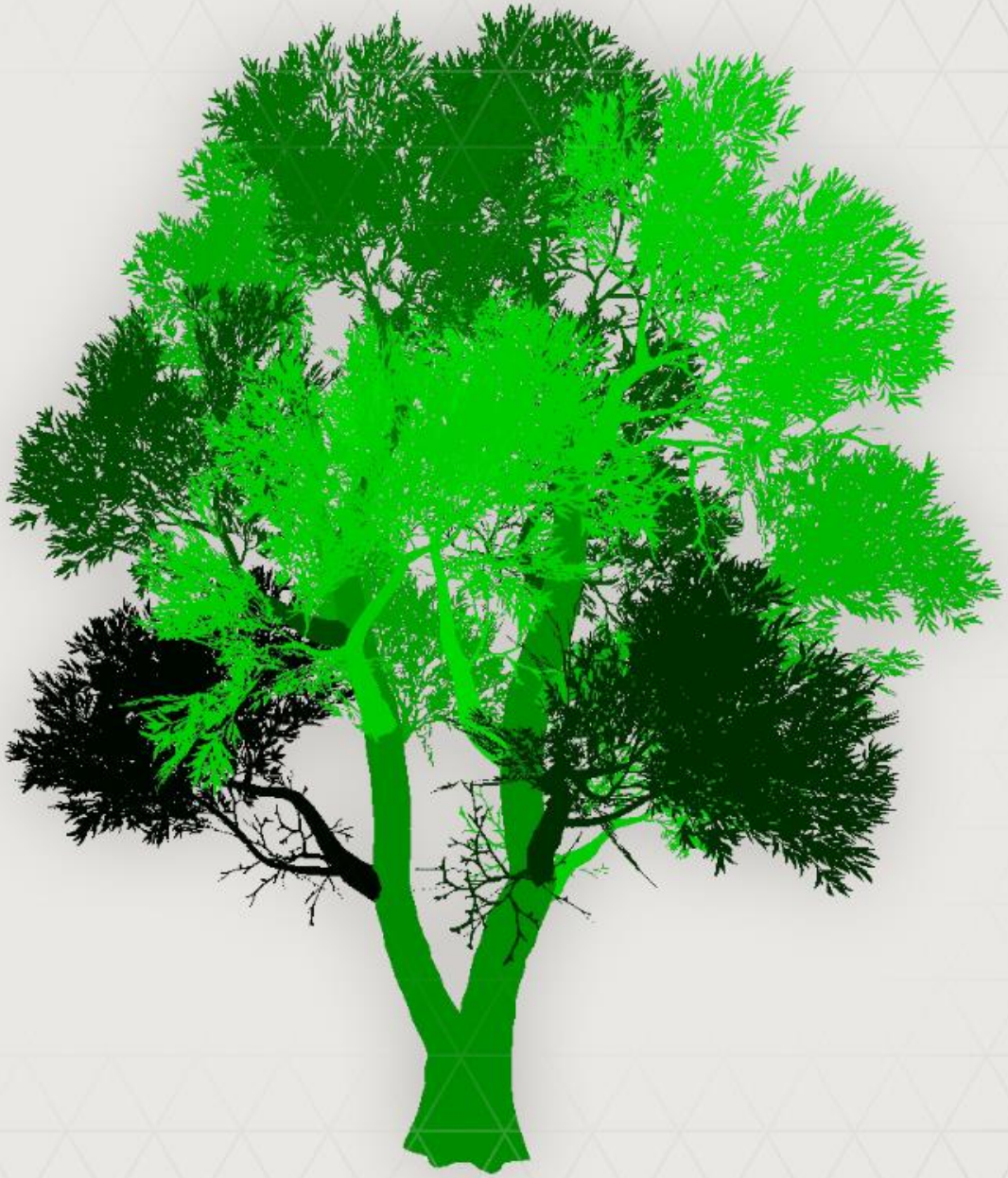
- Tree Movement (Bend)
  - Height of the Object
- Branch Movement
  - Distance to Trunk
- Leaf Movement
  - Distance to Branch

Simulation

Vertex Program: Trees

Three Levels of Motion:

- Tree Movement (Bend)
  - Height of the Object
- Branch Movement
  - Distance to Trunk
- Leaf Movement
  - Distance to Branch
- Other Data
  - Index / Offset



Simulation

Vertex Program: Trees

Three Levels of Motion:

- Tree Movement (Bend)
  - Height of the Object
- Branch Movement
  - Distance to Trunk
- Leaf Movement
  - Distance to Branch
- Other Data
  - Index / Offset
  - Baked Ambient Occlusion

Simulation

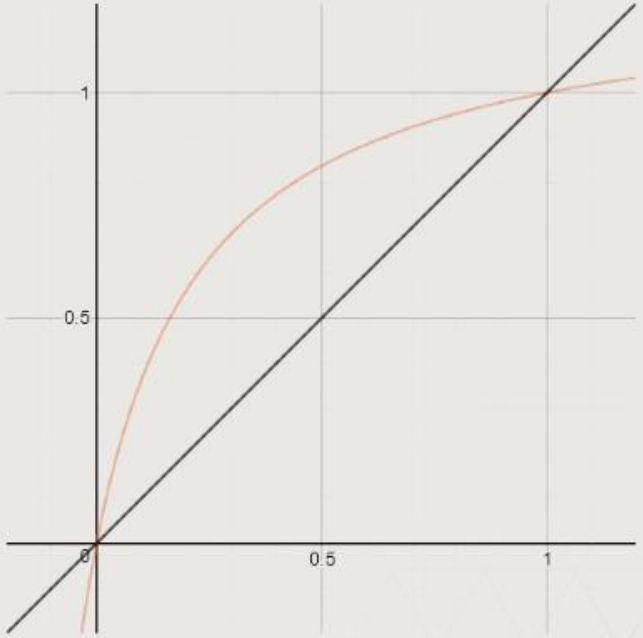
Vertex Program: Trees

- Sample from our Global Wind at Object Center
  - Drives the Bend of the Tree
    - Rigidity
  - Drives the Bend of the Branches
    - Bend
    - Sway
    - Lift
  - The length of the Sampled Force drives a tiny 3D Simplex Noise Texture (16x16x16) that we use for the motion of our Leaves.
    - Amount

Simulation

Vertex Program: Plants

- (Most) Plants: Remove Bend
- Ramp – Soft Clamp Formula:
  - f(x) = (x * (amount + 1)) / (x + amount)



Guerrilla Games – GDC 2018 – Between Tech and Art: The Vegetation of Horizon Zero Dawn

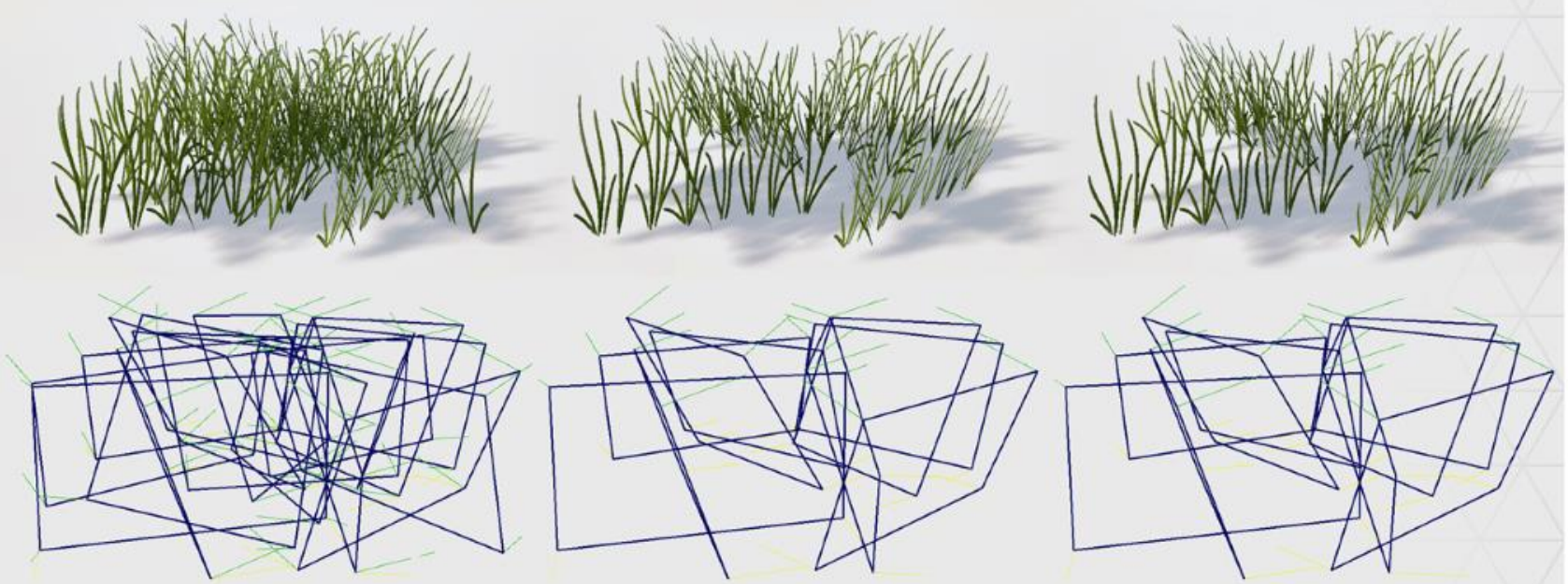
Grasses

Simulation

Vertex Program: Grass

Grass has three LODs:

- LOD1
  - 20-36 triangles
  - High shader
- LOD2
  - 10-18 triangles
  - High shader
- LOD3
  - 10-18 triangles
  - Low shader



Simulation

Vertex Programs: Making Grass Move

- Our Global Wind

Simulation

Vertex Programs: Making Grass Move

- Our Global Wind
- Ambient Motion
  - Large Scale Motion:

```
X = (2 * Sin (1 * (ObjectCenterX + ObjectCenterY + ObjectCenterZ + Time))) + 1

Y = (1 * Sin (2 * (ObjectCenterX + ObjectCenterY + ObjectCenterZ + Time))) + 0.5

Z = 0
```

Simulation

Vertex Programs: Making Grass Move

- Our Global Wind
- Ambient Motion
  - Large Scale Motion:

```
X = (2 * Sin (1 * (ObjectCenterX + ObjectCenterY + ObjectCenterZ + Time))) + 1
Y = (1 * Sin (2 * (ObjectCenterX + ObjectCenterY + ObjectCenterZ + Time))) + 0.5
Z = 0
```

  - Small Scale Motion:

```
Disp = (0.065 * Sin (2.650 * (PointWX + PointWY + PointWZ + Time)))
* NormalObject * (1, 1, 0.35)
```

Simulation

Vertex Programs: Making Grass Do More

- On top of the motion, we also add:
  - Camera Based Tilting

```
Disp = [Vec3 (0, 1, 0) View to Object Space] * ObjectPosZ
```

Simulation

Vertex Programs: Making Grass Do More

- On top of the motion, we also add:
  - Camera Based Tilting

```
Disp = [Vec3 (0, 1, 0) View to Object Space] * ObjectPosZ
```

Simulation

Vertex Programs: Making Grass Do More

- On top of the motion, we also add:
  - Ground Hugging

```
Disp = (0, 0, ([Sampled Height from Height map] - ObjectCenterZ))
```

Simulation

Vertex Programs: Making Grass Do More

- To facilitate better Lodding, over distance :
  - we scale the whole animation part down

    ```
    Displacement = [Percentage of All Animation] based on Distance to Camera
    ```

  - we vertically push the vertices of the mesh down

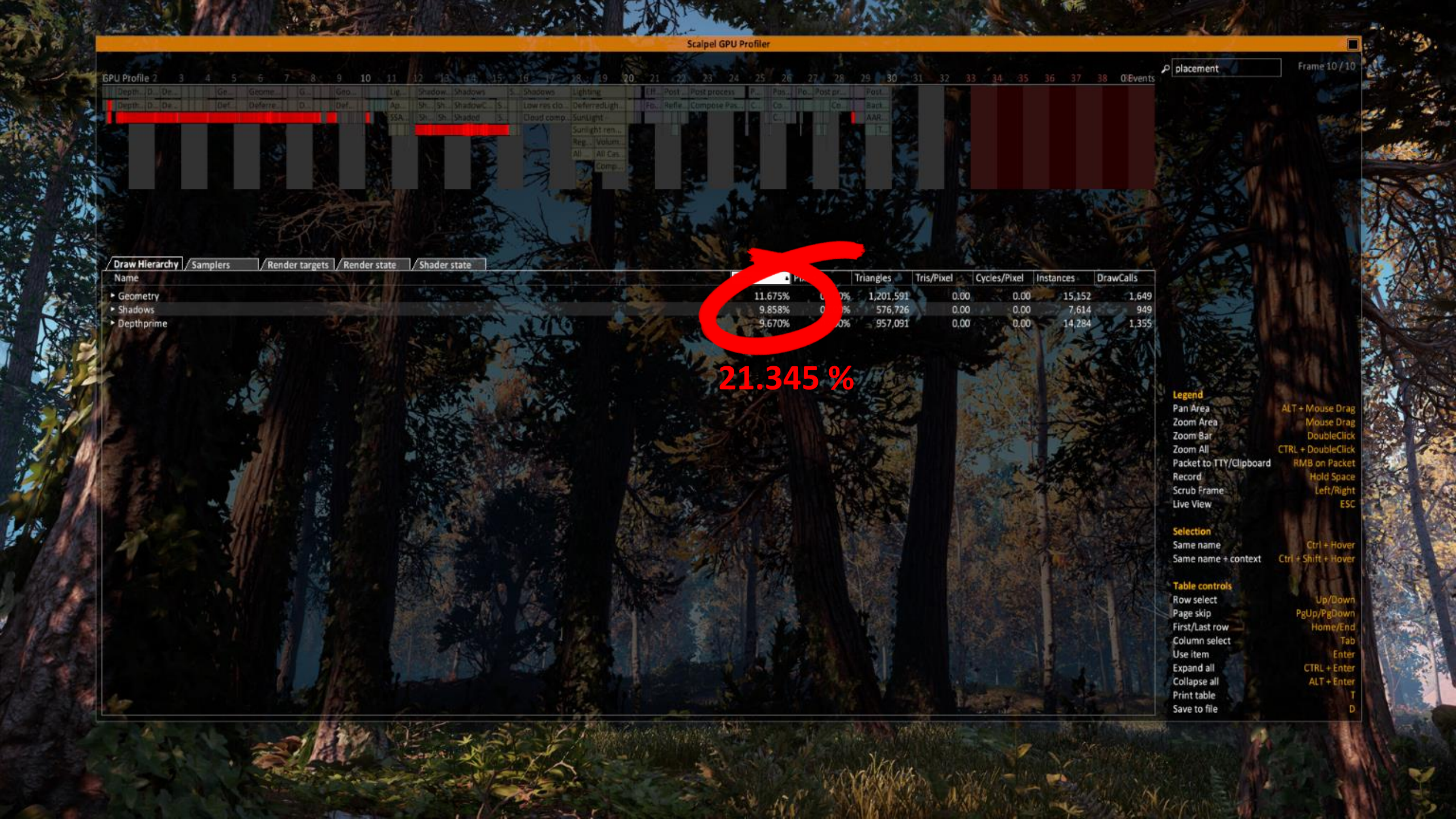
    ```
    Displacement = [Percentage of Object Height] based on Distance to Camera
    ```

Shading – Alpha

Shading

Pixel Program: Alpha

- Depth Only Pass:
  - **Very Cheap Depth Only Shader**
- Geometry Pass:
  - Depth Compare (Depth is Equal)
  - **Zero percent Overdraw!**


Scalpel GPU Profiler
placement
Frame 10 / 10
GPU Profile 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 0 Events
Draw Hierarchy
Samplers
Render targets
Render state
Shader state
Name
Triangles
Tris/Pixel
Cycles/Pixel
Instances
DrawCalls
Geometry 11.675% 1,201,591 0.00 0.00 15,152 1,649
Shadows 9.858% 576,726 0.00 0.00 7,614 949
Depthprime 9.670% 957,091 0.00 0.00 14,284 1,355
21.345 %
Legend
Pan Area ALT + Mouse Drag
Zoom Area Mouse Drag
Zoom Bar DoubleClick
Zoom All CTRL + DoubleClick
Packet to TTY/Clipboard RMB on Packet
Record Hold Space
Scrub Frame Left/Right
Live View ESC
Selection
Same name Ctrl + Hover
Same name + context Ctrl + Shift + Hover
Table controls
Row select Up/Down
Page skip PgUp/PgDown
First/Last row Home/End
Column select Tab
Use item Enter
Expand all CTRL + Enter
Collapse all ALT + Enter
Print table T
Save to file D

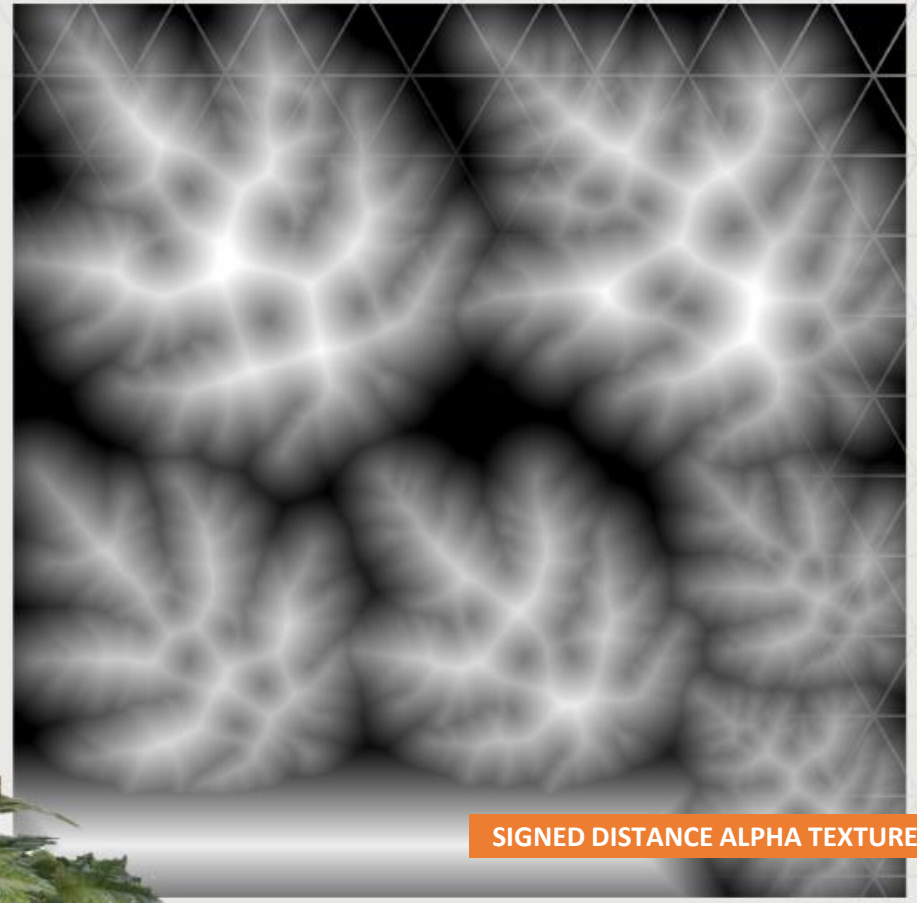

Scalpel GPU Profiler
placement
Frame 10 / 10
GPU Profile
0 Events
Draw Hierarchy
Samplers
Render targets
Render state
Shader state
Name
Triangles
Tris/Pixel
Cycles/Pixel
Instances
DrawCalls
Geometry
45.560%
0.000%
1,296,684
0.00
0.00
15,938
1,645
Shadows
10.853%
0.000%
597,924
0.00
0.00
7,981
1,145
45.560 %
Legend
Pan Area
ALT + Mouse Drag
Zoom Area
Mouse Drag
Zoom Bar
DoubleClick
Zoom All
CTRL + DoubleClick
Packet to TTY/Clipboard
RMB on Packet
Record
Hold Space
Scrub Frame
Left/Right
Live View
ESC
Selection
Same name
Ctrl + Hover
Same name + context
Ctrl + Shift + Hover
Table controls
Row select
Up/Down
Page skip
PgUp/PgDown
First/Last row
Home/End
Column select
Tab
Use item
Enter
Expand all
CTRL + Enter
Collapse all
ALT + Enter
Print table
T
Save to file
D

Shading

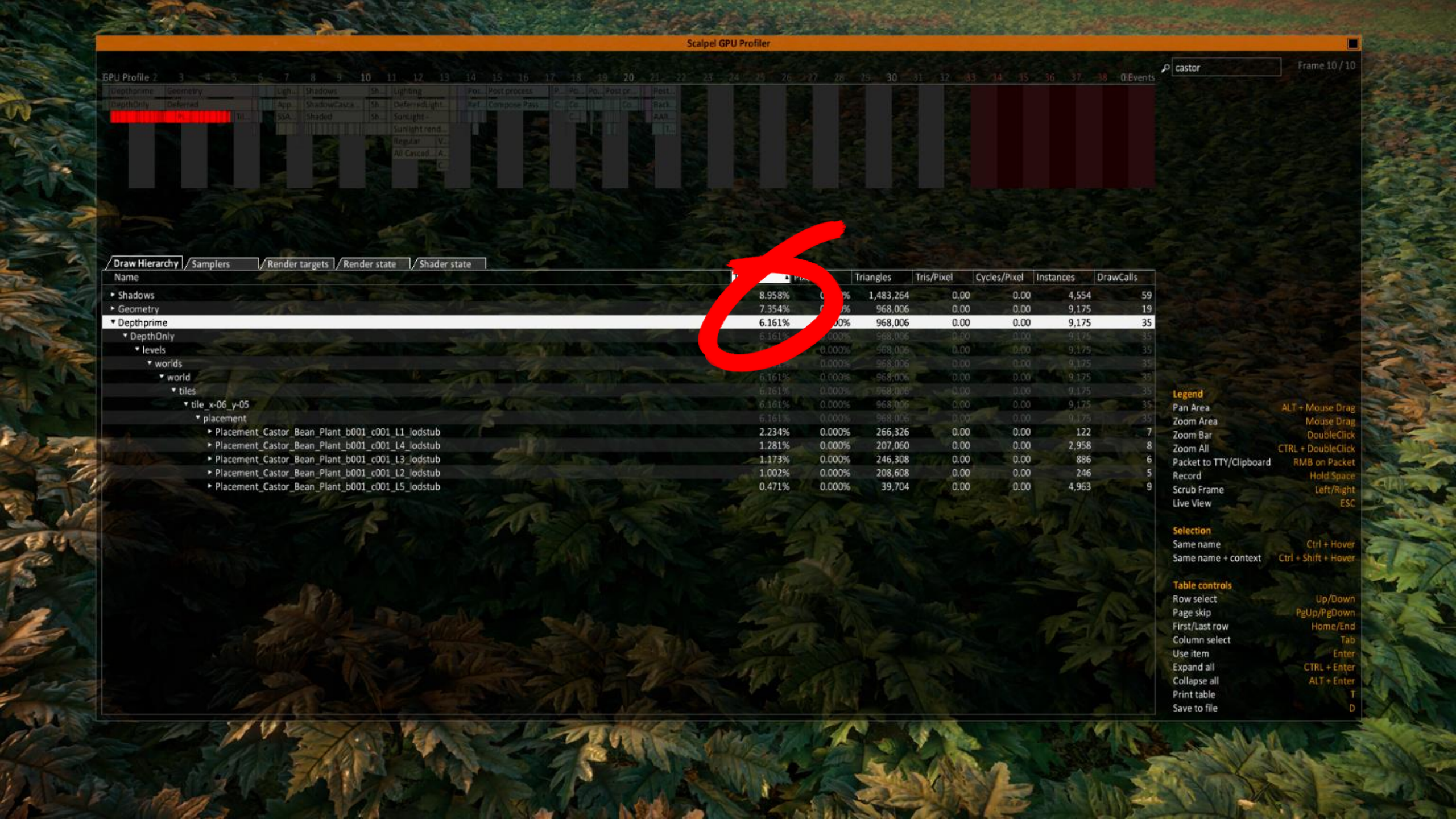
Pixel Program: Alpha

Alpha Testing, Initial HZD setup:

- Alpha Textures are Signed Distance Textures
- Artists controlled size in Shader
- Artists controlled over Distance Quality
- Snow(flakes) in our Shader adjusted the Alpha



SIGNED DISTANCE ALPHA TEXTURE


Scalpel GPU Profiler
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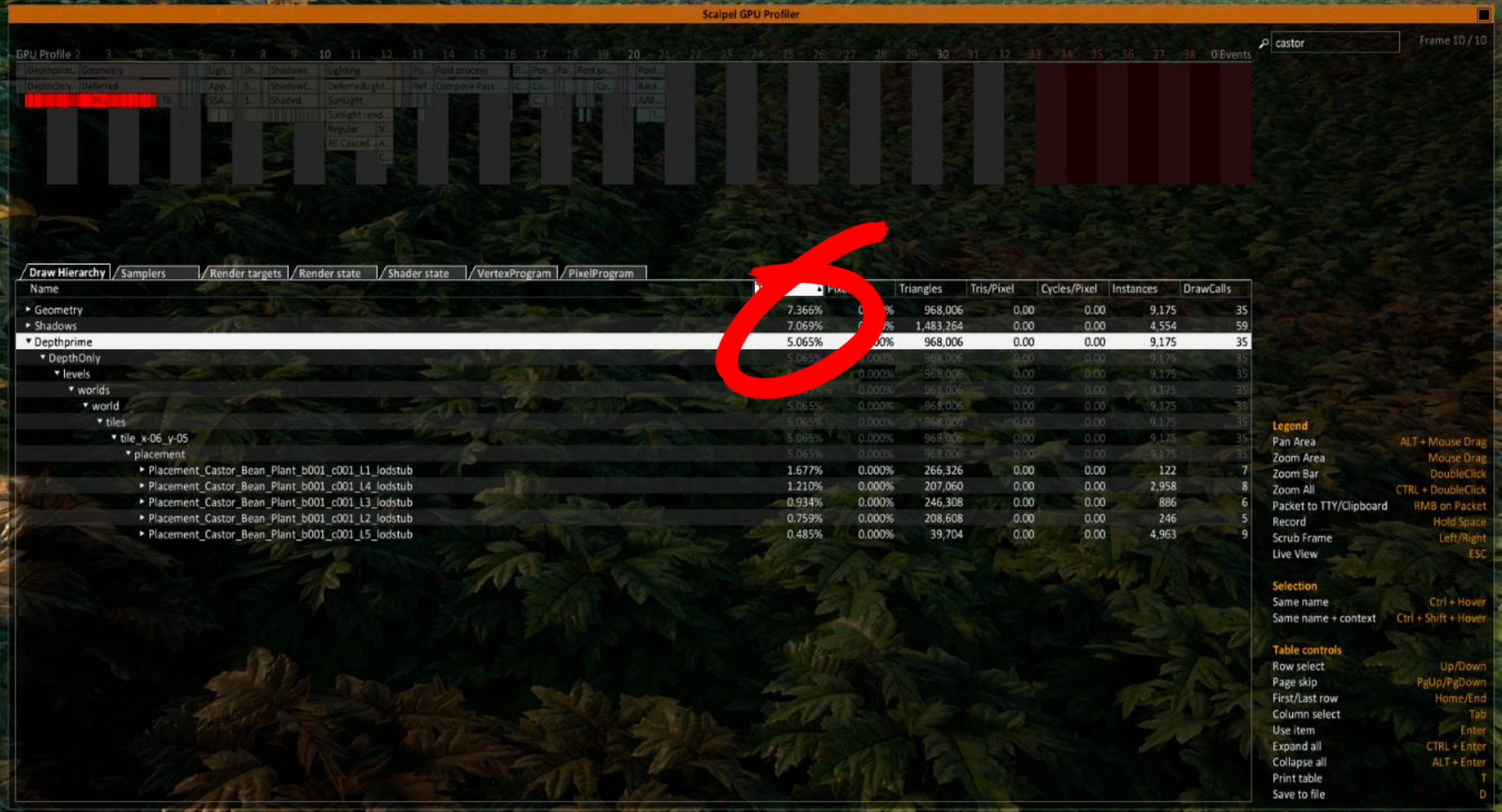
castor
Frame 10 / 10
0 Events
Draw Hierarchy
Samplers
Render targets
Render state
Shader state
Name
Triangles
Tris/Pixel
Cycles/Pixel
Instances
DrawCalls
Shadows 8.958% 1,483,264 0.00 0.00 4,554 59
Geometry 7.354% 968,006 0.00 0.00 9,175 19
Depthprime 6.161% 968,006 0.00 0.00 9,175 35
DepthOnly
levels
worlds
world
tiles
tile_x-06_y-05
placement
Placement_Castor_Bean_Plant_b001_c001_L1_lodstub 2.234% 0.000% 266,326 0.00 0.00 122 7
Placement_Castor_Bean_Plant_b001_c001_L4_lodstub 1.281% 0.000% 207,060 0.00 0.00 2,958 8
Placement_Castor_Bean_Plant_b001_c001_L3_lodstub 1.173% 0.000% 246,308 0.00 0.00 886 6
Placement_Castor_Bean_Plant_b001_c001_L2_lodstub 1.002% 0.000% 208,608 0.00 0.00 246 5
Placement_Castor_Bean_Plant_b001_c001_L5_lodstub 0.471% 0.000% 39,704 0.00 0.00 4,963 9
Legend
Pan Area ALT + Mouse Drag
Zoom Area Mouse Drag
Zoom Bar DoubleClick
Zoom All CTRL + DoubleClick
Packet to TTY/Clipboard RMB on Packet
Record Hold Space
Scrub Frame Left/Right
Live View ESC
Selection
Same name Ctrl + Hover
Same name + context Ctrl + Shift + Hover
Table controls
Row select Up/Down
Page skip PgUp/PgDown
First/Last row Home/End
Column select Tab
Use item Enter
Expand all CTRL + Enter
Collapse all ALT + Enter
Print table T
Save to file D


Scalpel GPU Profiler
GPU Profile
castor
Frame 10 / 10
0 Events
Draw Hierarchy
Samplers
Render targets
Render state
Shader state
VertexProgram
PixelProgram
Name
Triangles
Tris/Pixel
Cycles/Pixel
Instances
DrawCalls
Geometry 7.366% 968,006 0.00 0.00 9,175 35
Shadows 7.069% 1,483,264 0.00 0.00 4,554 59
Depthprime 5.065% 968,006 0.00 0.00 9,175 35
DepthOnly
levels
worlds
world
tiles
tile_x-06_y-05
placement
Placement_Castor_Bean_Plant_b001_c001_L1_lodstub 1.677% 0.000% 266,326 0.00 0.00 122 7
Placement_Castor_Bean_Plant_b001_c001_L4_lodstub 1.210% 0.000% 207,060 0.00 0.00 2,958 8
Placement_Castor_Bean_Plant_b001_c001_L3_lodstub 0.934% 0.000% 246,308 0.00 0.00 886 6
Placement_Castor_Bean_Plant_b001_c001_L2_lodstub 0.759% 0.000% 208,608 0.00 0.00 246 5
Placement_Castor_Bean_Plant_b001_c001_L5_lodstub 0.485% 0.000% 39,704 0.00 0.00 4,963 9
Legend
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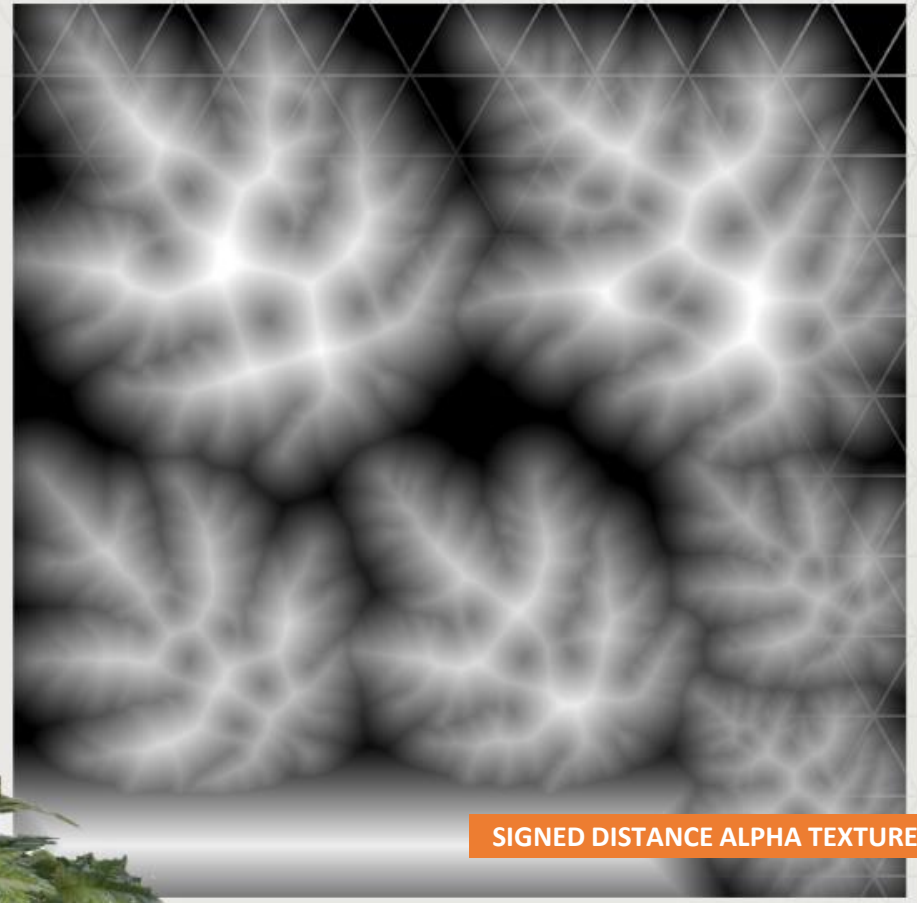
First/Last row Home/End
Column select Tab
Use item Enter
Expand all CTRL + Enter
Collapse all ALT + Enter
Print table T
Save to file D

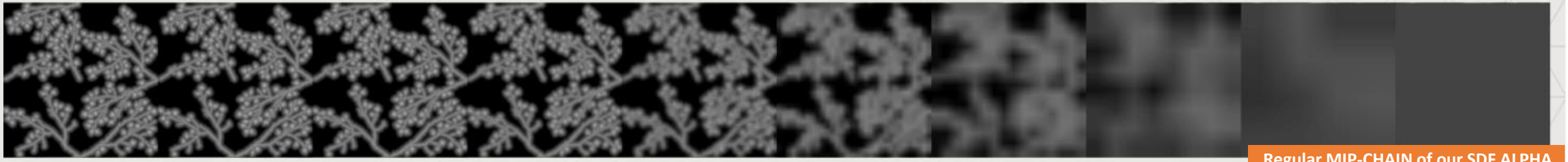
Pixel Program: Alpha

Alpha Testing, Solution:

- No more adjusting the Alpha in the Shader!
- ‘Custom Coverage’ Algorithm to build a better Mip Chain:
  - Calculate coverage of the input image (after alpha testing).
  - Generate a regular Mip-chain.
  - For each Mip:
    - Generate a histogram of this Mip after bilinear up sampling.
      In our case to 4096x4096.
    - Find the point P in the histogram
      that corresponds to the original coverage.
    - Scale the pixels by 0.5 / P so that P ends up
      at our alpha testing value of 0.5.

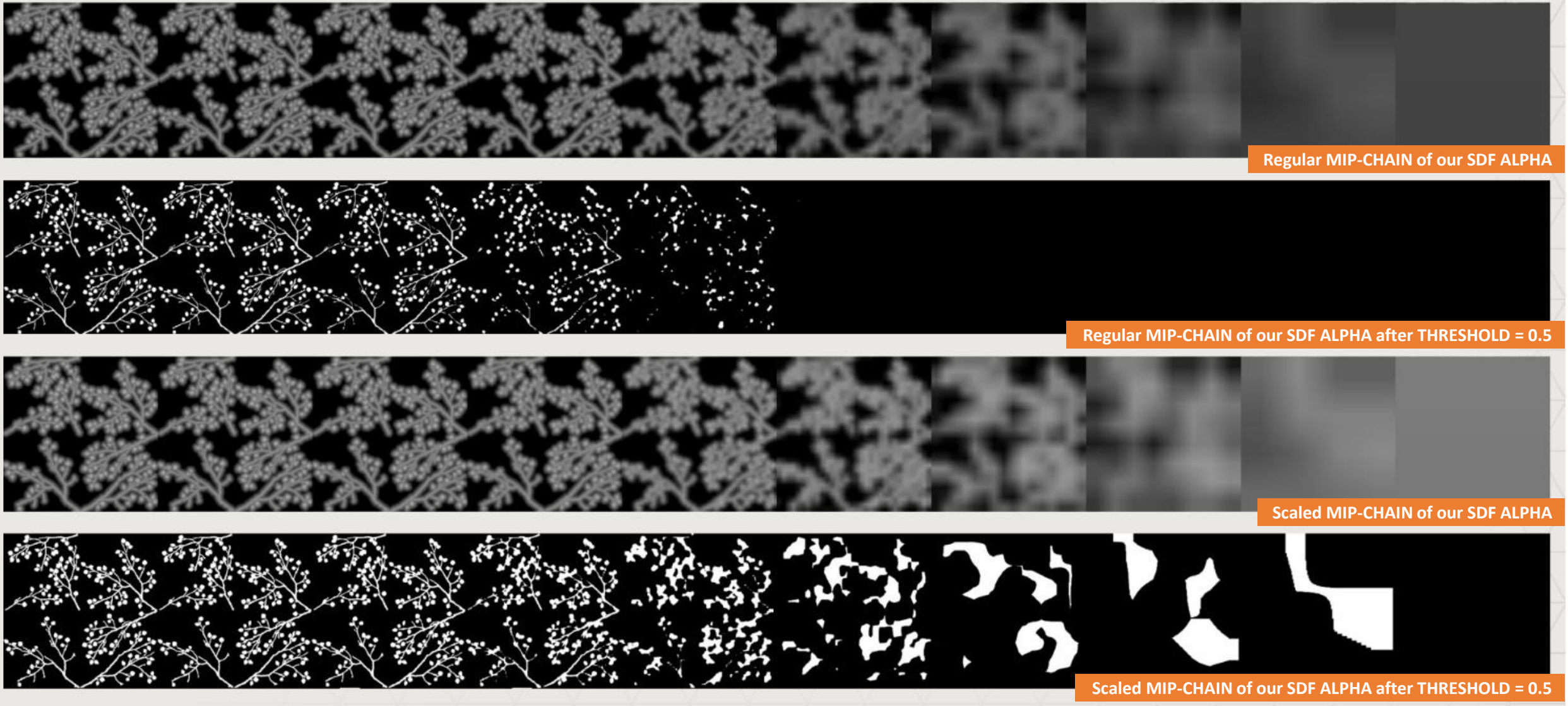


SIGNED DISTANCE ALPHA TEXTURE



Regular MIP-CHAIN of our SDF ALPHA

Regular MIP-CHAIN of our SDF ALPHA after THRESHOLD = 0.5

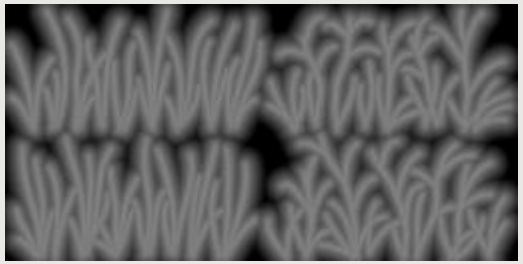

Regular MIP-CHAIN of our SDF ALPHA
Regular MIP-CHAIN of our SDF ALPHA after THRESHOLD = 0.5
Scaled MIP-CHAIN of our SDF ALPHA
Scaled MIP-CHAIN of our SDF ALPHA after THRESHOLD = 0.5

Shading

Pixel Program: Alpha

Alpha Testing Optimization:

- Make the Alpha fit in Cache!
- In our case, Small Assets and Grass



256x128 pixel Alpha Texture

- Need really good Anti-Aliasing!

Anti-Aliasing

SIGGRAPH 2017

Giliam de Carpentier - Guerrilla Games
Kohei Ishiyama - Kojima Productions

Decima Engine: Advances in Lighting and AA

- Typically 4 Samples in total
- Always two Samples per rendered pixel per frame
- At most 1 millisecond per frame at 1080 / PS4

Shading

Guerrilla Games – GDC 2018 – Between Tech and Art: The Vegetation of Horizon Zero Dawn

Shading

Pixel Program: G-Buffers

Our Vegetation Shaders write to Geometry Buffers:

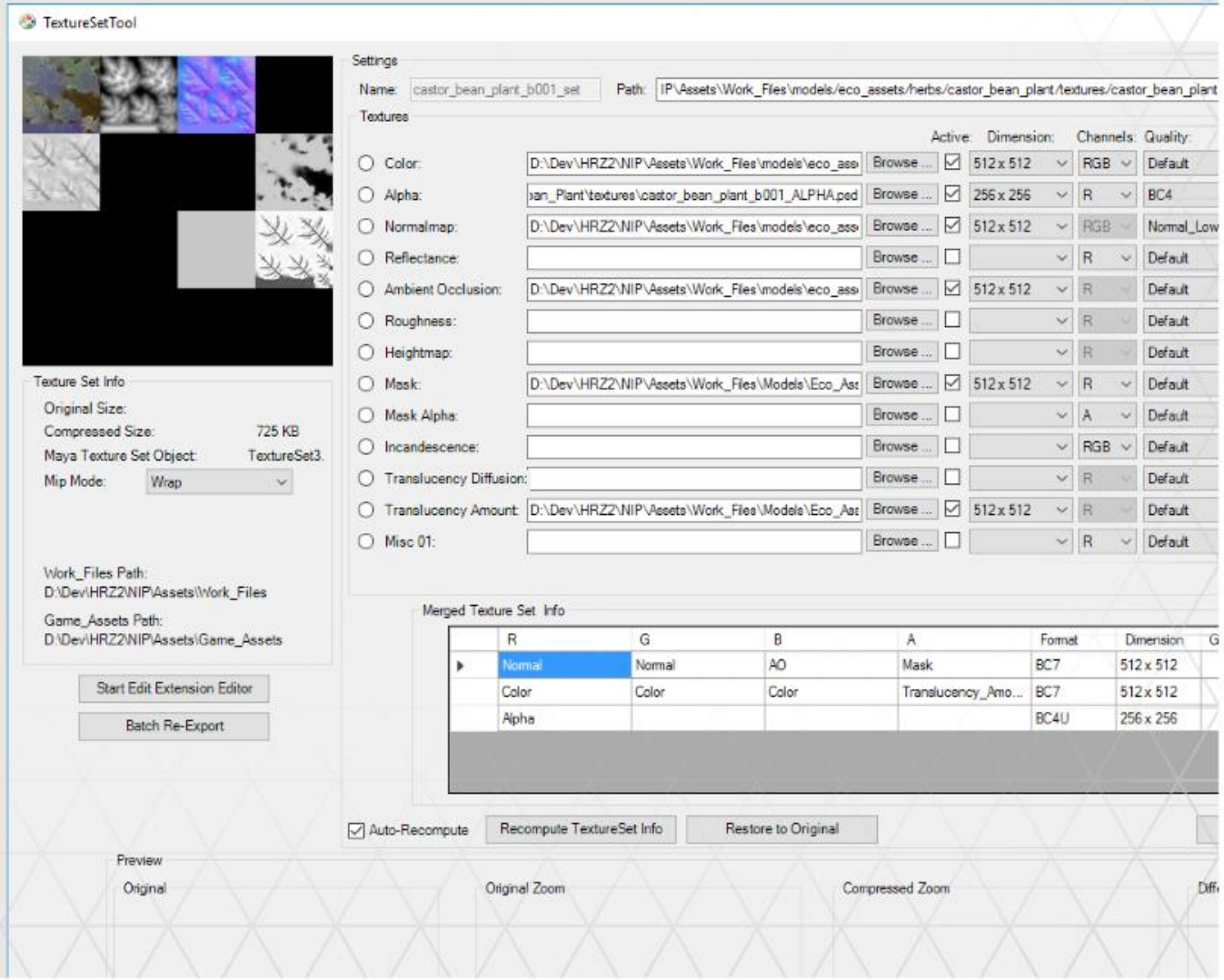
- Normal
- Albedo
- Roughness
- Reflectance
- Translucency Amount
- Translucency Diffusion
- Depth
- Motion Vectors - *(if placed by the Placement System)*

Shading

Pixel Program: Vegetation Textures

Vegetation Textures:

- Alpha
- Tangent Space Normal
- Albedo
- Translucency Amount
- Mask
- Ambient Occlusion
  - Not on Grass!



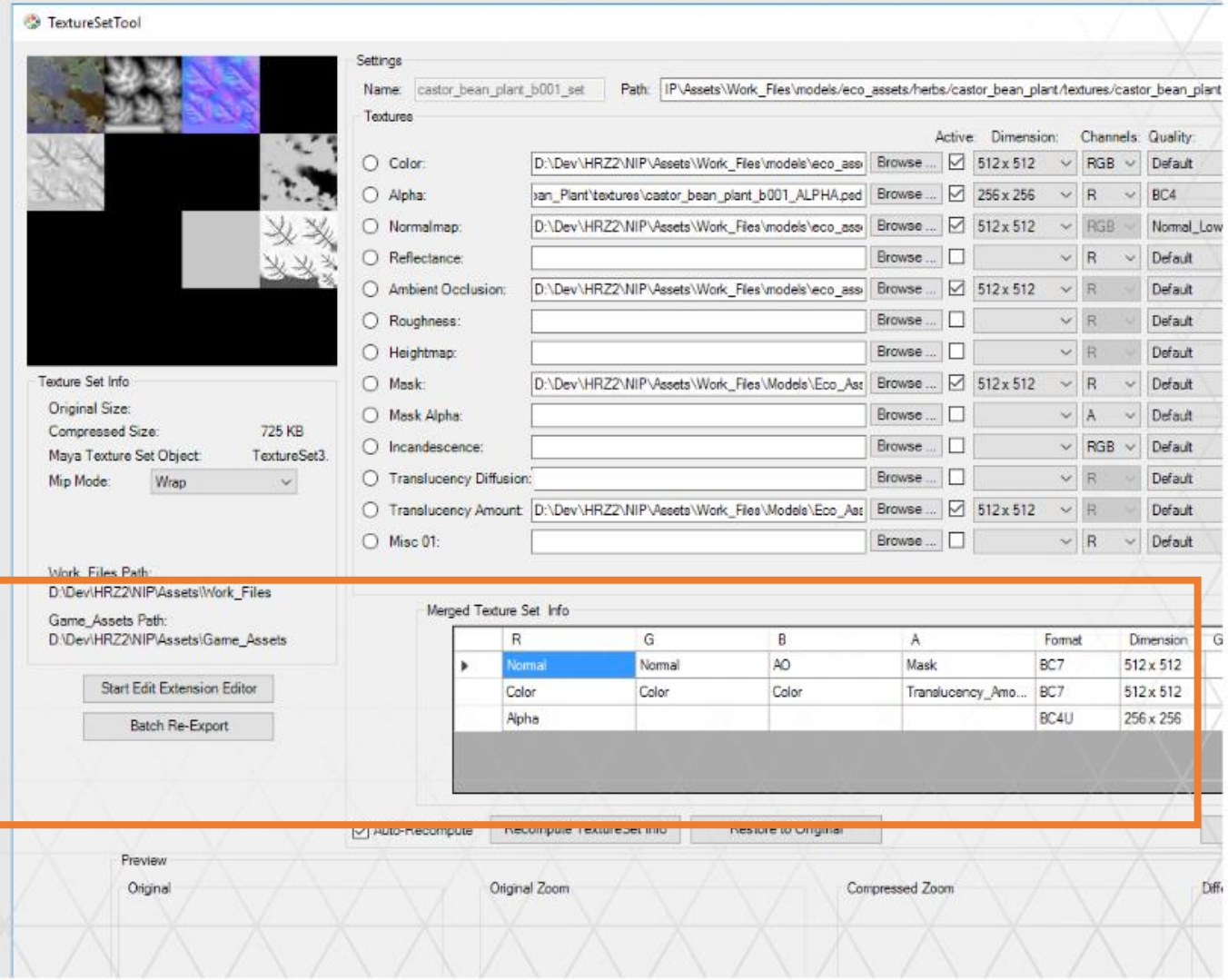
Pixel Program: Vegetation Textures

Vegetation Textures:

- Alpha
- Tangent Space Normal
- Albedo
- Translucency Amount
- Mask
- Ambient Occlusion
  - Not on Grass!

Get packed into:

- BC7: NMT / MSK / AO
- BC7: CLR / TRA
- BC4: ALPHA



Shading

Pixel Program: Normals

Our Normals, when Rendered Double Sided are:

- Flipped Correctly in Tangent Space
  - Most Plants, lots of Small Trees, most Pine Trees

Shading

Pixel Program: Normals

Our Normals, when Rendered Double Sided are:

- Flipped Correctly in Tangent Space
  - Most Plants, lots of Small Trees, most Pine Trees

Shading

Pixel Program: Normals

Our Normals, when Rendered Double Sided are:

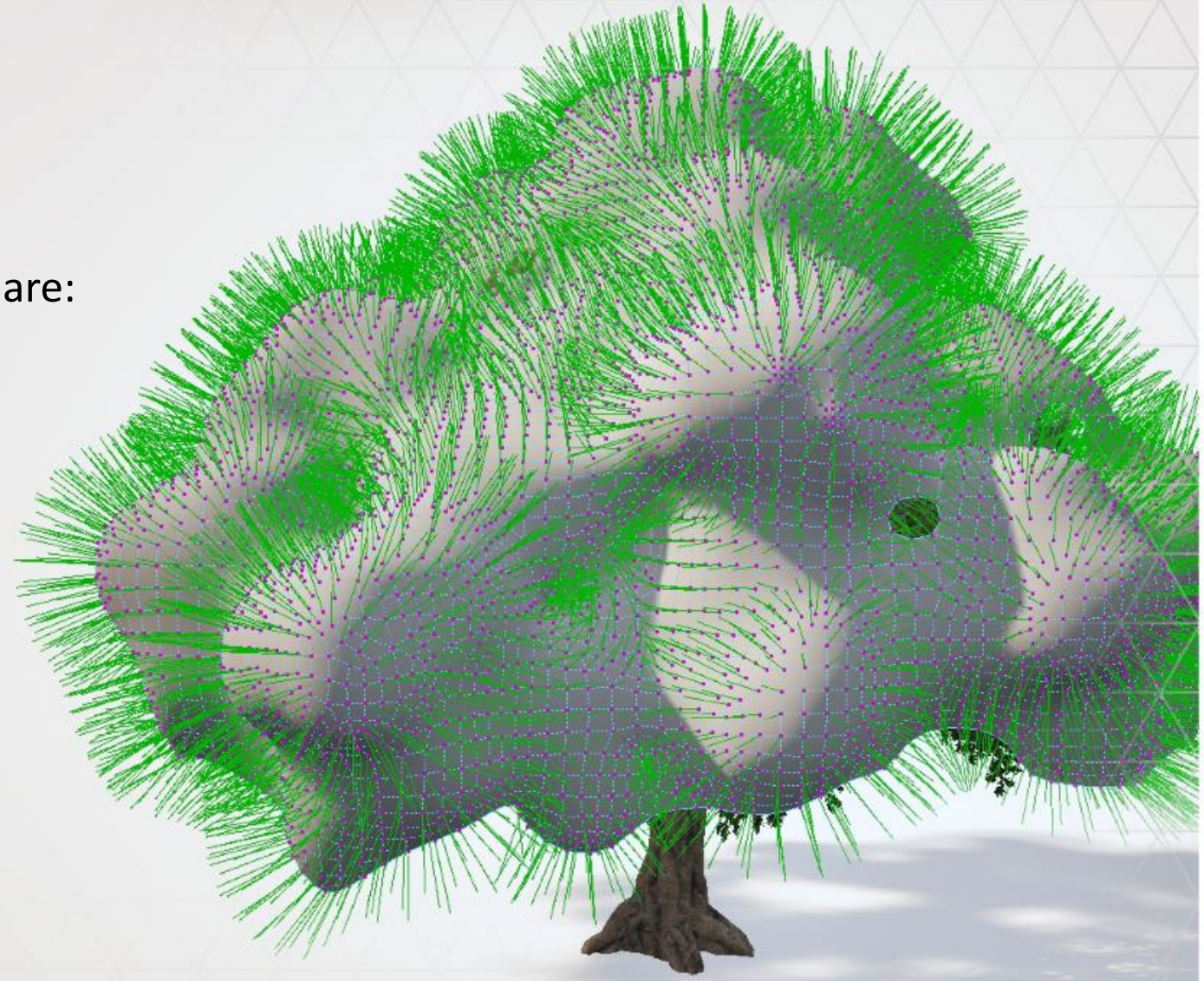
- Flipped Correctly in Tangent Space
  - Most Plants, lots of Small Trees, most Pine Trees
- Flipped ‘Incorrectly’
  - Adjusted Vertex Normals
  - Abs() the Z components of our Viewspace Normal
  - Grass and most of our Trees Canopies

Shading

Pixel Program: Normals

Our Normals, when Rendered Double Sided are:

- Flipped Correctly in Tangent Space
  - Most Plants, lots of Small Trees, most Pine Trees
- Flipped ‘Incorrectly’
  - Adjusted Vertex Normals
  - Abs() the Z components of our Viewspace Normal
  - Grass and most of our Trees Canopies



Shading

Pixel Program: Normals

Our Normals, when Rendered Double Sided are:

- Flipped Correctly in Tangent Space
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- Flipped ‘Incorrectly’
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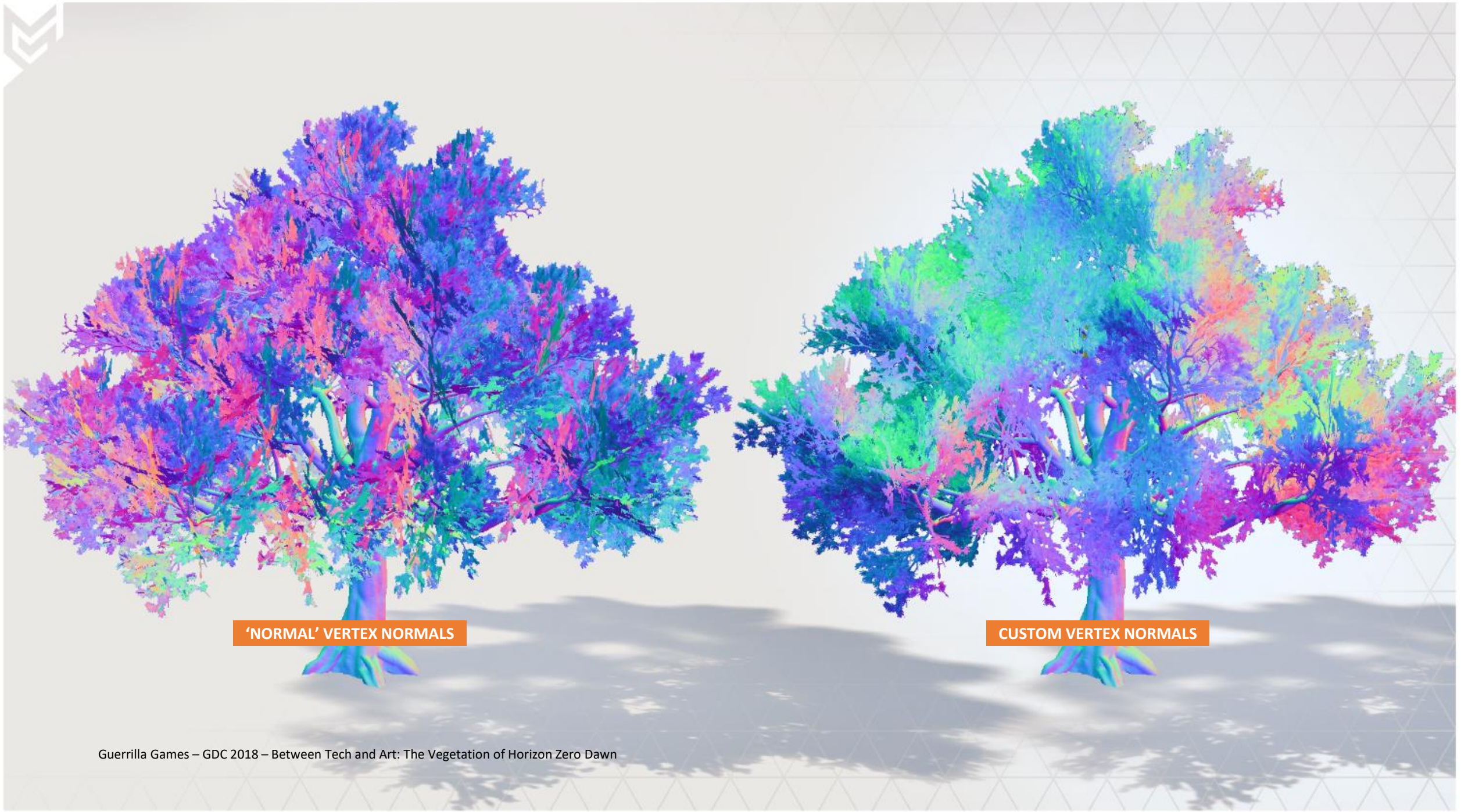
‘NORMAL’ VERTEX NORMALS
CUSTOM VERTEX NORMALS

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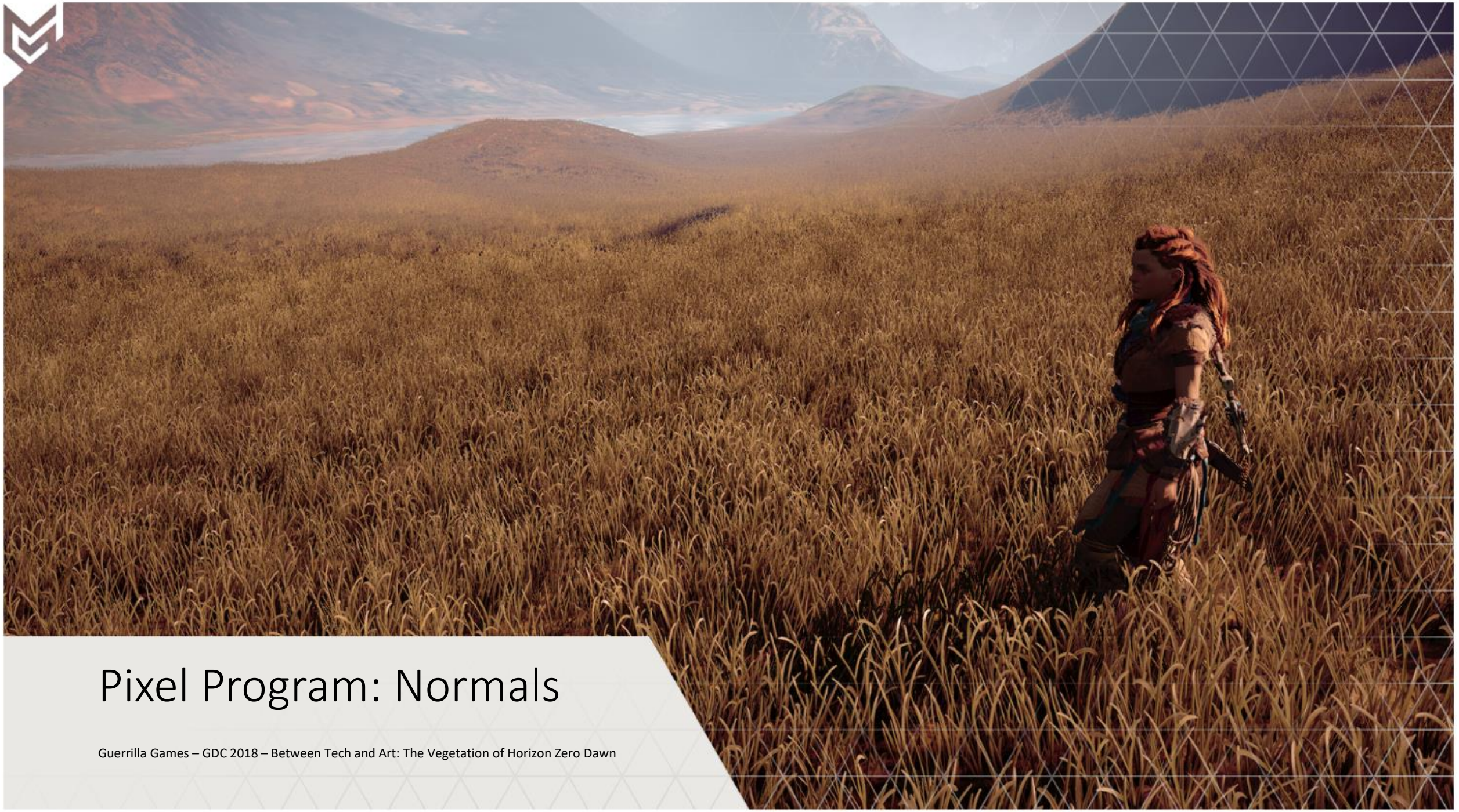
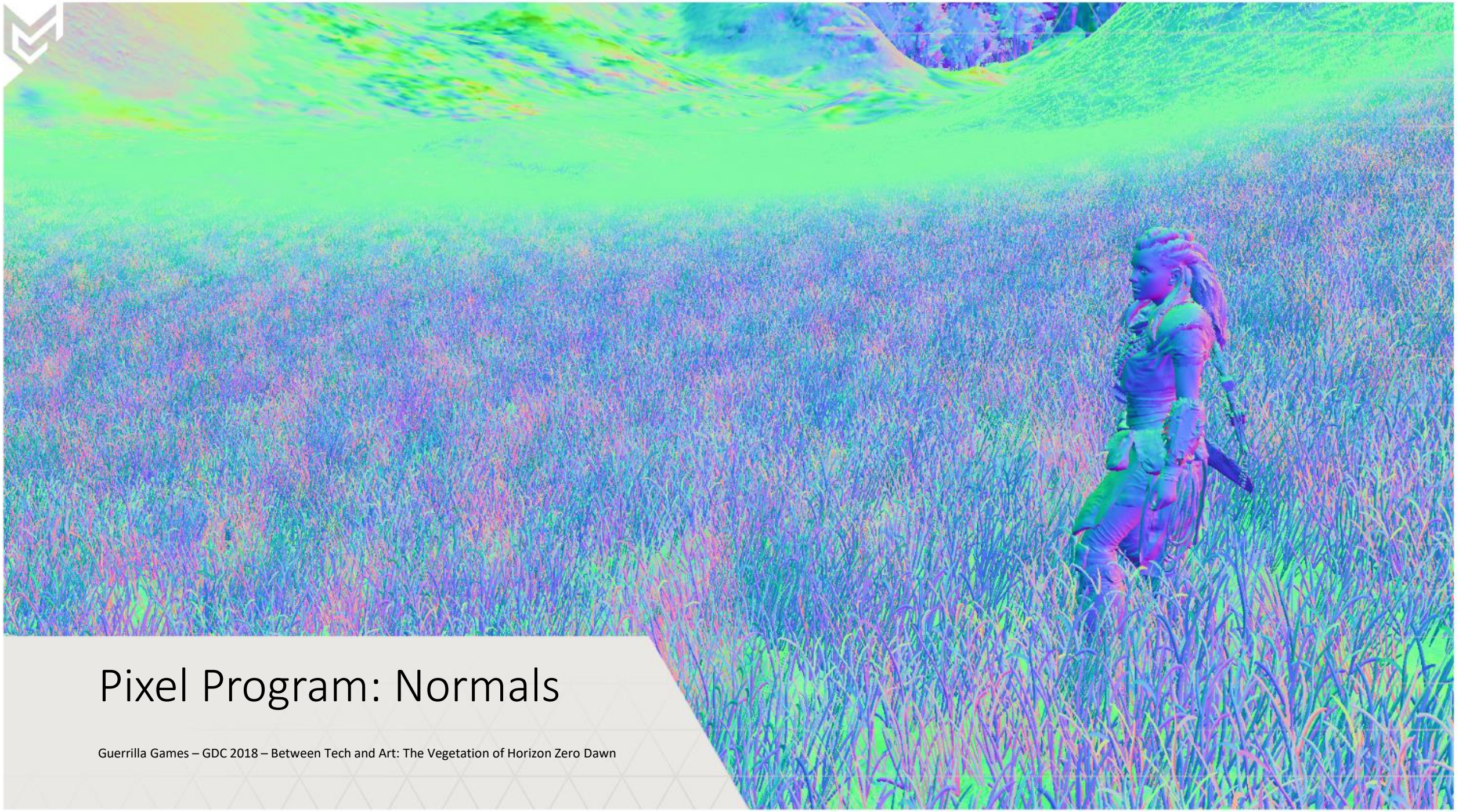


Pixel Program: Normals



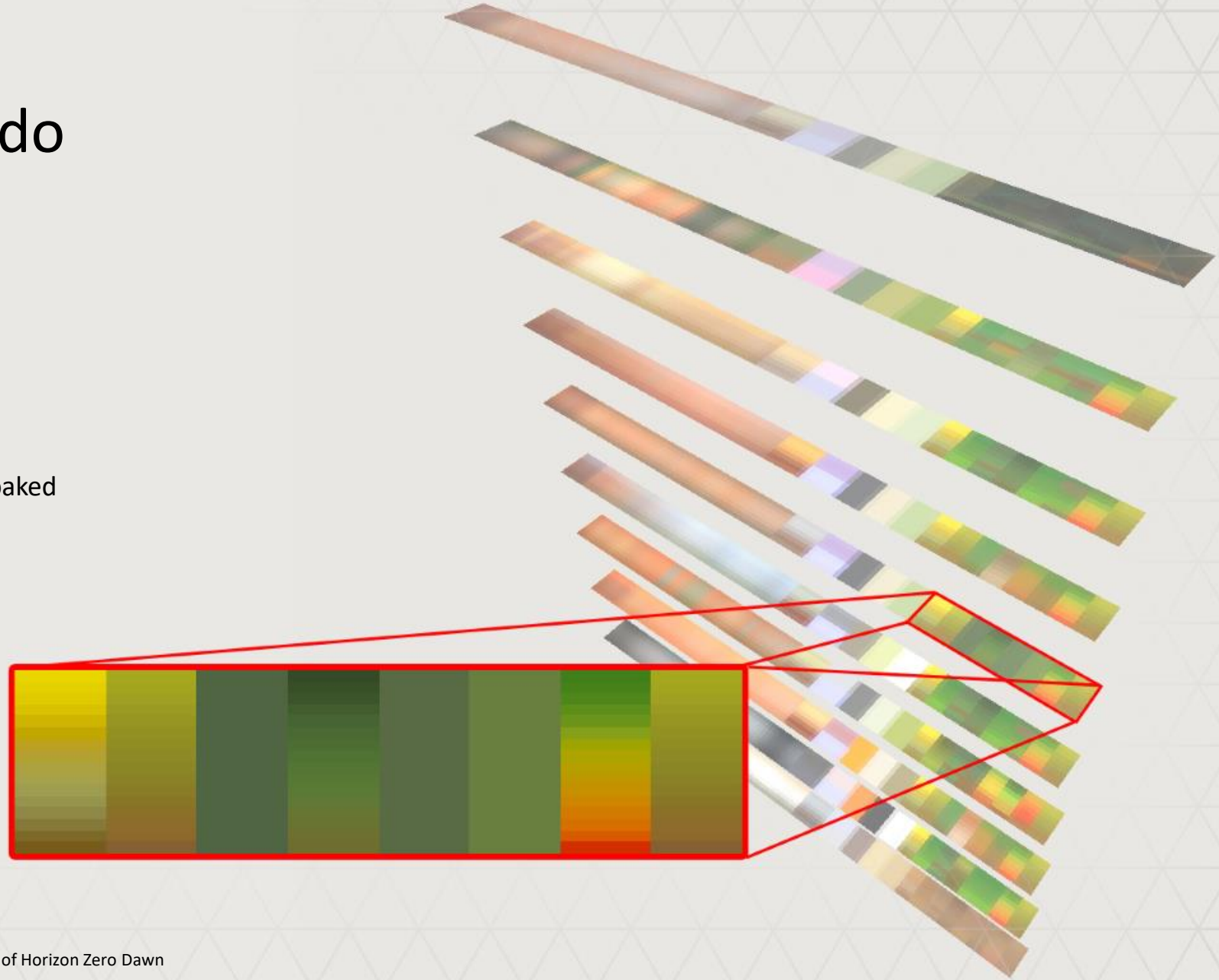
Pixel Program: Normals

Shading

Pixel Program: Albedo

Colorization Texture Array:

- Based on Asset Type
  - Artist driven
  - U-Component
- Based on World Data
  - Erosion, Flow, Closeness to Water baked into 512x512 Worlddata Texture
  - V-Components
- Based on Ecotope
  - Place in the World
  - W-Component

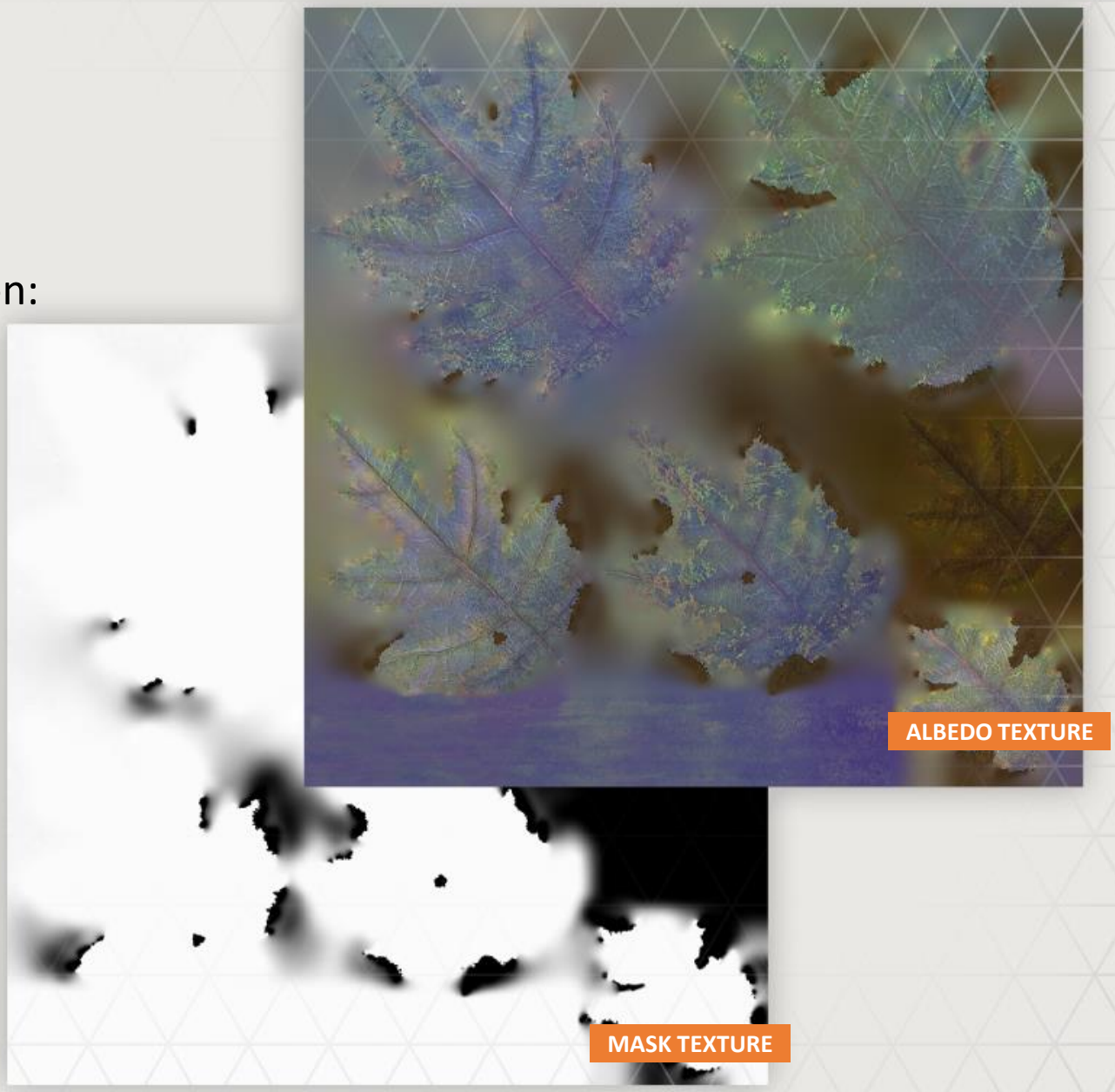


Shading

Pixel Program: Albedo

In our shader, we colorize most of our Vegetation:

- Two Textures drive colorization
  - Albedo
  - Mask
- Illuminate Blend Function
  - Result = Texture * (2 * Colorize * Mask + 1 – Mask)



Shading

Pixel Program: Roughness / Reflectance

- Reflectance – Fixed at 4% Dielectric
  - Baked Ambient Occlusion and Occlusion Texture
- Roughness – Artist controlled
  - Baked Ambient Occlusion, Occlusion Texture and Translucency Texture
- Grass – Similar Value Setup, but:
  - Influenced by Translucency Texture

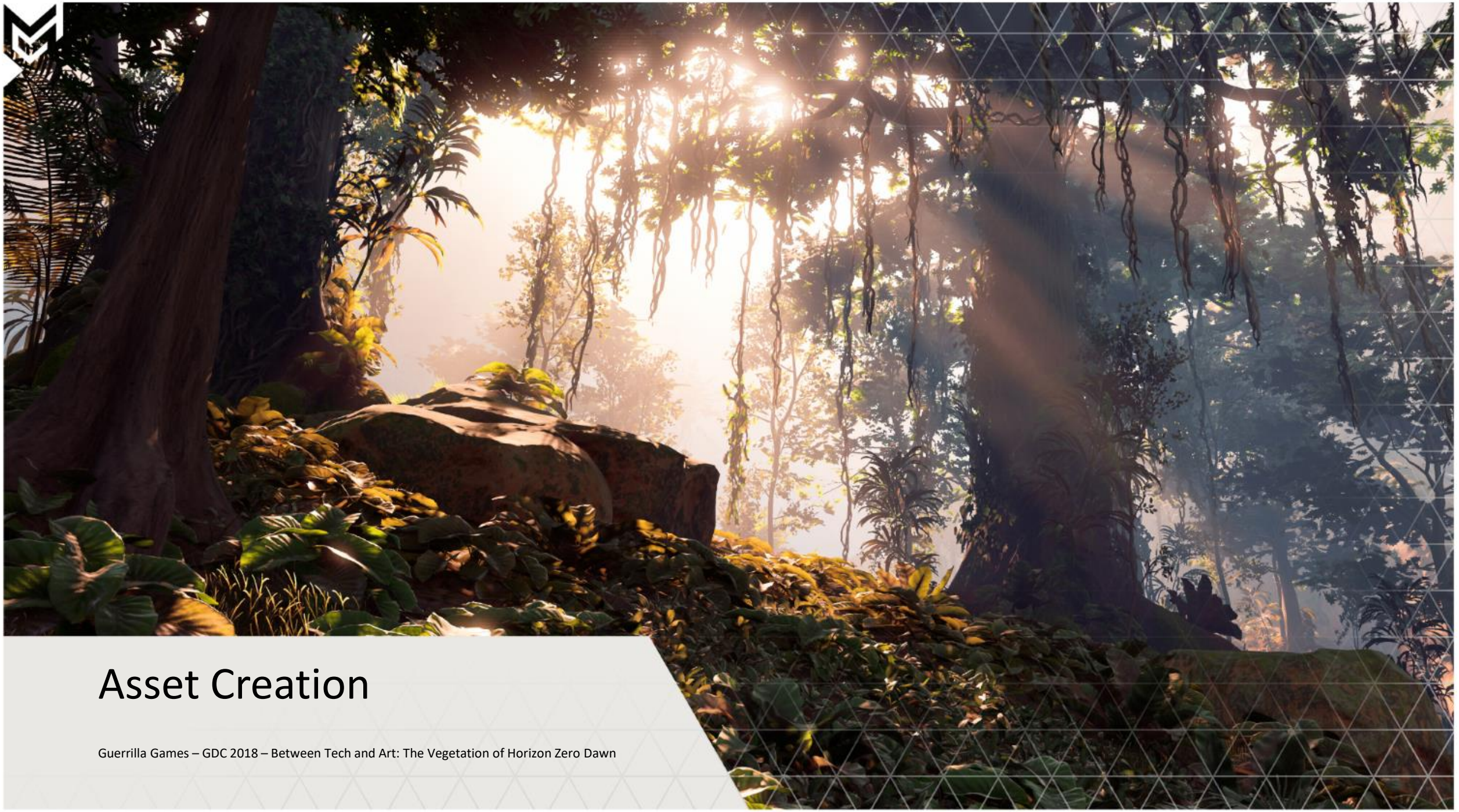
Shading

Pixel Program: Translucency

Our Translucency is the product of the following:

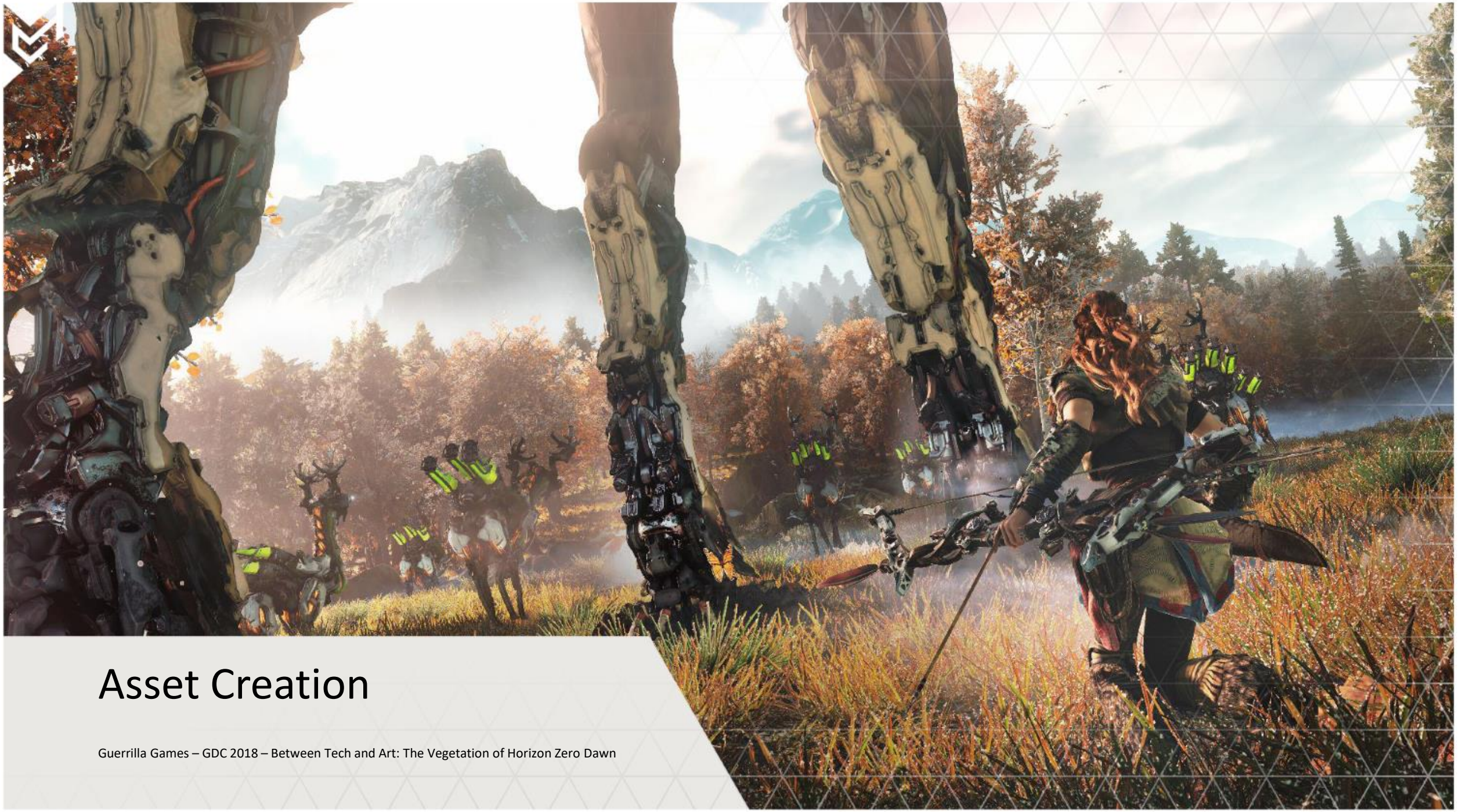
- Amount of light hitting the object from behind
- Angle between the camera, the lit pixel on screen and the light source
- ‘Max Luminance’ of Albedo Color

- Surface Thickness
- Pre-computed Ambient Occlusion
- Boost for Artistic Purposes



Asset Creation

Guerrilla Games – GDC 2018 – Between Tech and Art: The Vegetation of Horizon Zero Dawn



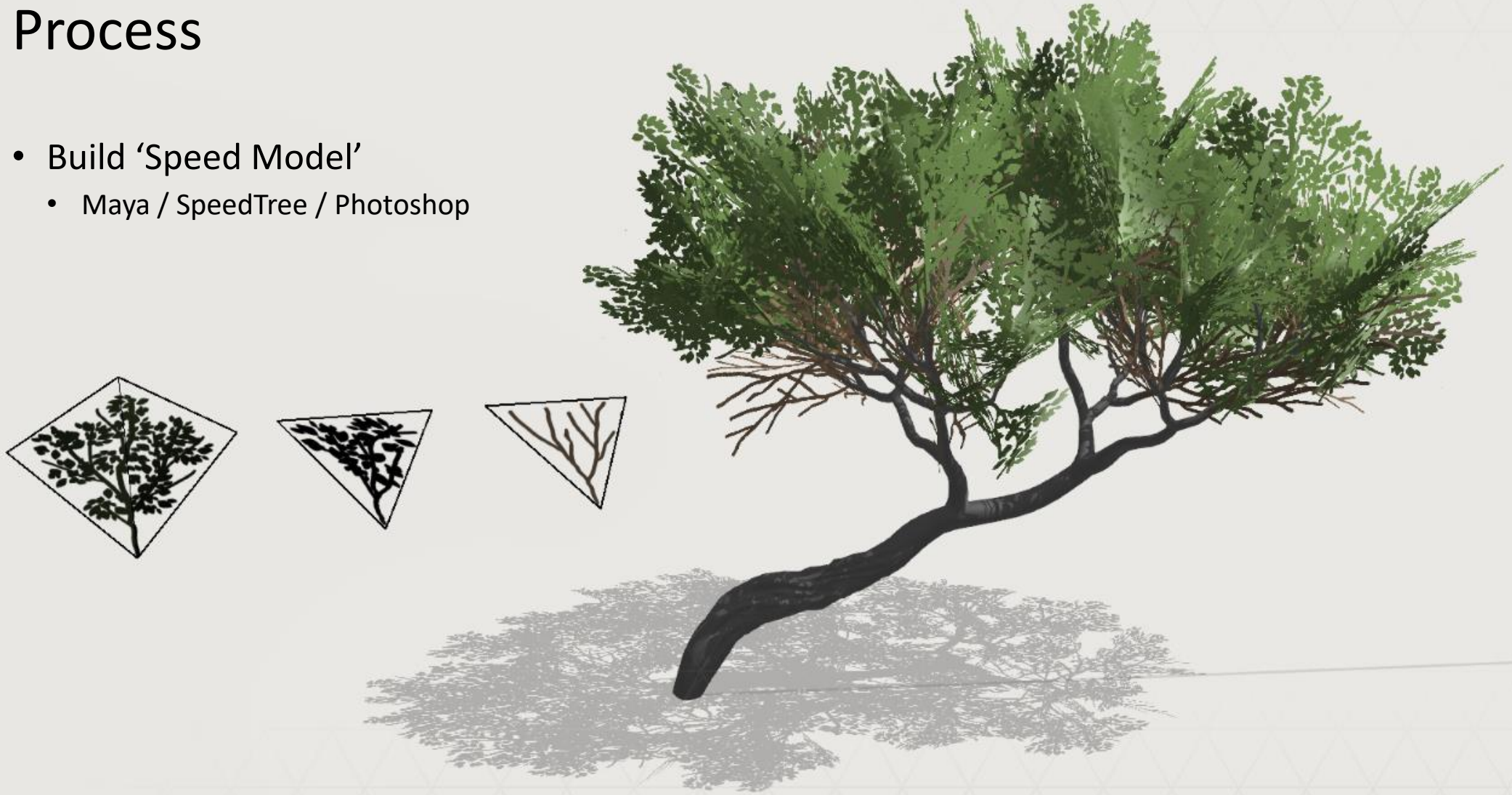
Asset Creation

Guerrilla Games – GDC 2018 – Between Tech and Art: The Vegetation of Horizon Zero Dawn

Creation

Process

- Build ‘Speed Model’
  - Maya / SpeedTree / Photoshop



Creation

Process

- High Detail Creation
  - Maya / SpeedTree / Photoshop

Creation

Process

- Baking into UV Space
  - Maya / SpeedTree / Photoshop

Creation

Process

- Build LOD Chain of Components
  - Maya

Creation

Process

Creation

Process

- Build Asset out of Components
  - SpeedTree

Creation

Process

- Build Asset out of Components
  - SpeedTree

Creation

Process

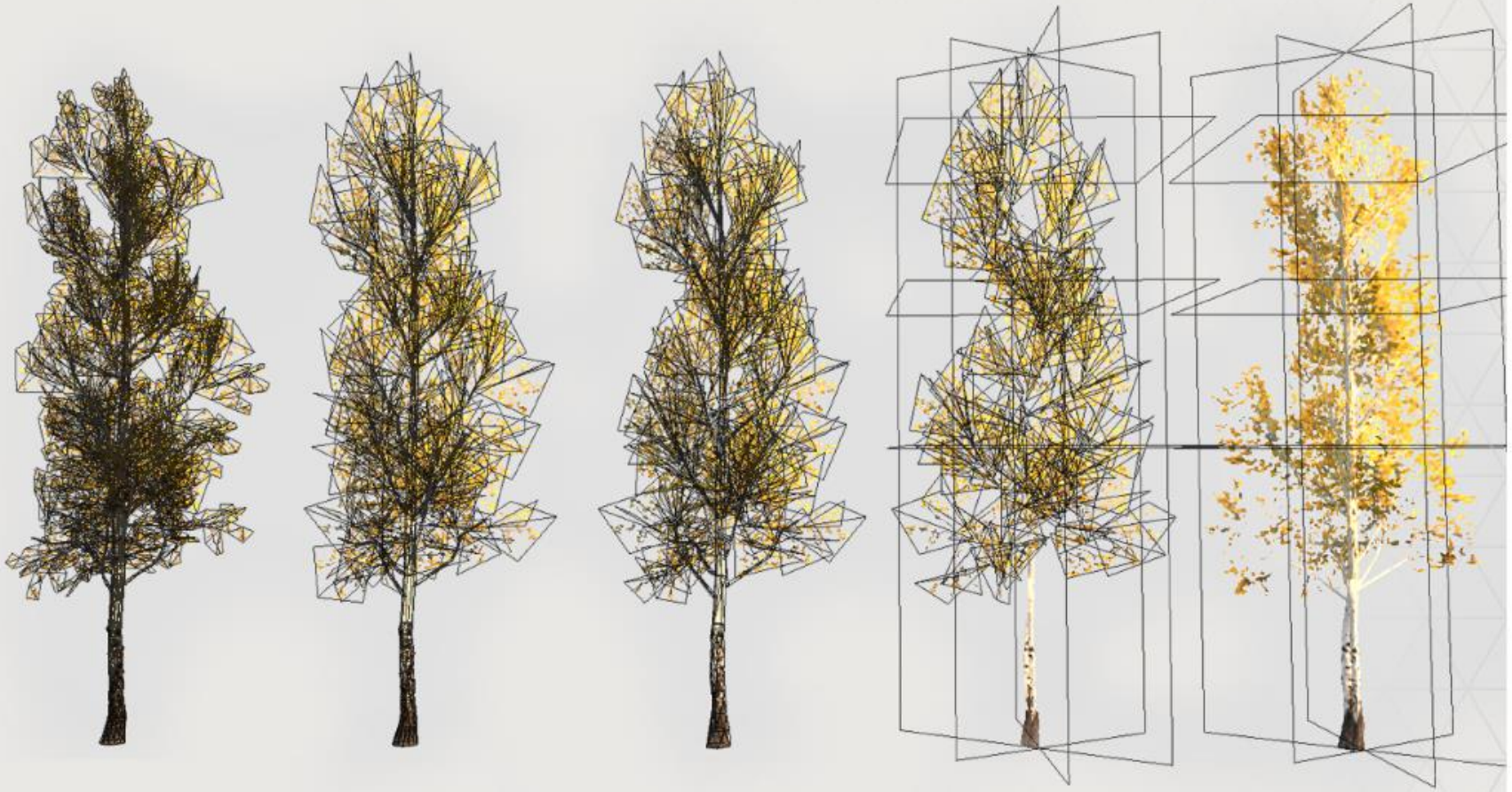
- SpeedTree Export to Maya
  - Houdini
- Asset Setup / Export to Game
  - Maya

Creation

Assets: Trees

Trees have five LODs:

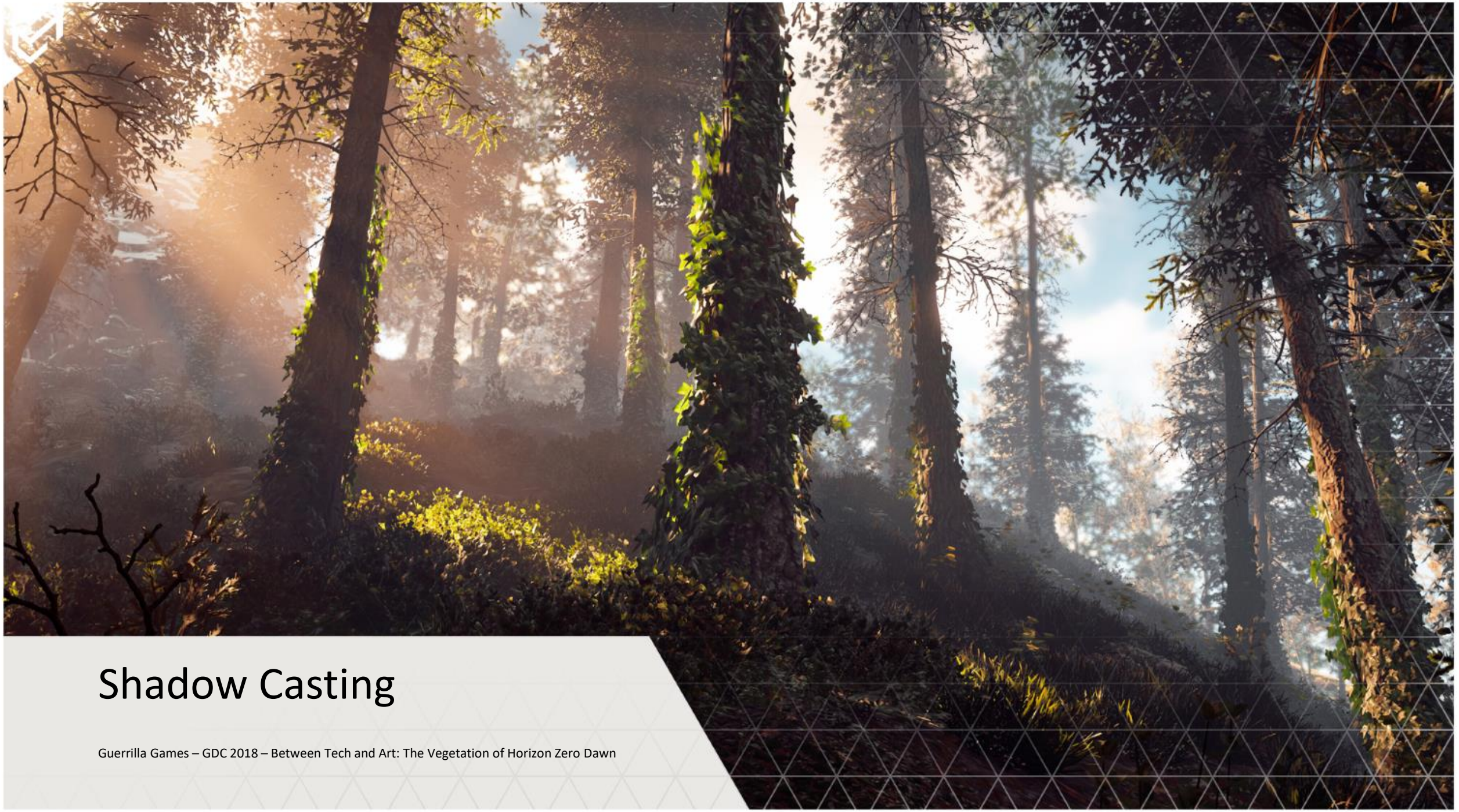
- LOD1
  - ~10000 triangles
  - High shader
- LOD2
  - ~2600 triangles
  - High shader
- LOD3
  - ~1200 triangles
  - Low shader
- LOD4
  - Low shader + fading in billboard
  - ~200 + 12 triangles
- LOD5
  - Billboard shader
  - 12 triangles



Creation

Assets: Plants

- Plants have three LODs:
- LOD1
  - ~2000 triangles
  - High shader
- LOD2
  - ~800 triangles
  - High shader
- LOD3
  - ~140 triangles
  - Low shader
- LOD4
  - 8 triangles
  - Billboard shader

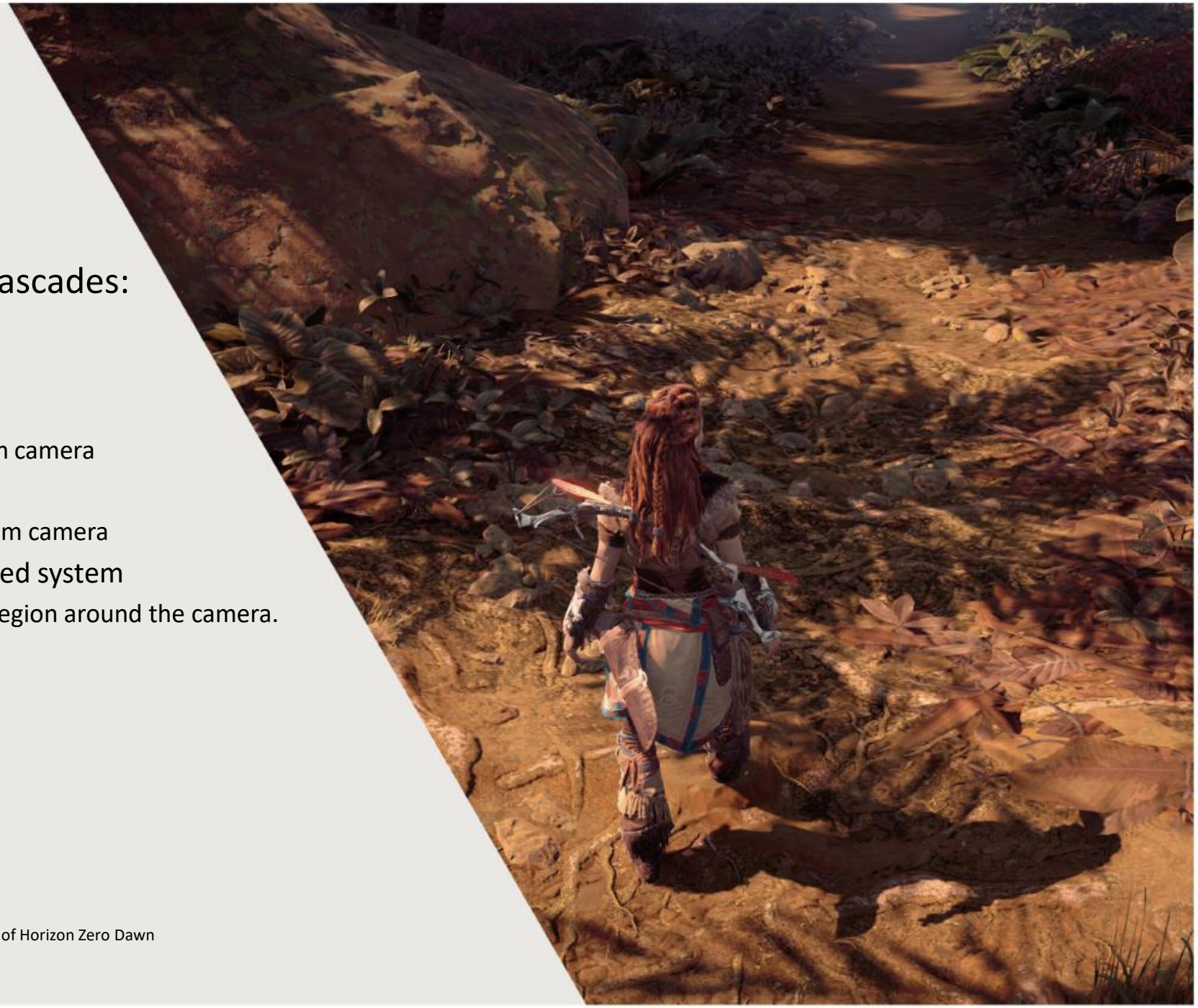


Shadow Casting

Shadow Casting

For sun shadows, we use four cascades:

- Compartment Cascade
  - 1024 x 1024 map - covers Aloy only
- Cascade 0
  - 2048 x 2048 map - to 8m away from camera
- Cascade 1
  - 2048 x 2048 map - to 80m away from camera
- Distant cascade – height-field-based system
  - 1536 x 1536 map - 1.5km x 1.5km region around the camera.



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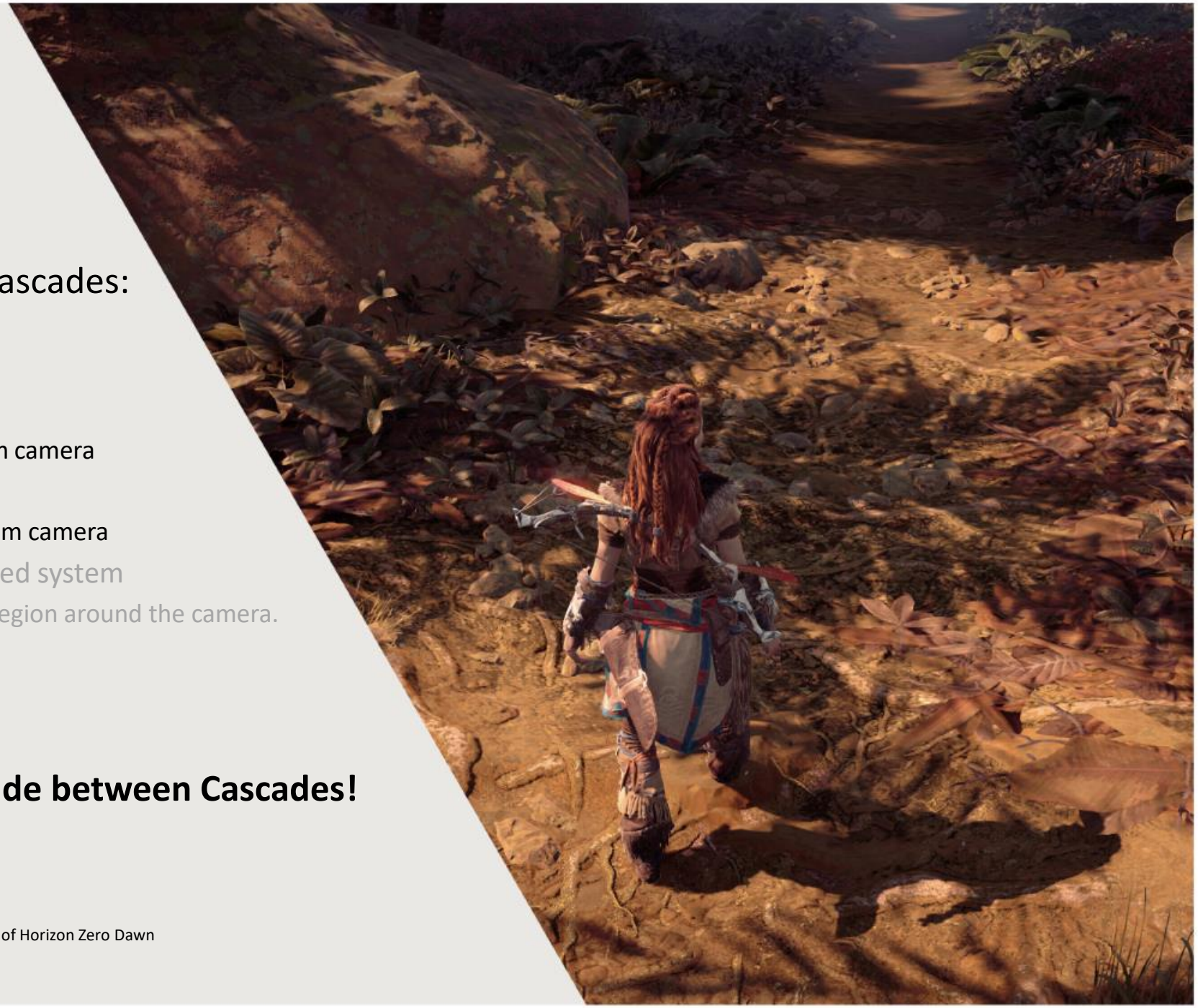
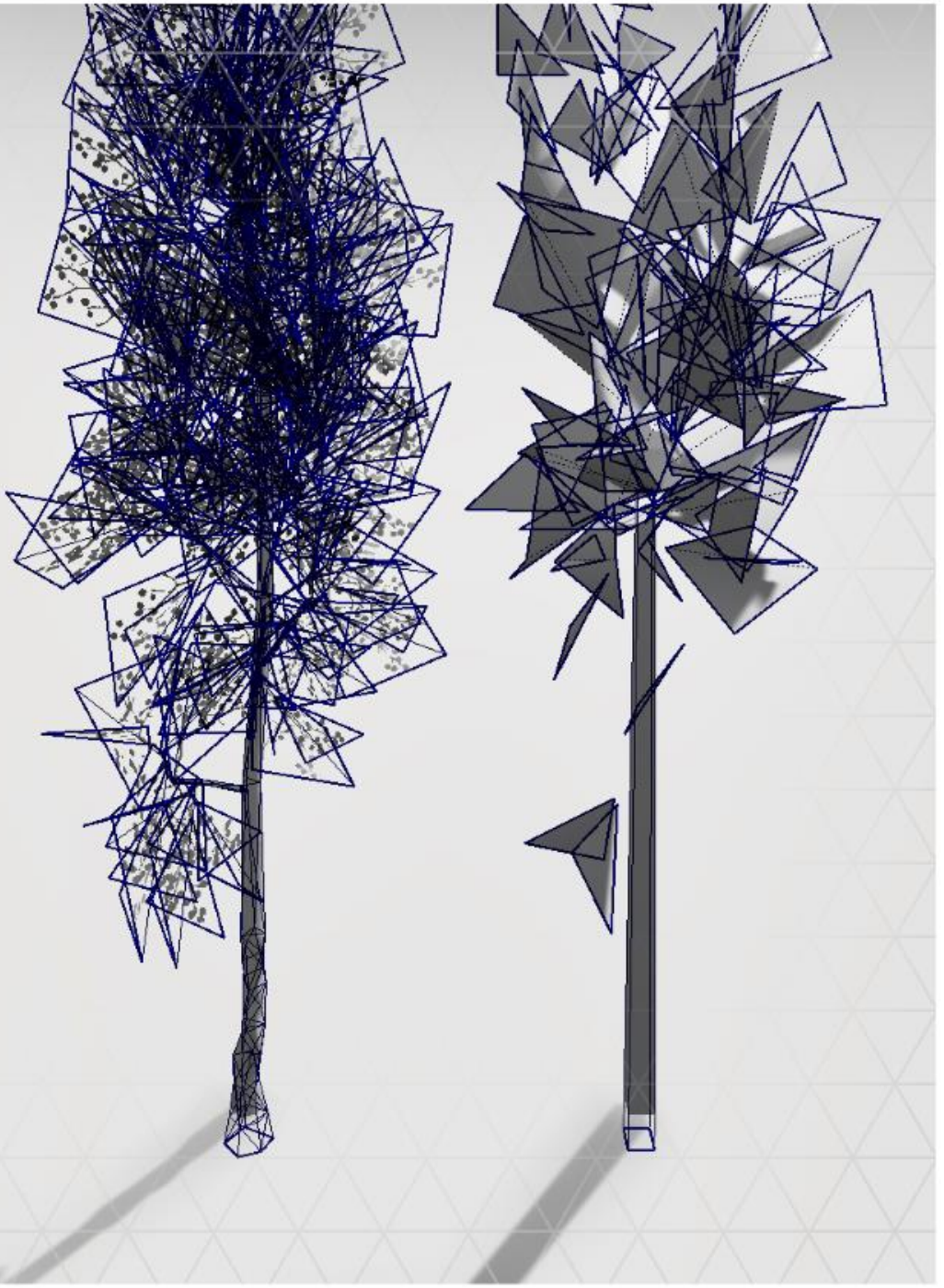


Smooth Alpha Blended Crossfade between Cascades!

Shadow Casting Vegetation

- Separate Visual Meshes and Shadow Casting Meshes
- Specific Meshes, Textures and Shaders for Cascade 0 and 1
  - S1:
    - LOD3 Visual Mesh
    - Alpha Tested, Animated
    - Depth Only Shader
  - S2:
    - Even less triangles
    - Non-Alpha Tested, Non-Animated
    - Depth Only Shader

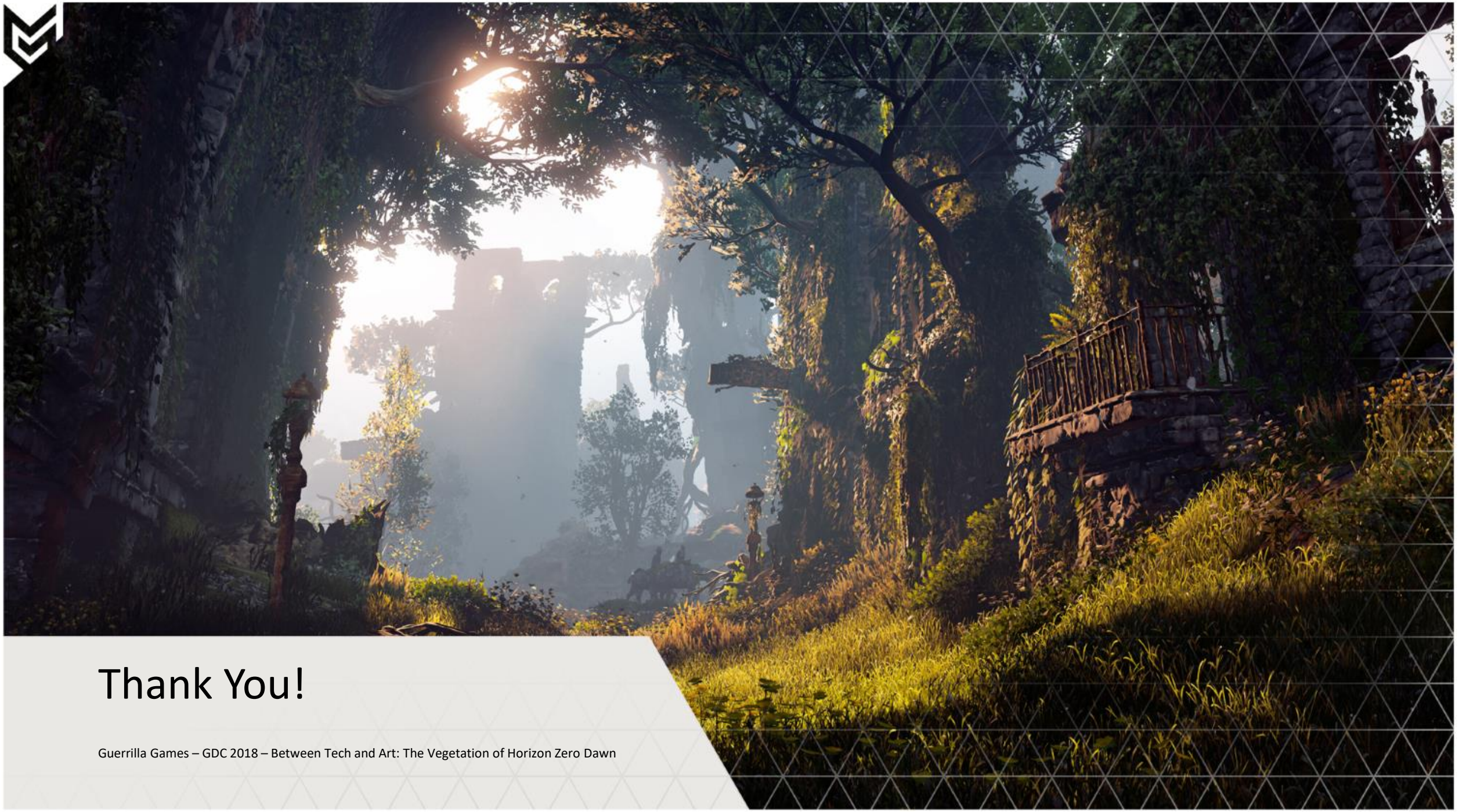


Summary

Summary

What worked for us?

- Depth Prime
- Custom Mip Chain
- LOD up, not down
- Shadow Casters separate
- Placement System
- All In-house



Thank You!

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