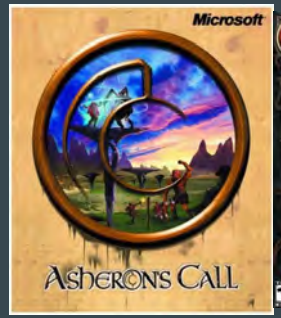
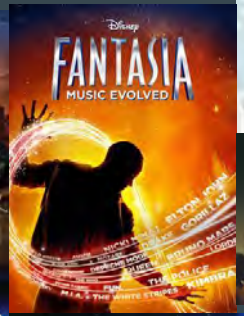
Behind the Assets

...

A technical deep dive into my assets, MicroSplat, MegaSplat, and One Batch





Jason Booth
3d Artist, Creative Director, Coder, Musician

Currently doing freelance contract coding, graphics and optimization

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- CPU or GPU, it's mostly about memory, not algorithms
  - On CPU, muladd < 1 cycle. Cache miss, 700+ cycles
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    - Especially when next stage is blocked
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    - Especially when next stage is blocked
      - Vertex -> fragment
      - Dependent texture reads
- New tech often driven by new optimization strategies

20 Assets in the Unity asset store

- MegaSplat
  - 256 texture splat mapping for Terrains and Meshes
- MicroSplat
  - Modular terrain shading system, broken into modules which can be individually purchased
- One Batch
  - Texture Array based atlasing for standard shader assets
- Stochastic Height Blending Node
  - For Unity's Shader Graph
  - For Amplify's Shader Graph

20 Assets in the Unity asset store

Common Tech themes

- Shader Generation Systems
  - Shader_feature too limiting (about 15 max features, want hundreds)
  - Rewrite shader code on demand based on features needed
    - No long build times due to shader variants!
  - MicroSplat add's interface based "modules" so that feature code can ship in different assets

20 Assets in the Unity asset store

Common Tech themes

- Shader Generation Systems
- Texture Arrays
  - Act as a single GPU resource
  - Users put in textures they have
    - Generate missing maps (normal, height, etc) from the data they give me
    - Pack into custom formats for speed or quality

20 Assets in the Unity asset store

Common Tech themes

- Shader Generation Systems
- Texture Arrays
- More performant than competition
  - With same feature spec, MicroSplat outperforms CTS by 2x-5x margin or more
  - One Batch allows hundreds of materials to be combined, retaining their unique settings

20 Assets in the Unity asset store

Common Tech themes

- Shader Generation Systems
- Texture Arrays
- More performant than competition
- Groundbreaking Features
  - Dynamically generated water and lava flows across terrains (MicroSplat)
  - Simple, one click terrain blending (MicroSplat)
  - 256 textures on one terrain or mesh with no performance penalty (MegaSplat)
  - Combining of hundreds of prefabs into a single material, supporting tiling and full texture resolution (One Batch)

MegaSplat

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  - All-in mindset
    - Not designed for average Unity hobby user
    - Replaces entire terrain workflow with it's own

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  - All-in mindset
    - Not designed for average Unity hobby user
    - Replaces entire terrain workflow with it's own
  - Doing minimal updates, but still sells well
    - $300-$800 a month
    - Unity featured heavily in the beginning

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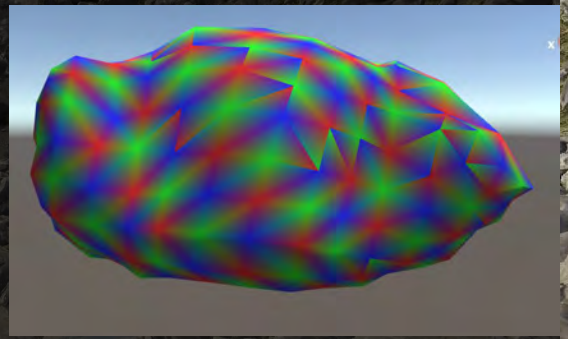
Problem: Interpolation of vertex data

MegaSplat : Solution

- Use Barycentric coordinates to reconstruct data
  - Mark each triangle with one red, one blue, and one green vertex
  - Preprocess mesh, or in Geometry Shader



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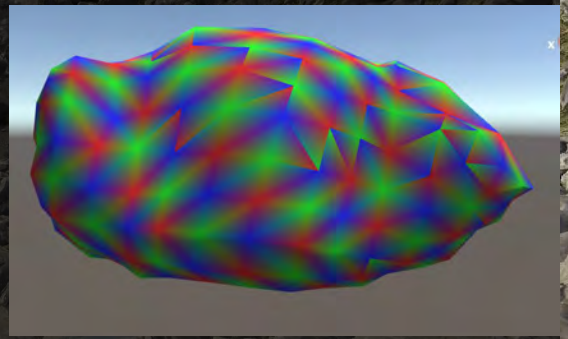
Encode (in vertex shader):

o.values.xyz = i.color.rgb * index;



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Decode (in fragment shader):

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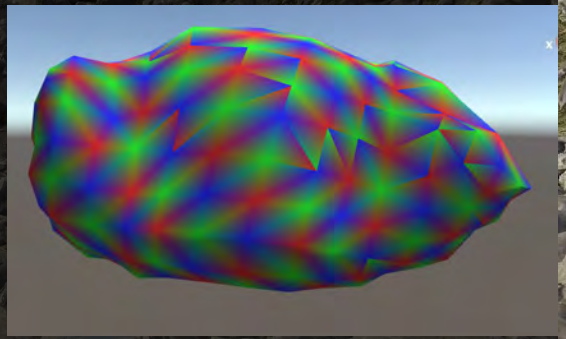
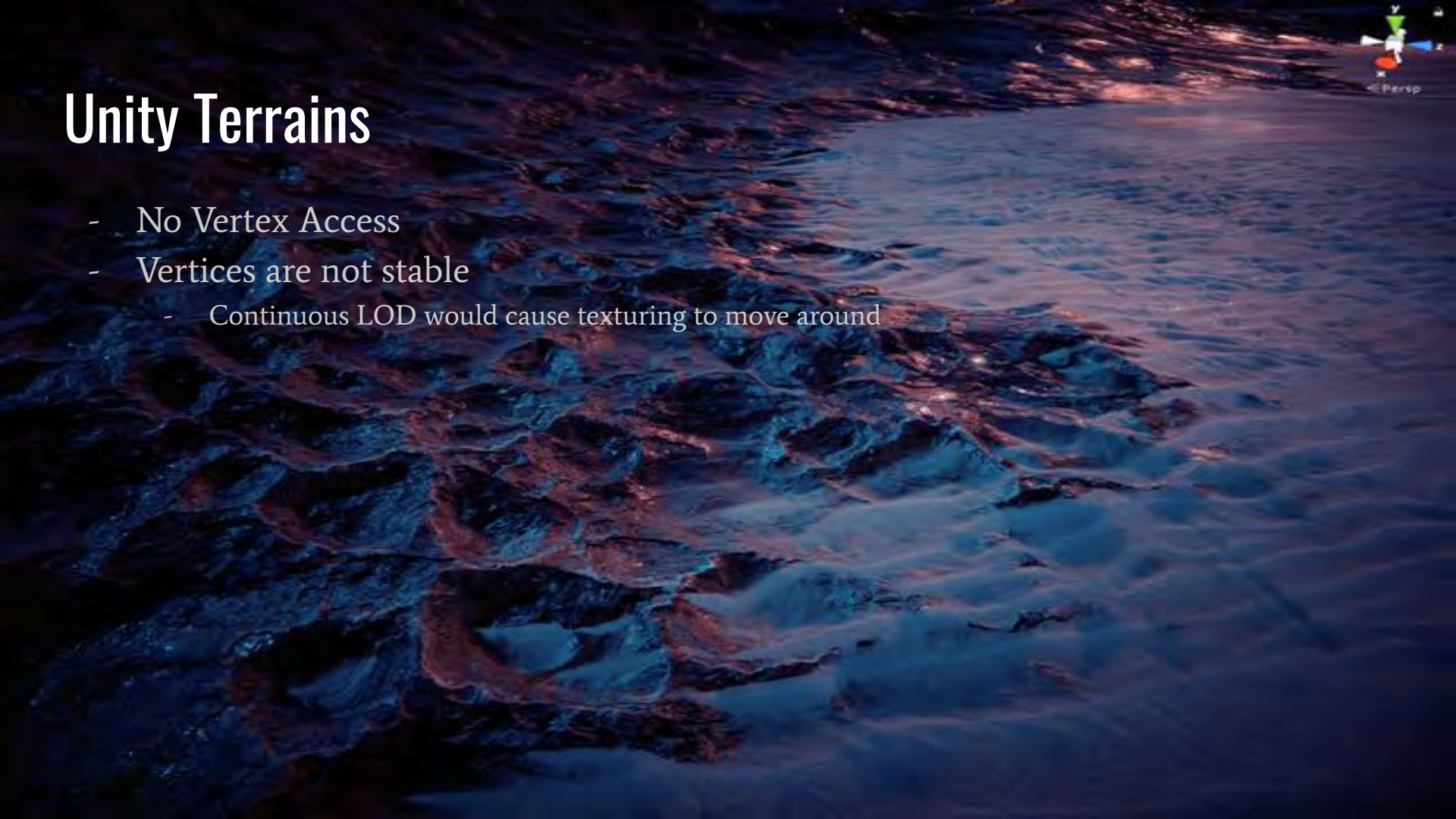
int i0 = round(o.values.x / max(o.color.x, 0.00001));
int i1 = round(o.values.y / max(o.color.y, 0.00001));
int i2 = round(o.values.z / max(o.color.z, 0.00001));
```



Unity Terrains

- No Vertex Access
- Vertices are not stable
  - Continuous LOD would cause texturing to move around



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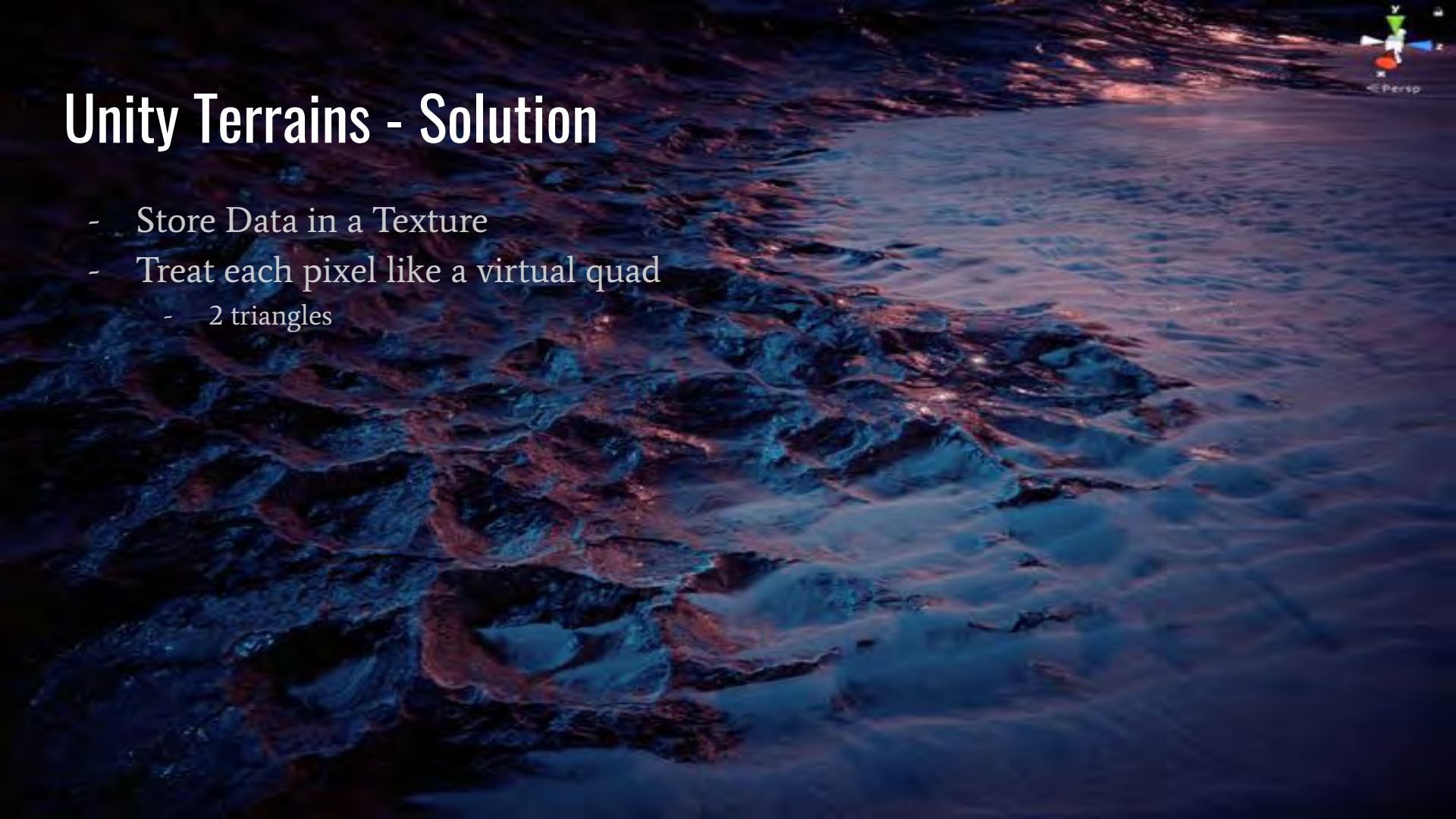
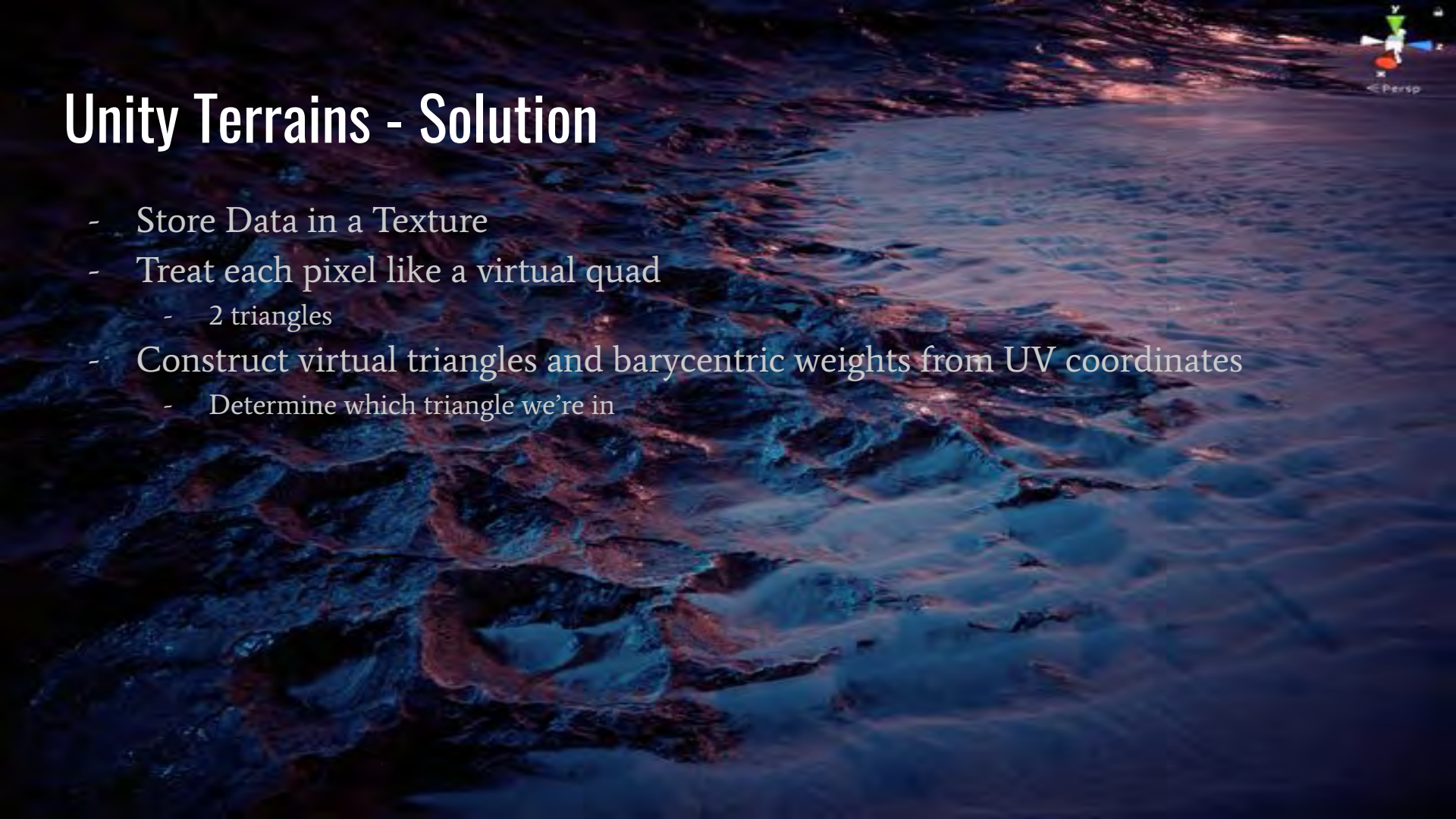


Unity Terrains - Solution

- Store Data in a Texture
- Treat each pixel like a virtual quad
  - 2 triangles
- Construct virtual triangles and barycentric weights from UV coordinates
  - Determine which triangle we're in



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- Treat each pixel like a virtual quad
  - 2 triangles
- Construct virtual triangles and barycentric weights from UV coordinates
  - Determine which triangle we're in
- Sample 3 indexes, textures, blend

Practical limitations

- One texture at each vertex
  - Must be 100% weighted at that vertex
  - This means blending area == triangle area
    - Doesn't always look great
    - Lower res control maps look better, but less control
- Blending is barycentric
  - 3 point blend can create zig zag effect
  - Soft blends often desirable

Practical Solutions

- Multiple ‘layers’
  - Encode second texture index in UV channel
  - Encode blend weight
  - Soft, controllable blends, but only between layers
  - Understanding layers can be confusing
- Tooling
  - ‘AutoBrush’ paints on lowest weighted layer
    - Makes best choice for you

Texture Clustering

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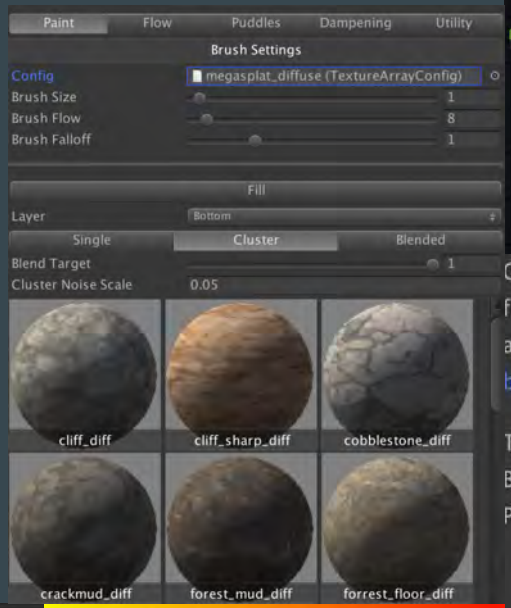
- Texture Clustering "first level concept" in MegaSplat

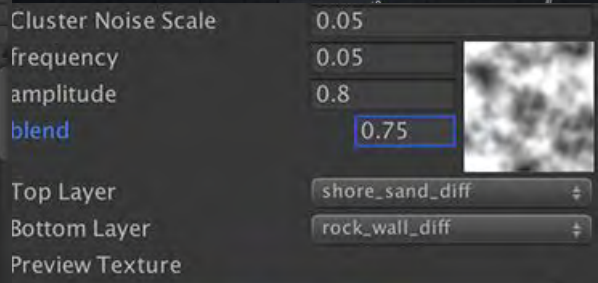
Woe of blending

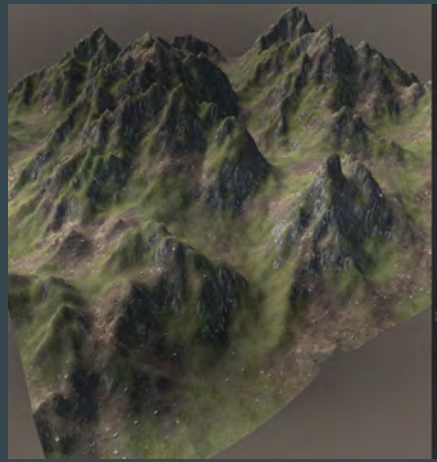
- Lots of research into how to make terrains look good with this technique
  - Texture Clustering as an expectation
    - Use substance/Mixer to produce variations on a theme
    - Mix several complementary surfaces with procedurals to create a meta-surface
  - Multi-Layers
    - Second index and blend weight
  - Auto Brush
    - Automatically selects the layer with the least weight to paint on
  - Texture Graph
    - Procedural, graph based texture tool
  - Terrain conversion tools
    - Map original texture -> cluster
  - Ideal ratio of vertex density to texture blends

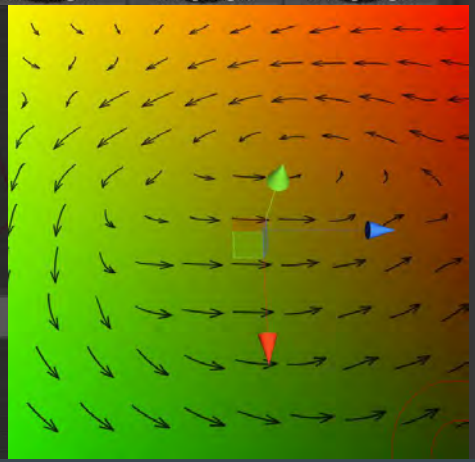
Highly customized tools

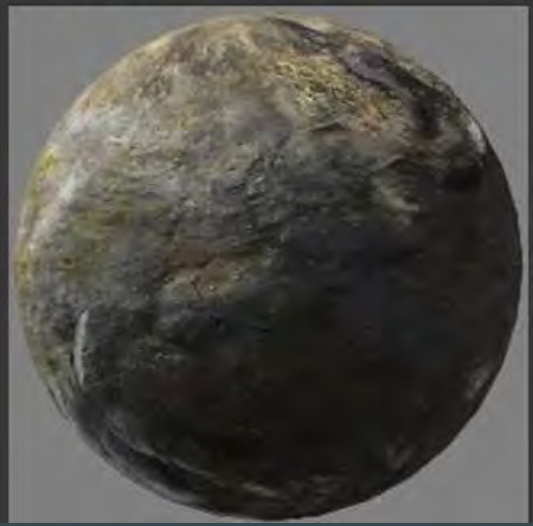
Graph based, painting, converting, previewing, etc..











MegaSplat

- MegaPackage
  - Hard for someone to evaluate what it does/doesn't do
  - Lots to maintain
    - Mesh vs. Terrain, Tessellated vs. Non tessellated, Vertex/Fragment shader
    - Lots of tools
    - Compatibility with other tools
  - What is actually being used?
  - One sale and done

MicroSplat

...


*Assets not included
FALCON AGE

MicroSplat - Goals

- CTS: Can you tell us why our shader is slow?
  - Yes!
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- CTS: Can you tell us why our shader is slow?
  - Yes!
  - How would I do this?
- Wanted something more:
  - Standard
  - Maintainable
  - Modular, expandable
  - Limited scope (terrain only, originally)
  - Easier to use for average user
  - Higher total price point and easy to evaluate

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    - 1200 downloads of free version each month
- Focused on ease of use
  - Simple to begin, gets more complex as you add modules

MicroSplat Modules

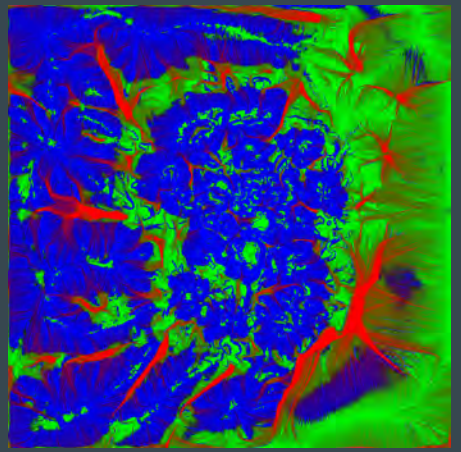
- Advanced Details (3rd party)
- AntiTile
- Global Texturing
- Lightweight Render Pipeline
- HDRP
- Mesh Terrains
- Mesh Workflow
- Runtime Procedural Texturing
- Snow

- Streams, Lava, Wetness, Puddles
- Terrain Blending
- Terrain Holes
- Tessellation & Parallax
- Texture Clusters
- Triplanar
- Wind and Glitter


MICROSPLAT
TERRAIN BLENDING

Unity Terrain

- Uses an RGBA control mask for every 4 textures on the terrain. Each channel represents a weight for that texture. This is normalized across all weights.



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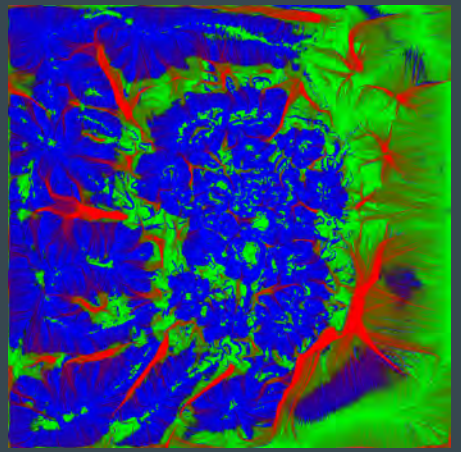

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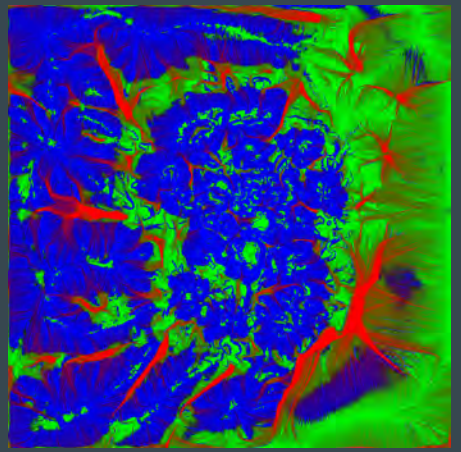

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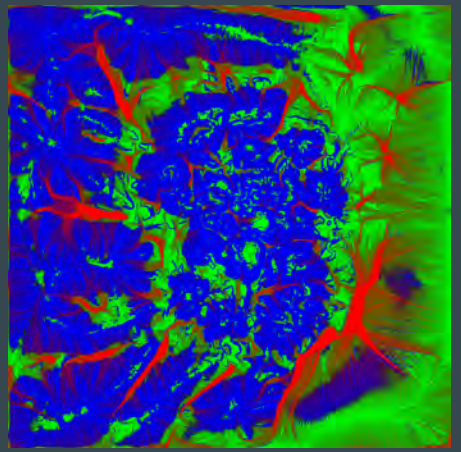

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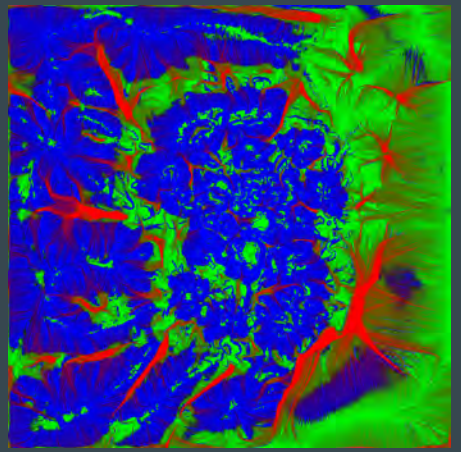

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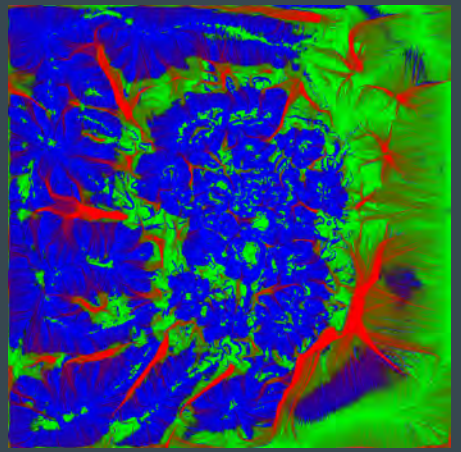
  Draw the terrain 4 times
- Simple, but inefficient and looks bad
  - Normals don't even blend right after 8 textures..

CTS - why so slow?

- Natural extension of Unity system (though single pass)
  - Textures packed into 3 arrays (diffuse+height, normal, smoothness/AO)
  - 16 textures = 48 samples + 4 control maps



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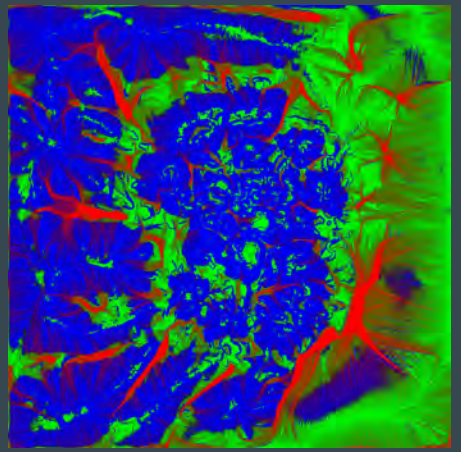

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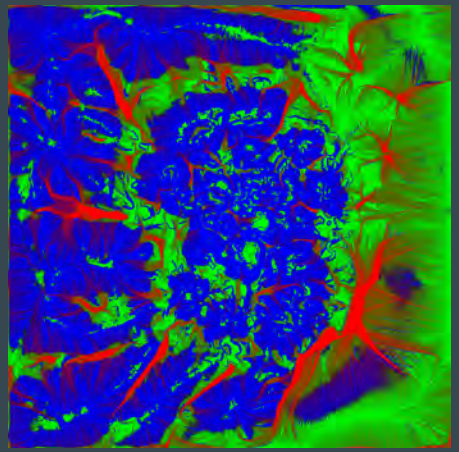
- Distance Resampling
  - 2x sample count, so 48*3*2 + 4 control (292 samples)



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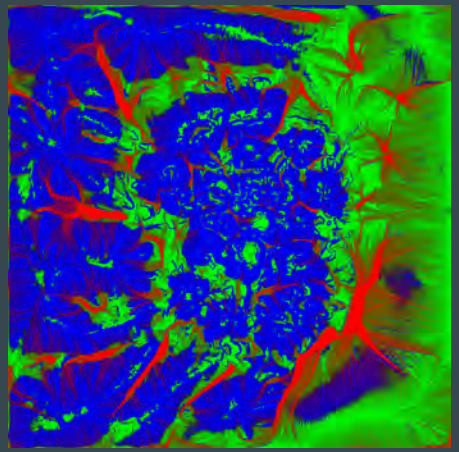

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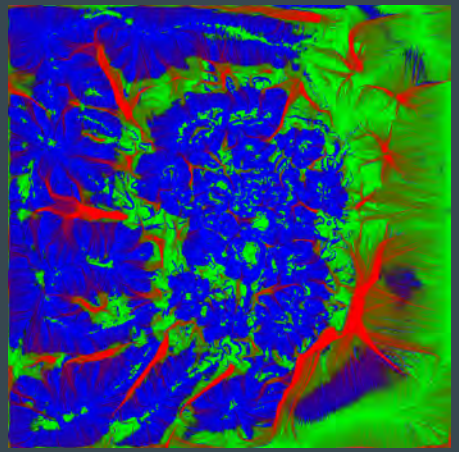
- Extraneous math
  - Each normal decoded and unpacked at sample time.
  - Shader graphs hide complexity and potential optimizations



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- Branches around texture samples break 2x2 block concurrency! 4x slower!
- Idea:
  - Sample control maps
  - Sort weights/indexes
  - Only sample fixed number of textures
    - This can be adjusted by the user for performance/quality tradeoff
    - Can use same trick in techniques that don't need as much fidelity (distance resampling)

MicroSplat - consistent sample counts FTW

- Default packing of textures in 2 arrays (can do 3 if you want)
  - Albedo + Height
  - Smoothness, Normal G, AO, Normal R
    - Normal in G/A gives best quality for compression
    - Compressors favor green, because the eye is more sensitive to green than other colors
    - Alpha channel is compressed separately from RGB

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    - Compressors favor green, because the eye is more sensitive to green than other colors
    - Alpha channel is compressed separately from RGB
- Only sample 4 most prominent texture sets
  - For 16 textures, 4 control maps, 4 albedo, 4 normal samples = 12 samples
  - Triplanar : 28 samples
  - Distance Resampling
    - Only perform on top 2 textures
    - Fast: Only do albedo, 2 additional samples (6 if triplanar)
    - Full: Albedo and Normal, 4 additional samples (12 if triplanar)

Compare

CTS, 16 texture terrain:

- Base: 48 samples + 4 control maps

MicroSplat, 32 texture terrain

- Base: 8 samples + 8 control maps

Compare

CTS, 16 texture terrain:

- Base: 48 samples + 4 control maps
- Triplanar 144 samples + 4 control maps

MicroSplat, 32 texture terrain

- Base: 8 samples + 8 control maps
- Triplanar: 24 samples + 8 control maps

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- Distance Resample 288 samples + 4 control

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- Distance Resample 36 samples + 8 control

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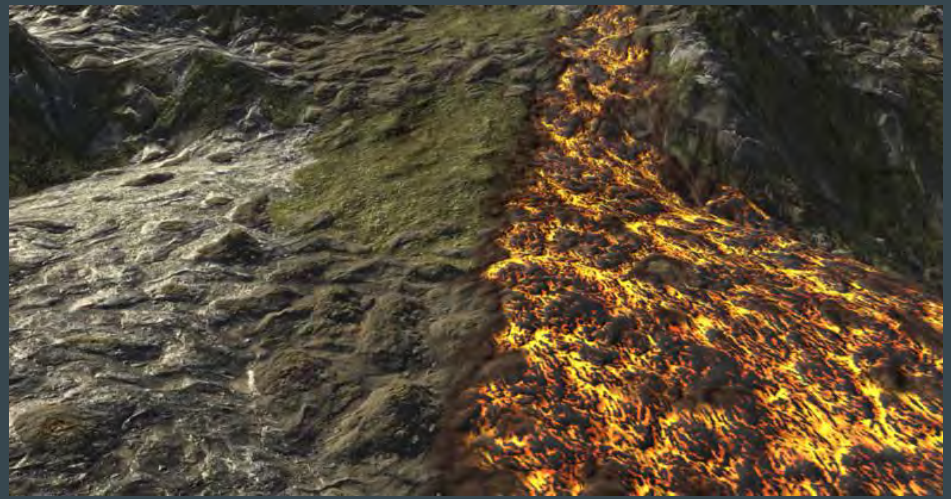
- Base: 8 samples + 8 control maps
- Triplanar: 24 samples + 8 control maps
- Distance Resample 36 samples + 8 control

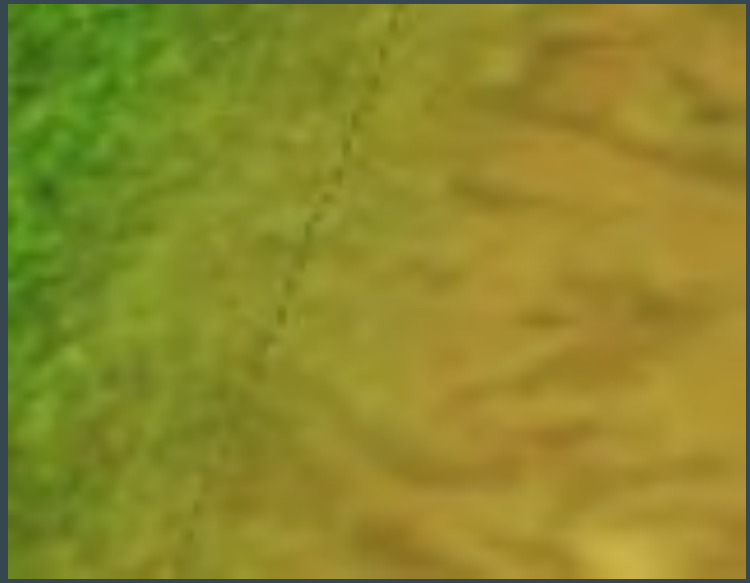
Which leaves tons of room for other features, like:

- Real time streams and Lava, flowing from emission controllers
- Automatic Terrain Blending with scene objects
- Wind and glitter effects
- Texture Clustering (96 textures on terrain)



No good deed goes unpunished

- A fantastic optimization
  - But errors when per texture UV scale is used
  - GPU's don't like it
  - Small seams between blending areas discovered
- WTF?
  - Took a while to figure out what was happening..
  - Texture Derivative issue with the way GPU's sample textures

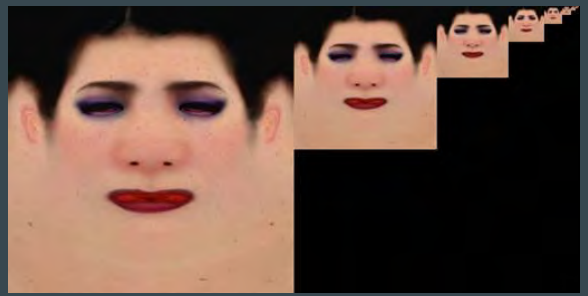


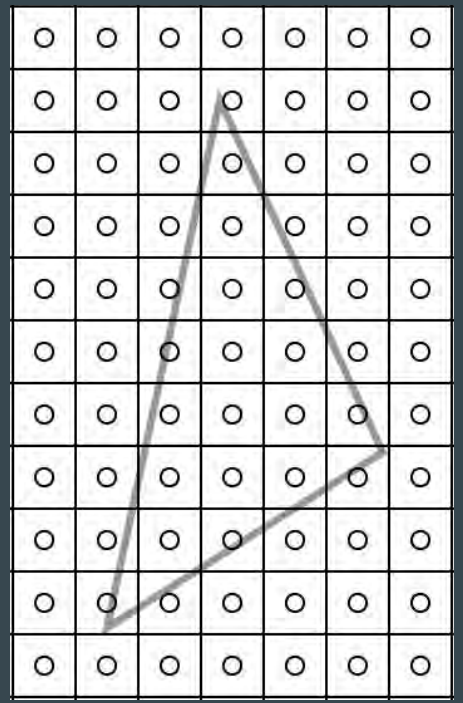
To understand, a deep dive into how GPUs work...

Texture Derivatives

As a triangle gets rasterized on screen:

- It needs to determine the mip-map's to sample from
  - "Based on distance from camera!" - NO
  - Based on texture size projected into screen space

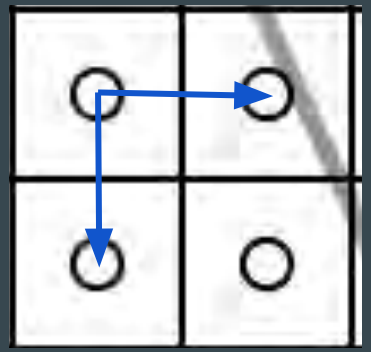


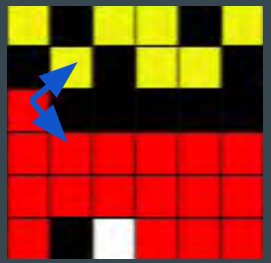


Texture Derivatives

As a triangle gets rasterized on screen:

- ddx(uv)
  - Vector pointing to next pixel in texel space on X axis
- ddy(uv)
  - Vector pointing to next pixel in texel space on Y axis
- Bilinear filtering
  - Look up 4 sample points, blend between them
- Trilinear
  - Look up 4 sample points at 2 different mip levels, blend between them

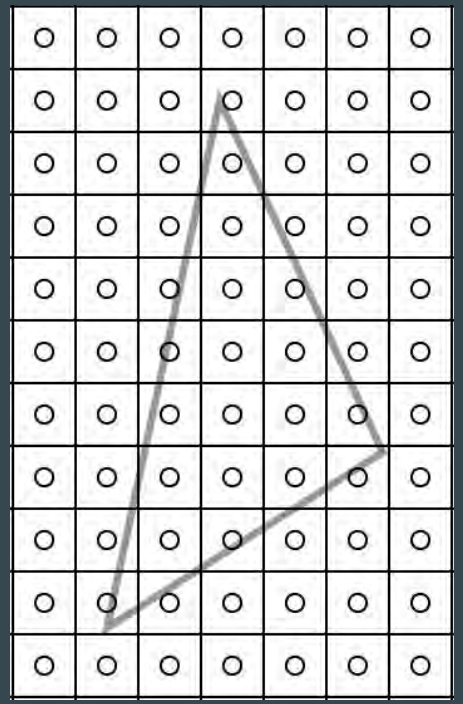




Texture Derivatives

GPU optimization

- When computing pixels, compute them in 2x2 blocks
  - You need to look up 4 pixels at once to compute bilinear blend
  - Fetching texture data can be shared between pixels!
    - Massive speedup in shading rate!
    - This is why Mip Maps are important : Cache Coherency



The Bug

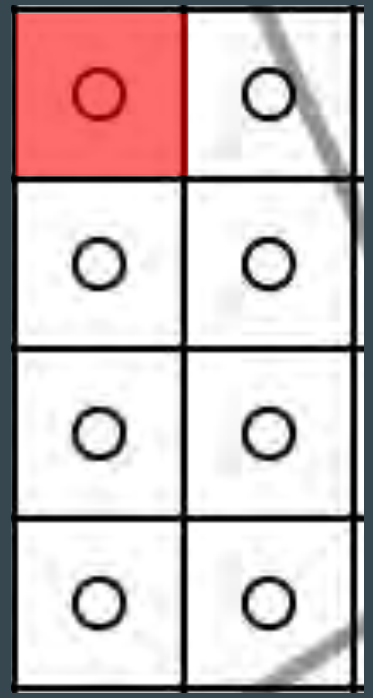
We sort textures based on weight:

0.49 weight, uv scale 1.5

0.43 weight, uv scale 0.8

0.07 weight, uv scale 1.1

0.01 weight, uv scale 0.8



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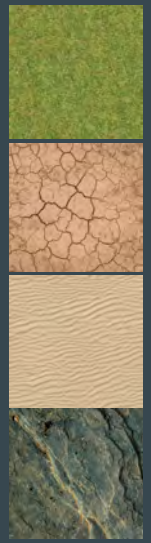

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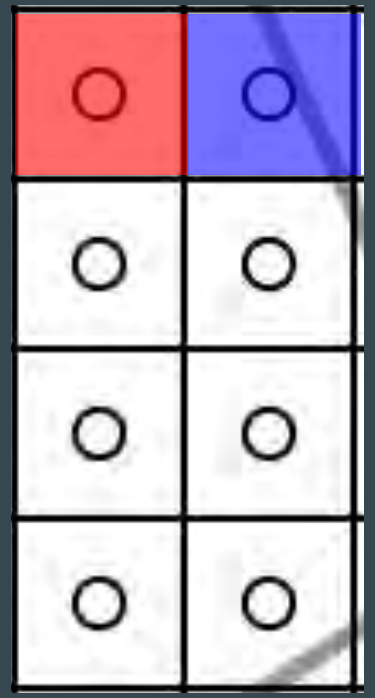

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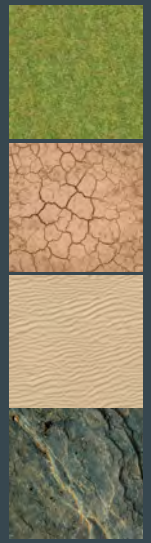

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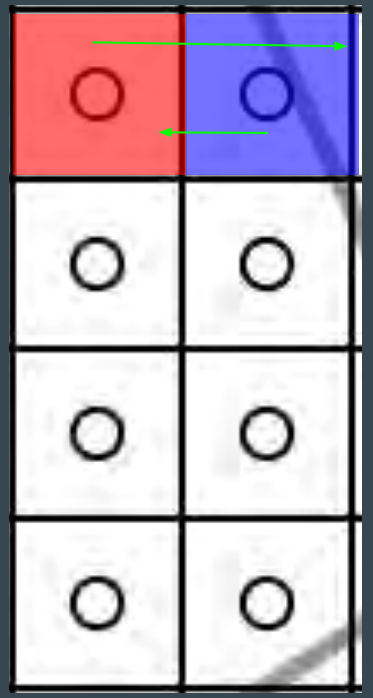

Pixels derivatives do not match! Mip mapping will be incorrect!

Options?

- Use LOD samplers, where you specify the LOD manually
  - Which LOD?
  - Breaks trilinear filtering and anisotropic filtering
  - Run's faster than using regular samplers!?

Options?

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  - How to compute? ddx(uv) will return different result for both pixels!

Options?

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  - Which LOD?
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  - Run's faster than using regular samplers!?
- Gradient Samplers
  - Gradient samplers let you supply your own derivatives rather than letting the GPU compute them
  - How to compute? ddx(uv) will return different result for both pixels!
- Break 2x2 optimization
  - Too slow!

Answer

- Get derivatives from unscaled UVs
- When UV scale is applied, also scale derivatives
- Average derivative per pixel based on layer weights

```
float4 dxdy = float4(ddx(uv), ddy(uv));
dxdy = dxdy * uvScale[0] * weights[0] +
       dxdy * uvScale[1] * weights[1] +
       dxdy * uvScale[2] * weights[2] +
       dxdy * uvScale[3] * weights[3];
```

- Closen mip level is interpolated across boundary, such that all 4 pixels get the same result.

And on it goes..

Triplanar Mapping:

- Compute UVs for each projection from world position
- Compute derivatives for each projection from world position
- Apply average scaling, etc.

```
float3 dxw = ddx(worldPos);
float3 dyw = ddy(worldPos);
float2 uvXdxdy = float4(dxw.zy, dyw.zy);
float2 uvYdxdy = float4(dxw.xz, dyw.xz);
float2 uvZdxdy = float4(dxw.xy, dyw.xy);
```

But one example

Other techniques:

- Keep normals packed (2 channel) through entire pipeline and decode at the end
- Sorting routine profiled and rewritten many times
  - Some that I expected would be fast were actually really slow! Always profile
  - Only sort when > 4 textures (low end optimization)
- Per texture property data stored in lookup texture (32x32, 16 bit)
  - No support for array's of properties anyway
  - Setting/lookup of property data slower than texture fetch!
- Every unused option compiled out
- Distance terrain uses a simpler shader

Modular Shaders

- FeatureDescriptor
  - GUI for turning features on/off
  - GUI for adjusting shader values
  - GUI for adjusting per-texture properties
  - Pack/Unpack serialization functions
  - Function to report shader cost
  - Write Properties, cbuffers, etc
  - Write functions

Modular Shaders

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  - GUI for adjusting per-texture properties
  - Pack/Unpack serialization functions
  - Function to report shader cost
  - Write Properties cbuffers, etc
  - Write functions
- Shader compiler
  - IRenderAdapter for adapting different wrappers around shaders
    - Used for Surface Shader vs. SRP shaders

Modular Shaders

- Keyword storage system
  - Uses scriptable object instead of material keywords
    - Unity has a limit of 256 per project
      - MicroSplat would use over 700
    - MicroSplat uses no actual Unity keywords

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- PropData object
  - Stores per-texture property data, which gets converted into a texture at runtime
    - Unity cannot correctly serialize RGBAHalf or RGBAFloat linear textures
- Core module has “master” shader code chunk
  - Calls all module functions with #if _SOMEFEATURE around calls
  - Core module must be in sync with external modules
    - Locking mechanism to skip modules which are not the current version

Modular Shaders

- Compiler
  - Writes header/properties
  - For each pass in IRenderLoopAdapter
    - Writes pass header
    - Writes properties
    - Writes #define keywords for enabled features
      - #define _SOMEFEATURE 1
    - Writes functions
    - Writes master shader

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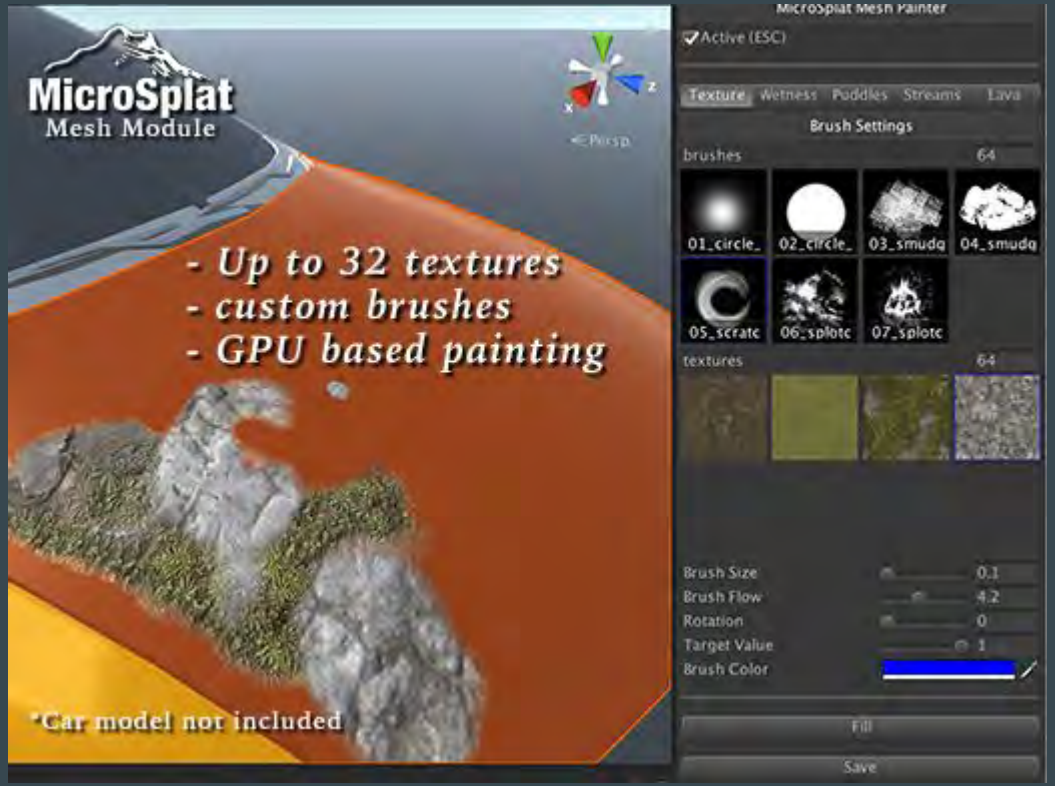
    - Writes #define keywords for enabled features
      - #define _SOMEFEATURE 1
    - Writes functions
    - Writes master shader
- Shaders are rewritten any time features are changed
  - Thus any unused feature is not in the actual code

Asset Store

- Regularly has 4-8 modules on the front page of terrain
- Free core module downloaded 1000 to 2000 times a month
  - Modules advertised in core module
  - Extra $50-$80 a month earned via affiliate program
- $1000-$3000 a month in sales (after unity's 30%)
  - Best month $6500
- Never featured by Unity
  - 95/98 written reviews are 5 star
  - On the 'most popular free assets' list every month
- Terrain Collection bundle released
  - More likely to be included in sales, which often have minimum pricing
  - Perfect 5 star rating (14 written reviews)
- Total price for all modules $224
  - But each one seems cheap for what you get

Coming soon

- Mesh workflows
  - Uses MicroSplat shader compiler back end, but with mesh painting
  - Can be blended with existing shaders
- Deformation module
  - Snow tracks
  - “Spin Tires” style games



Downsides

- Updating all modules with a version change is a pain
  - For me, and for users
- Not as “One Click” as could be
  - Having all features included means many can default to ON
  - Some people compare free version to $50 asset
- HDRP/LWRP/URP support is a nightmare
  - Unity constantly changing these pipelines
  - No abstraction layer
  - No automatic upgrading
  - No documentation

One Batch

One Batch

- Currently in Beta
- Idea came from MegaSplat users
  - House made of many separate pieces, thus multiple draw calls
  - Put all textures into texture arrays
  - Use painter to assign textures fully to each vertex
    - Door, wall, floor, etc..
  - Combine mesh
    - 1 material, 1 draw call
    - Can combine entire scene into one material
- Why not formalize into easier process?

One Batch

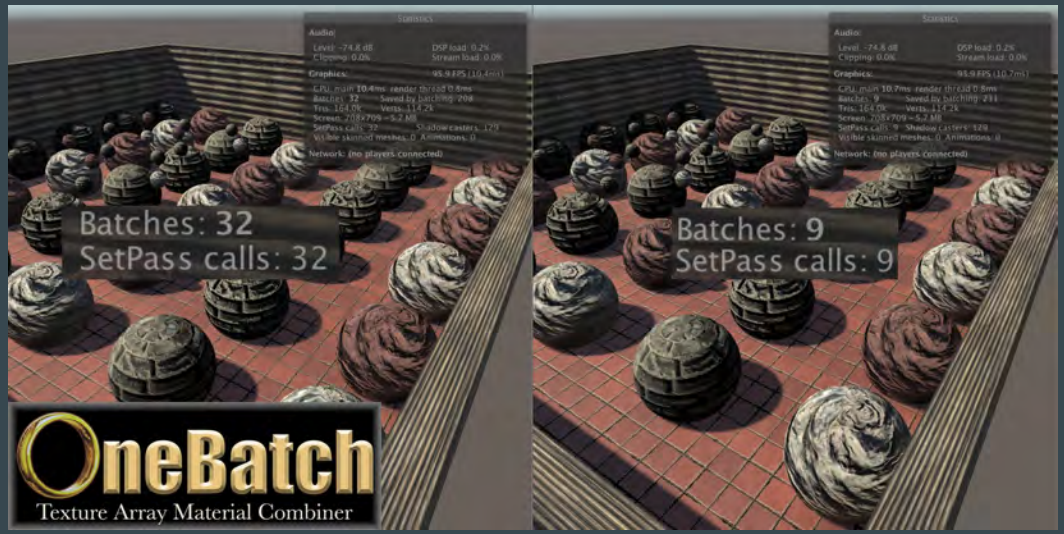
- From a list of prefabs:
  - Automatically extract all textures and material properties
  - Pack textures into arrays
  - Pack material properties into texture look up table
  - Store index for texture array and index for properties in mesh color channels
  - Combine all submeshes of an object
  - Assign single One Batch material and shader to everything
- Limitations
  - Currently tied to the standard shader only
    - No automatically convert user shaders to use texture arrays and a property LUT
  - Designed as a ‘late stage optimizations’
    - Take this kit bashed level and combine it
    - Can still edit material data after the fact, but easier to uncombine, edit, then recombine

Excellent results, in the right situation

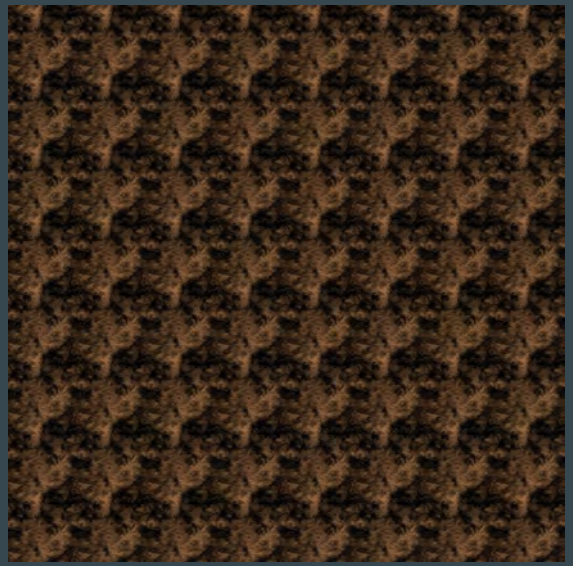
- Many things break static batching in Unity (lighting!)
- Already optimized (atlased) content has less to gain
- Does not suffer from atlasing restrictions
  - Can still tile textures
  - All textures don't need to be squeezed onto a single sheet

Niche product

- ~10 sales a month
- I have not done any marketing
- Very useful in contracting work
  - Draw calls a major issue for people asking me to optimize their games



A review of Anti-Tiling techniques



- Tiling textures a major issue in graphics
- Especially problematic on terrains
  - Best selling module for MicroSplat is the Anti-Tiling module
- Lots of attempts to cover it up over the years

Classic Technique: Distance Resampling

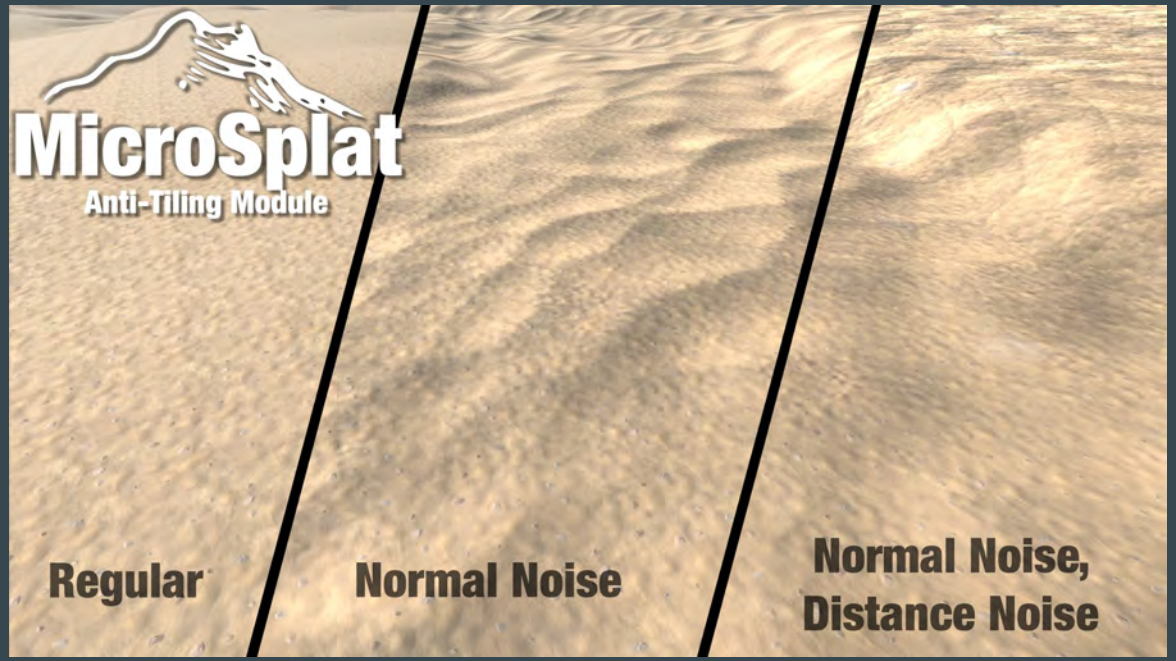
- AKA: UV mixing, etc..
- Basic idea:
  - Sample textures
  - Sample textures again at lower UV tiling rate
  - Blend result together based on distance from camera
- Looks ok, but
  - Blend is obvious
  - Doubles samples used
- Improvements (in MicroSplat)
  - Only sample diffuse layer
  - Height blend layers
  - Only sample top 2 weighted textures

Classic Technique: Macro/Micro texturing

- Basic idea:
  - Tile a small or large scale texture inside of the main one
  - First used in Unreal (the game)
  - Texture usually greyscale, and uses overlay or blend2x operator
- Fast and cheap
  - But doesn't fix tiling, rather creates large and small scale details to increase effective resolution
- Available in MicroSplat AntiTile

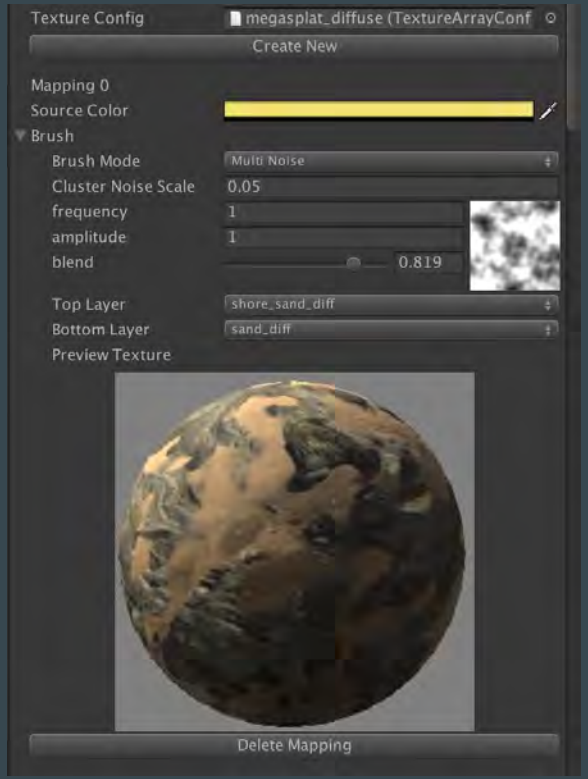
Classic Technique: Noise Normal

- Basic idea:
  - Blend a normal map in at a larger scale to create lighting variations across the surface
- Cheap, fast, works well
- Can have all of these per texture in MicroSplat



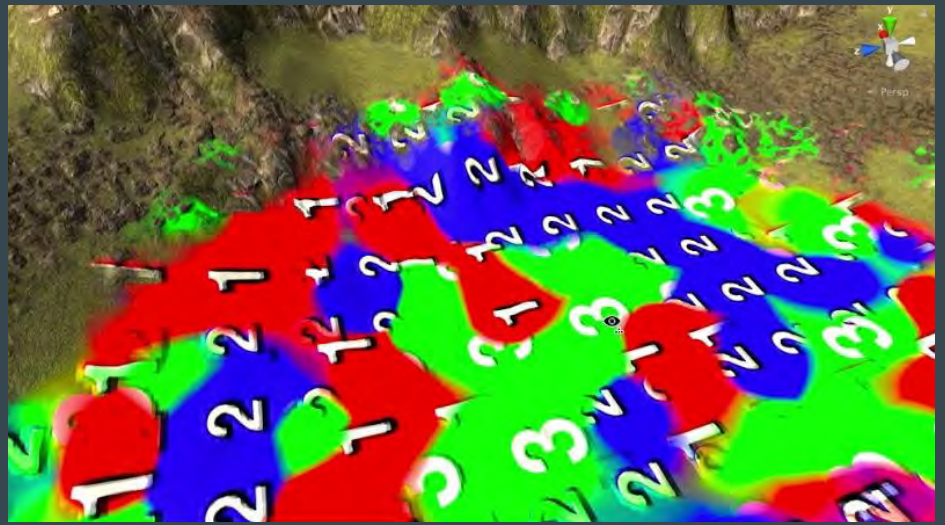
New Technique: Texture Clustering

- First introduced in MegaSplat
  - Intrinsic to how it blends textures
  - Answers my One Question : “What can you do with hundreds of textures?”
- Idea
  - Since MegaSplat has to sample three texture sets per face (one for each vertex), why not vary which texture gets sampled?
- First class system in MegaSplat
  - Cluster concept worked through all tools
  - Cluster can contain any number of textures, chosen by noise, slope, or height ranges

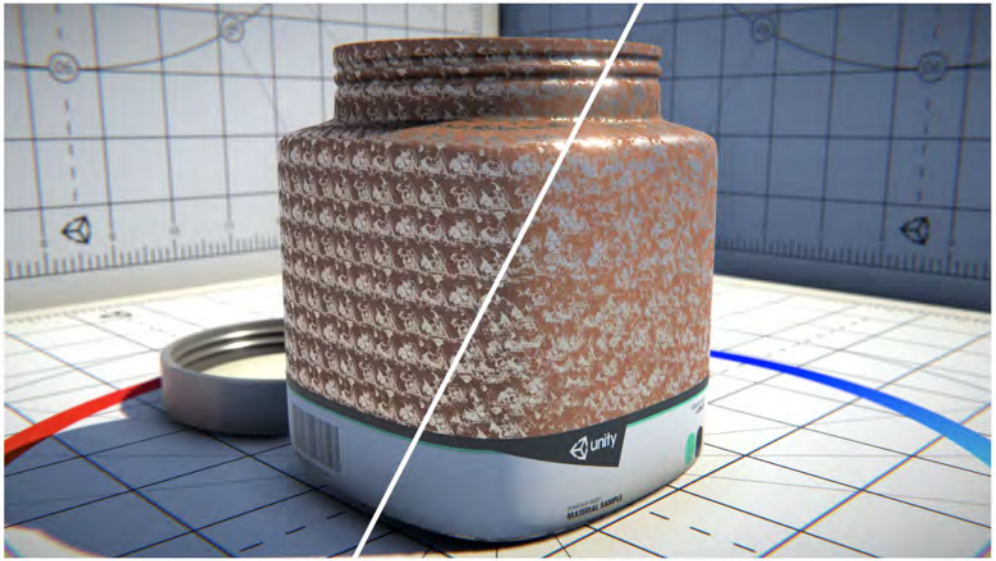


MicroSplat Texture Clustering

- Cannot use MegaSplat technique
  - Uses traditional splat weights
- Solution:
  - Sample a noise texture
  - Height blend between 3 textures
  - Store in parallel texture arrays
- 3x sample count, so expensive compared to MegaSplat
  - But easier to control
  - Not tied to vertex/control texture resolution
  - Not baked into paint job



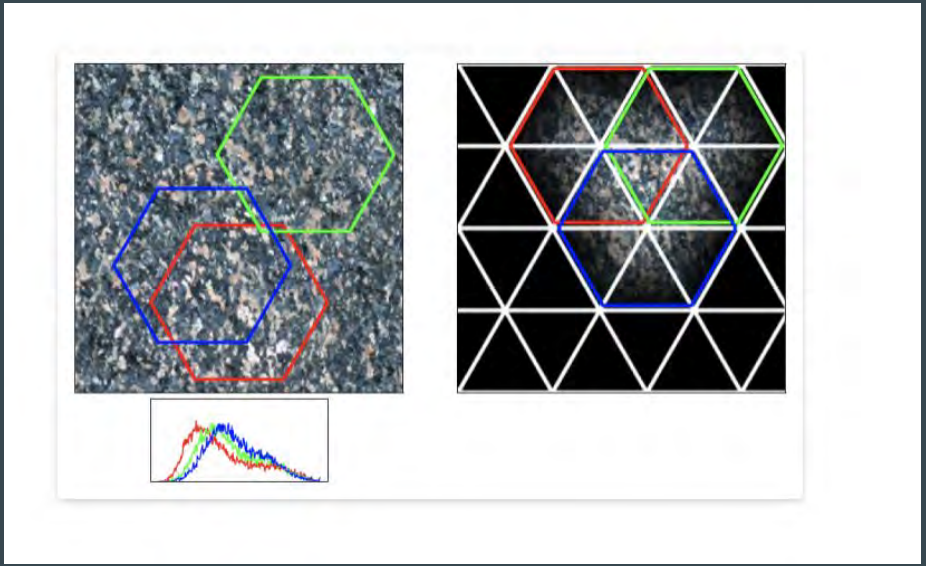
Stochastic Texture Sampling



Procedural Stochastic Texturing

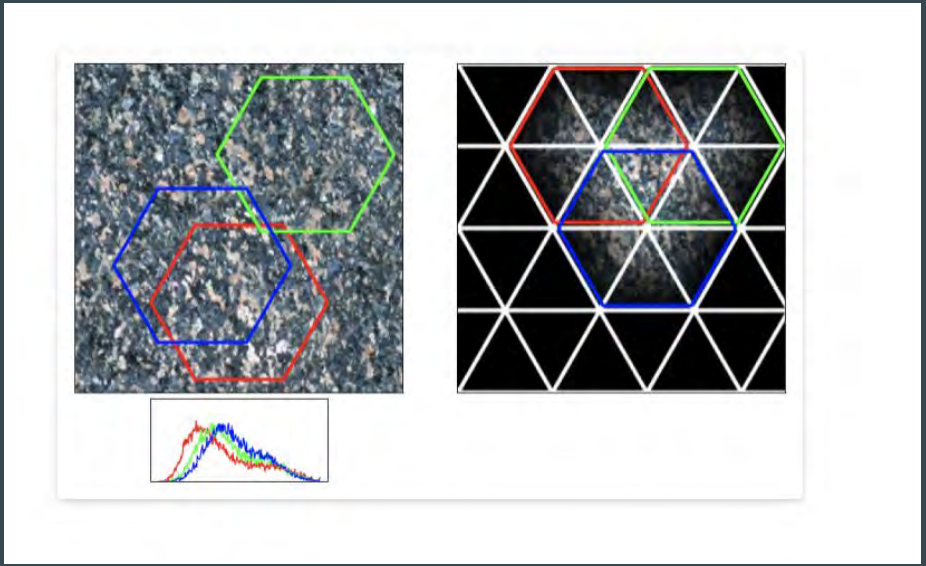
- Based on a paper by Eric Heintz
- Unity Labs released a version in February
- Anti-tiling technique

Basic Idea



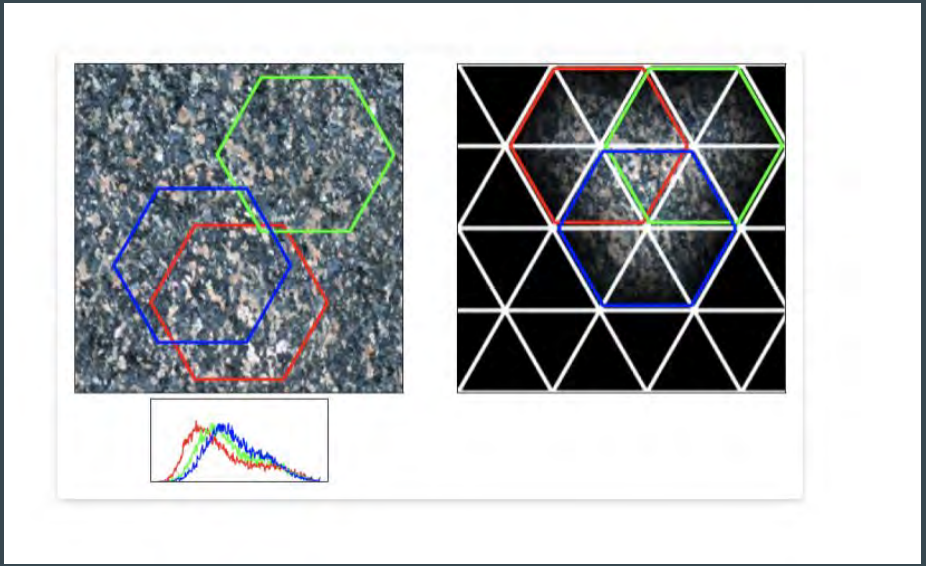
- Construct 3 virtual triangles, offset and randomized
- Sample textures 3 times
- Blend preserving histogram of original image

Massive Complexity for histogram preserving blend



- Must preprocess textures into custom format (SLOW)
- Must generate lookup tables and store in additional textures
- Need custom code based on texture format
  - Only uncompressed and DXT1 supported
- Lots of math, lots of code, dependent texture reads

Basic Idea



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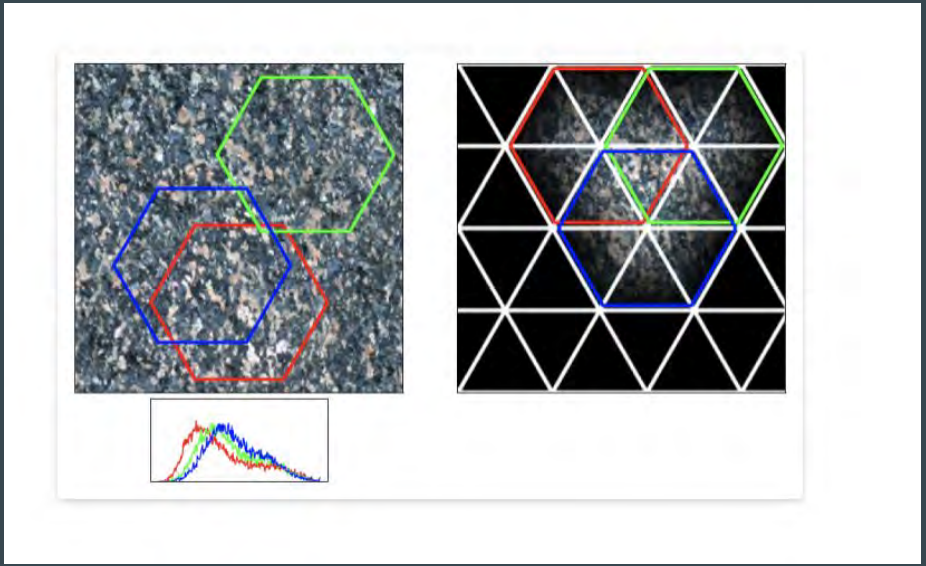
This sounds familiar

Basic Idea



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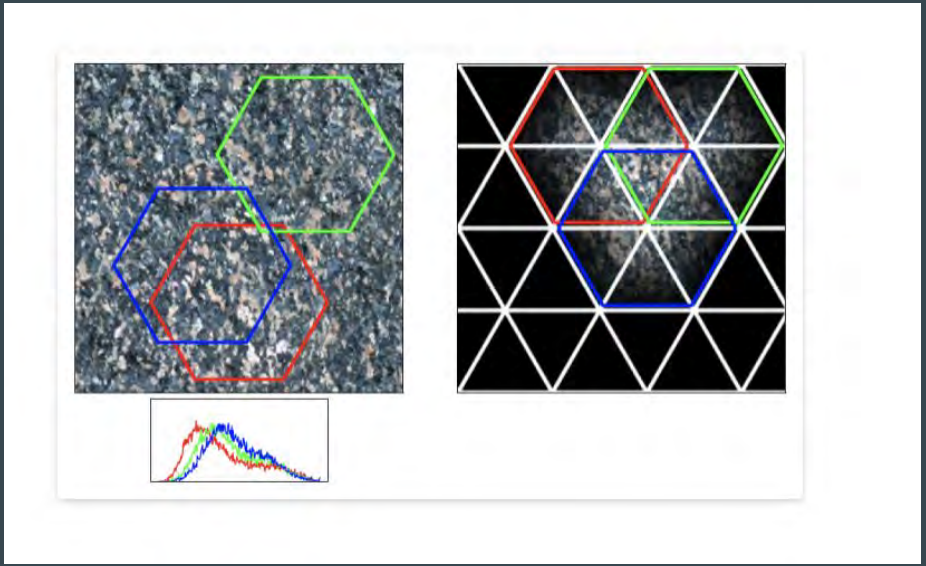

- Construct 3 virtual triangles, offset and randomized
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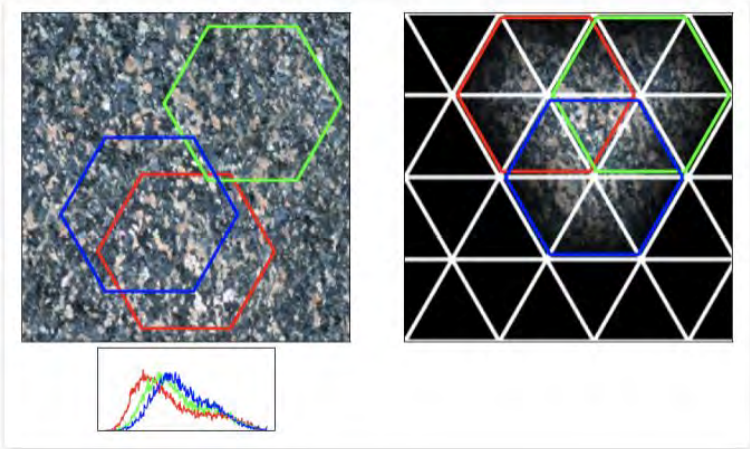
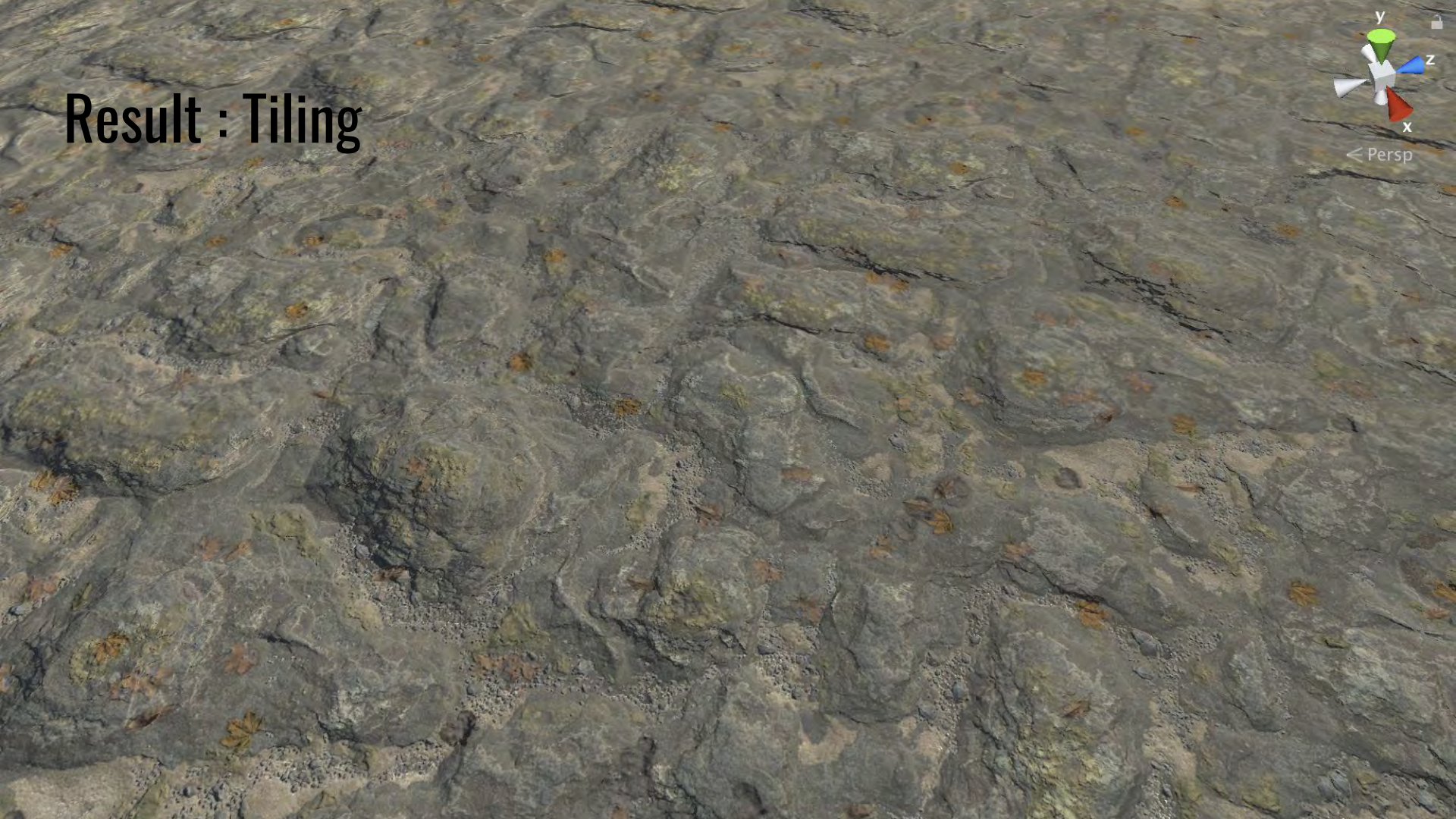
This sounds overly complex

Basic Idea

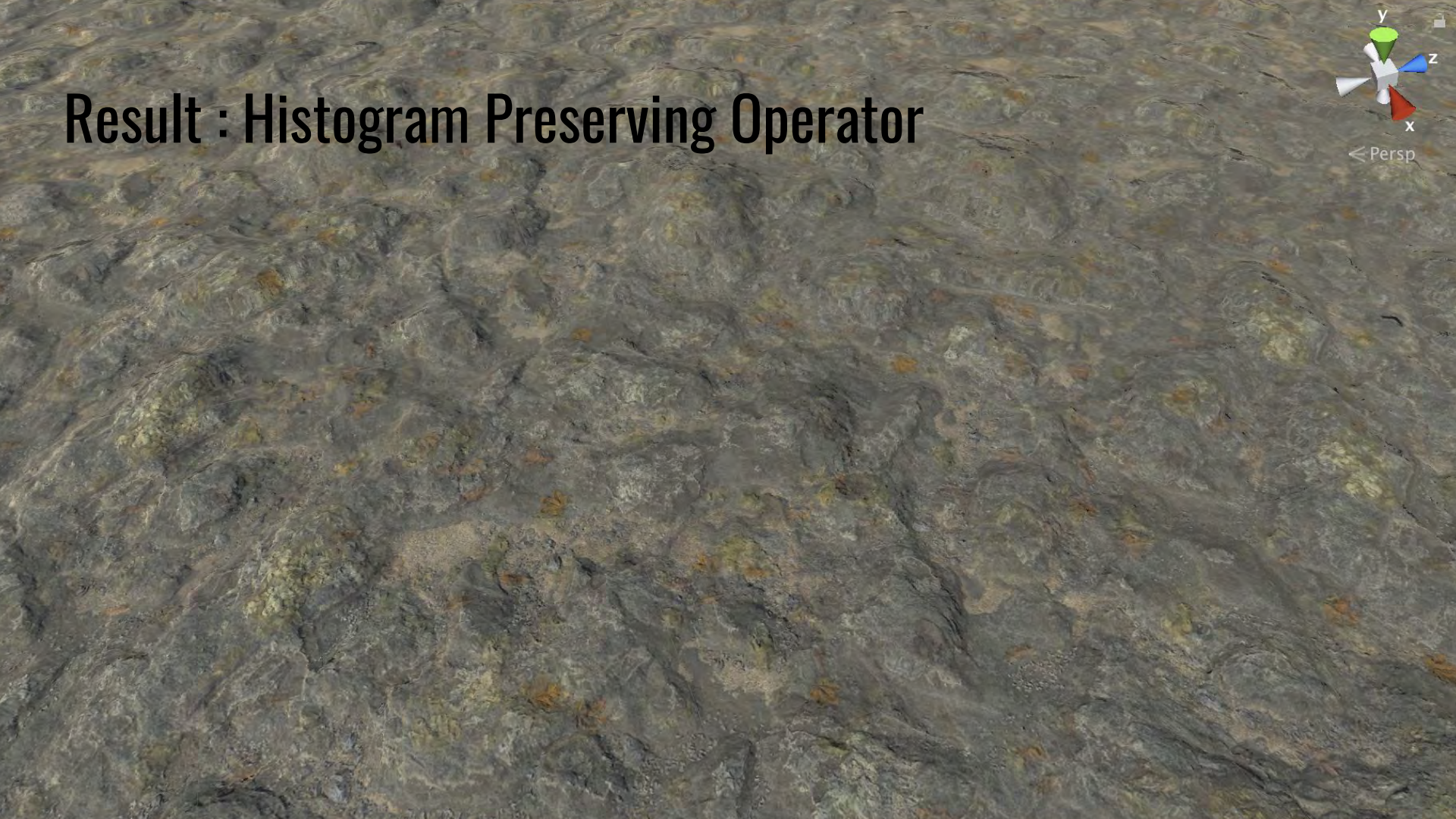


- Construct 3 virtual triangles, offset and randomized
- Sample textures 3 times
- ~~Blend preserving histogram of original image~~
- **Blend using height map operator**
  - Could use luminosity or other term if height map is not available

Result : Tiling



Result : Histogram Preserving Operator



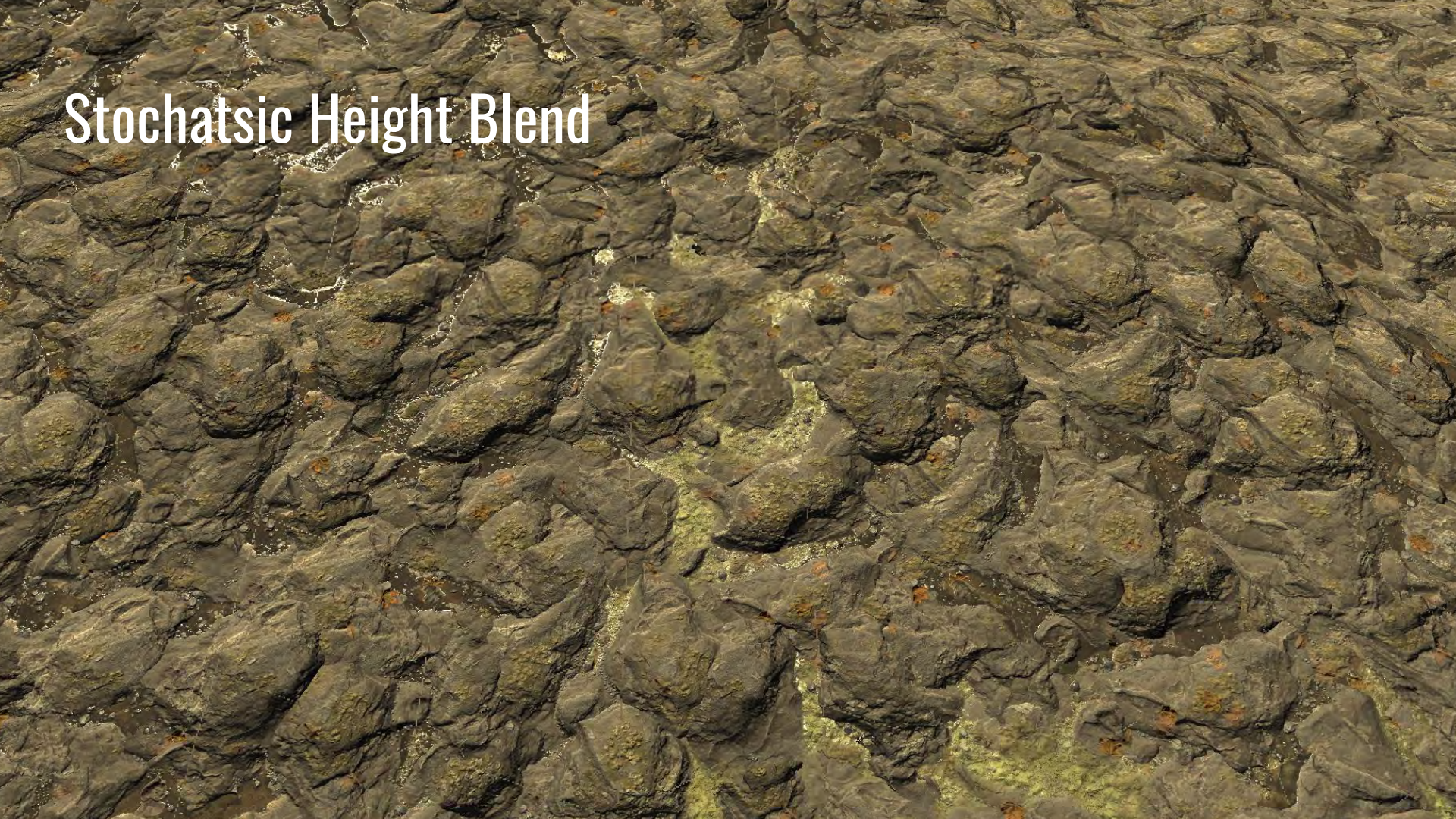
Result : Height Blend Operator

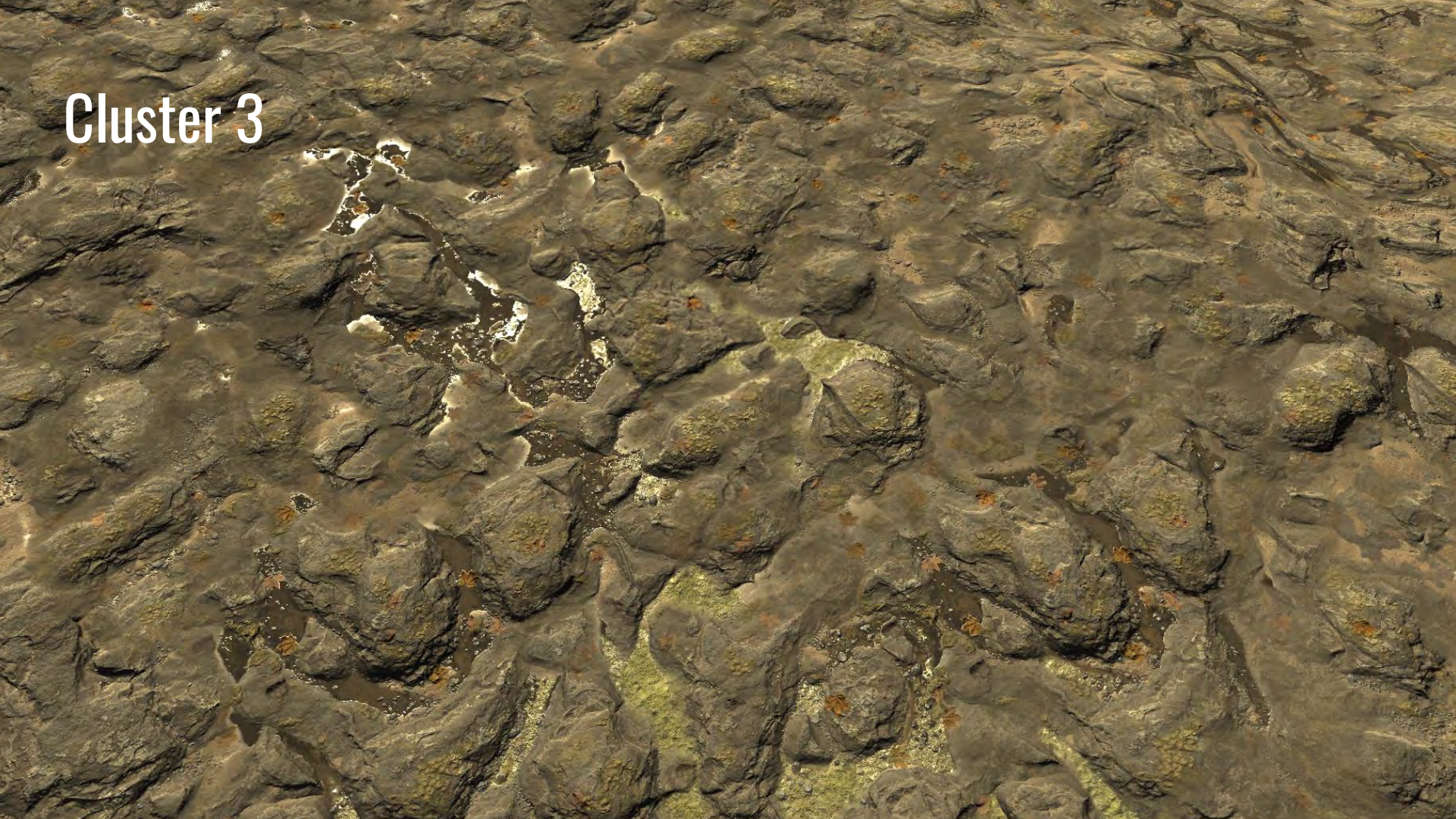
Advantages

- No preprocessing, no LUTs, works with any texture format, less code
- Retains look of original texture better
  - Height map operator has adjustable blend width
    - This means you see more of your texture un-modified
  - Histogram Preserving operator blends across entire virtual triangle
    - Everywhere is blending
    - Everything smearing towards sameness
- Added adjustable triangle scale parameter for user
  - Larger triangles show more of texture intact (but might exhibit tiling)
  - Smaller triangles synthesize more

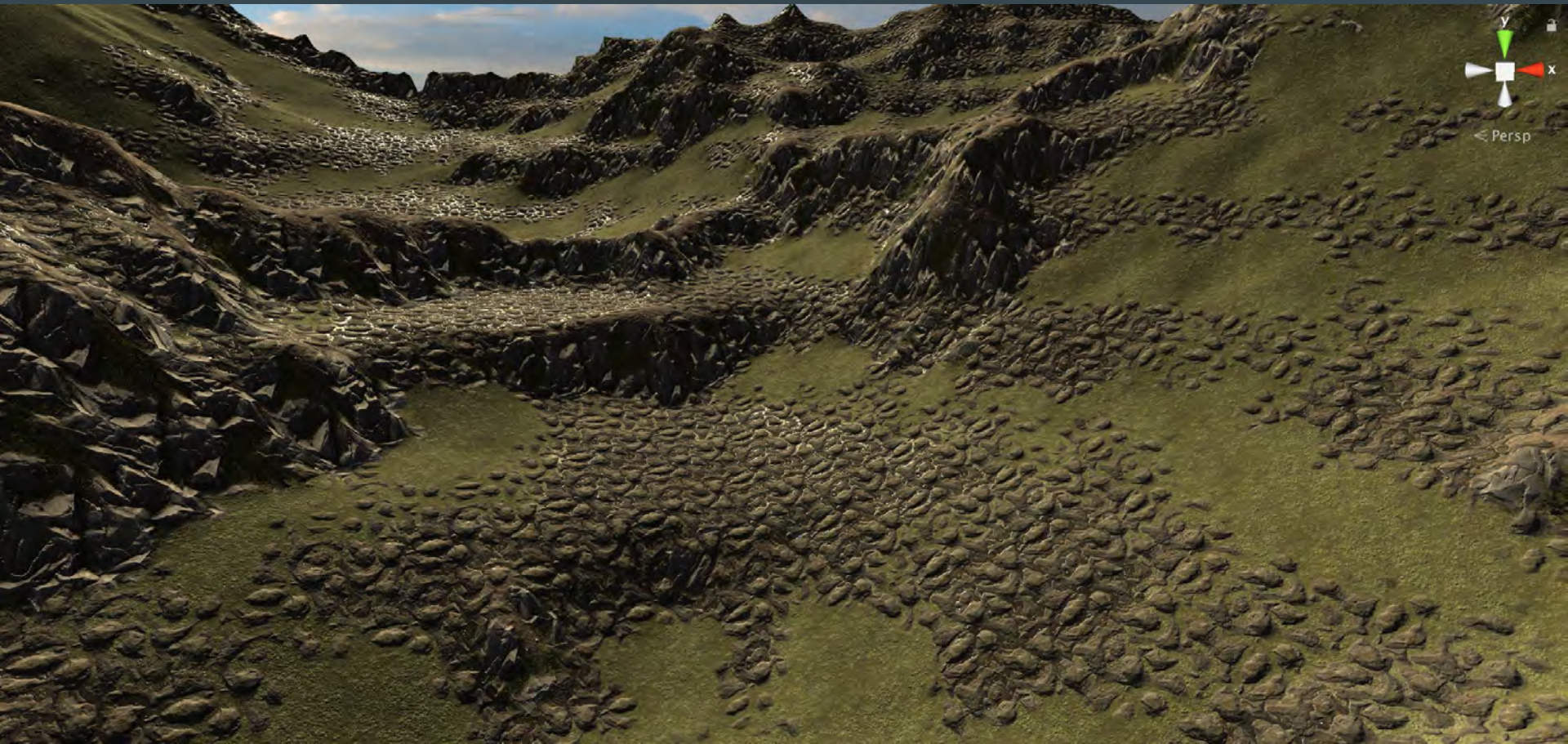
Tiling

Stochatsic Height Blend



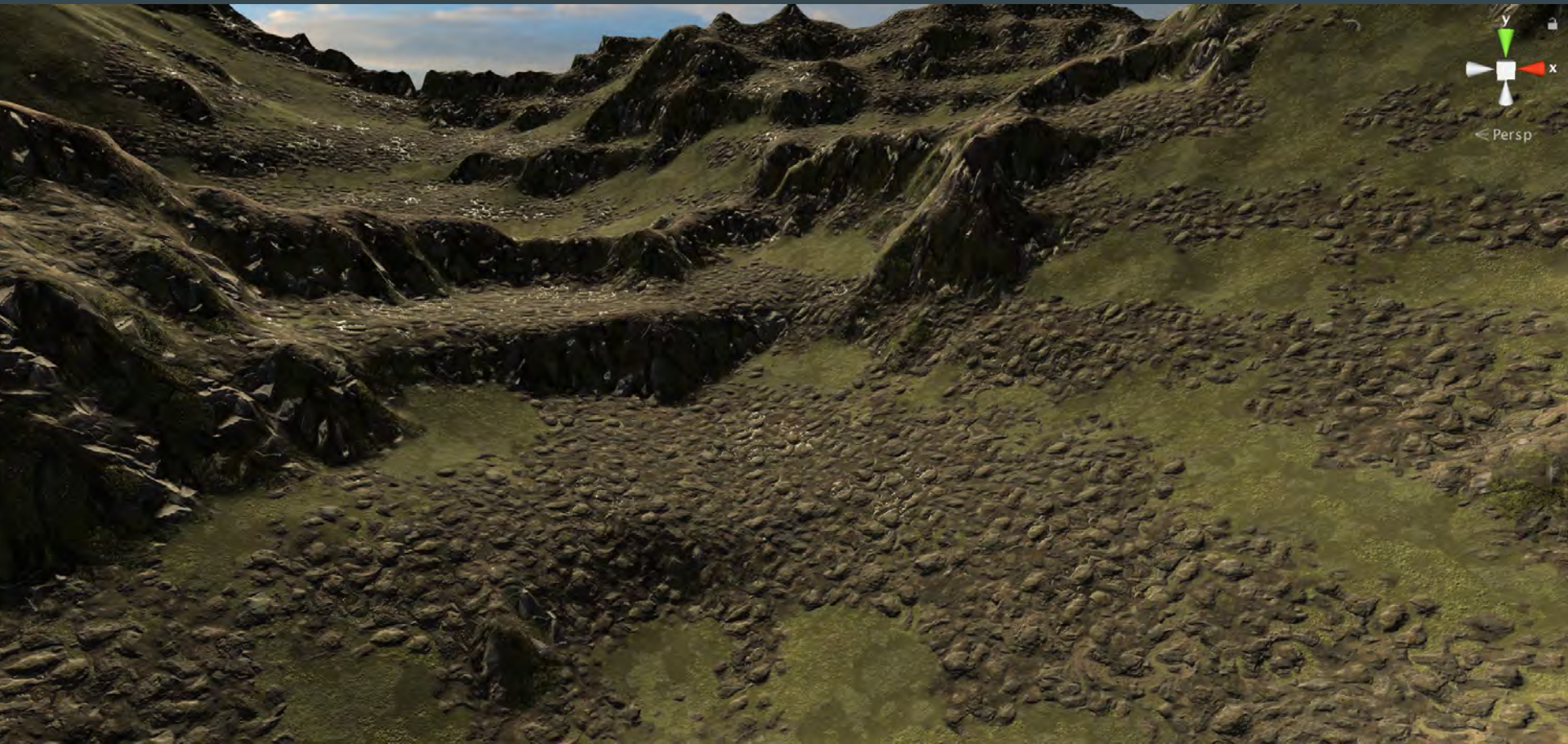

Cluster 3

Tiled



Stochastic Height Blend

Cluster 3



Research area

Histogram preserving operator:

- Biases too much towards a wash of the texture
- Frequency of features is increased

Height map operator

- Biases towards peaks of height map
  - Could bias to preserve valleys?
- Frequency of features is increased
- Luminosity of albedo often works surprisingly well

Overall

Height Map operator is superior to Histogram preserving blend

- No preprocessing
- No extra textures or custom texture formats
- Simpler shader code
- No extra uniforms needed
- No dependencies on compression format
- Preserves detail of original texture better
- Blend areas minimized, overall higher quality
- Other data can be used when height map is not available
    - Luminosity, Height from Normal, noise, etc..

Current Techniques in MicroSplat

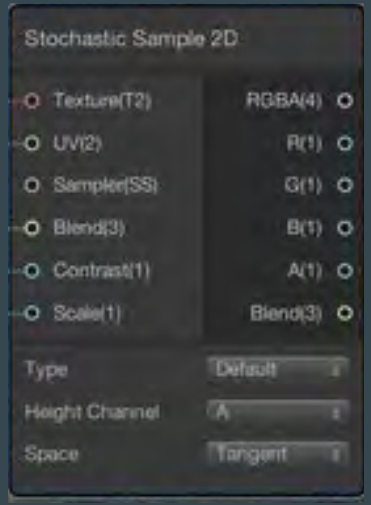
- Anti-tile
  - Distance Resampling
  - Detail Noise
  - Distance Noise
  - Normal Noise
- Texture Clusters
  - Stochastic Height Blend
  - Texture Cluster 2 layer
  - Texture Cluster 3 layer

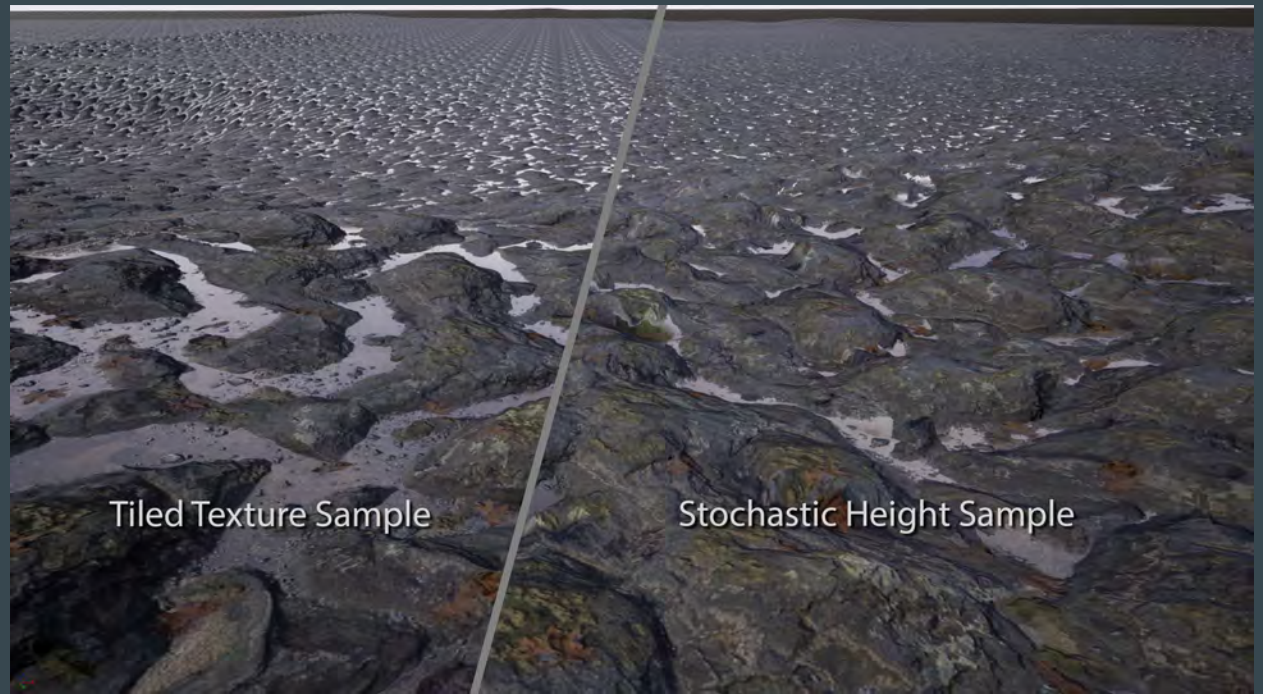
One Click

Require authoring texture variations

Stochastic Height Blend Node

- For Unity Shader Graph, Amplify Shader Editor, UE4 shader graph
- Blends based on selectable texture channel or luminosity of RGB channels





Shader Compilers

- Incredibly good at code stripping
  - Structs are not real, so will even strip unused structure members
    - Use structs to organize data
  - Unity's compiler sometimes strips things you're actually using though
    - o.Albedo *= saturate(i.viewDir + 2);
  - Lots of shaders (even Unity's) do tons of manual optimizations which their compiler would strip
    - Makes code more complex than it needs to be
- Can identify repeated texture samples and combine them
- Reorders code to start texture fetches as soon as possible
- Check generated and compiled output


Questions?
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