



GPU-based Procedural Placement in Horizon Zero Dawn

Jaap van Muijden

Senior Tech Programmer
Guerrilla Games



Motivation

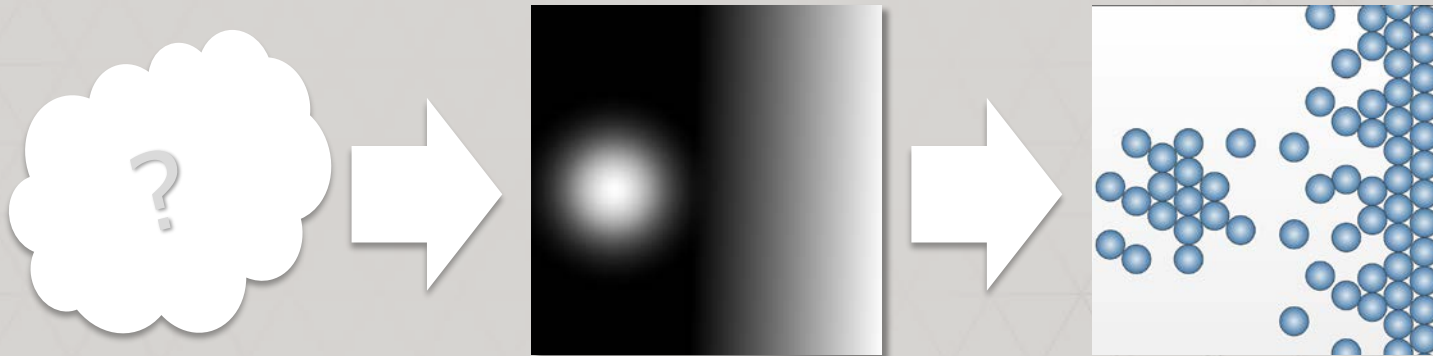
- Quick iterations
- Large variety
- Believable look
- Art Directable
 - Data driven
 - Deterministic
 - Locally stable





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

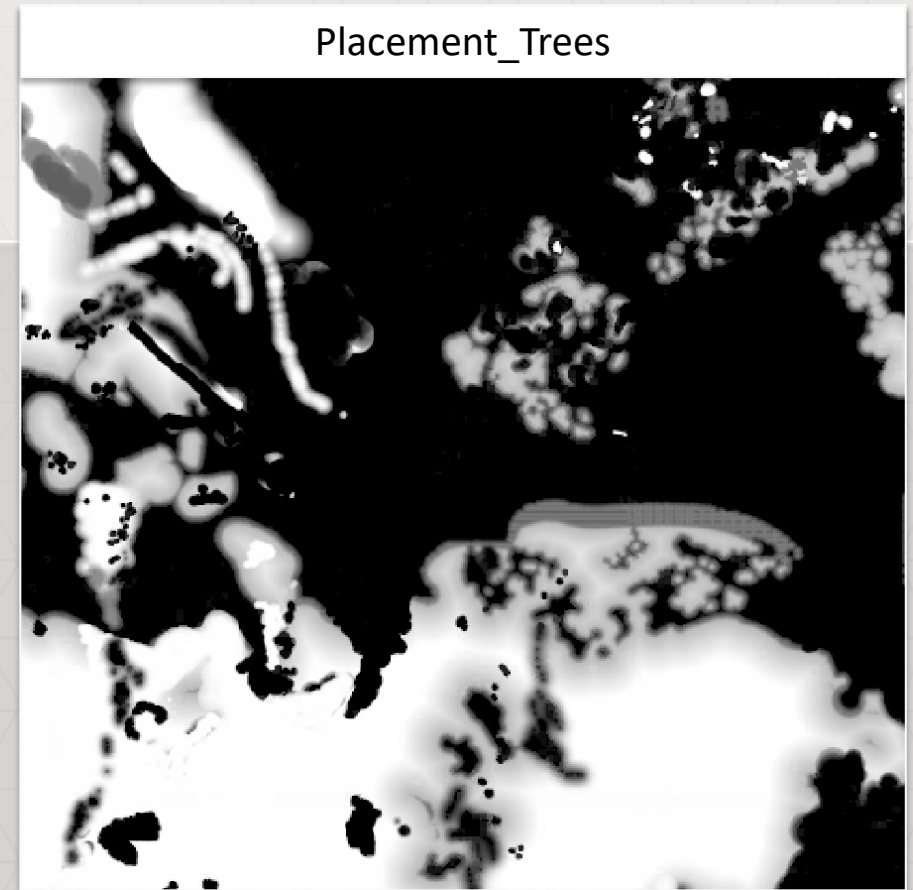
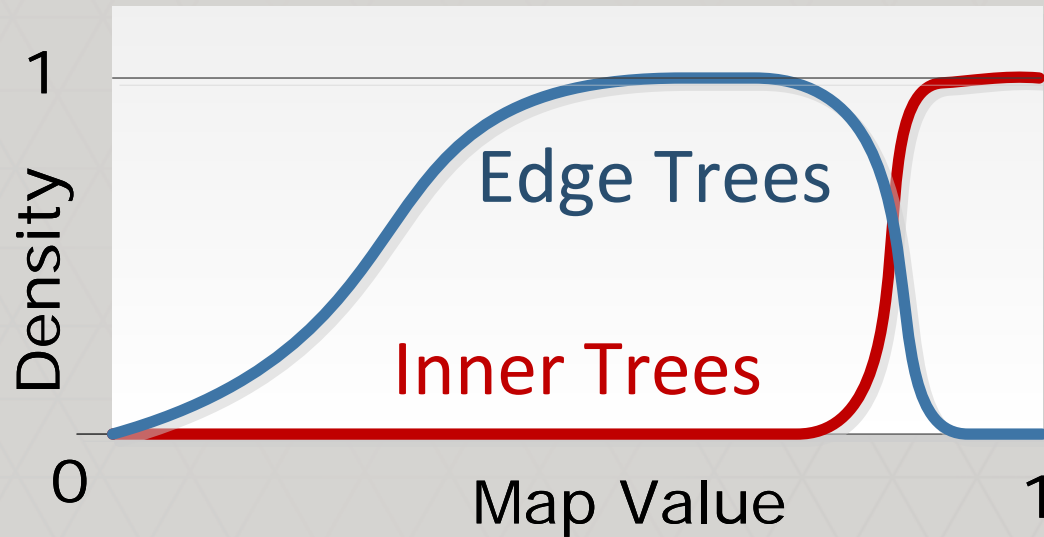
- Collection of 2D maps
 - Streamed in sections
 - All Generated
 - All Paintable
- ~4MB/km² exclusively





Painted World Data

- Extensively Hand Painted
- Decoding Logic





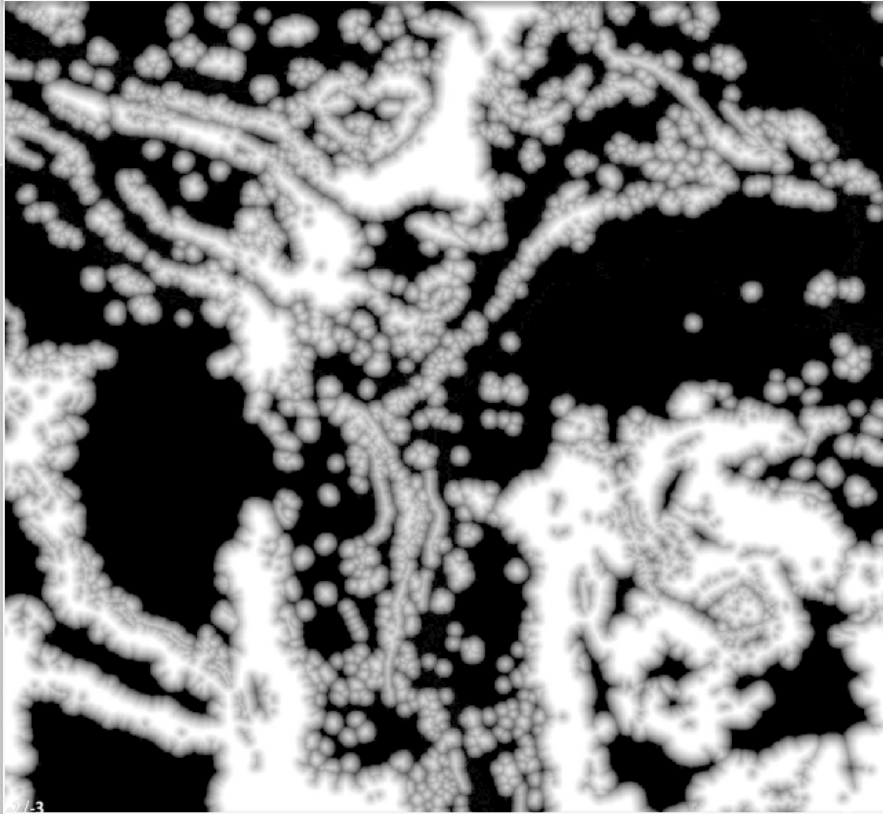
World Data List

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			

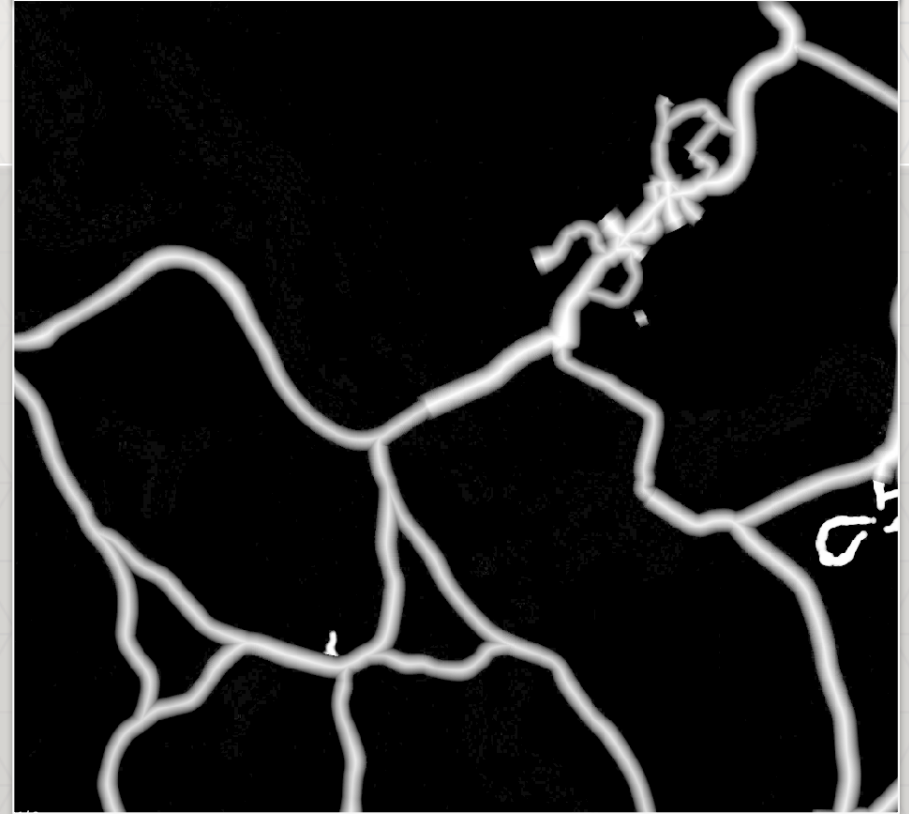


Generated World Data

Topo_Objects



Topo_Roads

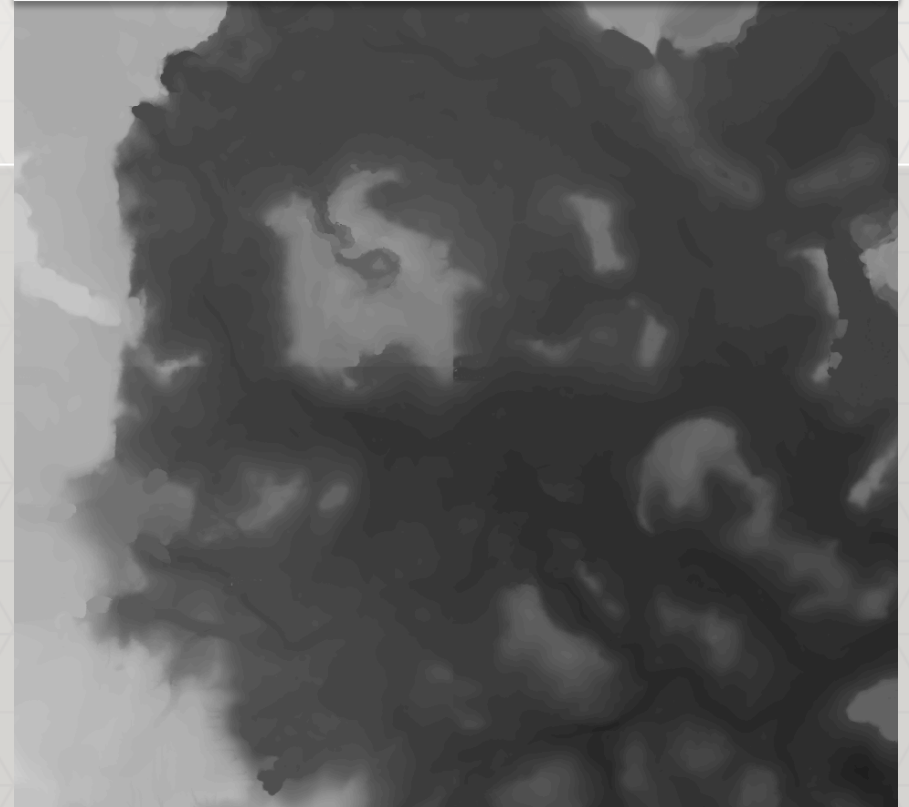




Multiple Height Layers

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



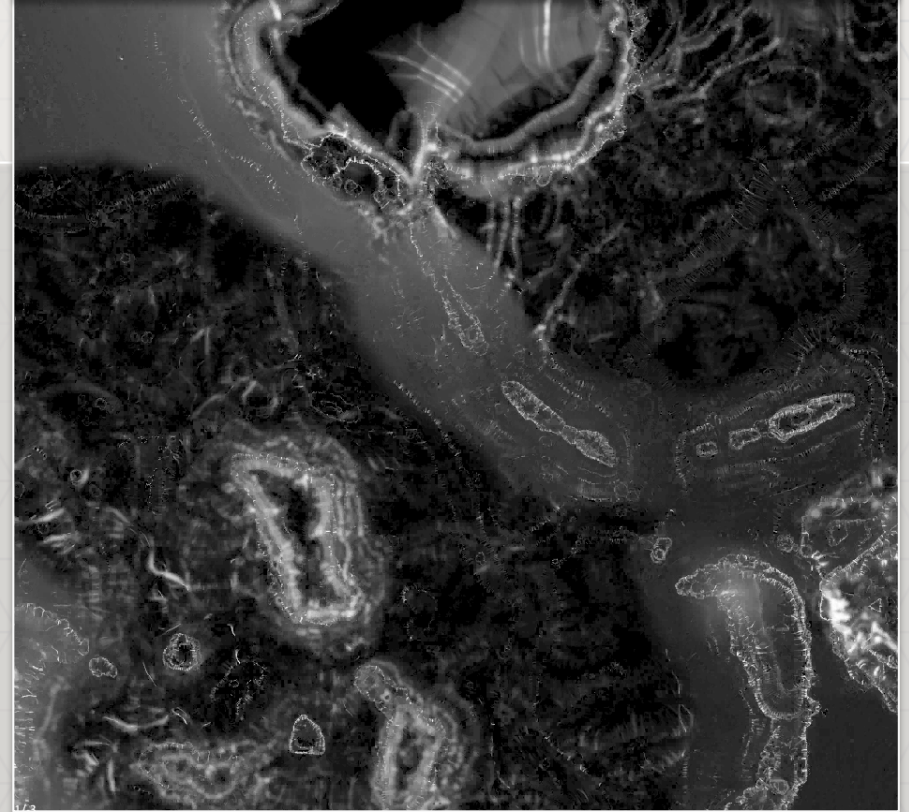


WorldData: Baked Maps

Erosion_Flow



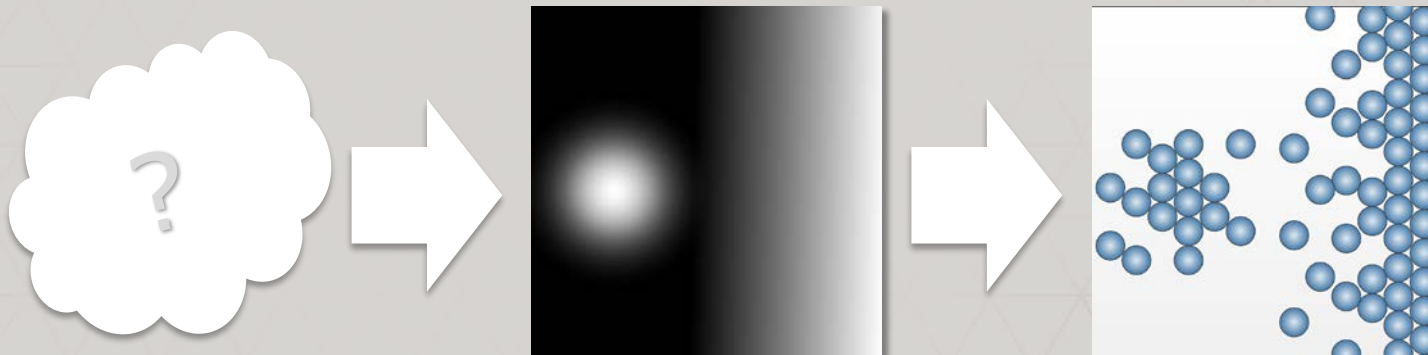
Erosion_Deposition

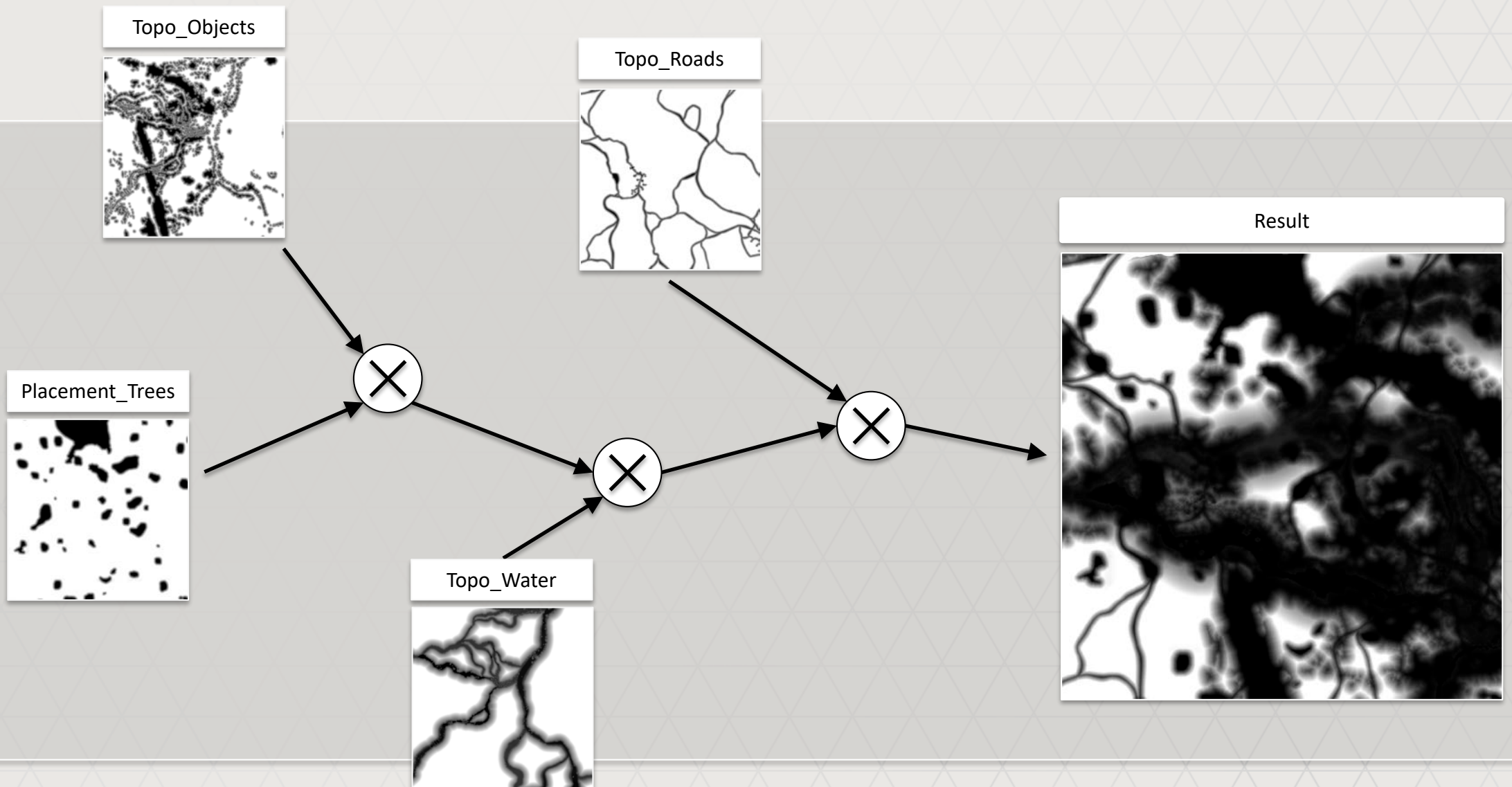




Density logic

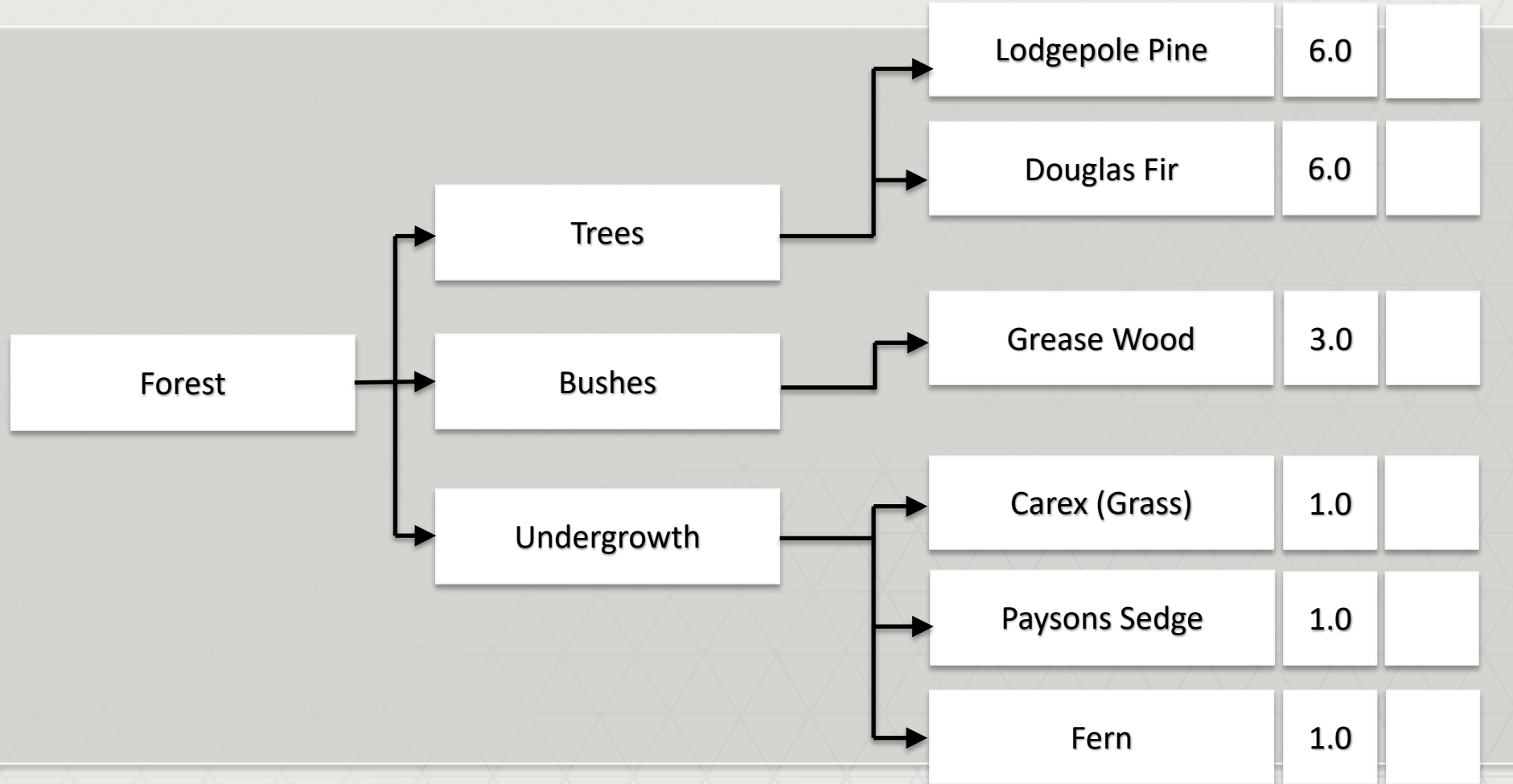
- Artists have full control
 - Hand authored assets
 - The Placement Data
 - **The Placement Logic**



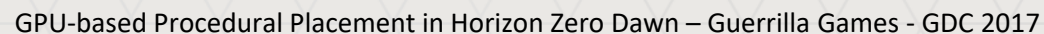




Ecotope Assets



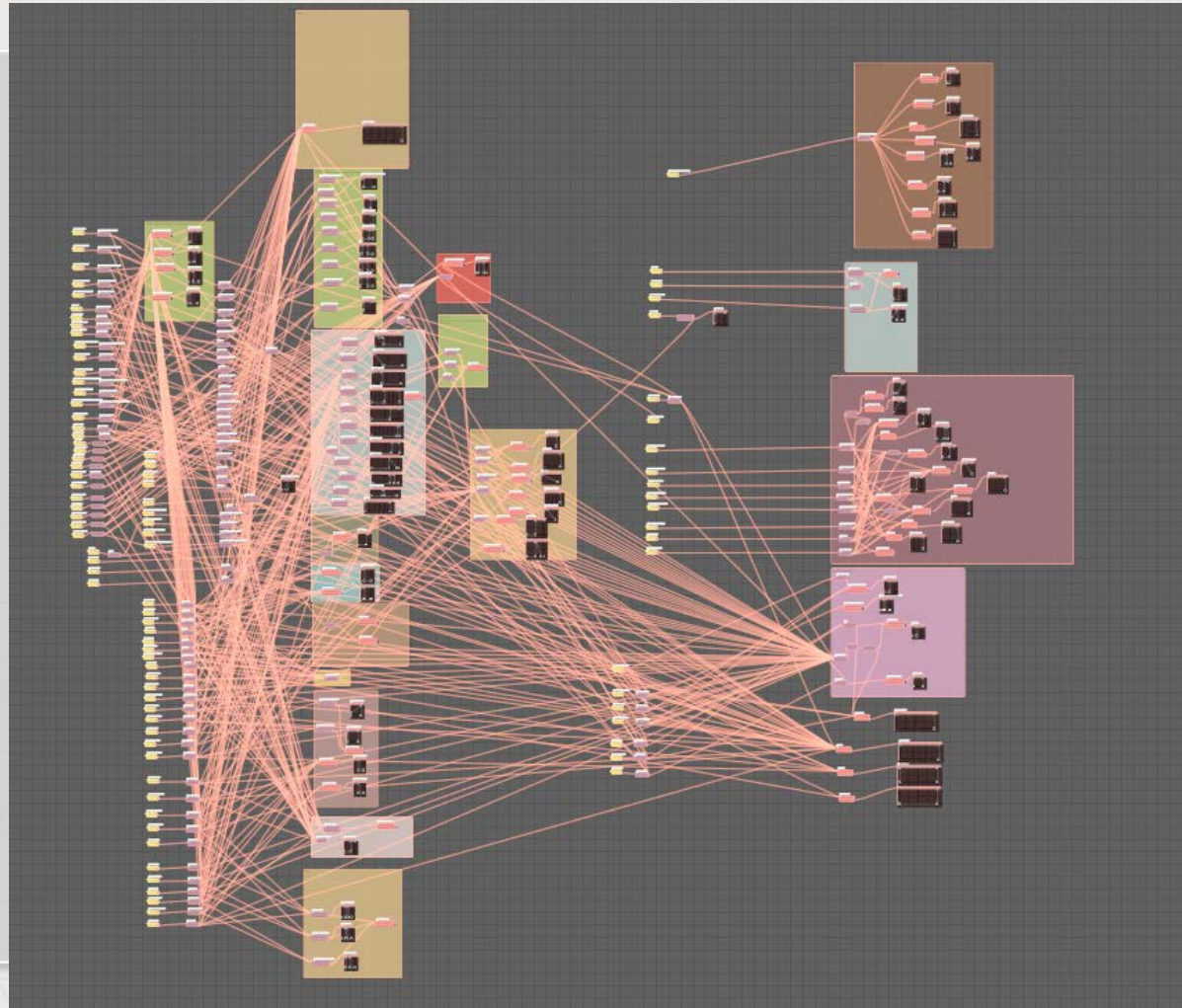








Production Logic



GPU-based Procedural Placement in Horizon Zero Dawn – Guerrilla Games - GDC 2017

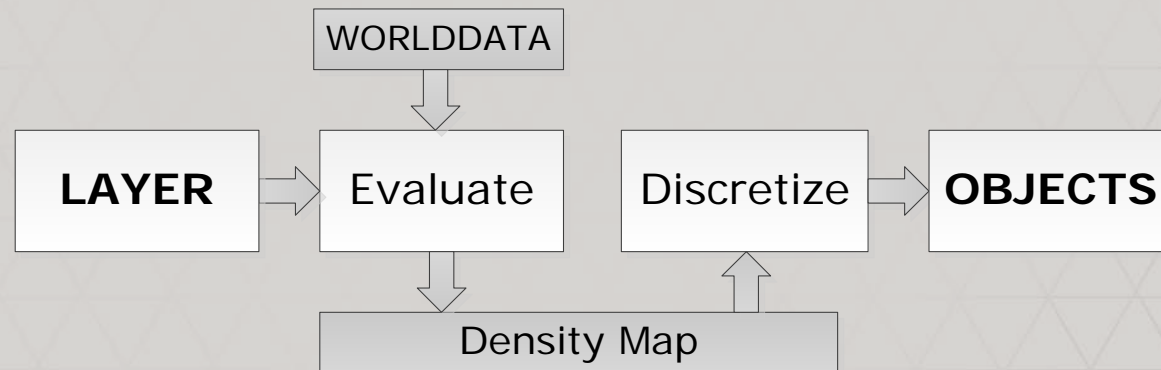






Layer Based Placement

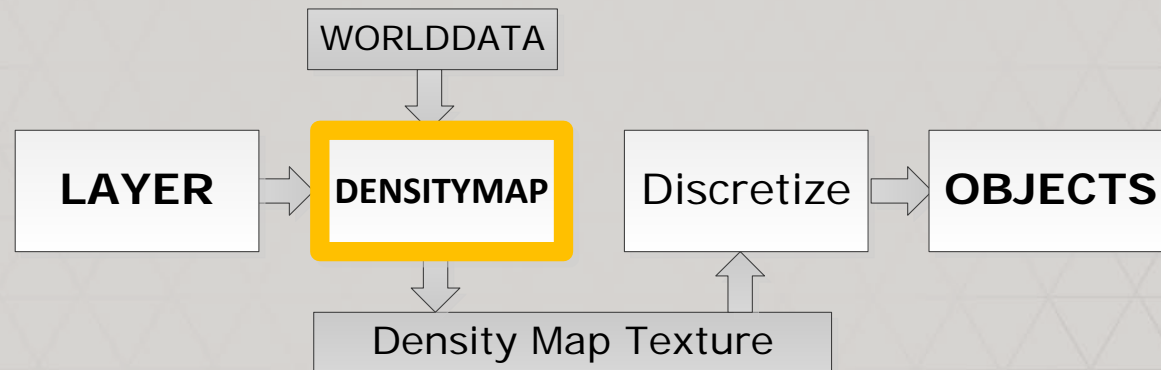
- Prepare our assets
 1. Flatten graph into **Layers**
 2. Compile intermediate form
 3. Optimize and Merge layers





Step1: DENSITYMAP

- Single Layer
- Scaleable granularity
- Mipmapped World Data



400 / 400

0 / MISSING STREAMING MEMORY: 59 MB

20

Placement Layers

Debug Map Size: 256

Search...

#	Tiles and Layers	Resource
326	Paysons_Sedge_Snow_b001_c001_proc_layer[4x]	Paysons_Sedge_Snow_b001_c001_proc_layer[4x]
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_layer[2x]
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/ecotope_20_colorado_plateaus/bi...
	Curve Lookup[55] - Curve: Groundcover...	ecotopes/ecotope_20_colorado_plateaus/bi...
	Load[0, B] - World Data: Placement_Unde...	ecotopes/ecotope_20_colorado_plateaus/bi...

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...
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	

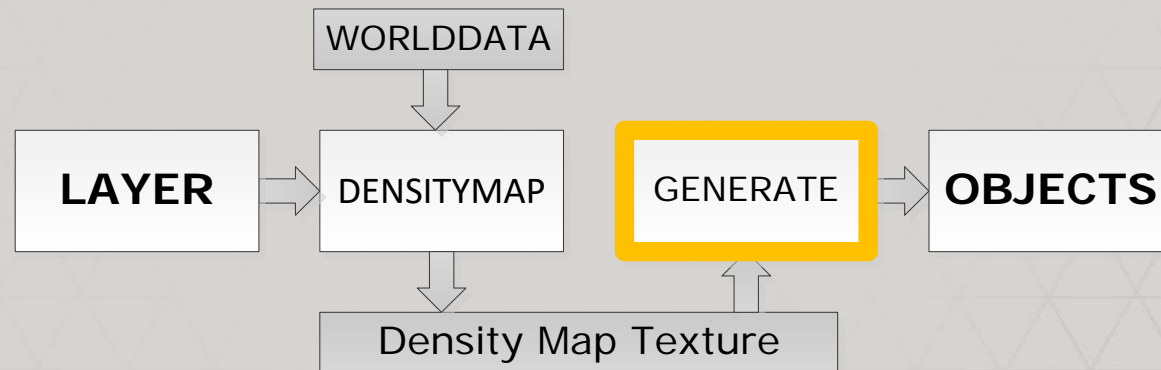
9

0/10



Step2: GENERATE

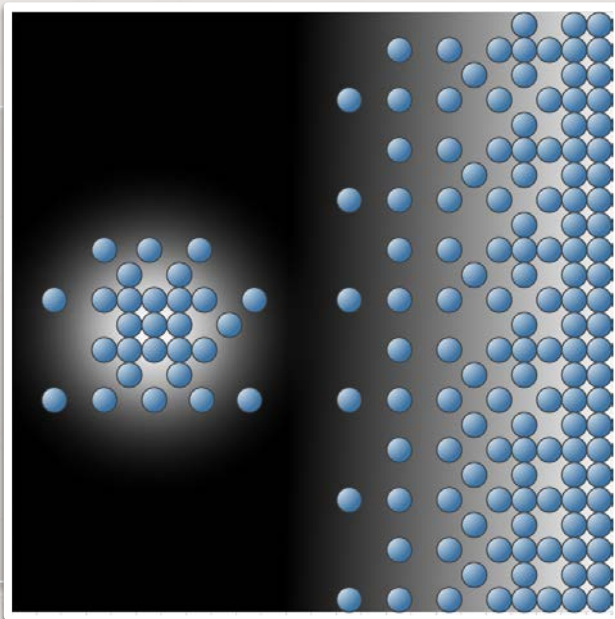
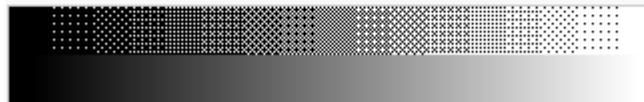
- Discretizing step
- **Dither based**
- Responsible for collision





Step2: GENERATE

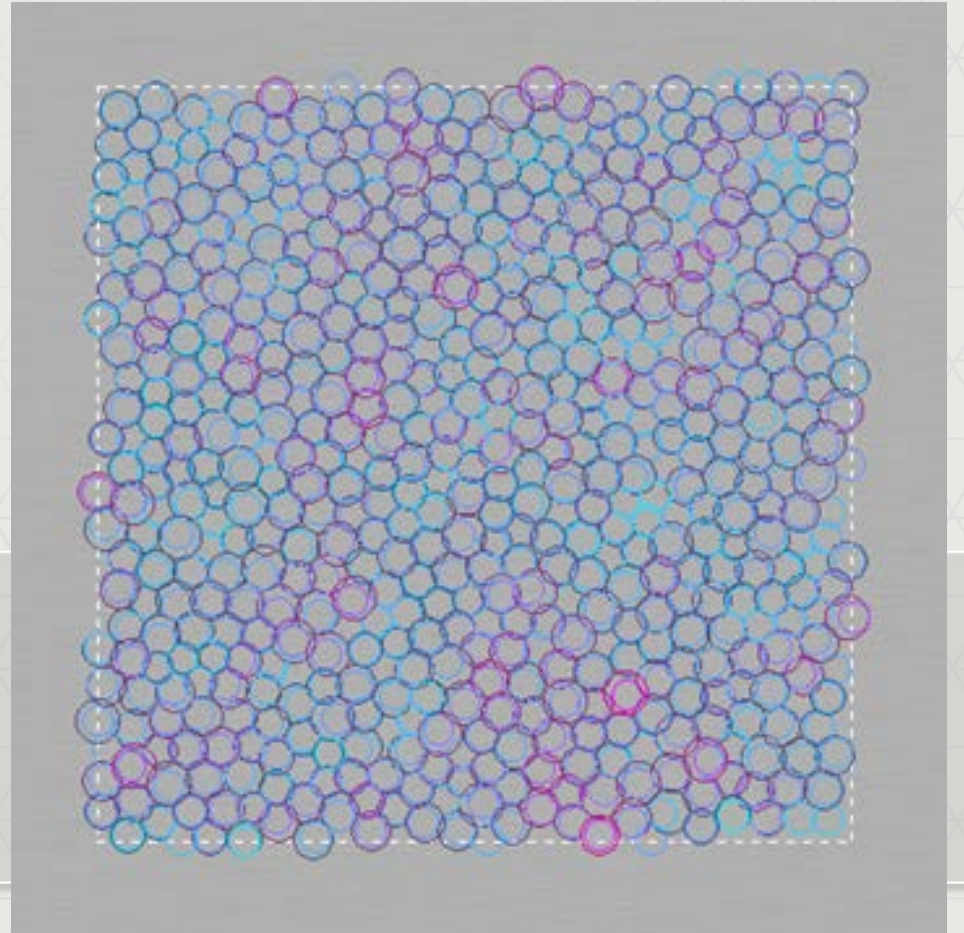
- Discretizing step
- Responsible for collision
- **Dither based**


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




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

1

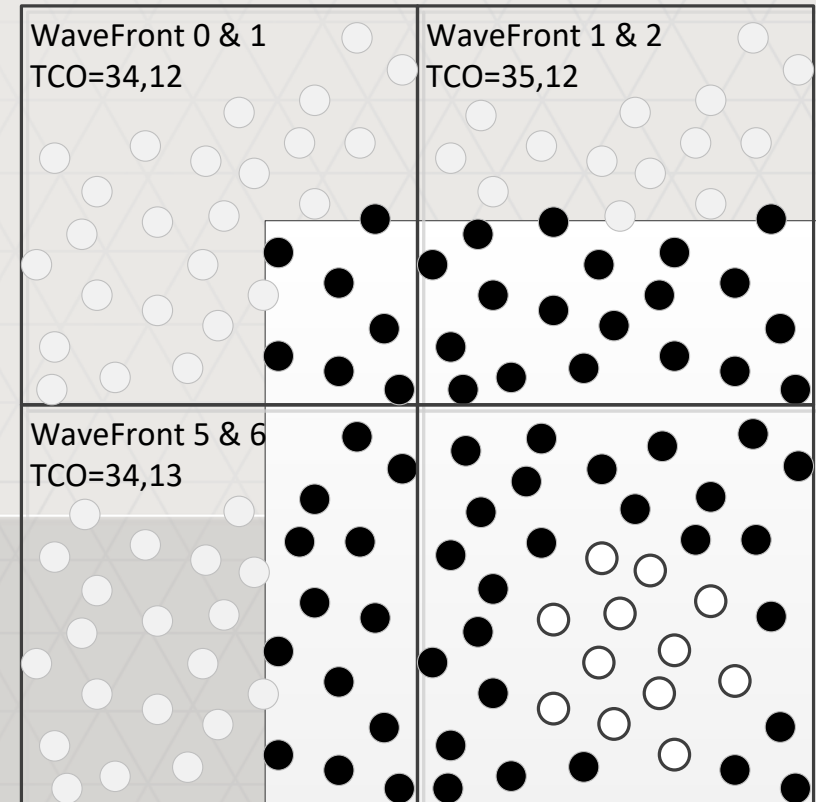




Step2: GENERATE

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

~10 μ s, VGPR: **28**, SGPR: **64**, Cycles: **342**





Search...

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

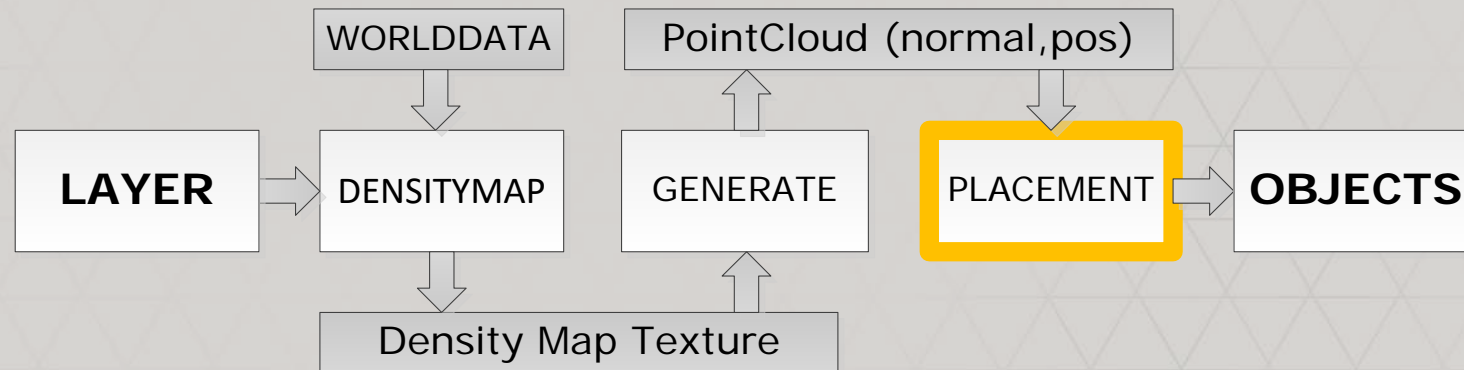
Property	Value	Resource
Group Flags	[A]ccum	
Merged Placements:		
Douglas_Fir_Snow_b001_c003		ecotopes/pl...
Douglas_Fir_Snow_b001_c003		ecotopes/pl...
Douglas_Fir_Snow_b001_c003		ecotopes/pl...
Douglas_Fir_Snow_b001_c003		ecotopes/pl...
Douglas_Fir_Snow_b001_c003		ecotopes/pl...
Name	Douglas_Fir_...	
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

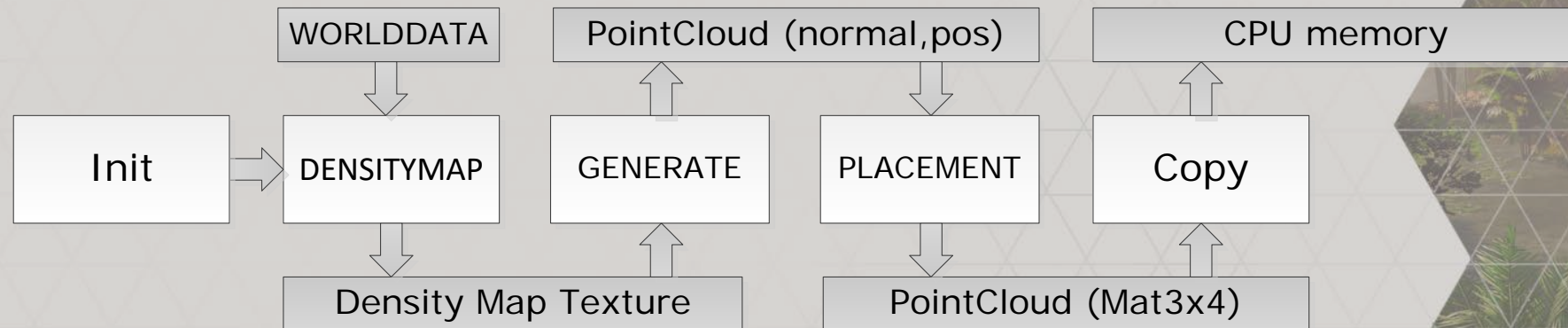
~7 μ s, VGPR: **28**, SGPR: **40**, Cycles: **347**





Pipeline overview

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





Solving Collision

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





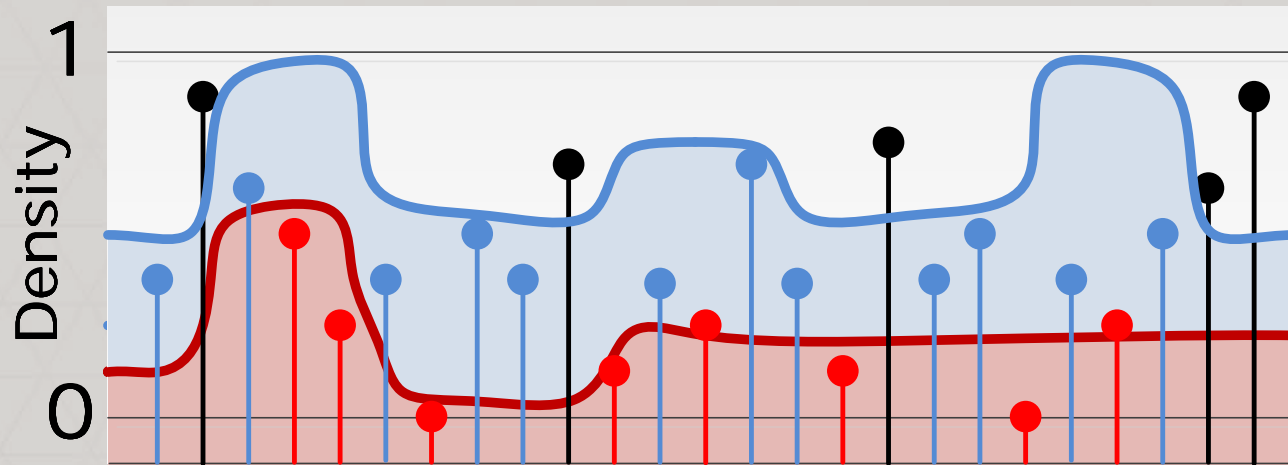
Layered Dithering





Layered Dithering

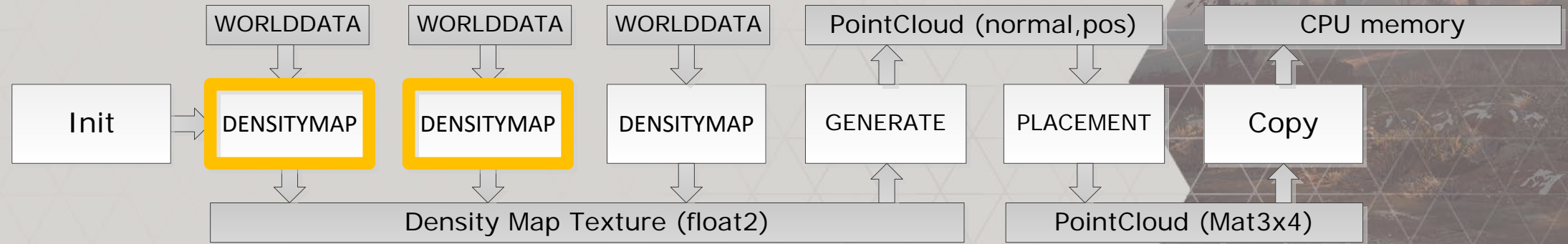
- Layered density maps
 - Two values in density map
 - Two-Sided threshold test





Layered Dithering

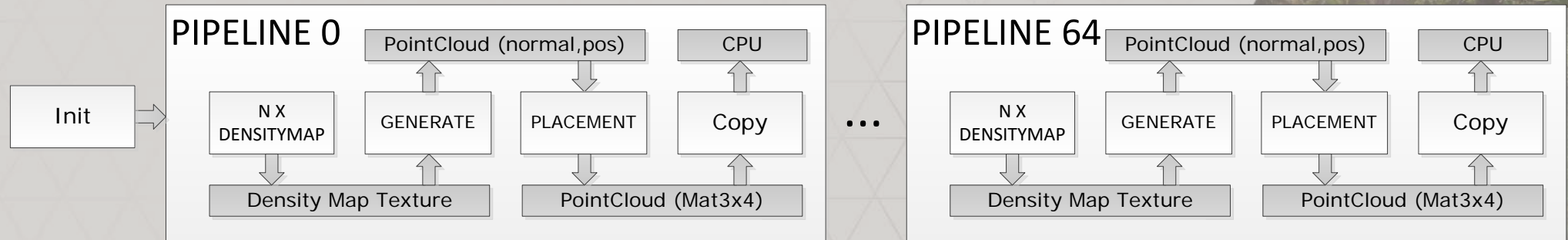
- DENSITYMAP overhead
 - Independent eval
 - Might need DENSITYMAP for non-placing layers
 - More work, but No Flushes
 - Sparse placement causes dependency overhead
 - Use ordering heuristics to reduce DENSITYMAP/GENERATE





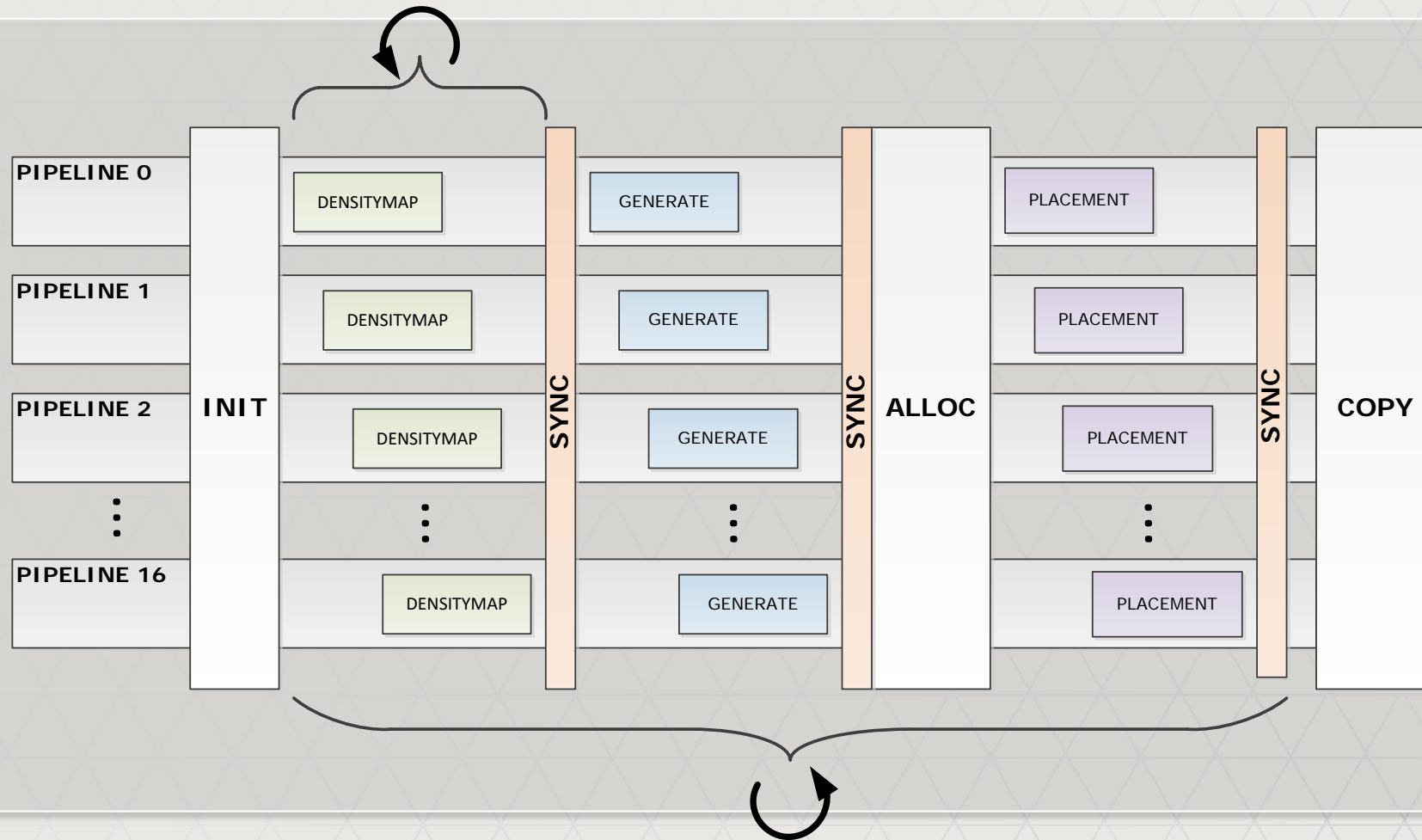
Pipelining on GPU

- 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?

