GPU-based Procedural Placement in Horizon Zero Dawn

Jaap van Muijden

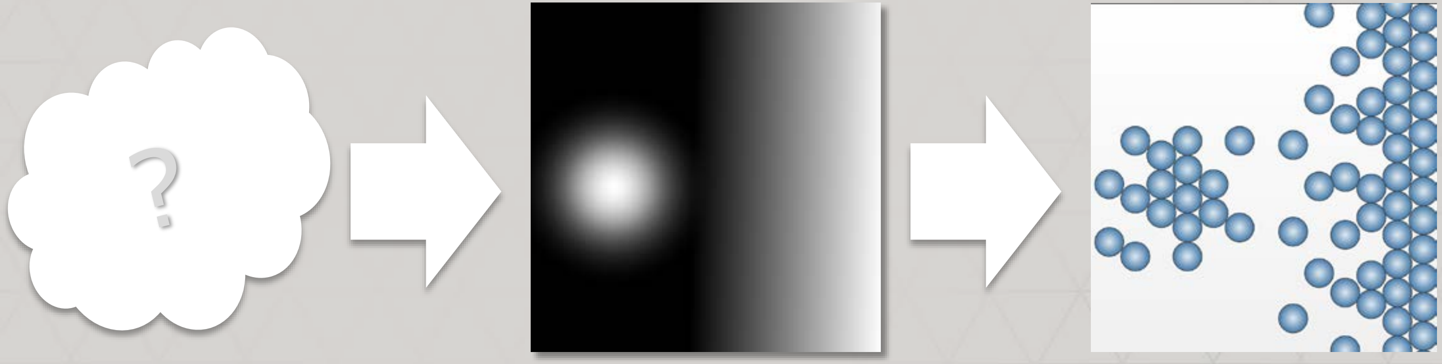
Senior Tech Programmer
Guerrilla Games

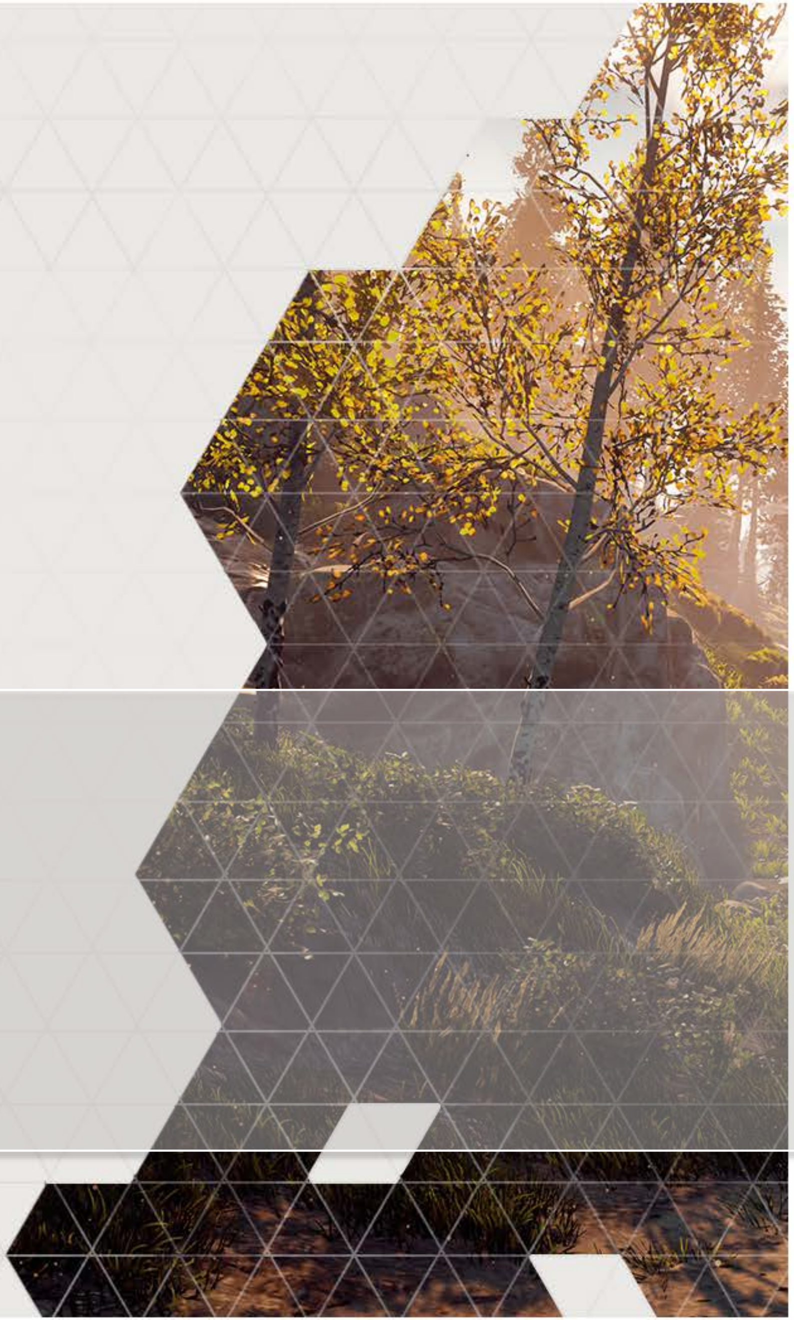
Motivation

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

Real-Time Procedural Placement

- Started traditional CPU
- Moved to GPU based
- Real-Time Placement
- Density Based Placement

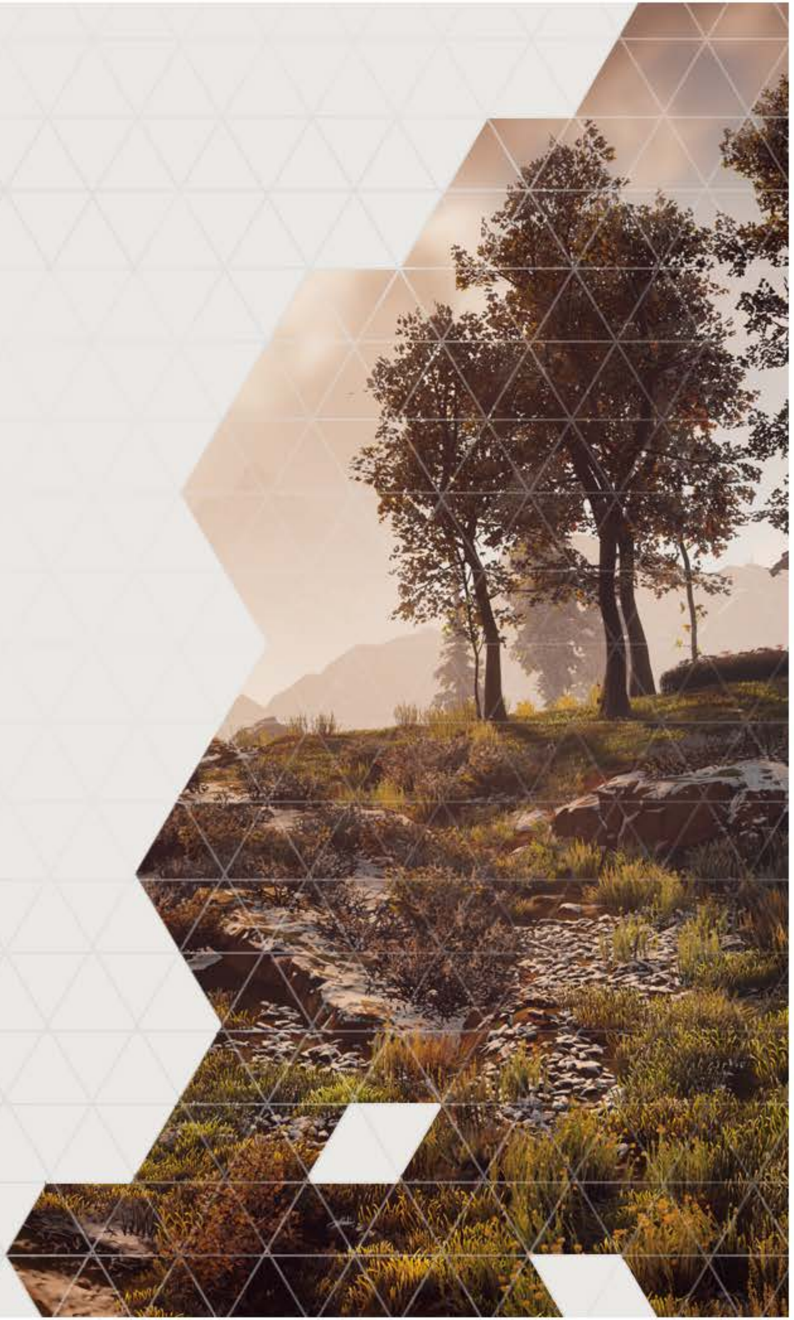




Results

We use procedural placement for all nature!

- **500+** asset types
- **100.000+** objects in scene
- **~250µs** avg busy load on GPU



Creating diversity

- Ecotope describes environment
- Ecotopes determine:
  - Asset types
  - Asset distribution
  - Colorization
  - Weather
  - Effects
  - Sound
  - Wildlife

Placing an Ecotope

- Create a believable world
- Artists have full control
  - The Placement **Data,**
  - The Placement **Logic**
  - Hand authored **Assets**

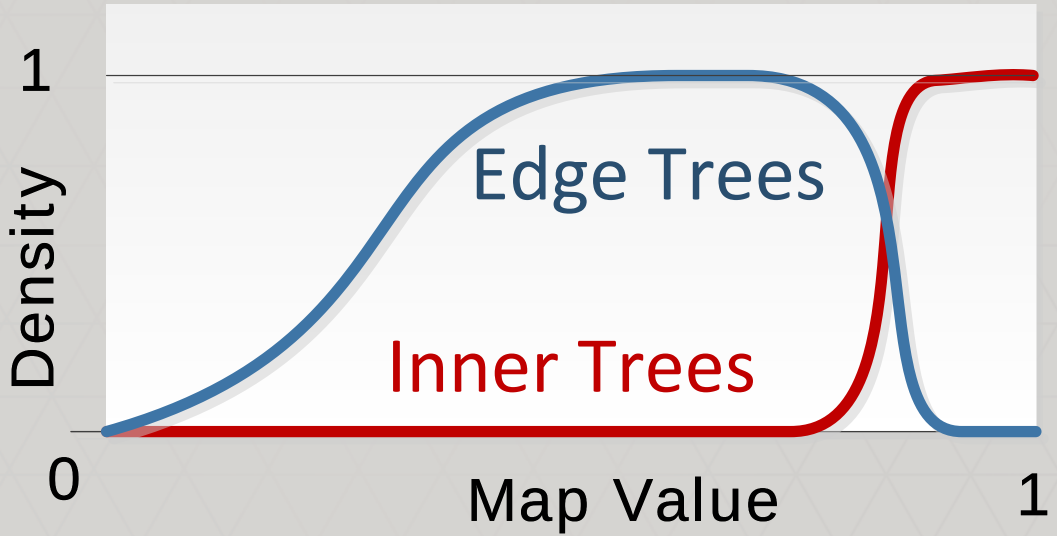
WorldData

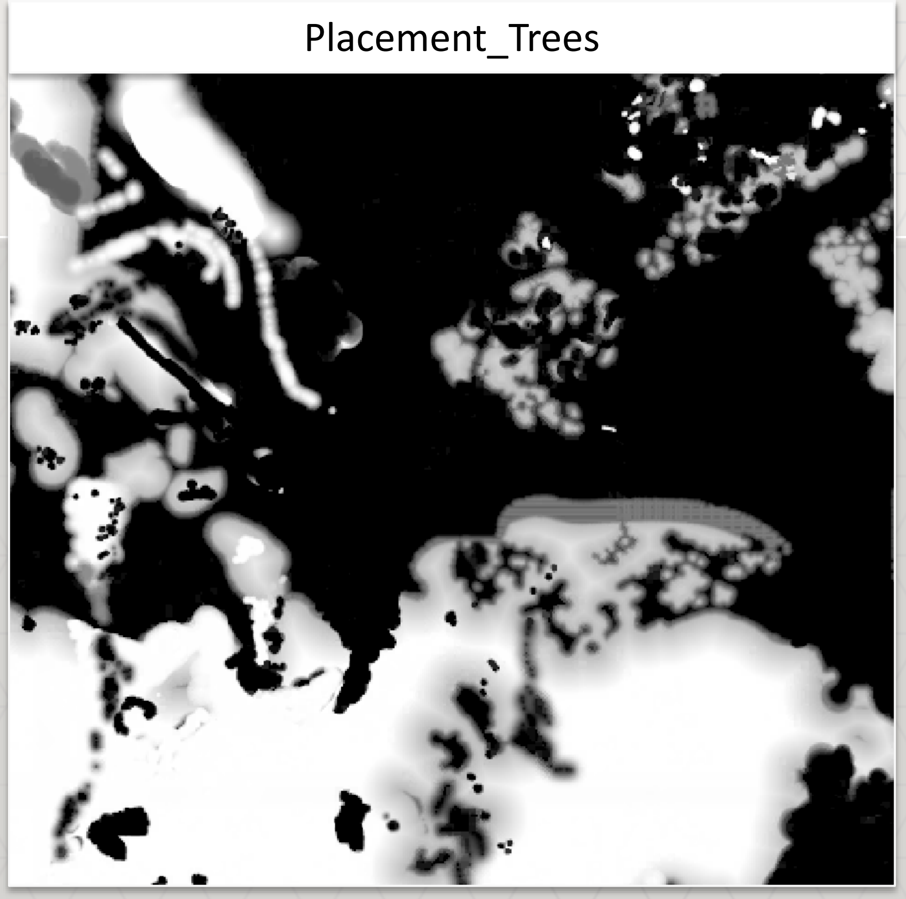
- Collection of 2D maps
  - Streamed in sections
  - All Generated
  - All Paintable

- ~4MB/km^2 exclusively

Painted World Data

- Extensively Hand Painted
- Decoding Logic



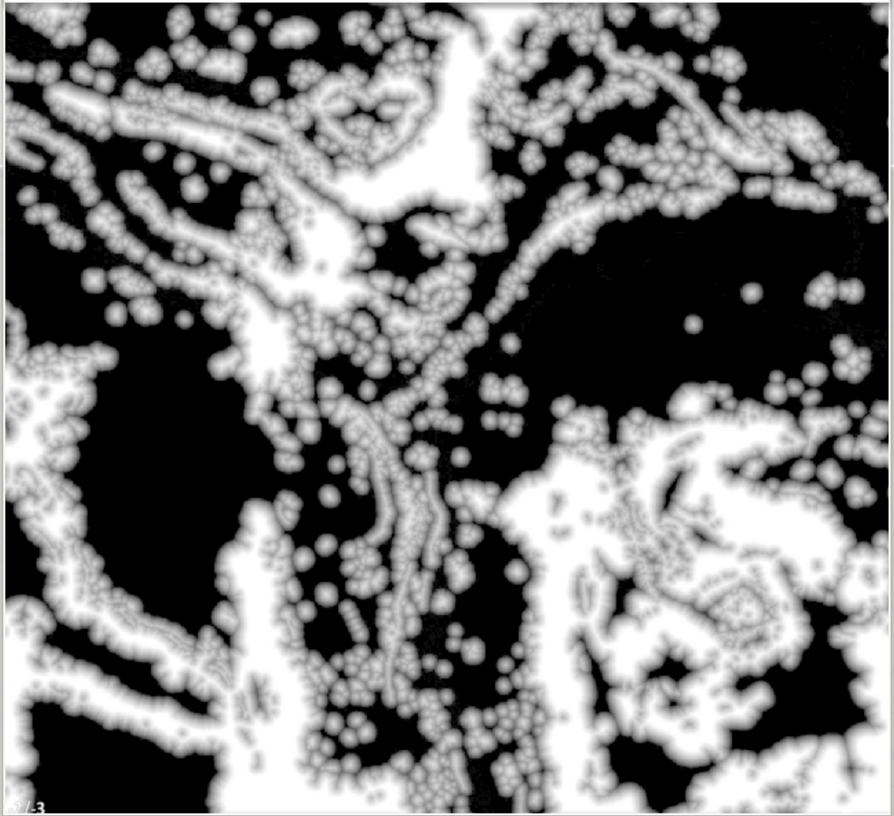


World Data List

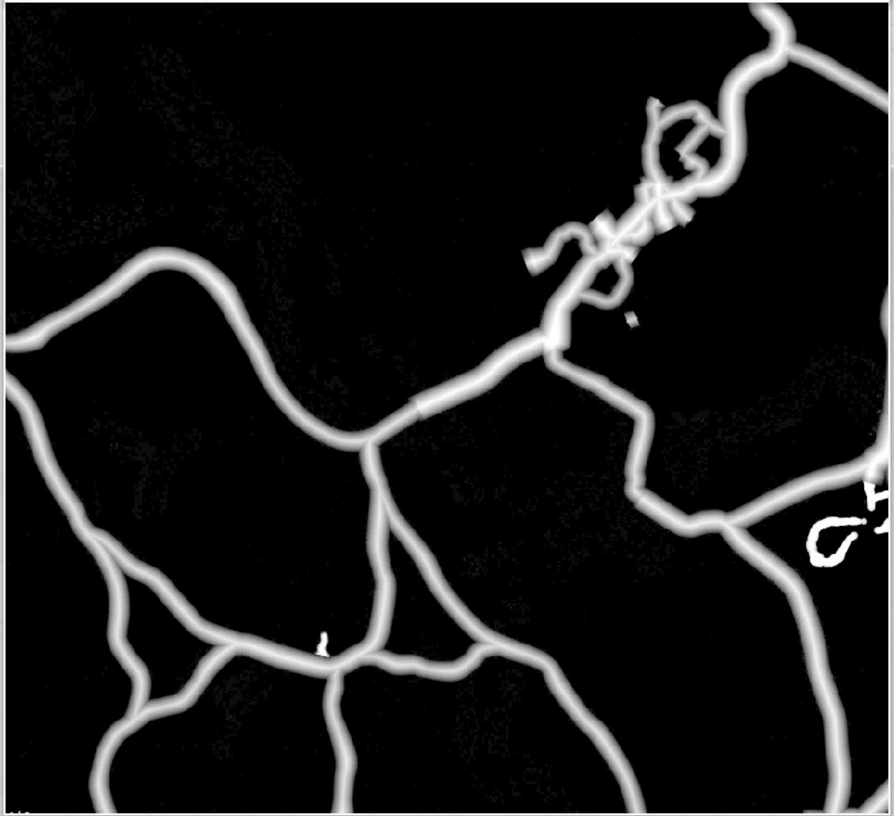
Name	Res	Format	Name	Res	Format
Height_Terrain	0.5 m	16 bit	Placement_Trees	1.0 m	BC7
Height_Objects	0.5 m	16 bit	Placement_BlockBush	1.0 m	BC7
Height_Water	0.5 m	BC6U	Placement_Undergrowth	1.0 m	BC7
Variance_Trees_Bush	2.0 m	BC7	Placement_StealthPlants	1.0 m	BC7
Variance_UnderGrowth_Stealth	2.0 m	BC7	Placement_PickUps	2.0 m	BC7
Variance_RockColor	1.0 m	BC7	Placement_Natural_Resources	2.0 m	BC7
Variance_Foliage_Color	1.0 m	BC7	Region_Destructibility	2.0 m	BC7
Variance_Lichen_Density	1.0 m	BC7	Region_Activity_Space	2.0 m	BC7
Erosion_Wear	0.5 m	BC7	Topo_Roads	0.5 m	BC7
Erosion_Flow	0.5 m	BC7	Topo_Water	0.5 m	BC7
Erosion_Deposition	0.5 m	BC7	Topo_Objects	0.5 m	BC7
Terrain_Cavity	0.5 m	BC7	Ecotope_Effect	0.5 m	BC7
Water_Flow	0.5 m	BC7 RGB	Ecotopes A-H	2.0 m	BC7
Water_Vorticity	0.5 m	BC7			

Generated World Data

Topo_Objects



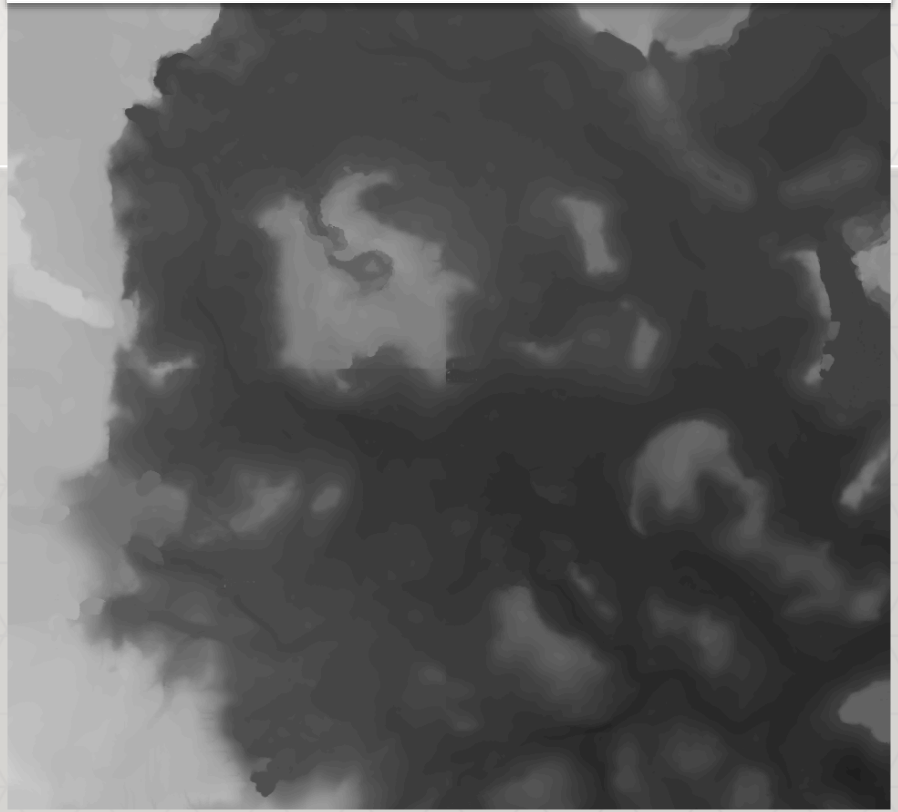
Topo_Roads



Mulitple Height Layers

Name	Res	Format
Height_Terrain	0.5 m	16 bit
Height_Objects	0.5 m	16 bit
Height_Water	0.5 m	BC6U

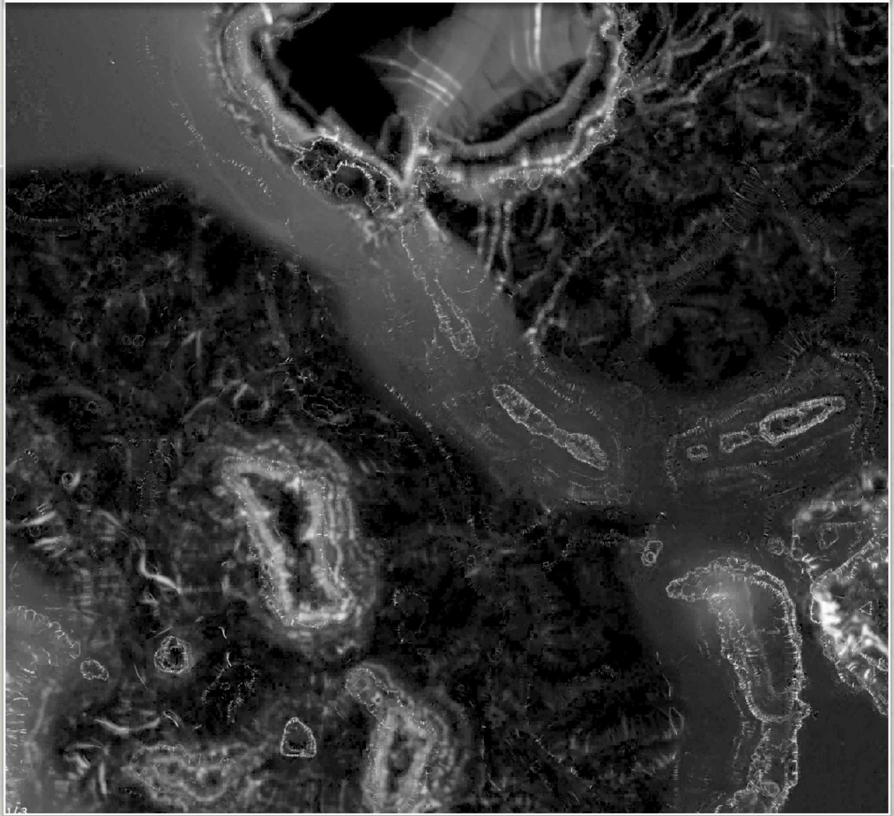
Height_Terrain



WorldData: Baked Maps

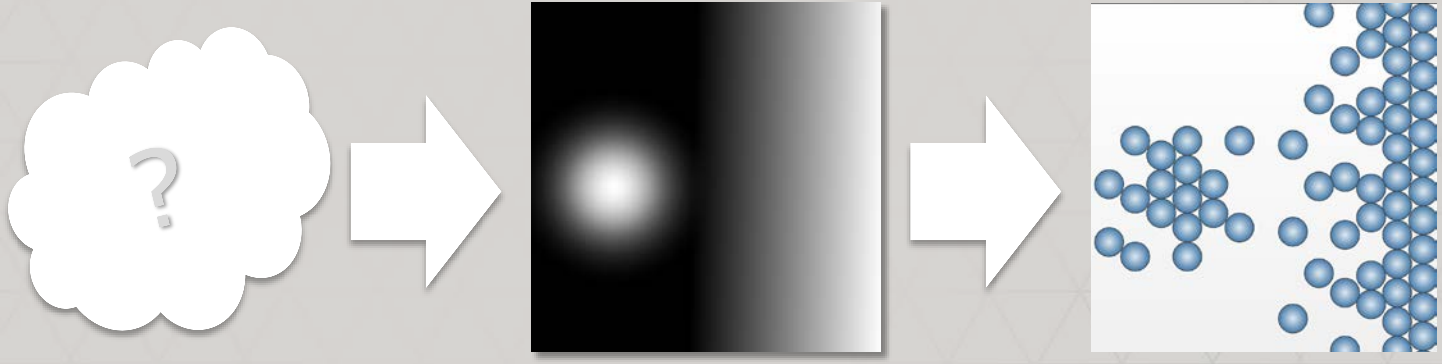
Erosion_Flow

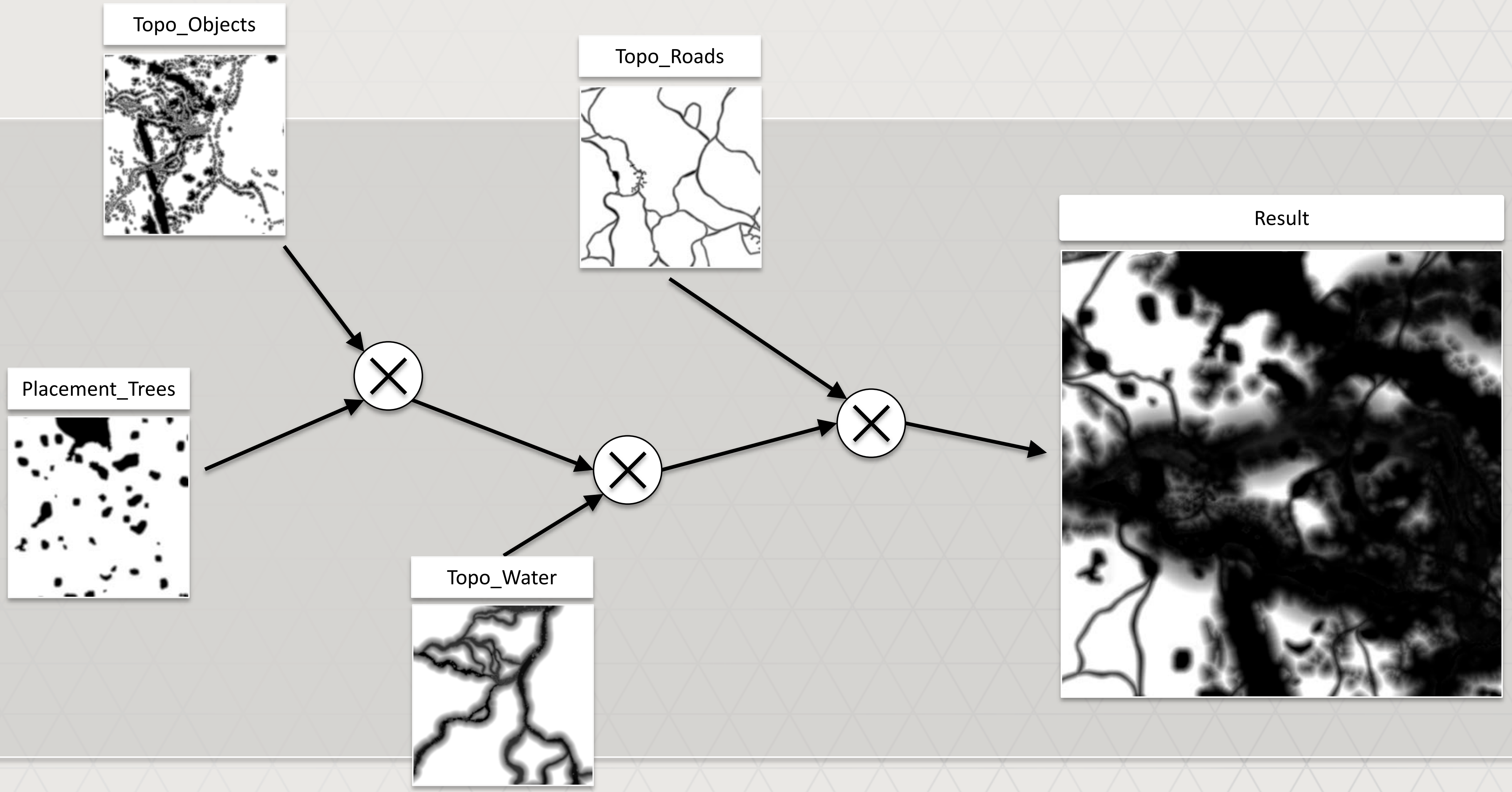
Erosion_Deposition



Density logic

- Artists have full control
  - Hand authored assets
  - The Placement Data
  - **The Placement Logic**



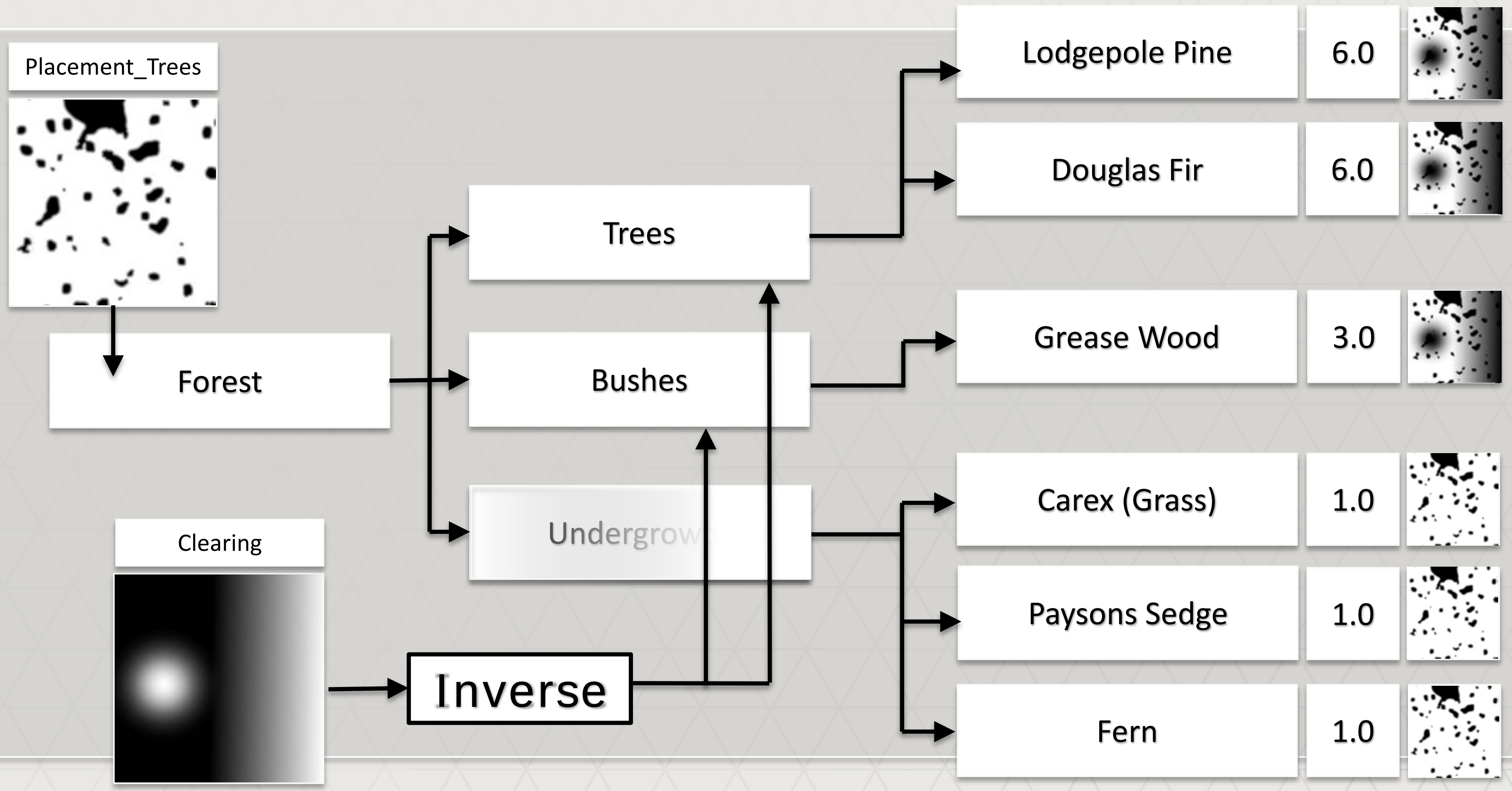


Topo_Objects
Topo_Roads
Placement_Trees
Topo_Water
Result

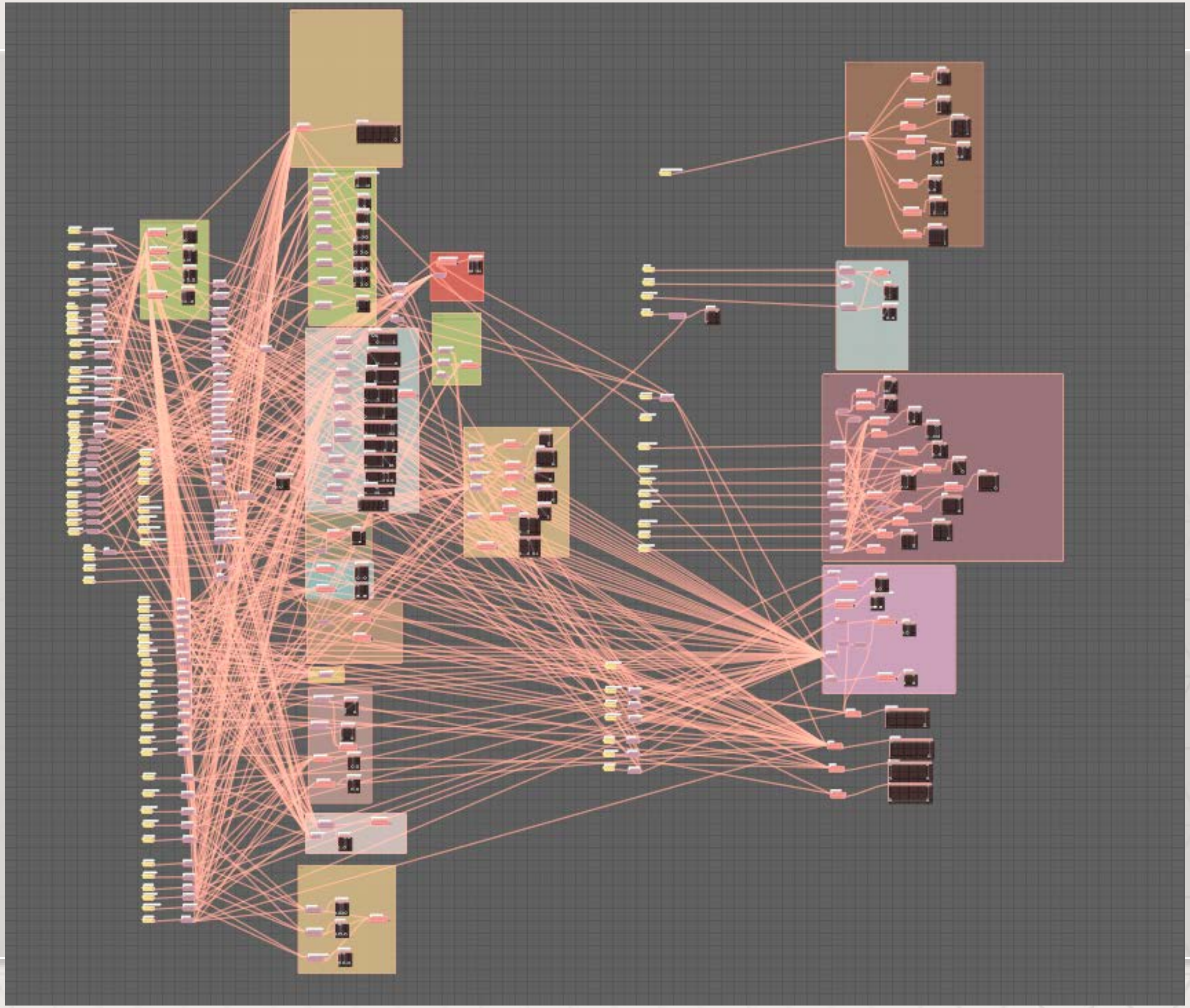
Ecotope Assets

			footprint	density
Forest	Trees	Lodgepole Pine	6.0	
		Douglas Fir	6.0	
	Bushes	Grease Wood	3.0	
	Undergrowth	Carex (Grass)	1.0	
		Paysons Sedge	1.0	
		Fern	1.0	

Ecotope Assets

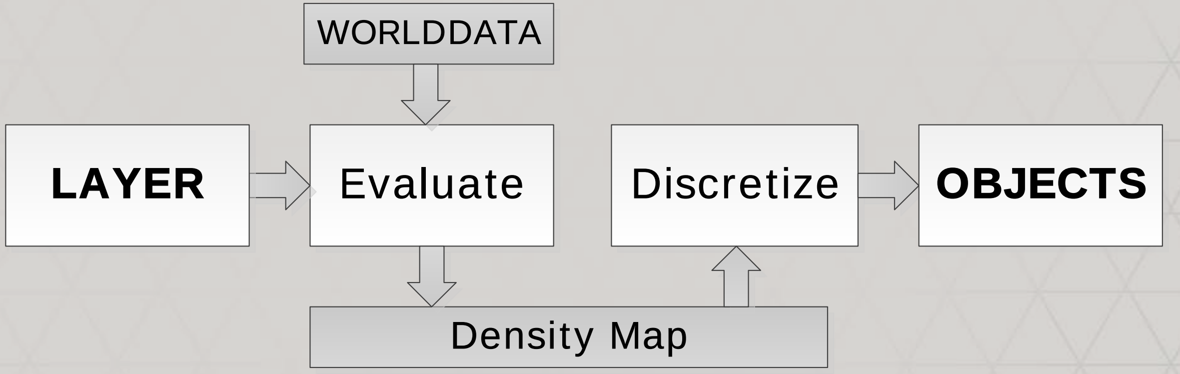


Production Logic



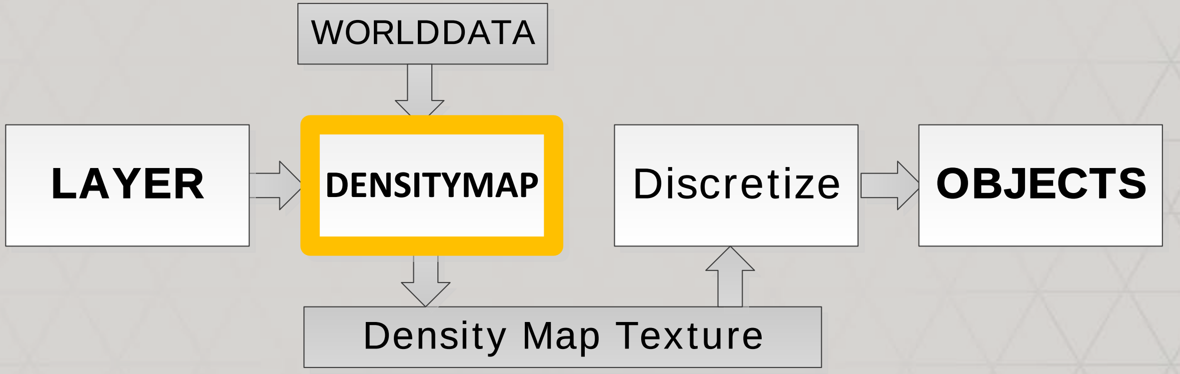
Layer Based Placement

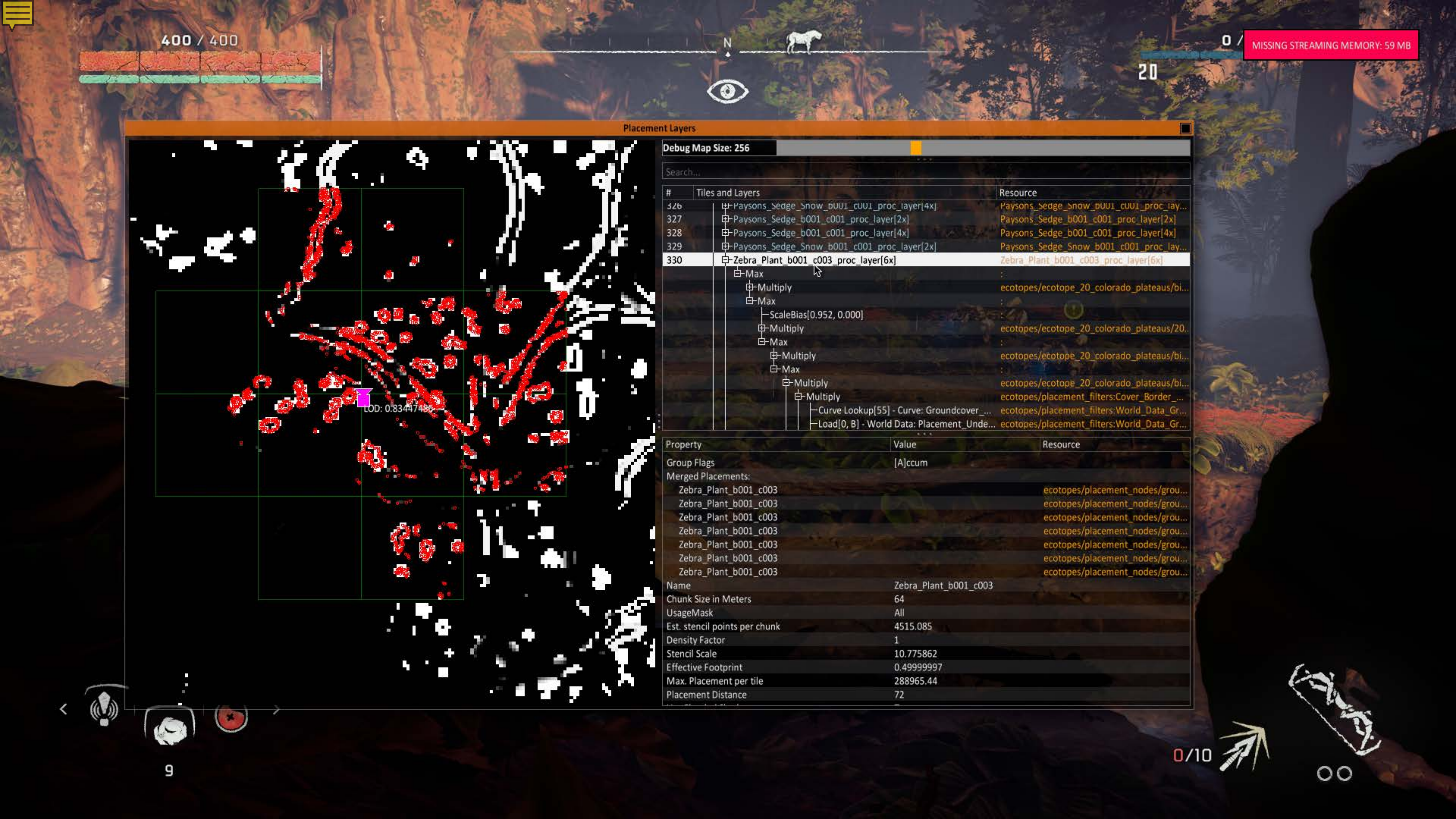
- Prepare our assets
  1. Flatten graph into **Layers**
  2. Compile intermediate form
  3. Optimize and Merge layers



Step1: DENSITYMAP

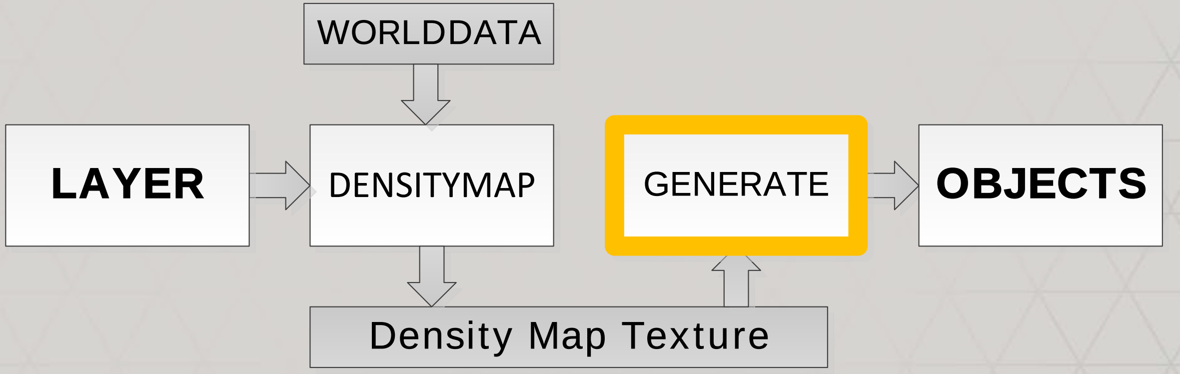
- Single Layer
- Scaleable granularity
- Mipmapped World Data




400 / 400
N
MISSING STREAMING MEMORY: 59 MB
20
Placement Layers
LOD: 0.83447486
Debug Map Size: 256
Search...
| Tiles and Layers | Resource
327 Paysons_Sedge_b001_c001_proc_layer[2x] Paysons_Sedge_b001_c001_proc_layer[2x]
328 Paysons_Sedge_b001_c001_proc_layer[4x] Paysons_Sedge_b001_c001_proc_layer[4x]
329 Paysons_Sedge_Snow_b001_c001_proc_layer[2x] Paysons_Sedge_Snow_b001_c001_proc_lay...
330 Zebra_Plant_b001_c003_proc_layer[6x] Zebra_Plant_b001_c003_proc_layer[6x]
Max
Multiply ecotopes/ecotope_20_colorado_plateaus/bi...
Max
ScaleBias[0.952, 0.000]
Multiply ecotopes/ecotope_20_colorado_plateaus/20...
Max
Multiply ecotopes/ecotope_20_colorado_plateaus/bi...
Max
Multiply ecotopes/ecotope_20_colorado_plateaus/bi...
Multiply ecotopes/placement_filters:Cover_Border_...
Curve Lookup[55] - Curve: Groundcover_... ecotopes/placement_filters:World_Data_Gr...
Load[0, B] - World Data: Placement_Unde... ecotopes/placement_filters:World_Data_Gr...
Property | Value | Resource
Group Flags [A]ccum
Merged Placements:
Zebra_Plant_b001_c003 ecotopes/placement_nodes/grou...
Zebra_Plant_b001_c003 ecotopes/placement_nodes/grou...
Zebra_Plant_b001_c003 ecotopes/placement_nodes/grou...
Zebra_Plant_b001_c003 ecotopes/placement_nodes/grou...
Zebra_Plant_b001_c003 ecotopes/placement_nodes/grou...
Zebra_Plant_b001_c003 ecotopes/placement_nodes/grou...
Zebra_Plant_b001_c003 ecotopes/placement_nodes/grou...
Name Zebra_Plant_b001_c003
Chunk Size in Meters 64
UsageMask All
Est. stencil points per chunk 4515.085
Density Factor 1
Stencil Scale 10.775862
Effective Footprint 0.49999997
Max. Placement per tile 288965.44
Placement Distance 72
9
0/10

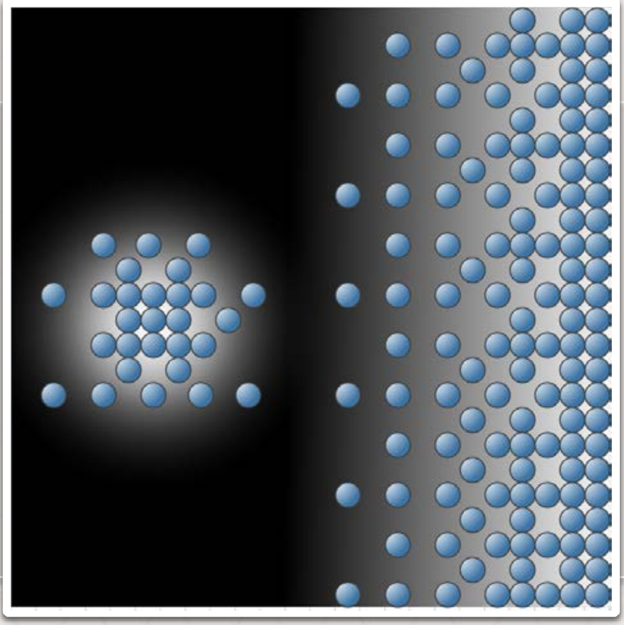
Step2: GENERATE

- Discretizing step
- **Dither based**
- Responsible for collision

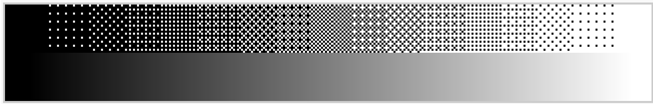


Step2: GENERATE

- Discretizing step
- Resonsible for collision
- **Dither based**

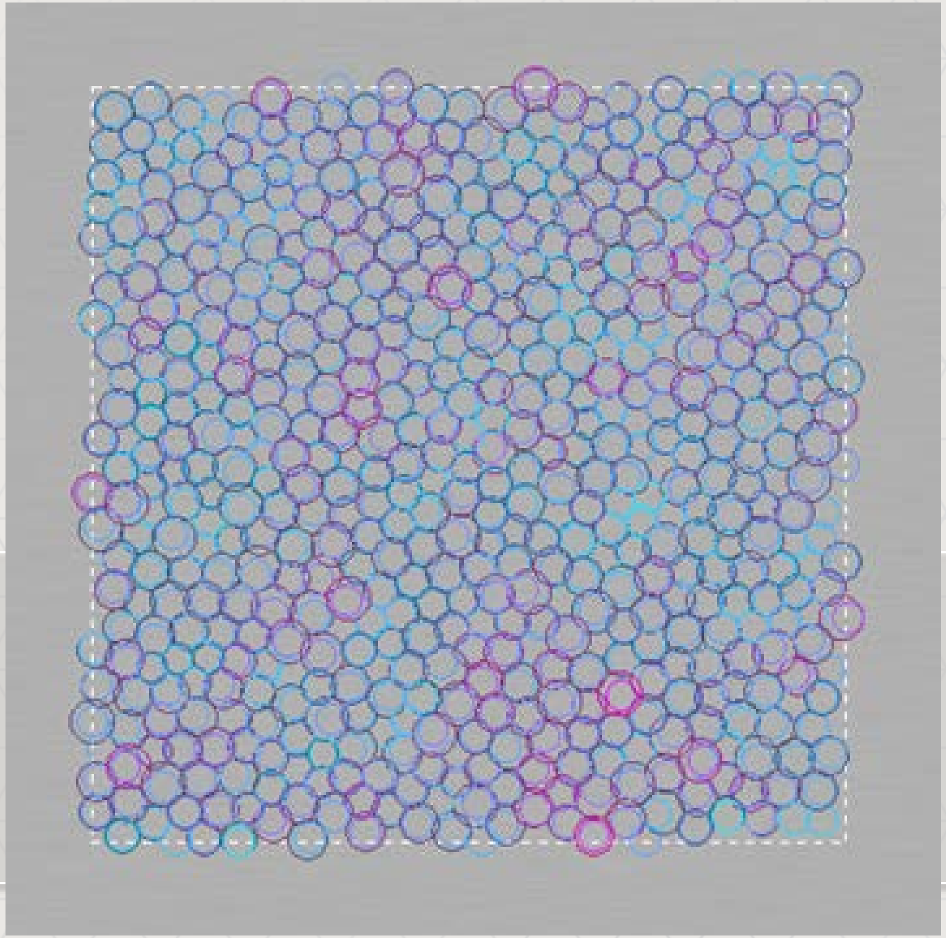


$$\begin{bmatrix} 1 & 9 & 3 & 11 \\ 13 & 5 & 15 & 7 \\ 4 & 12 & 2 & 10 \\ 16 & 8 & 14 & 6 \end{bmatrix}$$



Generating the pattern

- Generation Tool
- Rules to follow:
  - Even spread thresholds
  - Maximize 2D distance
- Uniform 2D distance **w**
- Scale to **w** = footprint

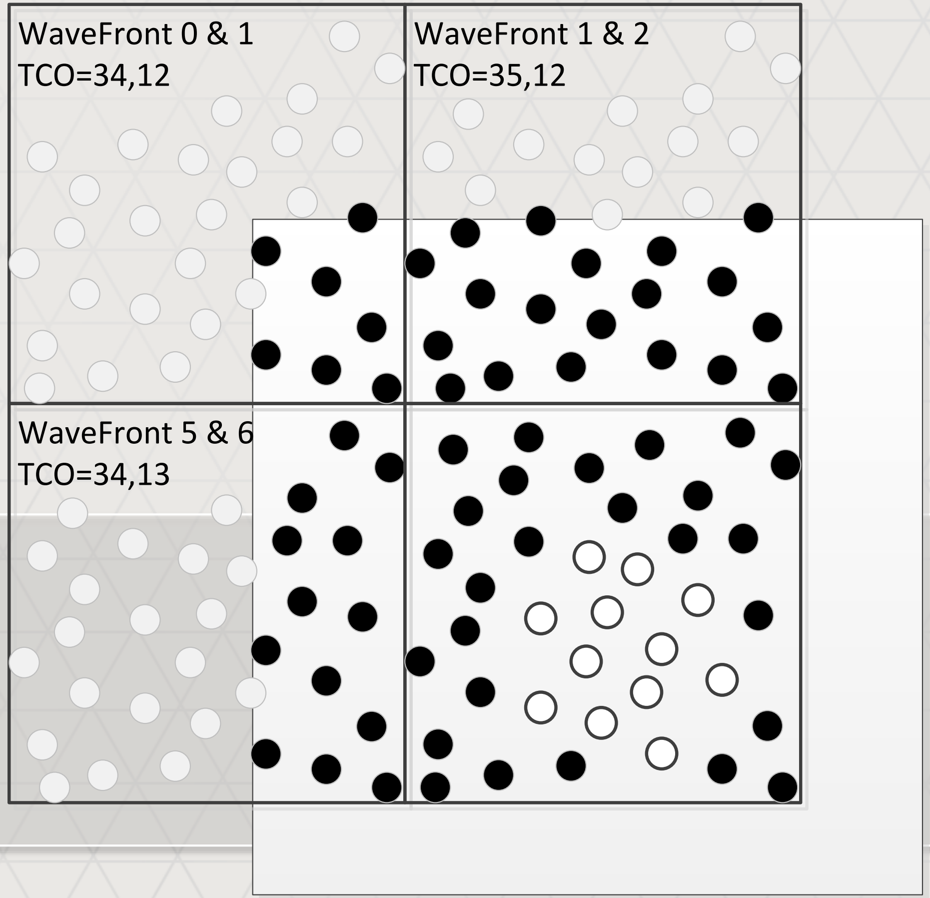



210 / 210
W
0 / 1000

Step2: GENERATE

- One pattern per group
- One sample per thread
  1. Range Test
  2. Threshold Test
  3. Position generate
  4. Normal construction
  5. Stage to buffer

~10µs, VGPR: **28**, SGPR: **64**, Cycles: **342**



Search...

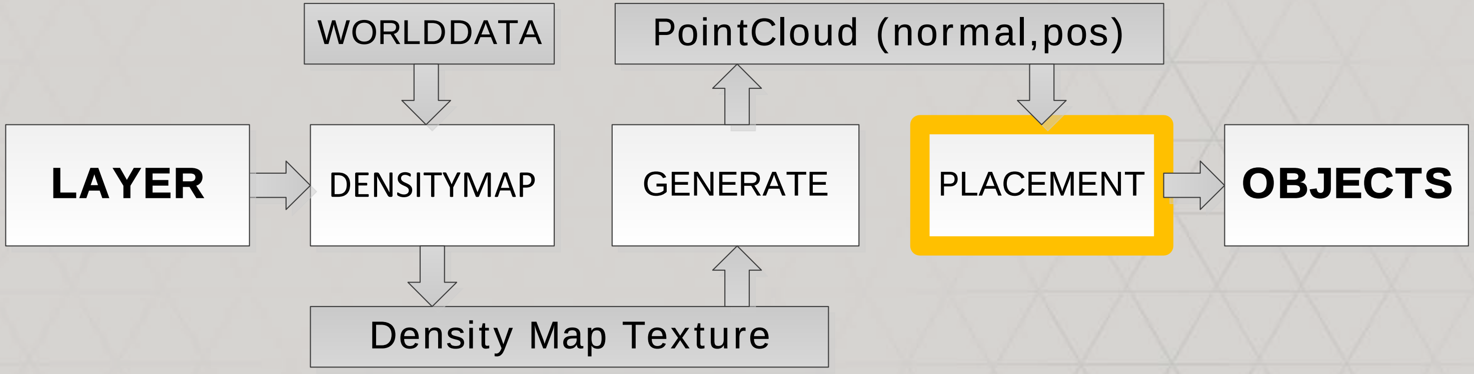
#	Tiles and Layers
115	Krummholz_b001_c003_proc_layer[2x]
116	Krummholz_b001_c003_proc_layer[2x][split]
117	Peachleaf_Willow_b001_c002_proc_layer[7x]
118	Peachleaf_Willow_b001_c002_proc_layer[7x][split]
119	Dead_Pine_b001_c001_proc_layer[5x]
120	Dead_Pine_b001_c001_proc_layer[5x][split]
121	Colorado_Pinyon_b001_c003_3m_proc_layer[8x]
122	Colorado_Pinyon_b001_c003_3m_proc_layer[8x][split]
123	Douglas_Fir_Snow_b001_c003_proc_layer[4x]
124	Douglas_Fir_Snow_b001_c003_proc_layer[4x][split]
125	Krummholz_b001_c001_data_layer
126	Krummholz_b001_c001_data_layer[split]
127	Krummholz_b001_c002_data_layer
128	Krummholz_b001_c002_data_layer[split]
129	Krummholz_b001_c004_data_layer
130	Krummholz_b001_c004_data_layer[split]
131	Krummholz_b001_c003_data_layer
132	Krummholz_b001_c003_data_layer[split]
133	Colorado_Pinyon_b001_c003_3m_proc_layer[3x]
134	Colorado_Pinyon_b001_c003_3m_proc_layer[3x][split]
135	Southern_live_oak_b001_c001_proc_layer[2x]
136	Southern_live_oak_b001_c001_proc_layer[2x][split]

Property	Value	Resource
Group Flags	[A]ccum	
Merged Placements:		
Douglas_Fir_Snow_b001_c003		ecotopes/pl
Douglas_Fir_Snow_b001_c003		ecotopes/pl
Douglas_Fir_Snow_b001_c003		ecotopes/pl
Douglas_Fir_Snow_b001_c003		ecotopes/pl
Douglas_Fir_Snow_b001_c003		ecotopes/pl
Name	Douglas_Fir_...	
Chunk Size in Meters	128	
Est. stencil points per chunk	501.67599	
Density Factor	1	
Stencil Scale	64.655174	
Effective Footprint	3	
Max. Placement per tile	8026.8159	
Placement Distance	512	
Height Map	Height_Terra...	
Rotation Type	1 (1 deg - 0 d...	
Base Elevation	0	
Elevation Variance	0	
Wandering Distance	1.25	
Tilt Random/Terrain/Up	0.20000000/...	
Base Scale	1	
Scale Variance	0.2	

Step3: PLACEMENT

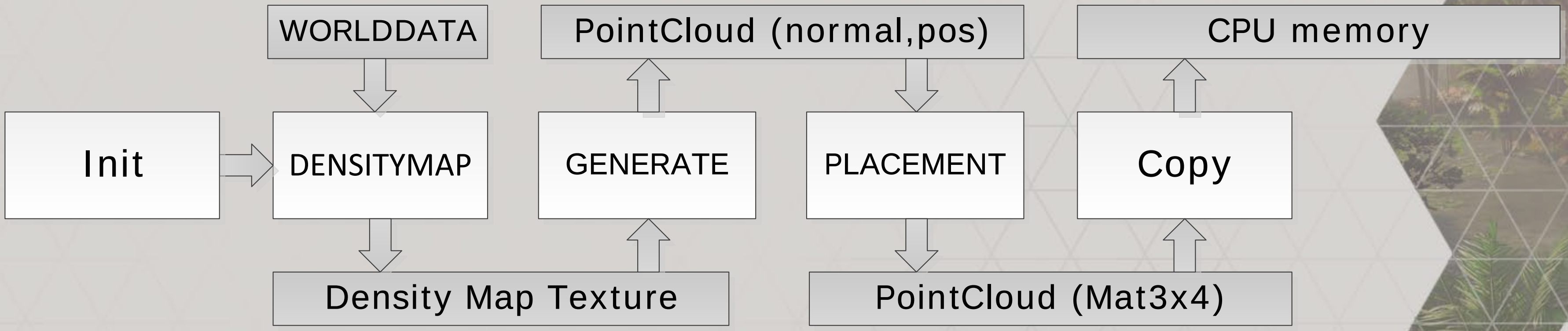
- Needs pattern idx/id for RNG
- Basis generation
- Bounding box generation

~7µs, VGPR: **28**, SGPR: **40**, Cycles: **347**



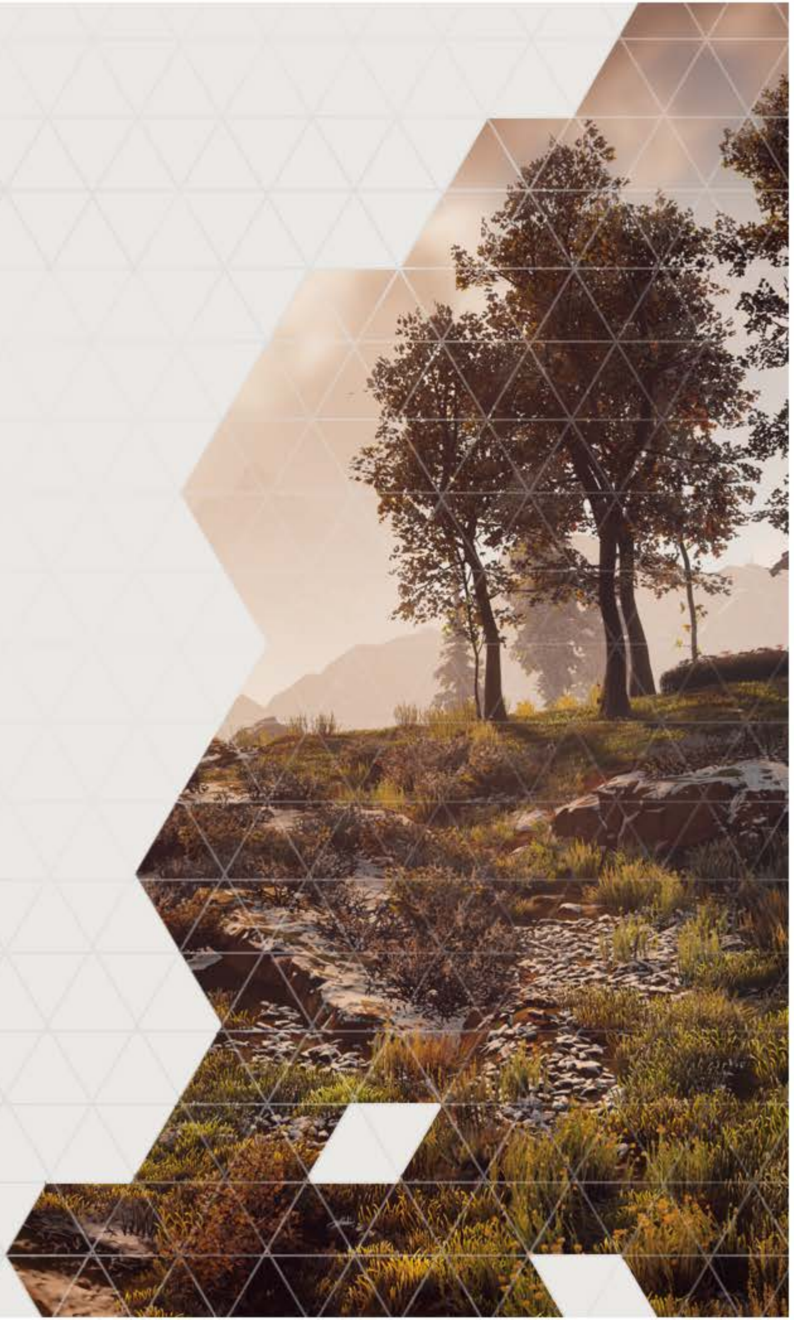
Pipeline overview

- Run pipeline for each layer
- Independently discretizing
- **Collision?**

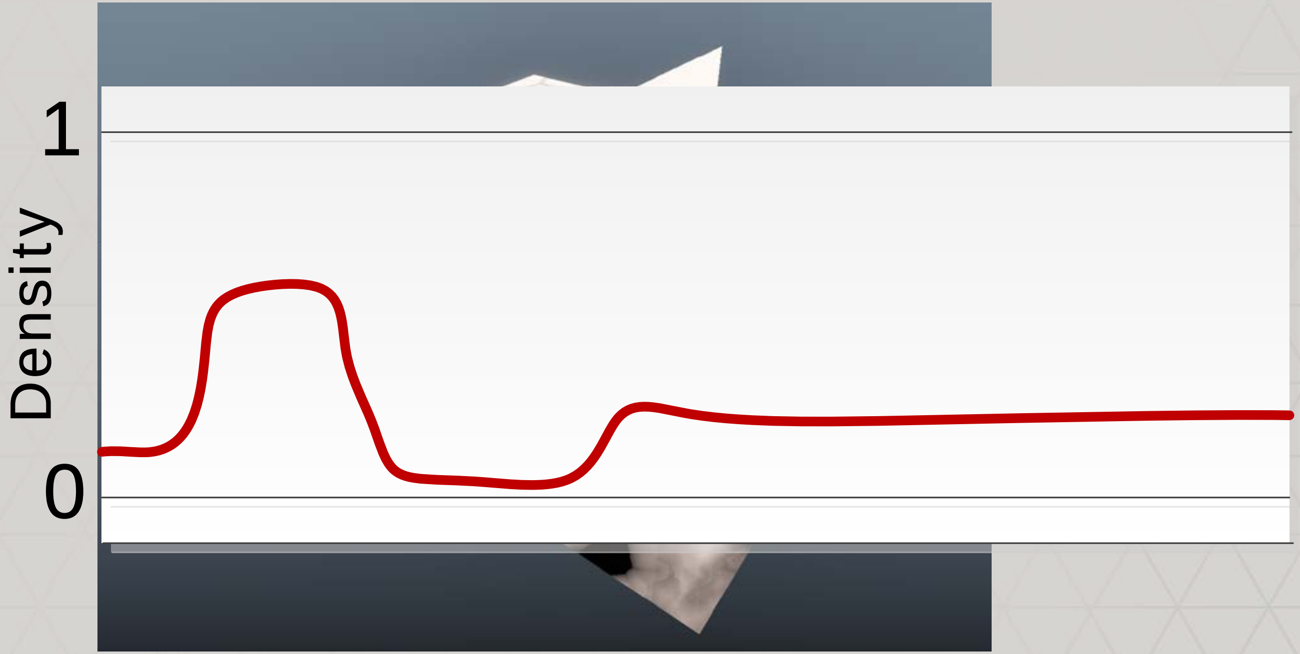


Solving Collision

- Different footprint?
  - Read-back, dependencies ☹
- Same footprint?
  - Layered Dithering ☺

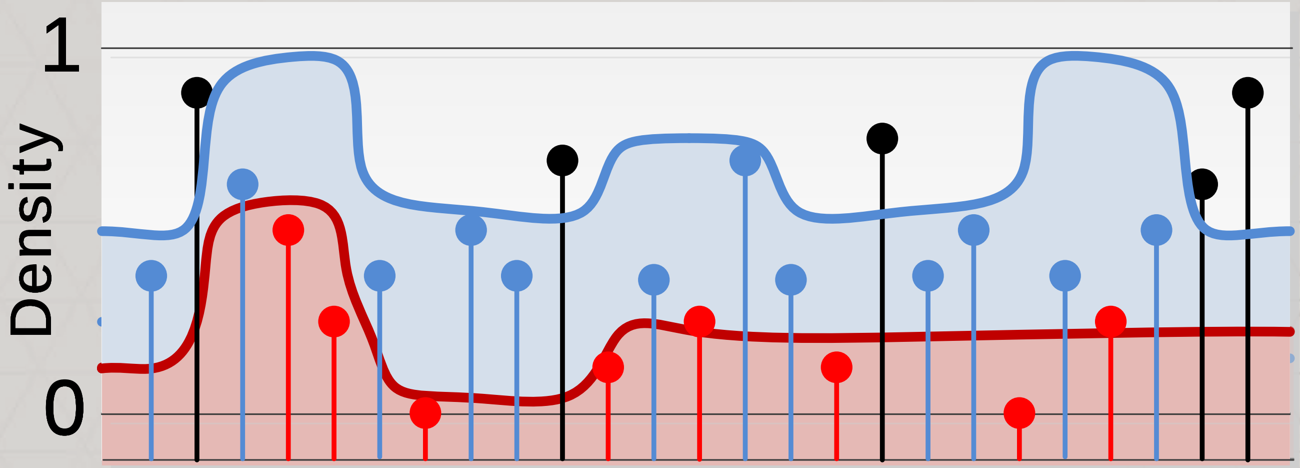


Layered Dithering



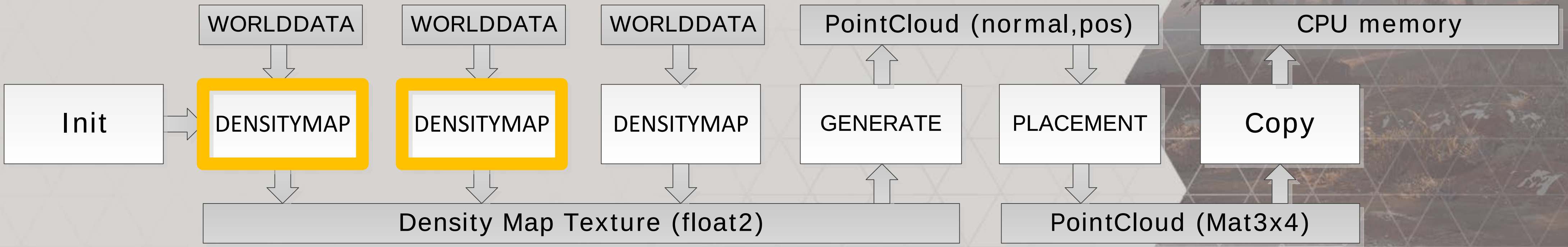
Layered Dithering

- Layered density maps
  - Two values in density map
  - Two-Sided threshold test



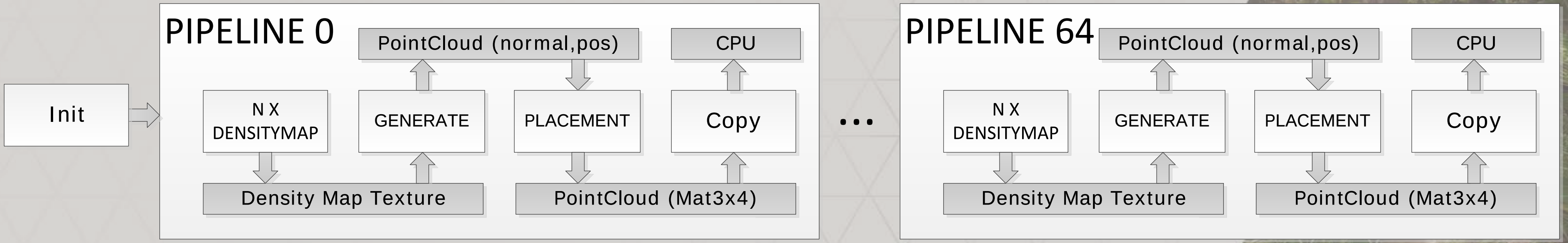
Layered Dithering

- DENSITYMAP overhead
  - Independent eval
  - Might need DENSITYMAP for non-placing layers
  - More work, but No Flushes
  - Sparse placement causes dependency overhead
  - Use ordering heuristics to reduce DENSITYMAP/GENERATE

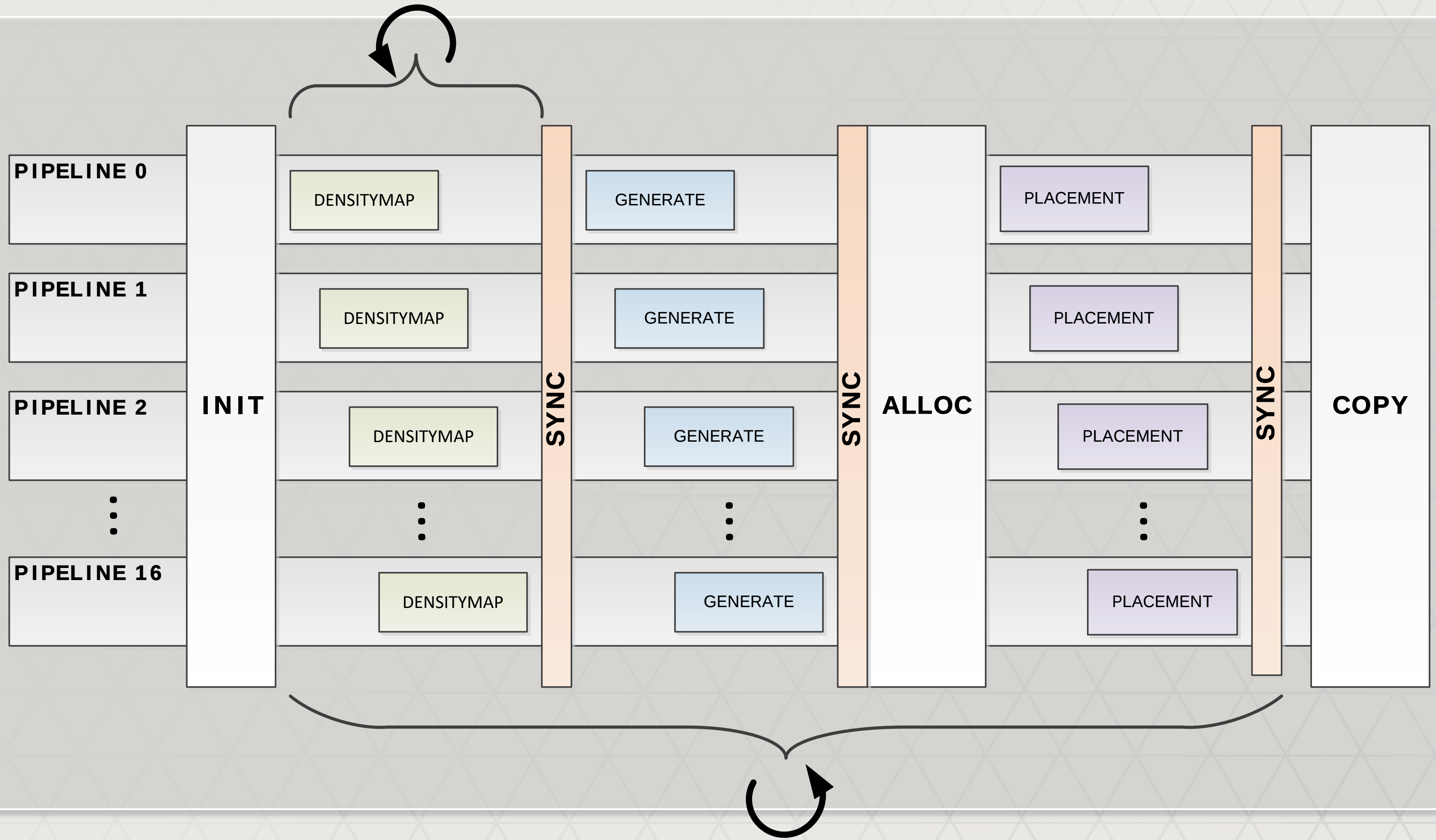


Pipelining on GPU

- Instantiate pipeline 64 times
- Each pipeline has multiple DENSITYMAP
- Each pipeline emits one layer
- Lots of unnecessary flushes within pipeline

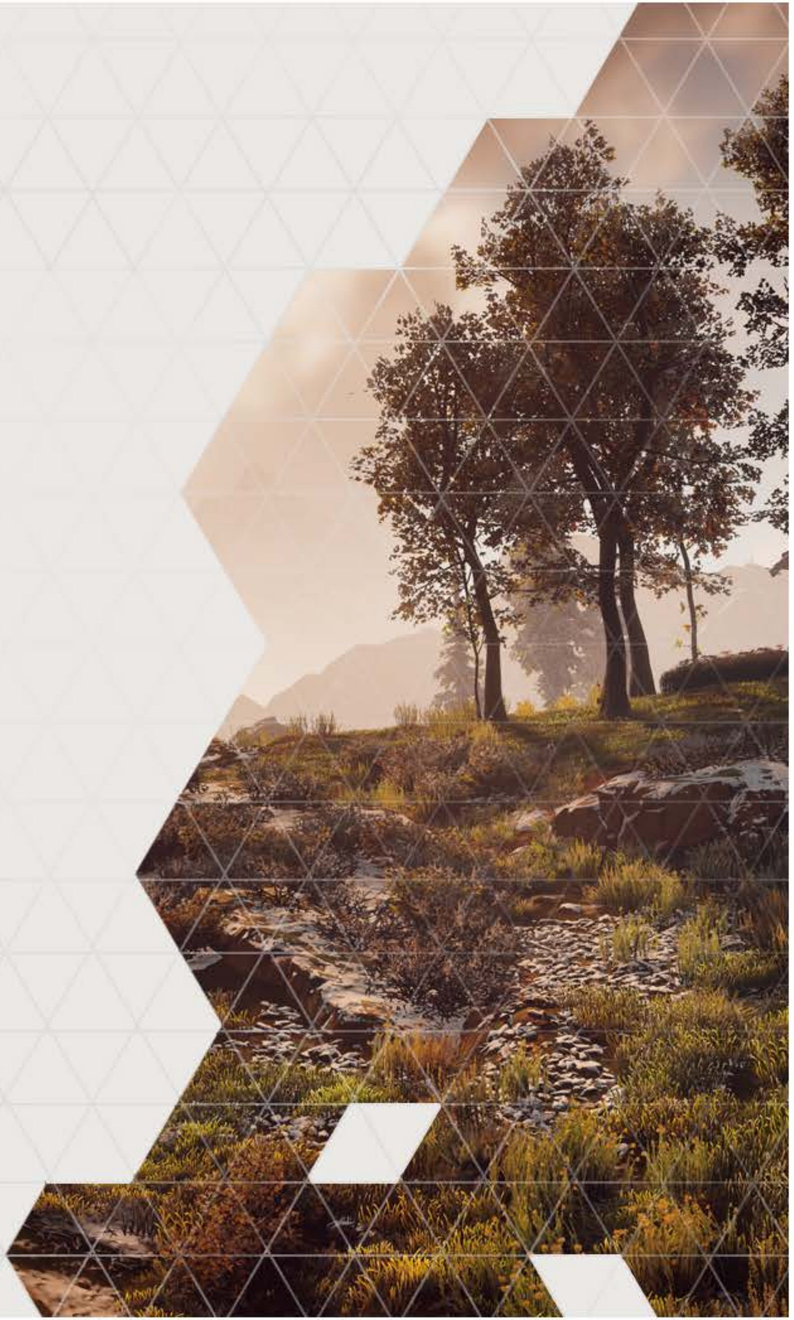


Pipelining on GPU



Conclusion

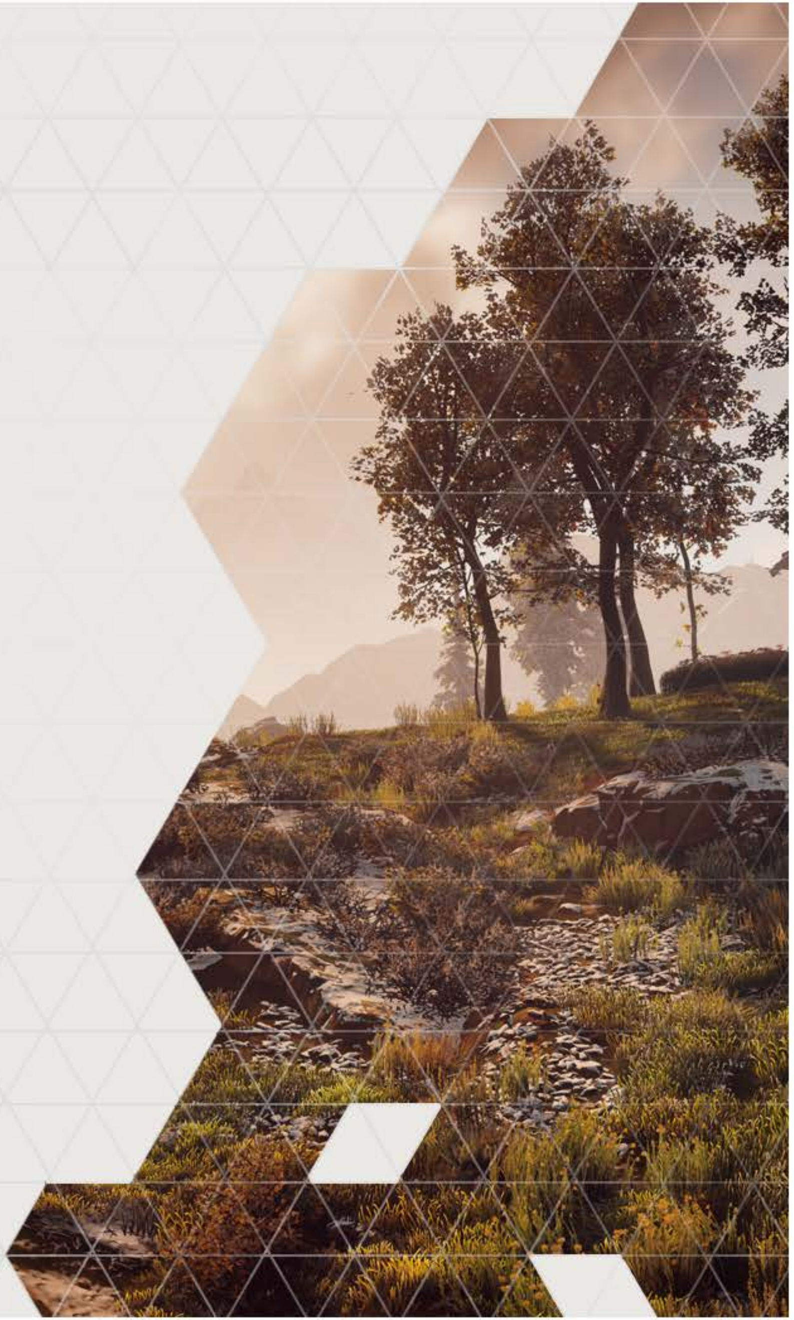
- Procedural Placement is extensively used
- Good visual quality
  - Suitable for art direction
  - Unpolished areas in shippable quality
- 250µs avg. busy load
- Powerful tool in making natural worlds
  - Nature assets created by 3 people
  - Ecotopes made by 1 person



User Screenshots

Proof of success:

Users are making screenshots of our output!



Questions?