Optimizing Mobile Games with Gameloft and ARM

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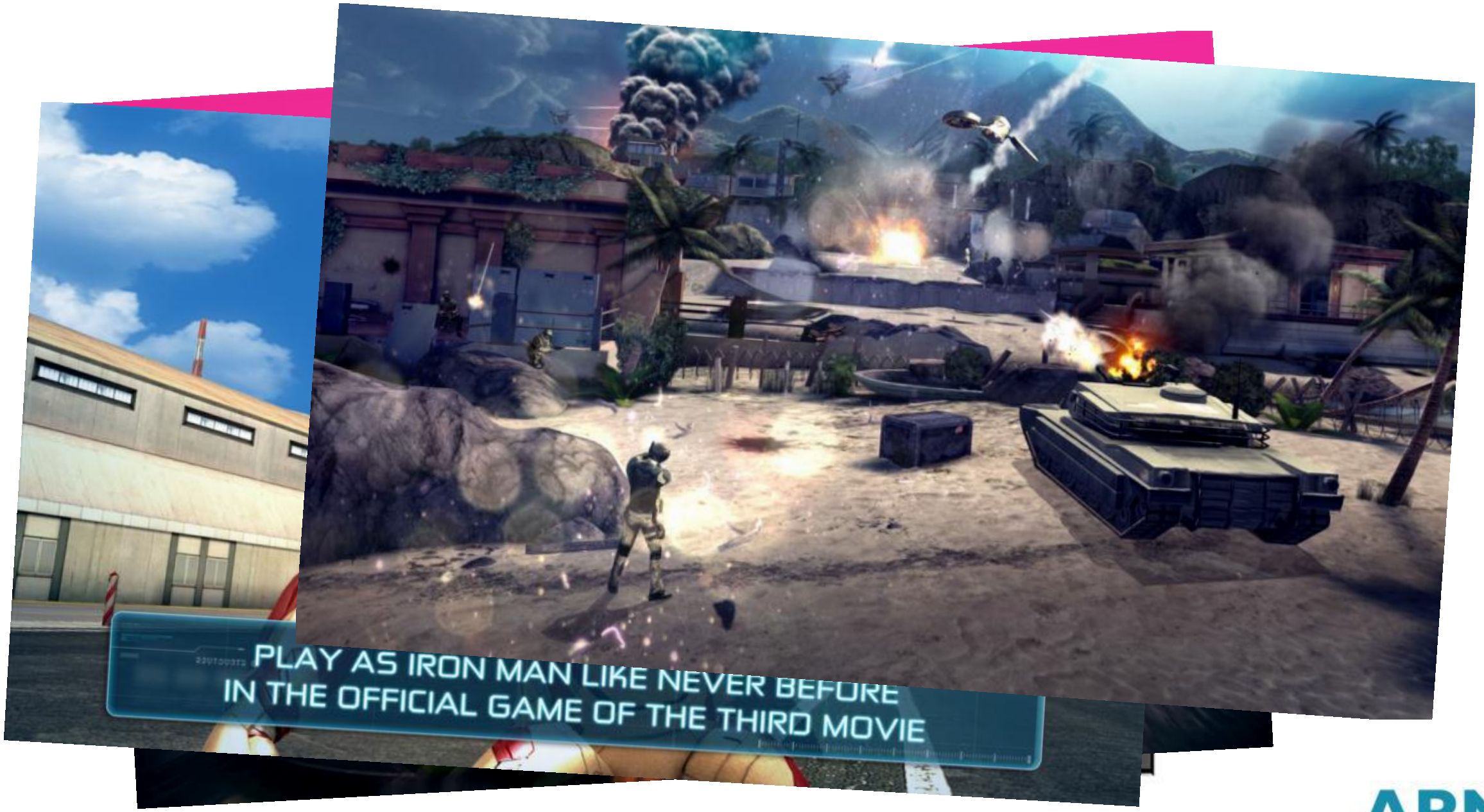
ARM Ecosystem

- My first role in ARM was in Developer Relations
- Developers came to us to ask for help
- We couldn't share their problems with the world
- We couldn't help everyone on a one to one basis

Developer Education

- Developer Education addresses that need
- Since 2012 we've been sharing advice for graphical development
- Developers working with Developer Relations have remained separate
- Until now!


PLAY AS IRON MAN LIKE NEVER BEFORE
IN THE OFFICIAL GAME OF THE THIRD MOVIE

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Today's Agenda

- Gameloft
  - Batching (Iron Man 3)
  - Culling and LOD (Gangstar Vegas)
  - Texture compression (Asphalt 8)

- ARM (That's me)
  - Entry level implementations
  - How to achieve similar results

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Iron Man 3

Improving Draw Calls and Rendering Techniques

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Sorting Objects Before Rendering

- There is no good or bad way to determine which sorting method works best for a game
- Sorting methods reduce overdraw and material changes at the cost of CPU
- Sorting algorithms used for Iron Man 3:
  - Sorting by material
  - Sorting by distance

What Happens When No Sorting Is Applied?

- Mid-range device: average 18FPS, constant micro-freezes
- Over 35 program changes per frame
- The skybox is rendered in the 27th draw call / 150

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Sorting Objects Before Rendering

- Every shader program change is costly
- It will depend a lot on the number of programs your game has
- Using a texture atlas will create the same materials, thus allowing better material sorting
- Sorting front to back will reduce the overdraw

Material Sorting Results

- Reduced program changes to an average of 16
  - Micro-freezes are reduced.
- Average 22FPS, smoother gameplay

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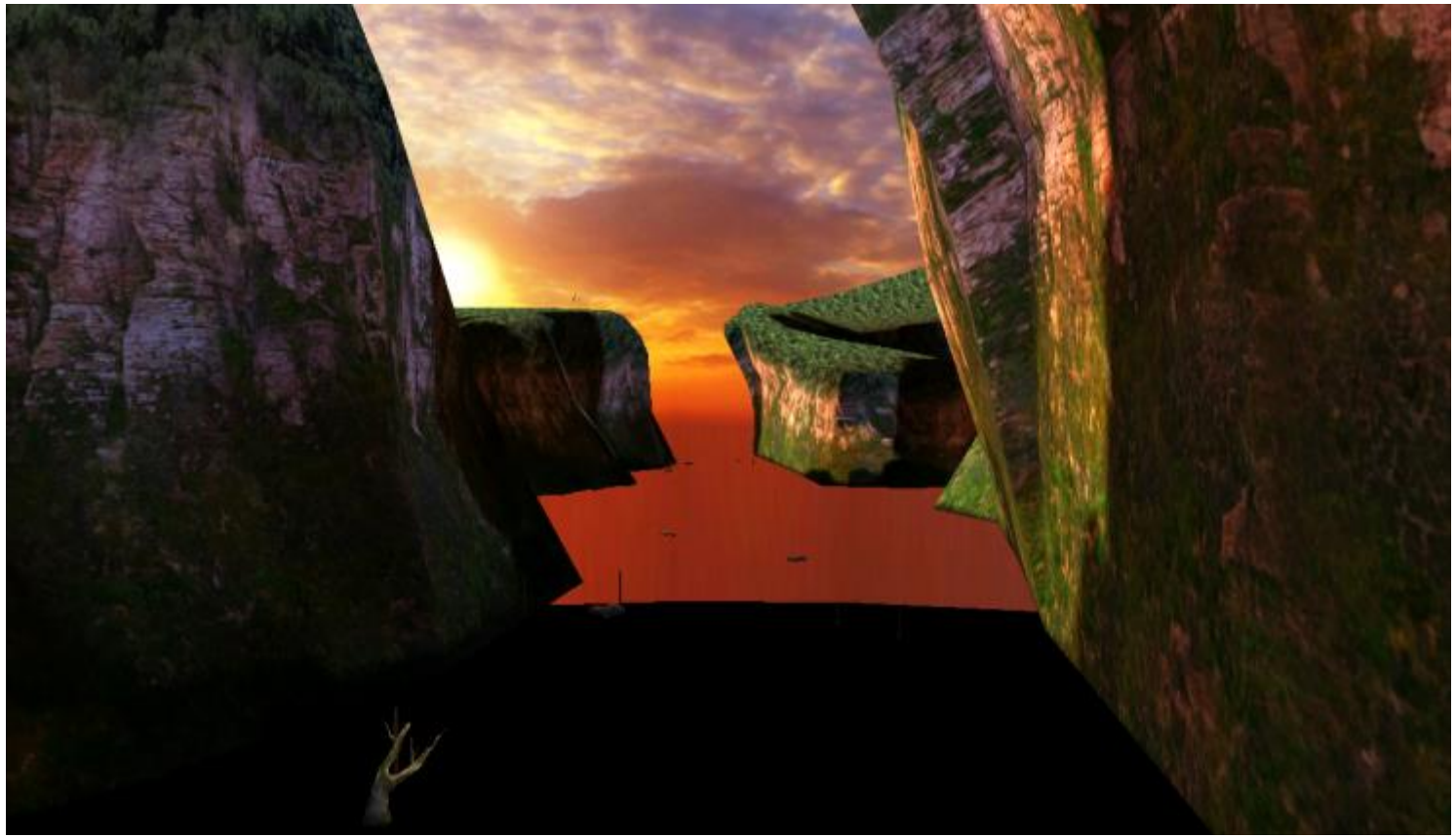
Material Sorting Results

- But we still have a lot of overdraw…



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Front to Back Sorting

- And this is the desired result…

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Front to Back Sorting

- Sorting by distance
  - Front to back sorting will reduce the overdraw, skipping fragment shader execution for all the dropped fragments
  - The transparent objects must be drawn back to front for a correct ordering. The blending is done with what is already drawn in the color buffer
  - For OpenGL® ES 3.0, avoid modifying the depth buffer from the fragment shader or you will not benefit from the early Z testing, making the front to back sorting useless

Front to Back Sorting Results

- Sorting first by material, objects with the same material then sorted front to back
- Constant 24FPS
- The skybox is rendered in the 82nd draw call / 135, being the last opaque object

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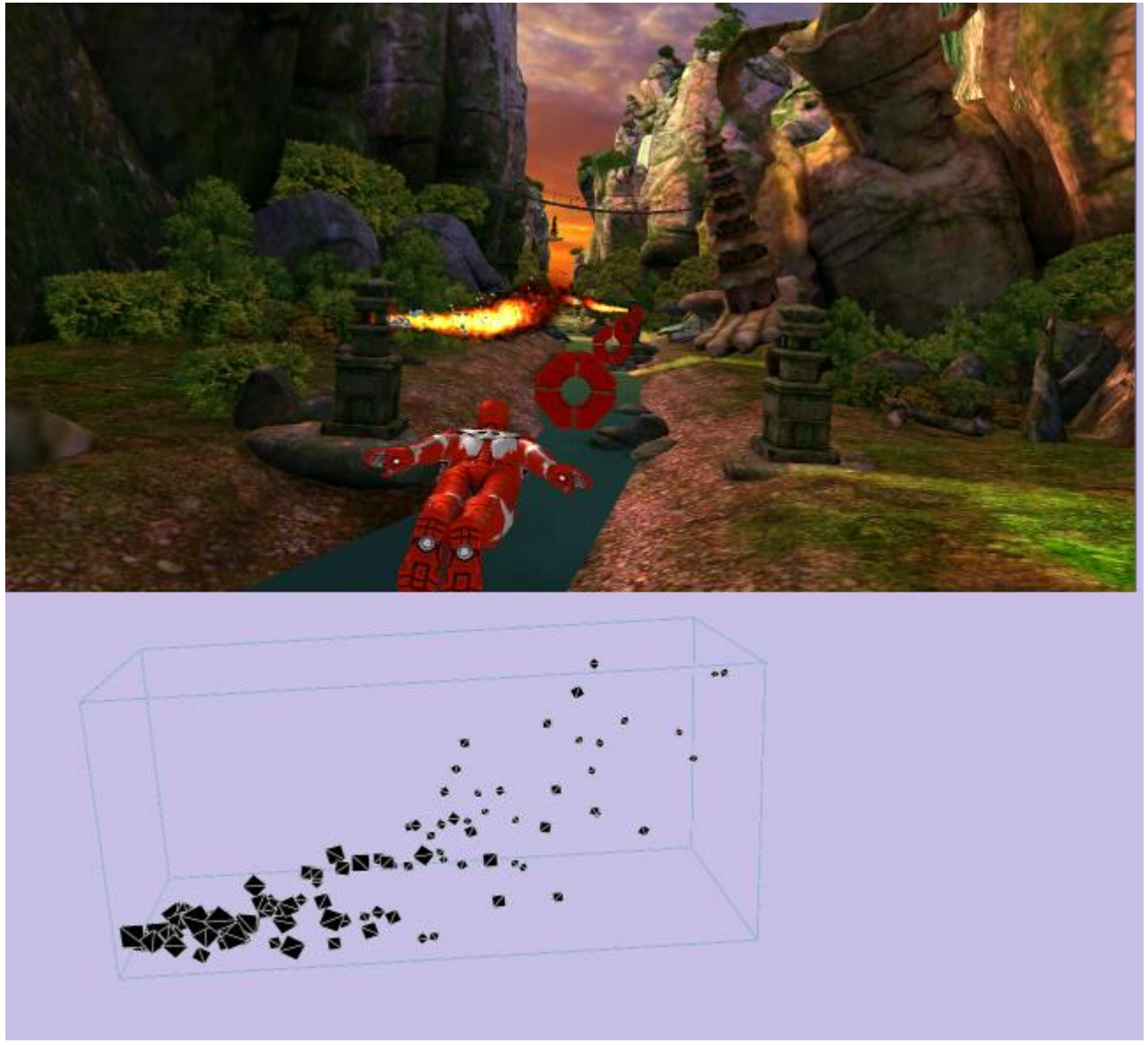
Dynamic Batching

- Objects that are not static batched and by nature require dynamic movement can be batched at runtime
- Objects need to share the same material to be batched into one single draw call
- Dynamic batched objects require new geometry and the duplication of all the vertex attributes, adding a constraint on the number of vertices

Dynamic Batching

- Should be applied to dynamic objects that share the same material, with a constraint on number of vertices, like particles



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Dynamic Batching

- In order for objects to be batchable at runtime:
  - Objects need to use the same program
  - Objects require identical textures
  - Because of draw order constraint, objects require the same transparency property
  - Because of duplicating vertex attributes, dynamic batching on objects requires a lower number of vertices

Sorting Objects Before Rendering

- Good approach to render your scene:
  - Sort all opaque objects based on material and distance from camera
  - This reduces scene overdraw
  - Reducing material change will help a bit on FPS, depending on the hardware, but also helps with micro-freezes
  - For every consecutive draw call that has the same material, dynamic batching is simple and easy to achieve
  - Reduces the actual number of draw calls
  - Reduced micro-freezes and gained ~6FPS by applying sorting algorithms

The Importance of Batching

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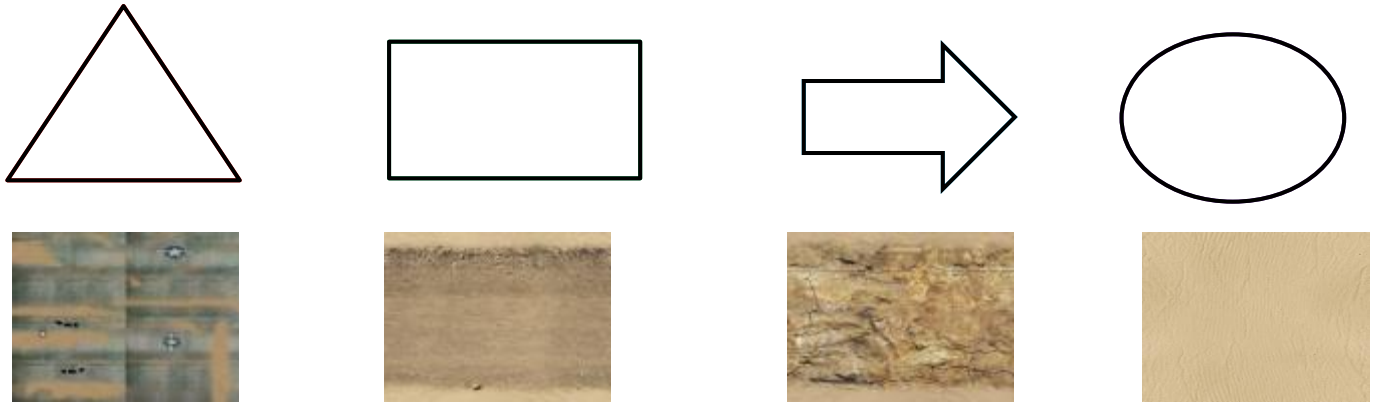
Batching

- Deferred immediate mode rendering
- glDrawElements and glDrawArrays have an overhead
- Less draw calls, less overhead
- DrawCall class stitches multiple objects into one draw call
- Macro functions in shaders make batching as simple as:

```
vec4 pos=transform[getInstance()]*getPosition();
```

Batching



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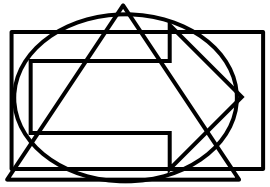
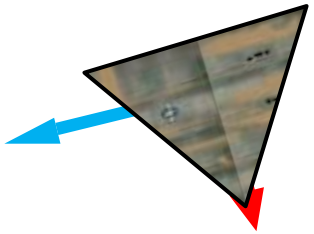
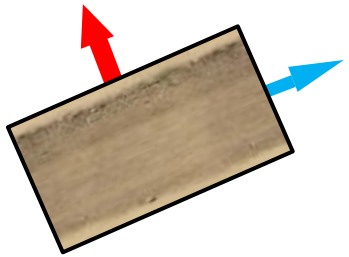
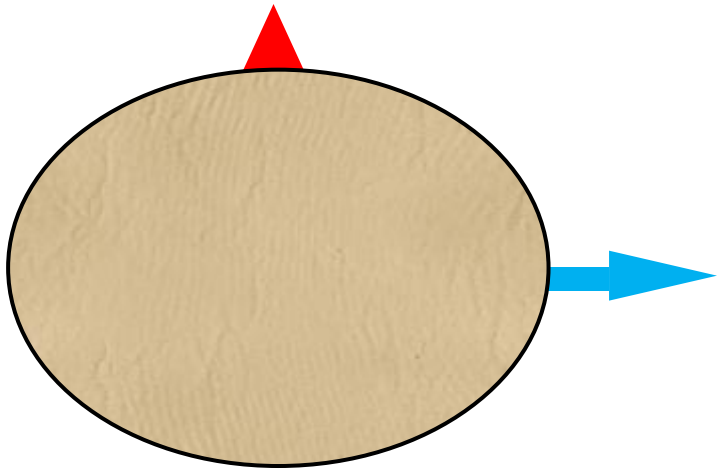
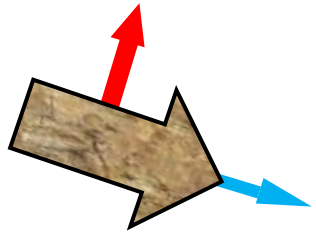
Batching











uniform mat4 transforms[4];

Mixing up a Batch

Mesh 1 [(1,1),(0,1),(0,0),(1,0)]
Mesh 2 [(1,2),(0,2),(0,0)]
Mesh 3 [(2,2),(2,1),(1,1)]
Index1: [0,1,2,0,2,3]
Index2: [0,1,2]
Index3: [0,1,2]

Attrib1:[(1,1),(0,1),(0,0),(1,1),(1,2),(0,0),(1,0),(2,2),(2,1),(1,1)]
Attrib2:[0,0,0,0,1,1,1,2,2,2]

Index: [0,1,2,0,2,3,4,5,6,7,8,9]

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Serving up a Batch

Vertex shader:

```
uniform mat4 transforms[3];
attribute vec4 pos;
attribute float id;
void main(){
    mat4 trans=transforms[(int)id];
    glPosition=trans*pos;
}
```

GL Code:

```
float transforms[16*instanceCount];
.
. /* Load matrices into float array */
.
glUniformMatrix4fv(transID,4,false,transforms);
```

Scene Batching

- Multiple geometries drawn in a single draw call:
- `drawbuilder.addGeometry(geo1);`
- `drawbuilder.addGeometry(geo2);`
- `drawbuilder.addGeometry(geo3);`
- `drawbuilder.Build();`

- Always draws in the same order from a start and end index. Unused objects can be scaled out to zero
- Can lead to inefficiency of vertex shaders

Remixing a Batch

Mesh 1 [(1,1),(0,1),(0,0),(1,0)]
Mesh 2 [(1,2),(0,2),(0,0)]
Mesh 3 [(2,2),(2,1),(1,1)]
Index1: [0,1,2,0,2,3]
Index2: [0,1,2]
Index3: [0,1,2]

Attrib1:[(1,1),(0,1),(0,0),(1,1),(1,2),(0,0),(1,0),(2,2),(2,1),(1,1)]
Attrib2:[0,0,0,0,1,1,1,2,2,2]

Index: [0,1,2,0,2,3,4,5,6,7,8,9]

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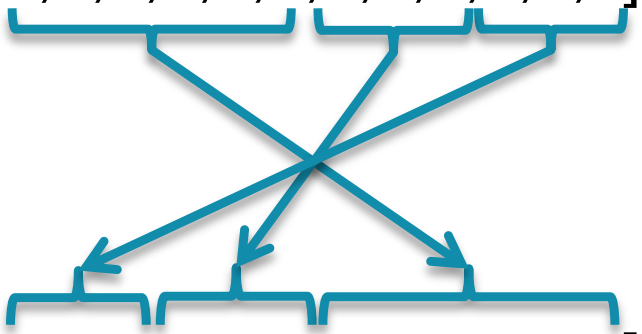
Remixing a Batch

Attrib1:[(1,1),(0,1),(0,0),(1,1),(1,2),(0,0),(1,0),(2,2),(2,1),(1,1)]

Attrib2:[0,0,0,0,1,1,1,2,2,2]

These IDs are the same

Index: [0,1,2,0,2,3,4,5,6,7,8,9]



Index: [7,8,9,4,5,6,0,1,2,0,2,3]

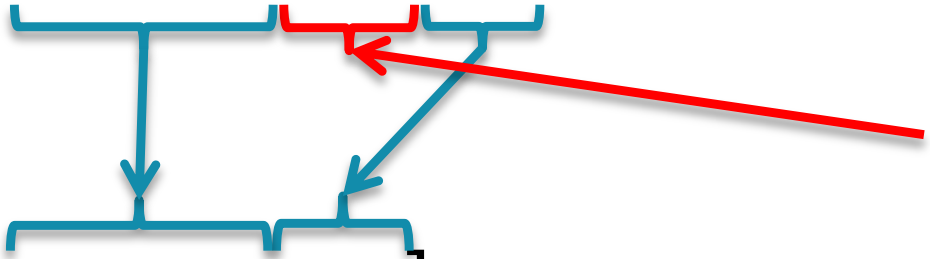
But now the draw order is different

Remixing a Batch

Attrib1:[(1,1),(0,1),(0,0),(1,1),(1,2),(0,0),(1,0),(2,2),(2,1),(1,1)]

Attrib2:[0,0,0,0,1,1,1,2,2,2]

Index: [0,1,2,0,2,3,4,5,6,7,8,9]



Index: [0,1,2,0,2,3,7,8,9]

These vertices are still processed

…But never get drawn

Object Instancing

- Multiple geometries or single object instances:

```
for(int i=0;i<50;i++)
  drawbuilder.addGeometry(geo1);
drawbuilder.Build()
```

- Can implement LOD switching when objects are sorted front to back and correctly culled

- So let's talk about culling

Batching / Draw Call Reduction

Case Study: Gangstar Vegas

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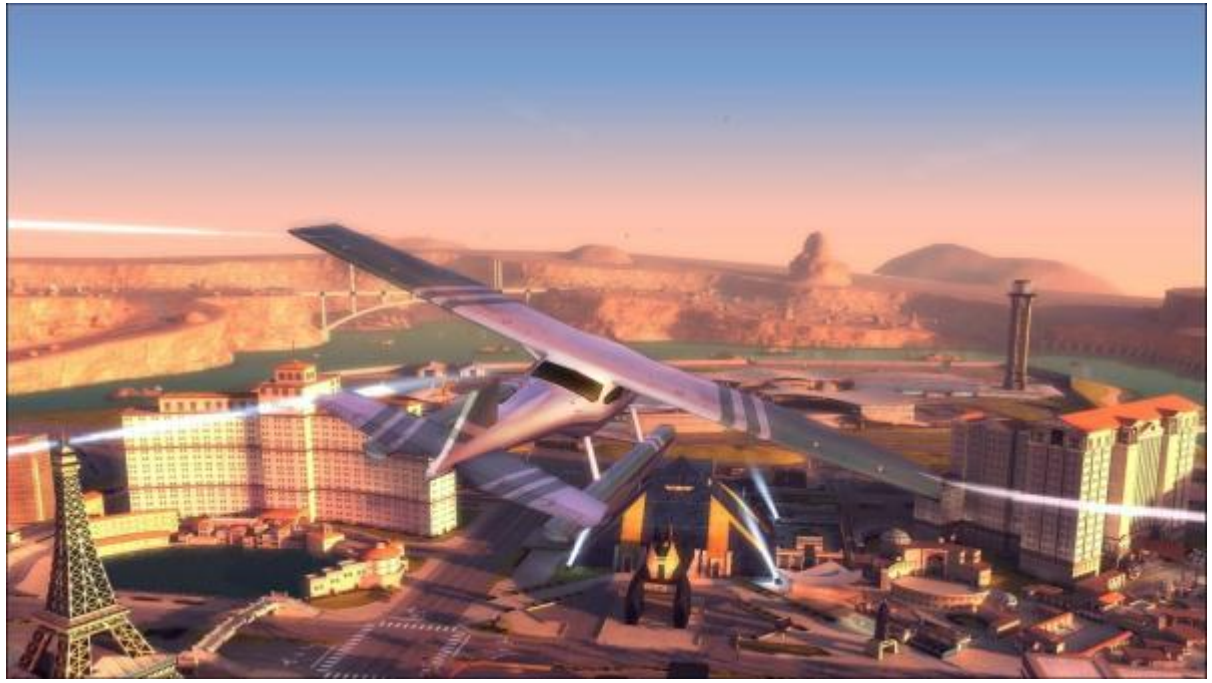
Challenges

- Big map: ~16 km²
  - Move by foot / by car / by plane
  - Interior/exterior environments



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Streaming

- Constant streaming is needed :
  - Meshes / LODs
  - Streaming thread with second OpenGL® context
  - Textures
  - Same streaming thread as meshes
  - Lower mipmap level always available

- Also streamed :
  - Animations
  - Sounds
  - Physics data

Reducing Draw Call Count & Cost

- Draw calls are one of the major bottlenecks on mobiles
  - On a very powerful device, stay under 300 draw calls
  - On most devices => 100 to 200 at max
- Techniques used to reduce draw call count:
  - Static batching
  - 2D grid culling
  - Near/far city
- To reduce draw call cost:
  - Index & Vertex Buffer Objects (IBO / VBO) for static geometry

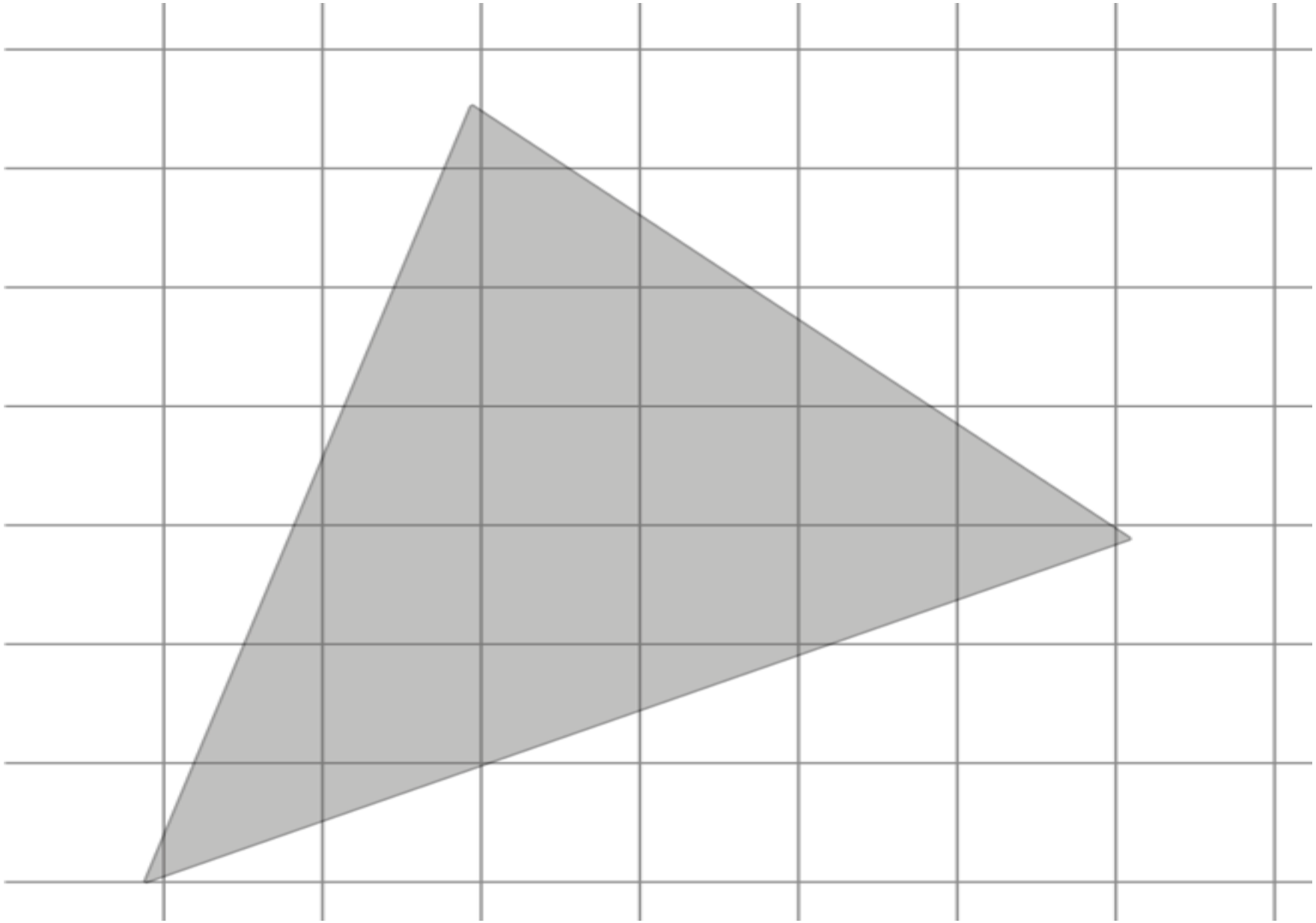
2D Grid Culling

- Objects are linked to the cells of a grid
  - A simple 2D grid is used:
  - 128x128 cells
  - Cell size : 30m x 30m
  - An object can belong to one or more cells

- Culling process:
  - Get cells visible by camera's frustum 2D projection on grid
  - Middle cells: fully in frustum
  - Border cells: partially in frustum
  - Middle cell objects: directly added to render list
  - Border cell objects: AABBoxes are tested vs camera frustum

- Grid is also used for streaming:
  - Radius Add (175m) / Radius Safe (205m)

Frustum & Grid



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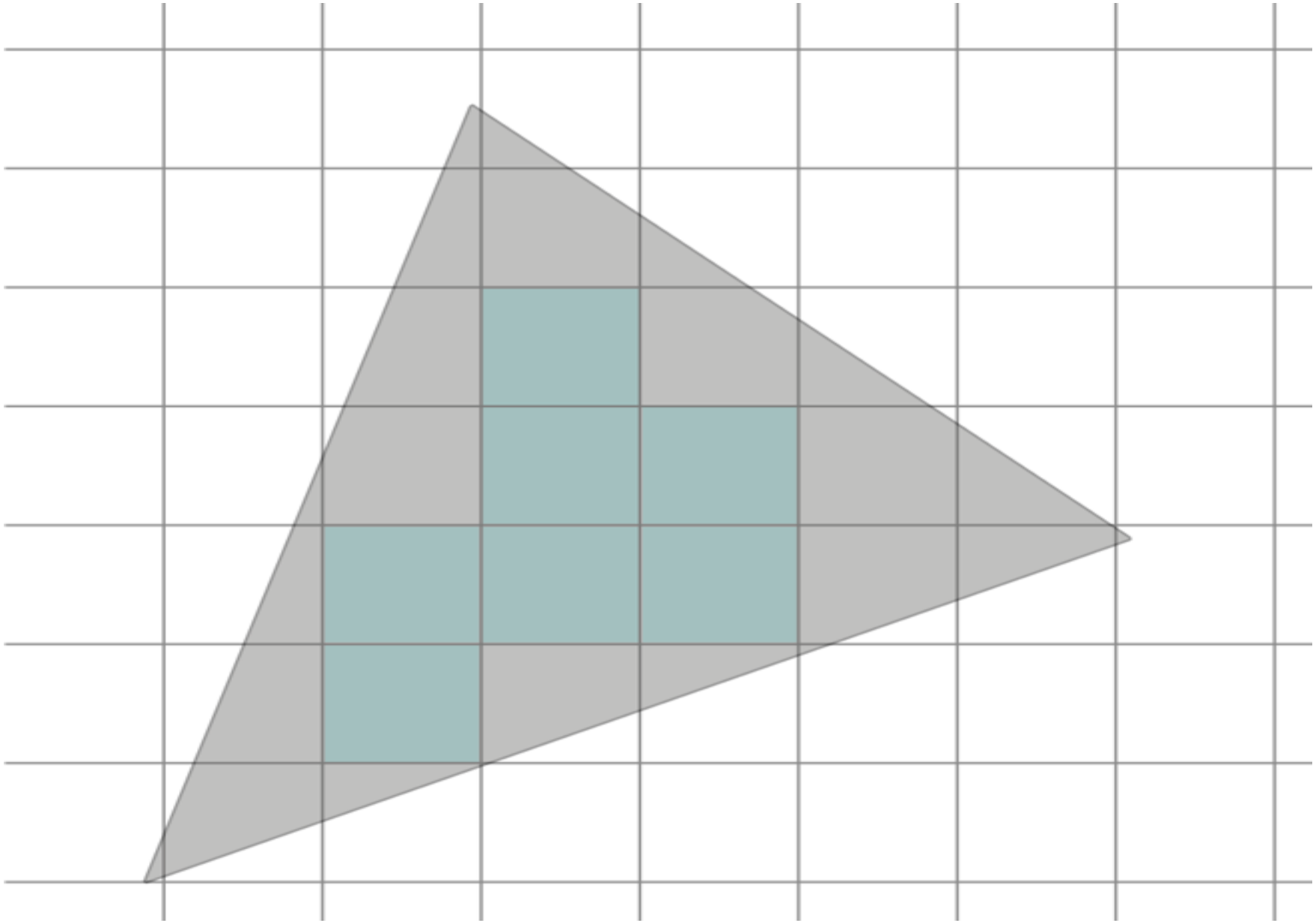
Middle Cells



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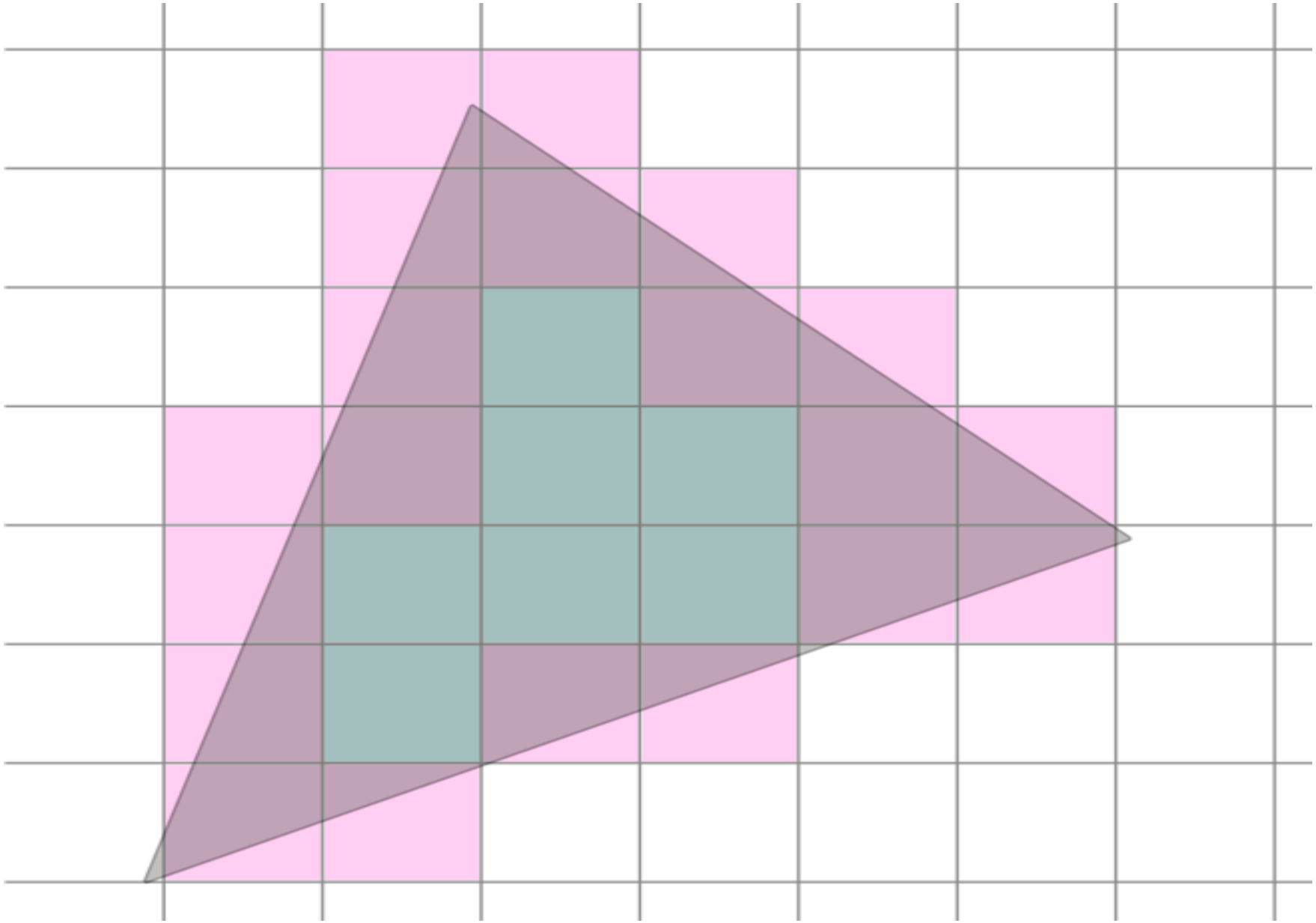
Border Cells



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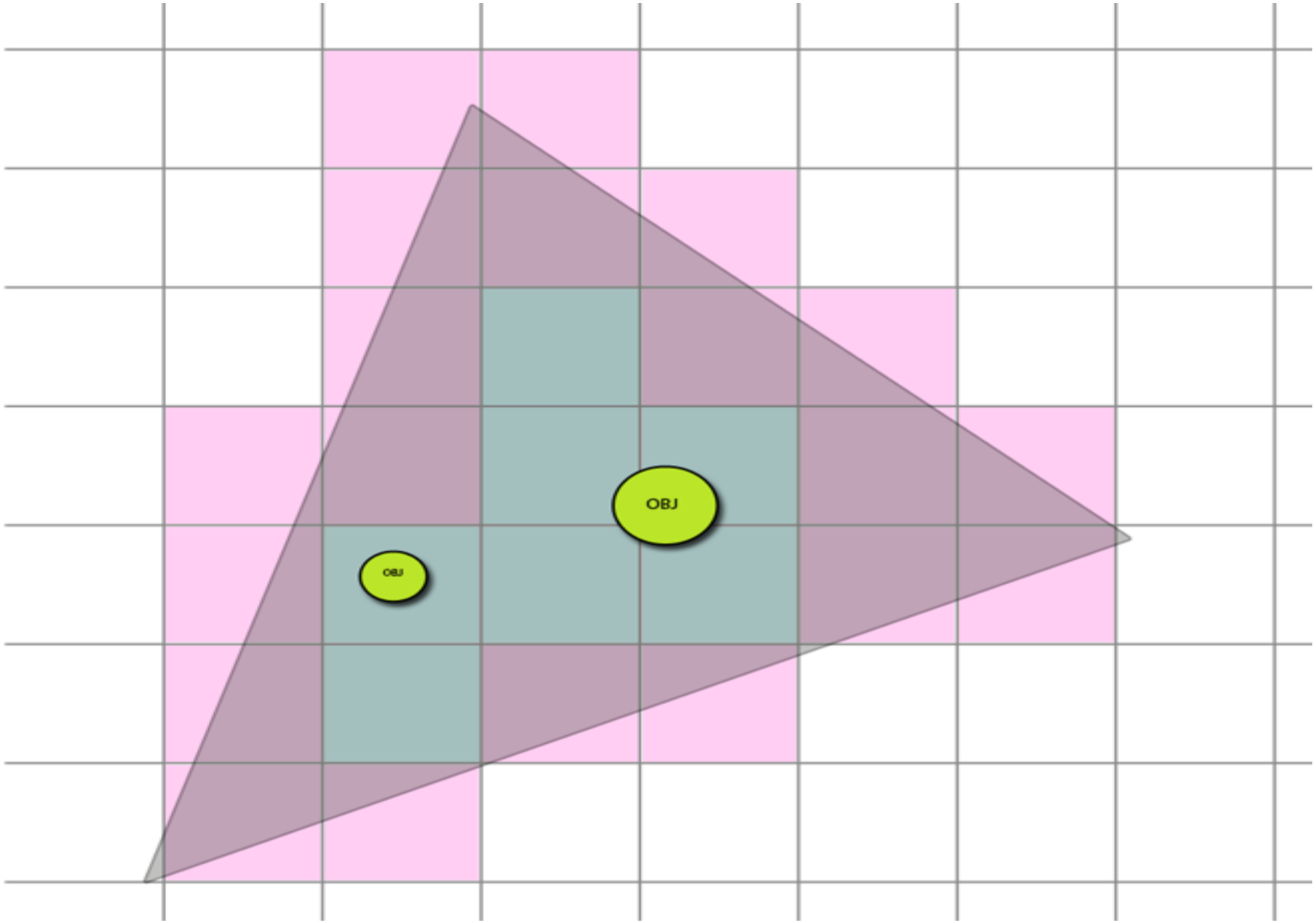
Objects will be drawn directly



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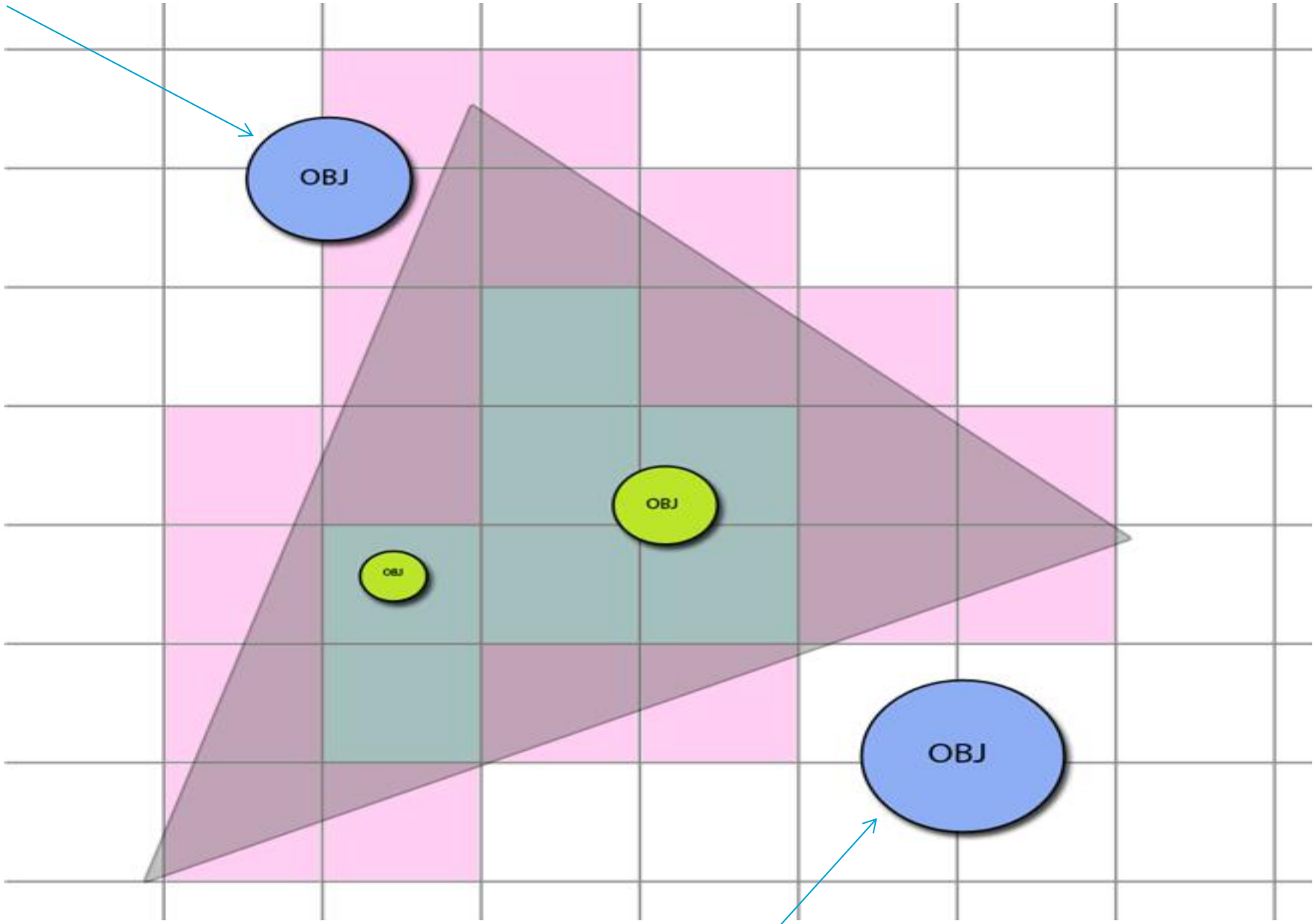
AABOX culling => culled



Outside frustum => directly culled

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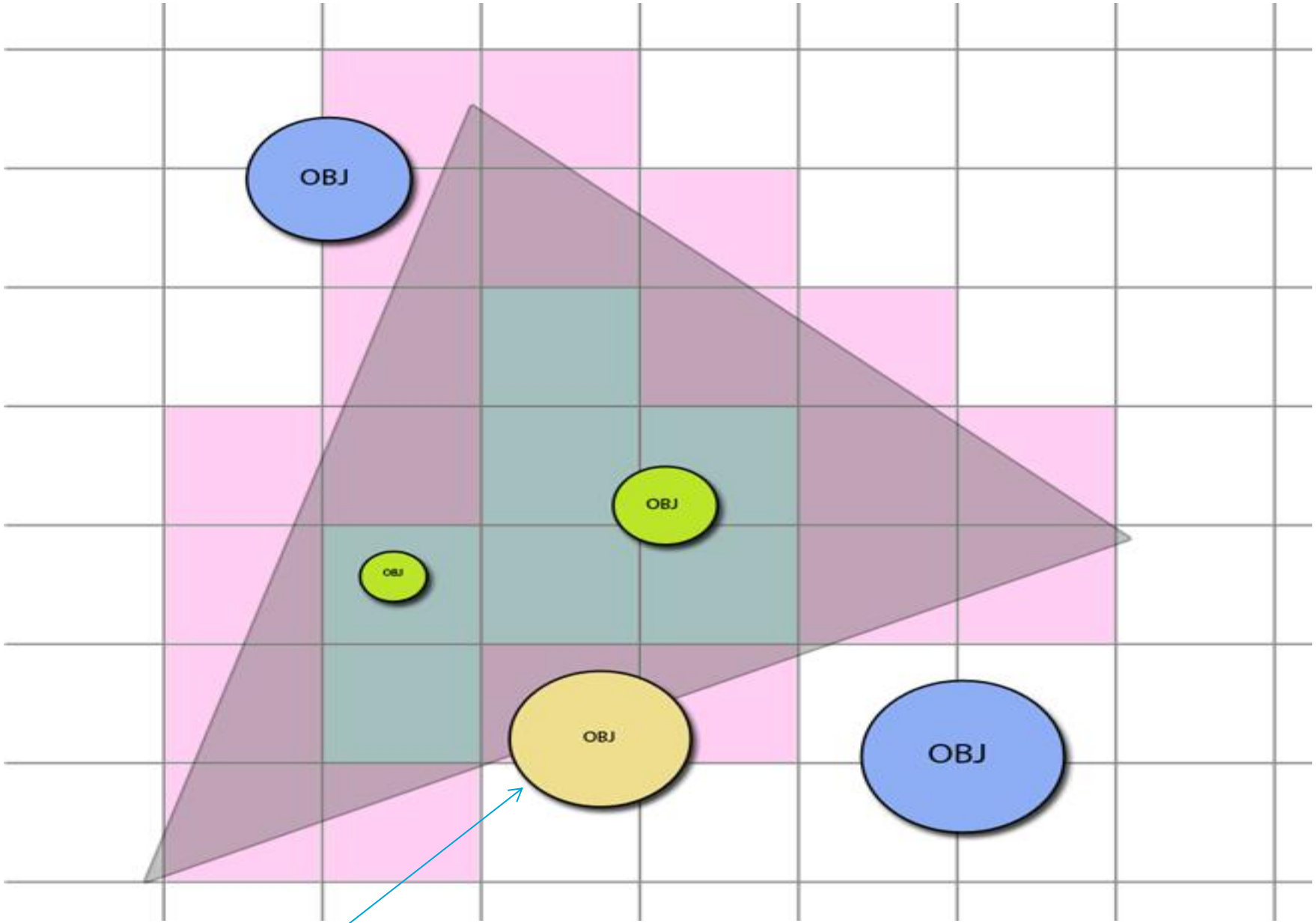

AABOX culling => visible

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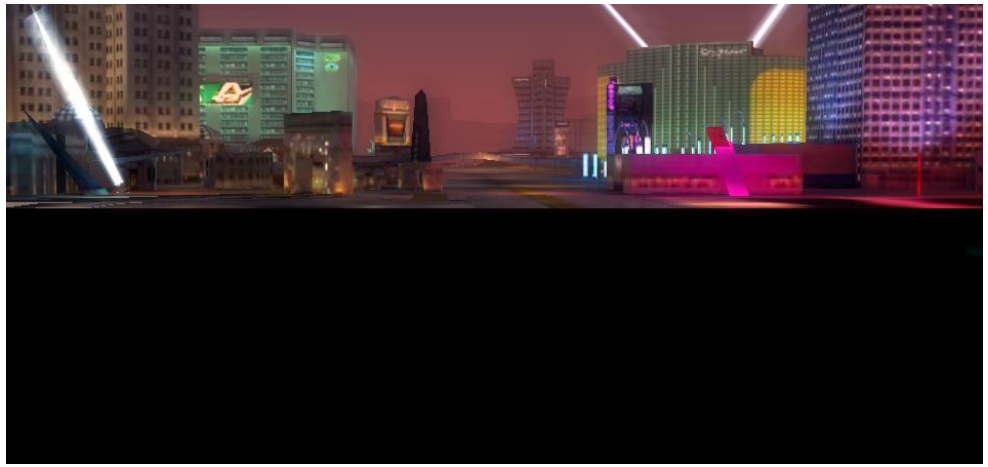
Near/Far Cities

- Two different city meshes are used:

1. Near city:
   - High resolution
   - Streamed
2. Far city
   - Low resolution
   - Always available



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Full city: 77 draw calls

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Near City : 48 draw calls

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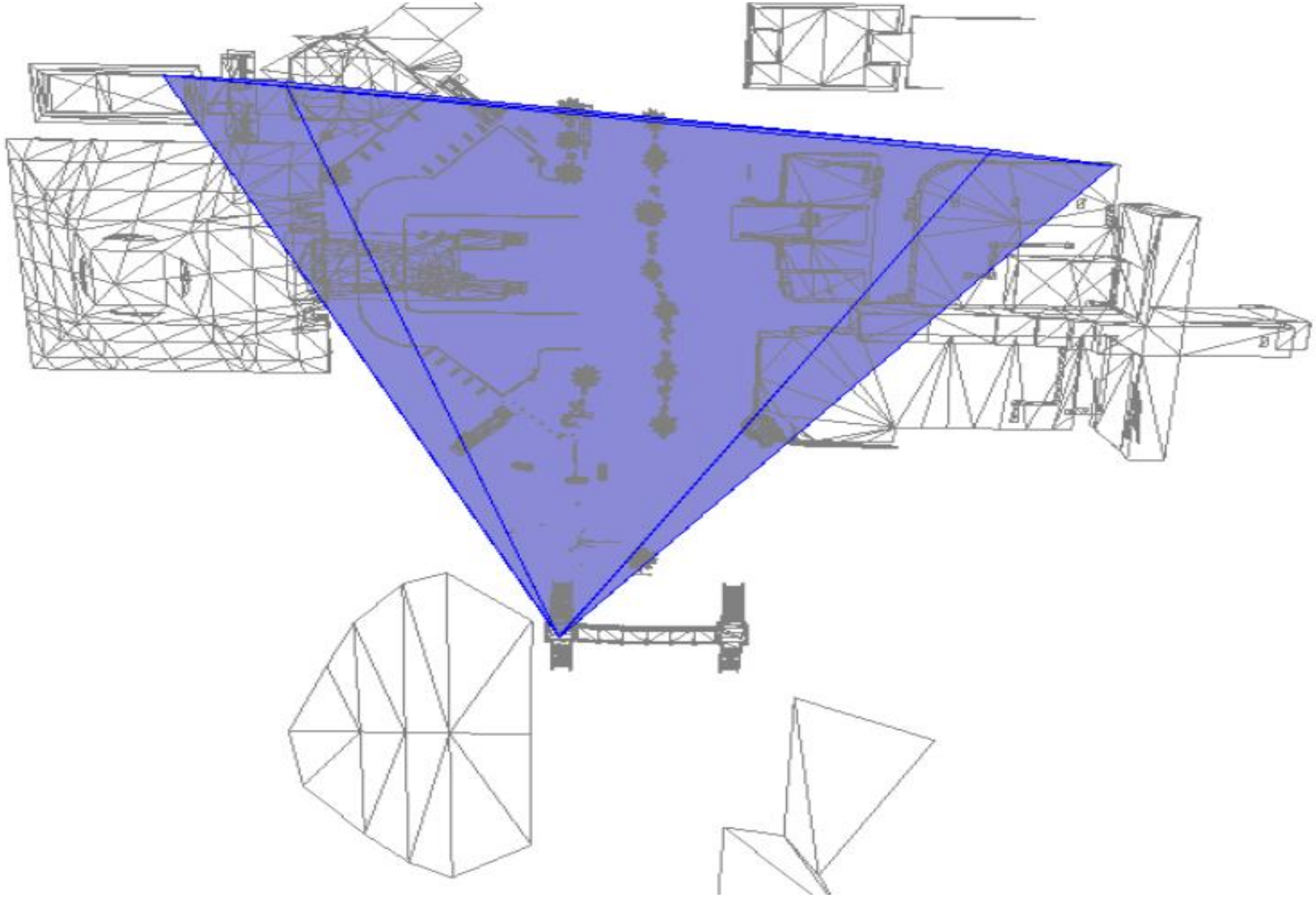

Top view, near city slice

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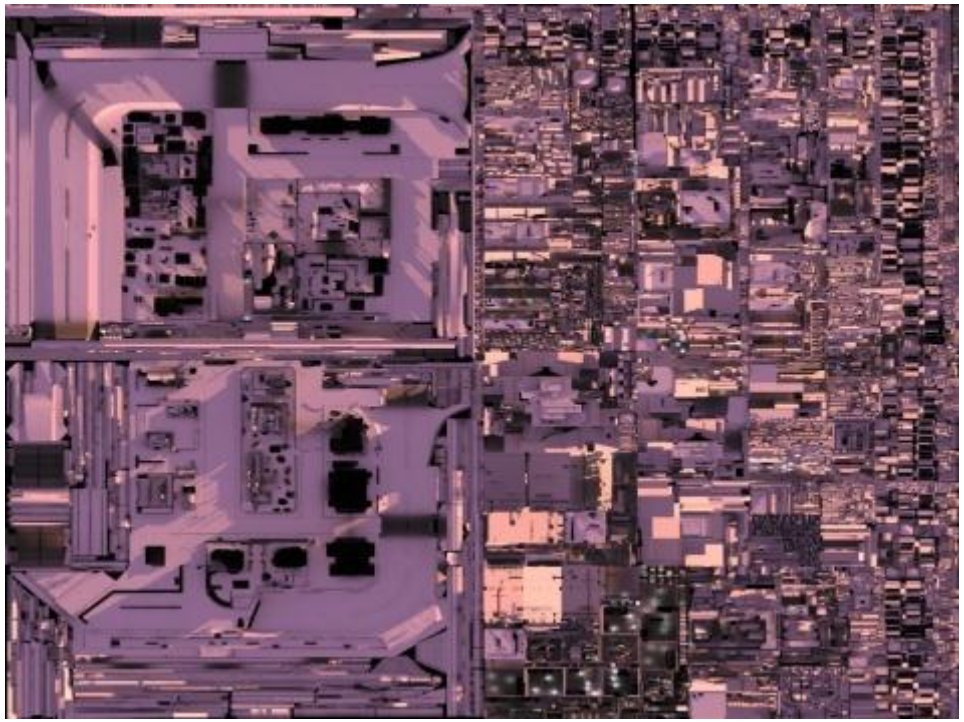
Near City Materials

- Atlasing of albedo textures (batching & memory)
- Lightmaps
- Complex shaders (e.g. specular / reflection)



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Full City: 77 draw calls

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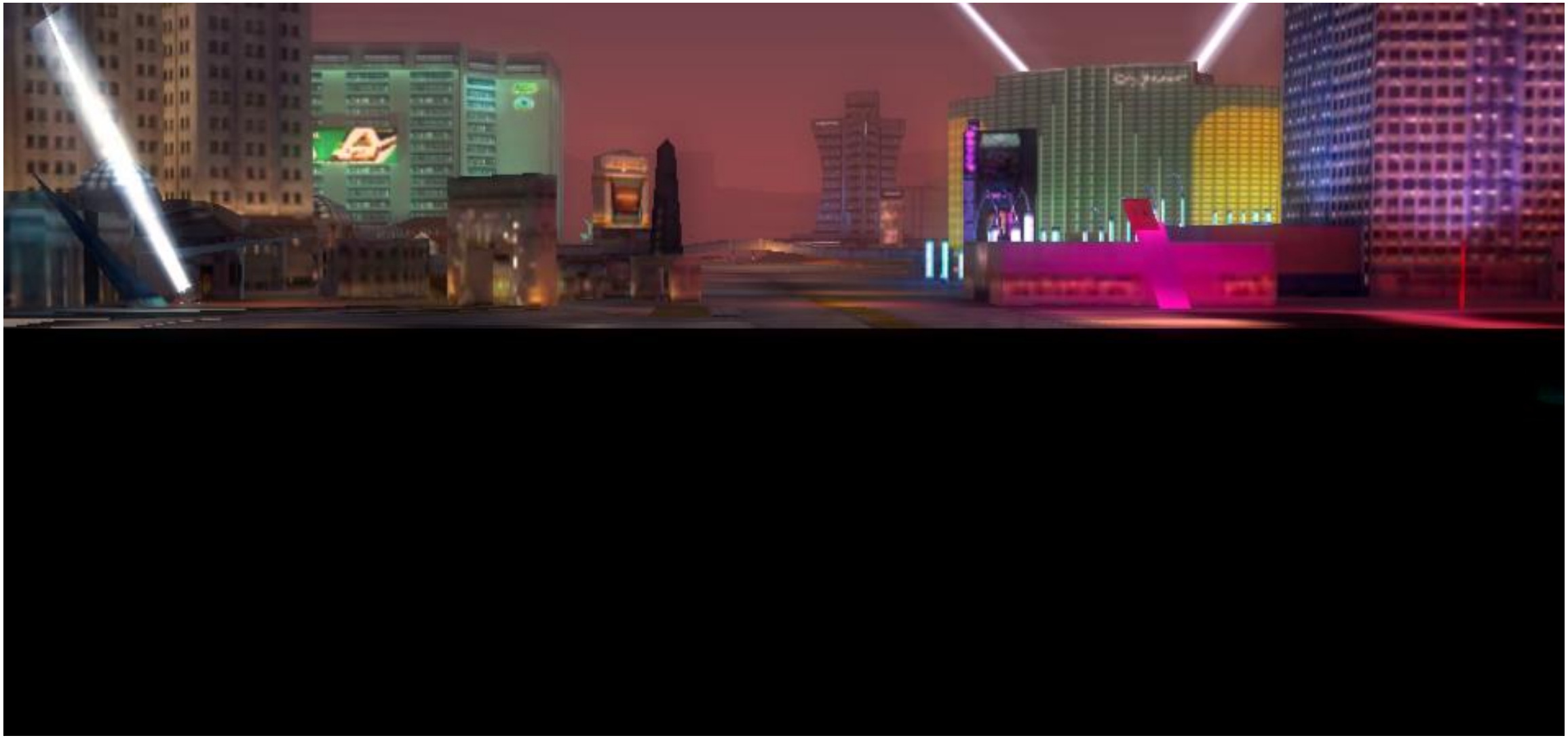

Far City: 29 draw calls

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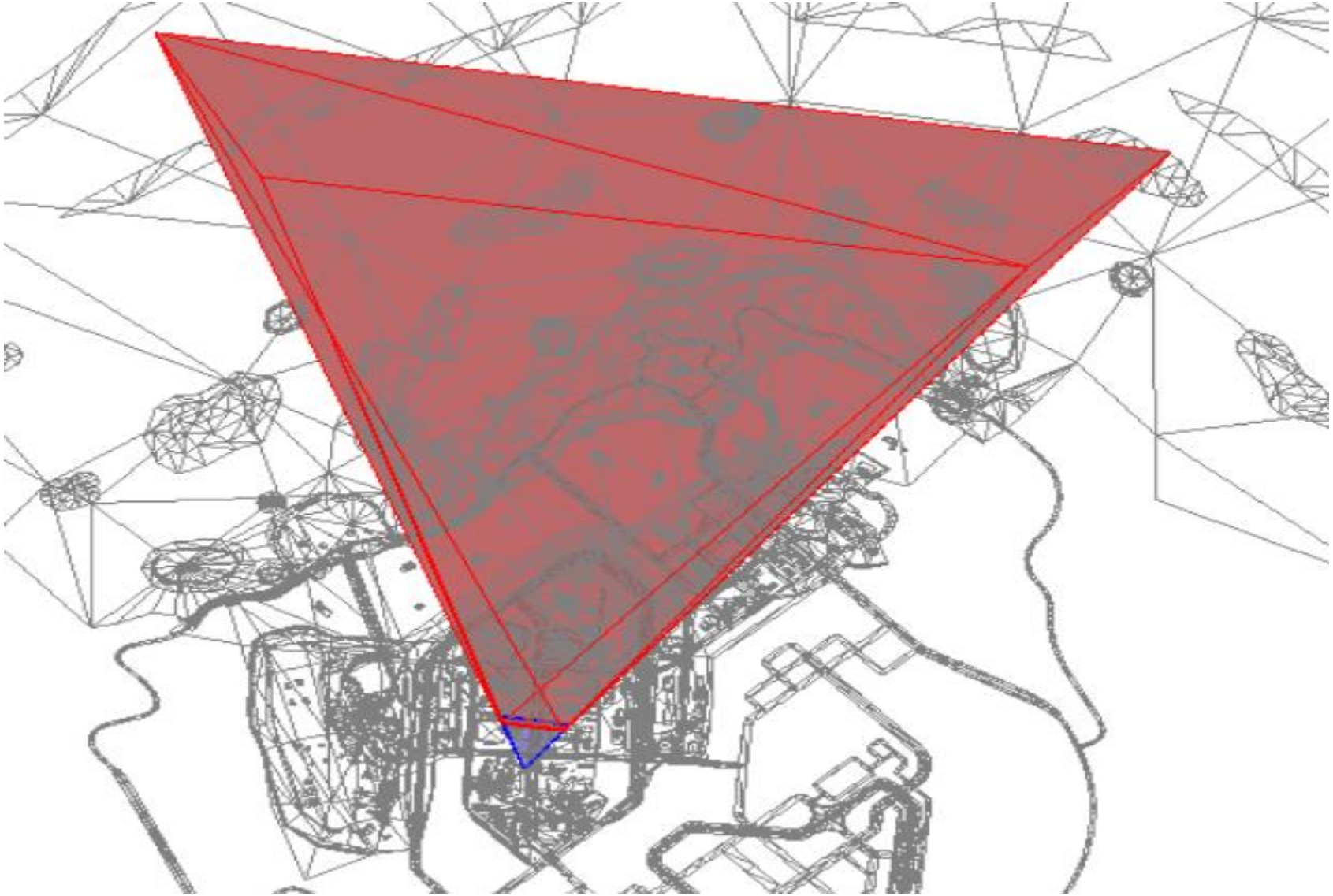
Cities Depth Slices

- Each city version has its own « depth slice »
  - Using **`glDepthRange`**
  - Little overlapping zone between the two (20m).

```
glDepthRange(0.0, 0.08);
CamZnear = 0.2;
CamZFar  = 160;
RenderHighresCity();

glDepthRange(0.08, 1);
CamZnear = 140;
CamZFar  = 2000;
RenderLowresCity();
```



Top view: far city and full frustum

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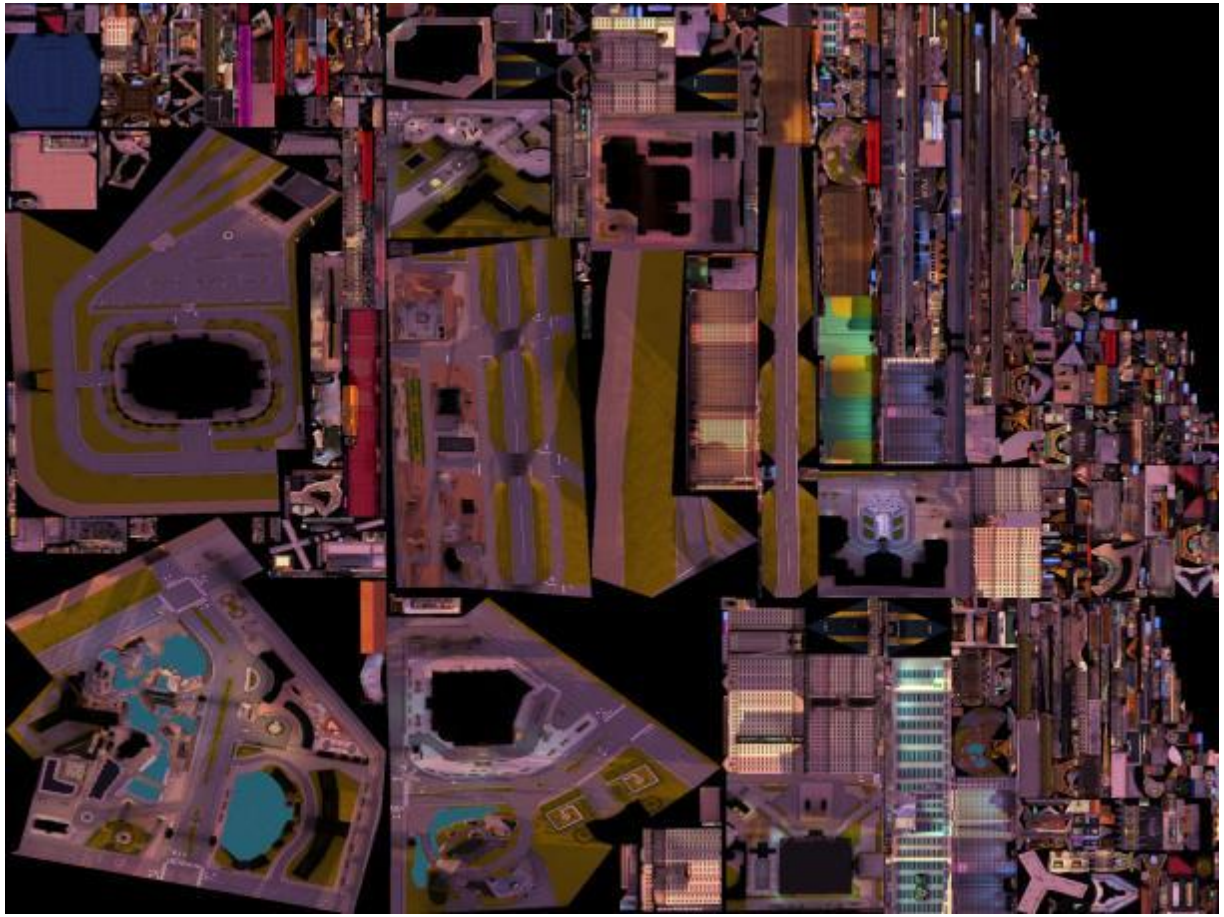
Far City Materials

- Heavy atlasing
- Premultiplied Lightmaps
- Low cost shaders



LODs and Culling

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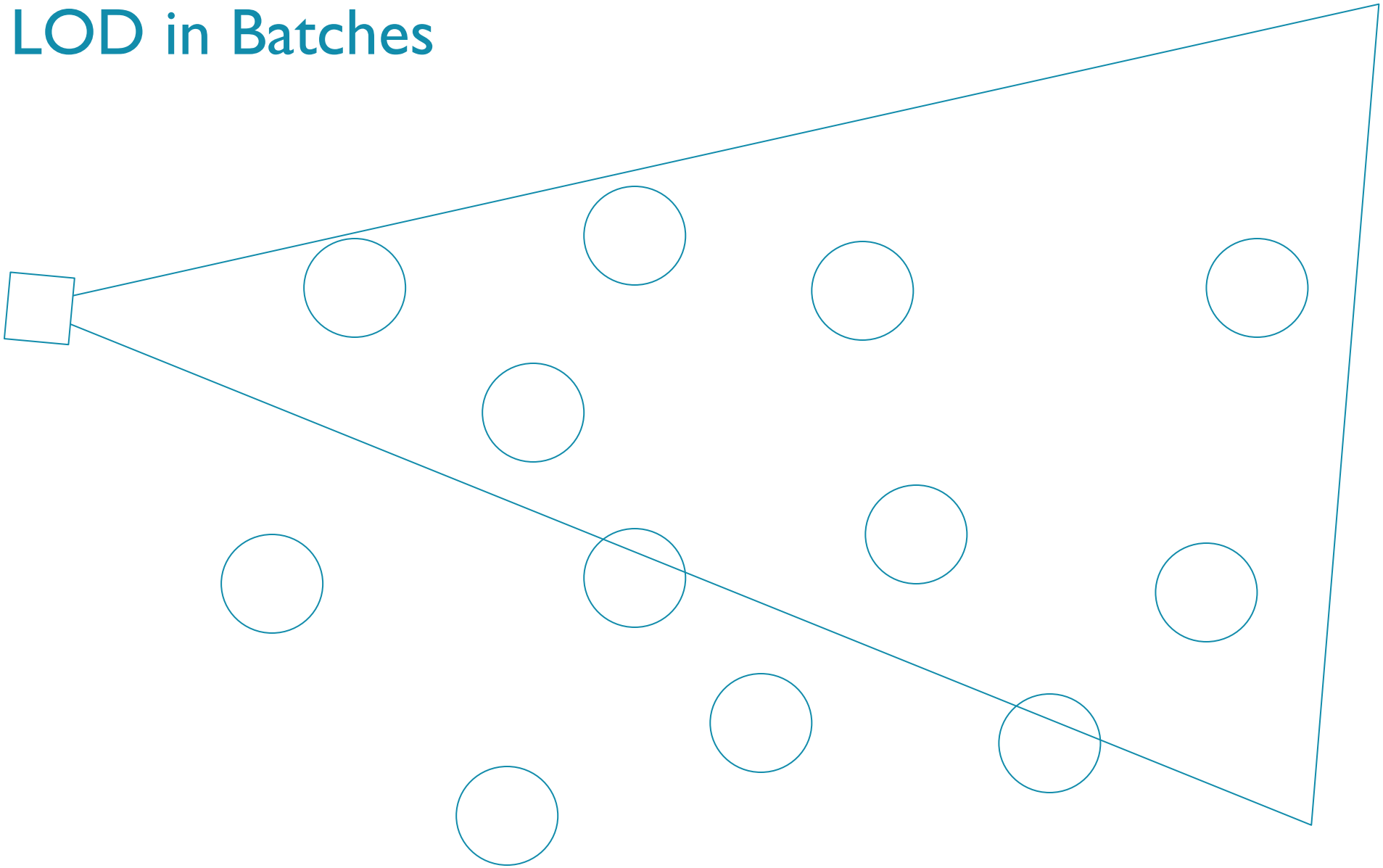
LOD in Batches



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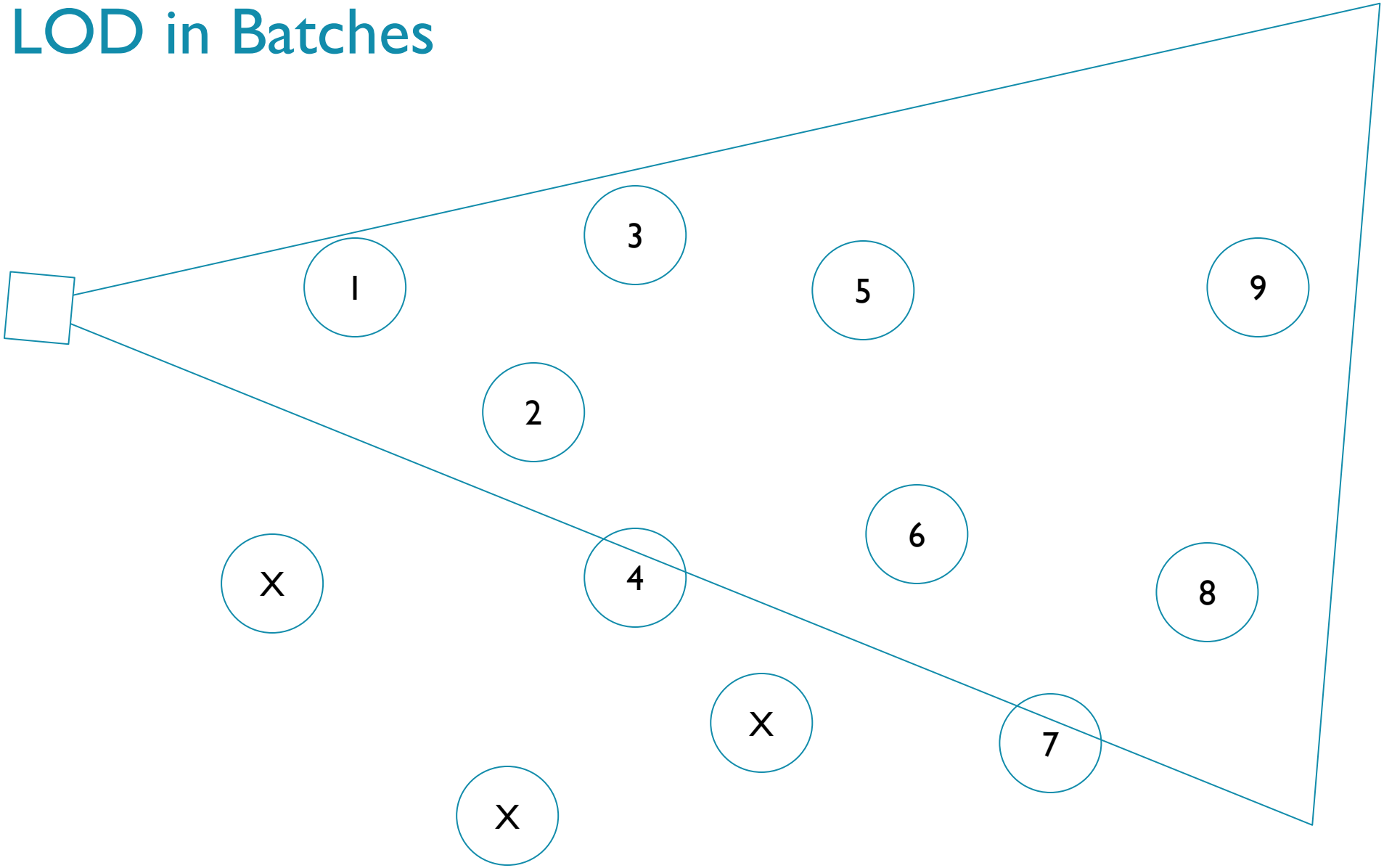
LOD in Batches



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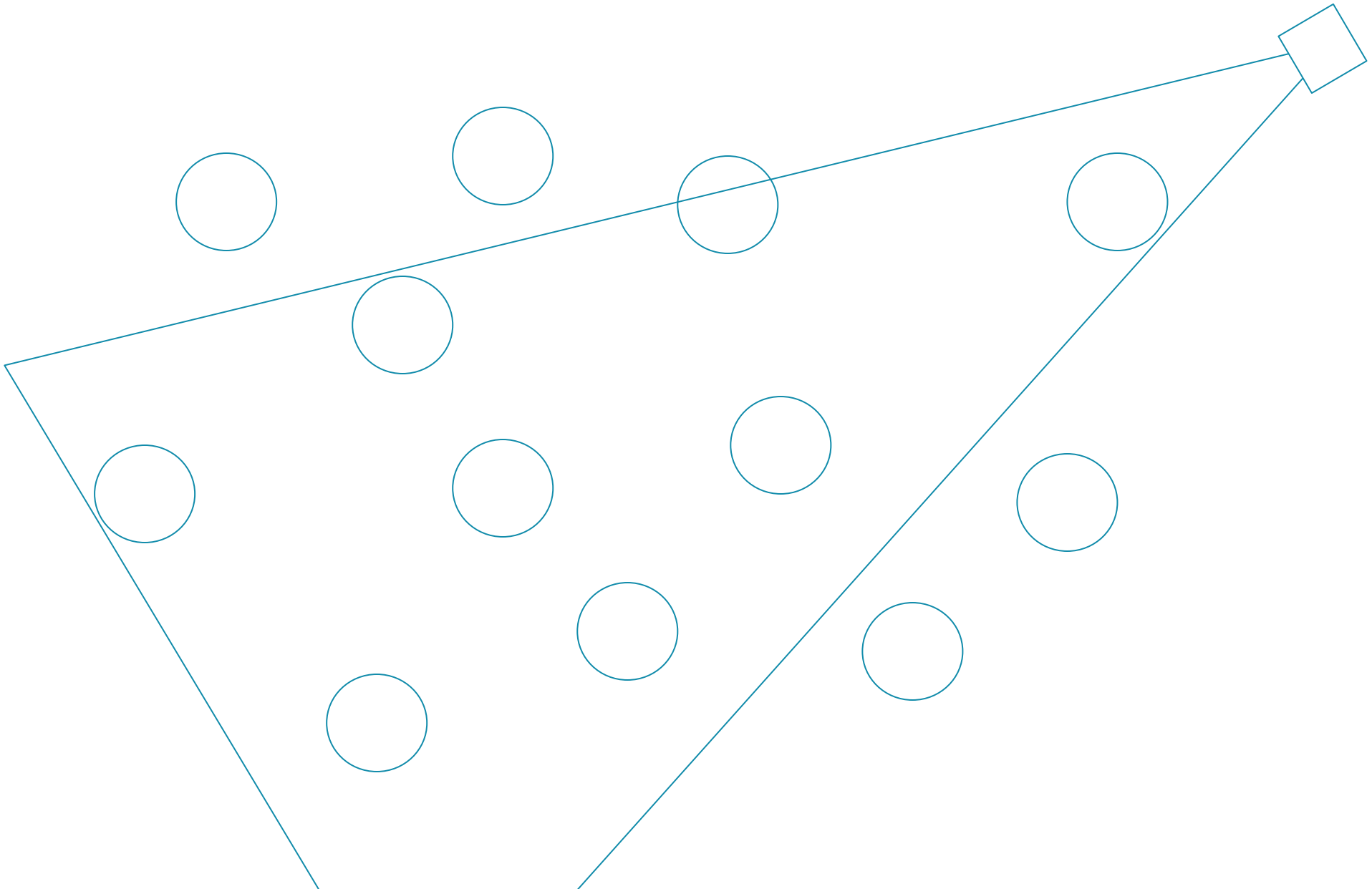
LOD in Batches



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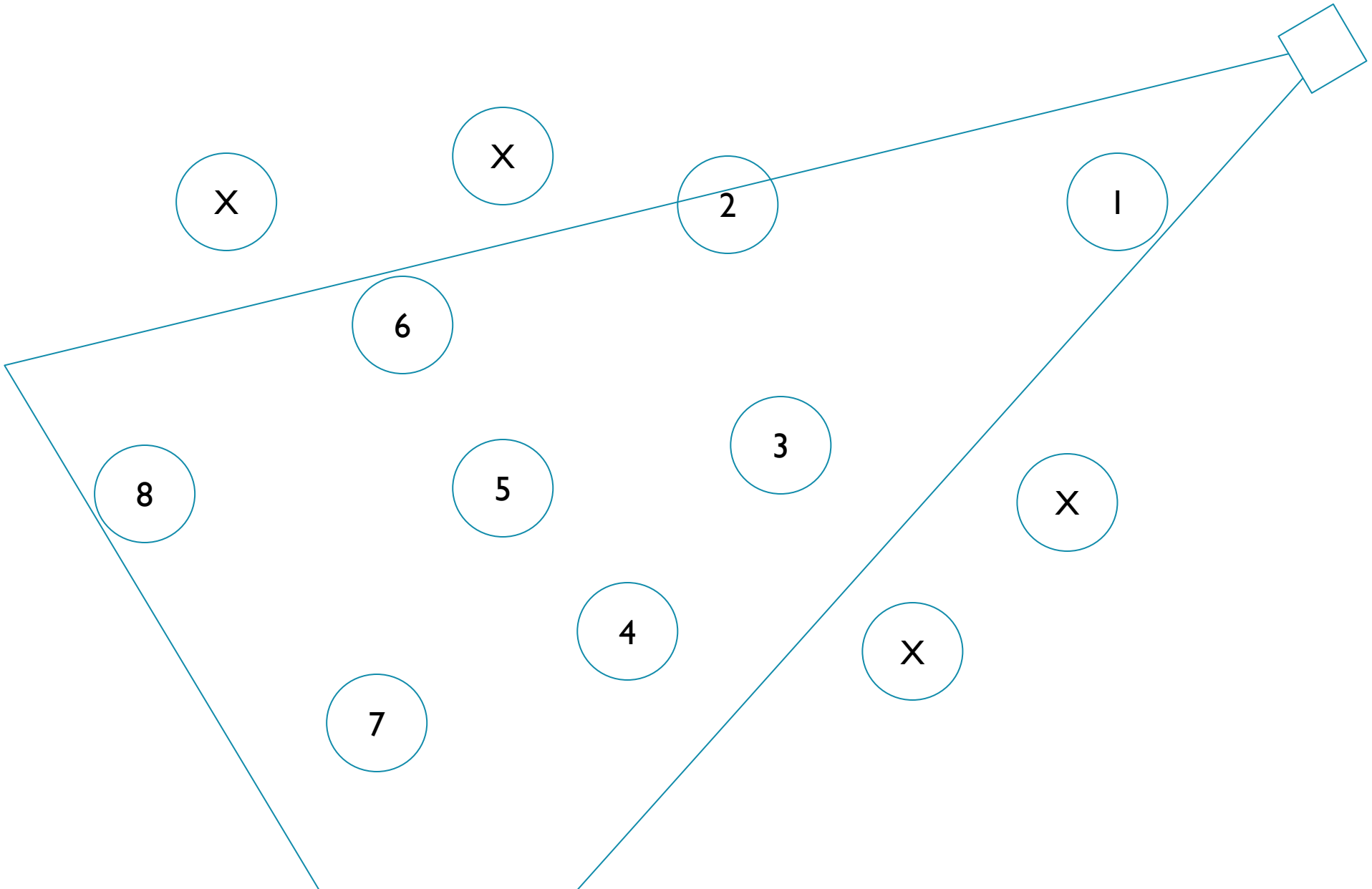
LOD in Batches



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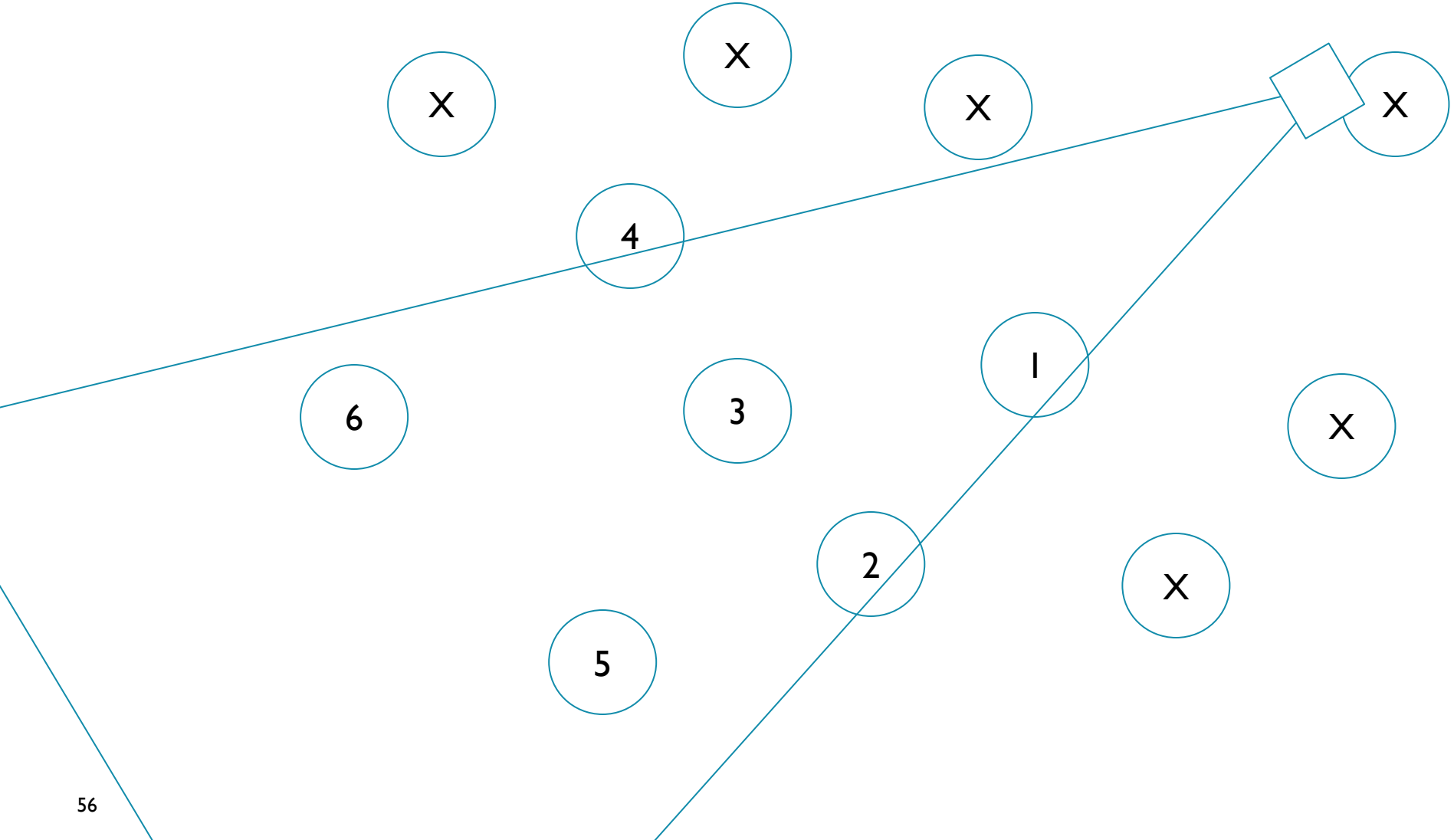
LOD in Batches



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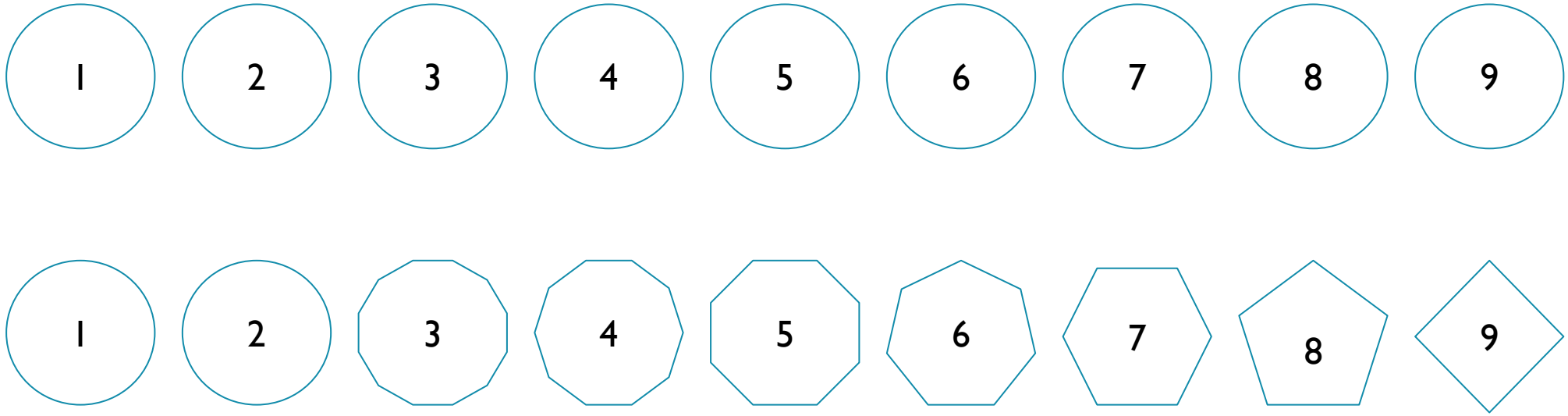
LOD in Batches



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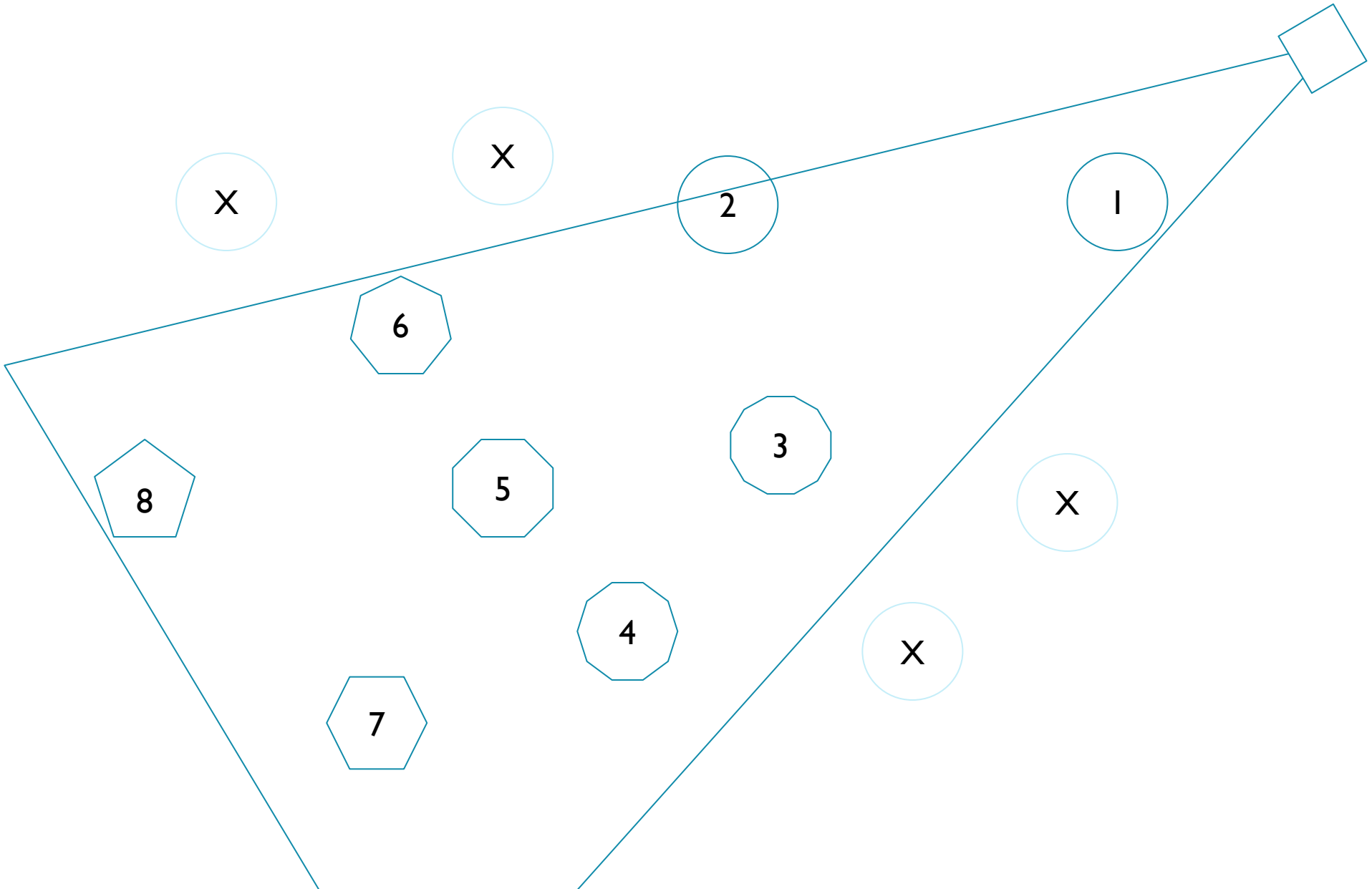
LOD in Batches



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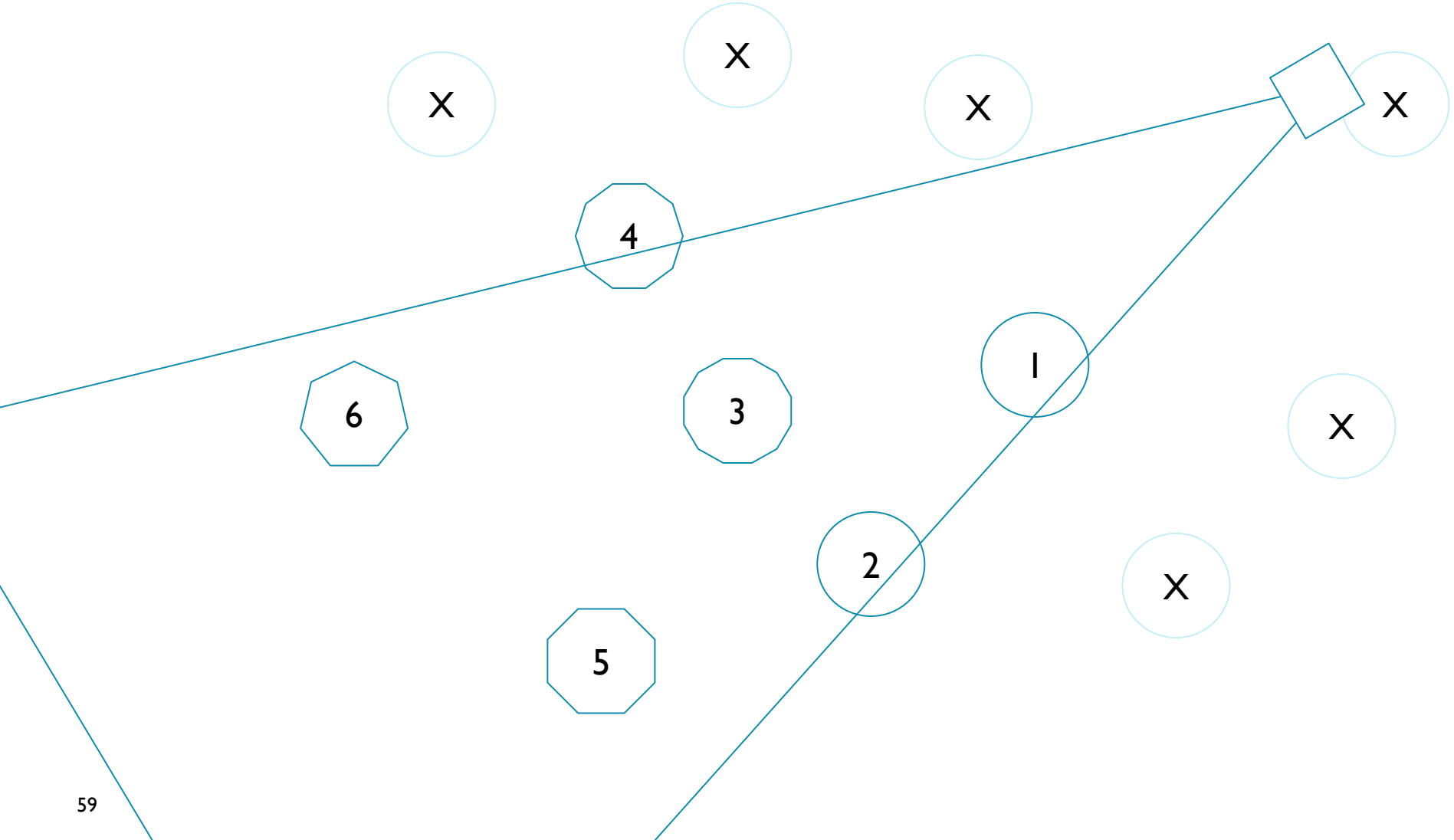
LOD in Batches



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A View to a Cull

Scene Batching

Timbuktu has 22 objects per environment layer

S= Skipped R=Rendered X=Scaled out

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
		R	R	R							R	R						R		R	

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Imposterable

- Timbuktu's Foliage:
  - 4 types of alpha blended geometries, depth sorted
  - Unpredictable interleaving of Grass, Tree, Bush and Shrub
- First suggestion:

  GTBSGTSBGTSBGTSBGTBSGTBSGTSBGTSBGTS
  - No more than 3 dead models in a row
  - Clumping of similar entities makes worst case more common

- Second suggestion:

  GGTTBBSSGGTTBBSSGGTTBBSSGGTTBBSS
  - Allows consecutive pairs more cheaply
  - Worst case still arises frequently, and is now even worse

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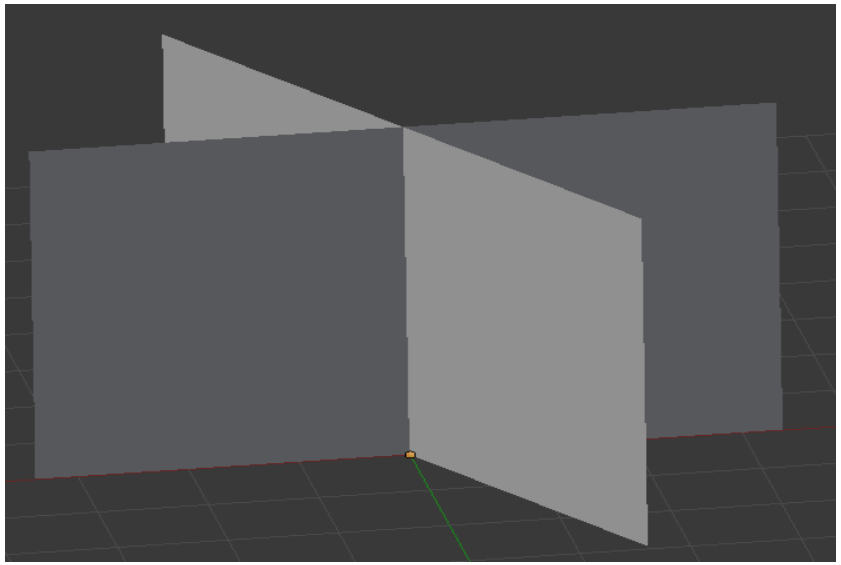
Imposterable

- Solution:
  - Foliage only varies in texture and scale
  - All models topologically identical
  - Zero skips
  - Extra vec4 per instance



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Asphalt 8

Effects, Draw Calls & Texture Data

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The Game

- Explosive action racing
  - Multiplayer
  - Physics engine
- Main FXs :
  - Realtime soft shadows
  - Realtime reflections
  - Paraboloid
  - Road reflections
  - Proxies
- Main post FXs:
  - Motion blur
  - Lens flare dirt
  - Color grading
  - Vigneting

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Game Effects

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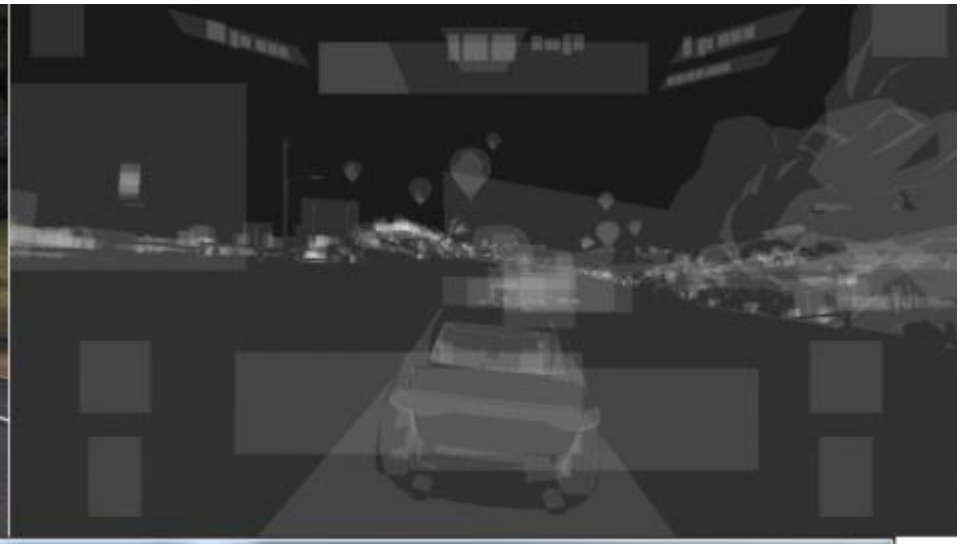
Optimizations / Draw Call Reduction

- Culling adapted to a racing game :
  - PVS (Potential Visibility Sets)
  - AABBox culling
  - Software occlusion culling
  - LODs (distance or screen projection size)
  - VBOs / IBOs for 95% of mesh data
- Physics on a separate thread
- Texture streaming to reduce loading times
- On a medium device (Samsung Galaxy SIII):
  - 120 to 250 draw calls, depending on track

ARM® Mali™ Graphics Debugger (on a Samsung Galaxy SIII)



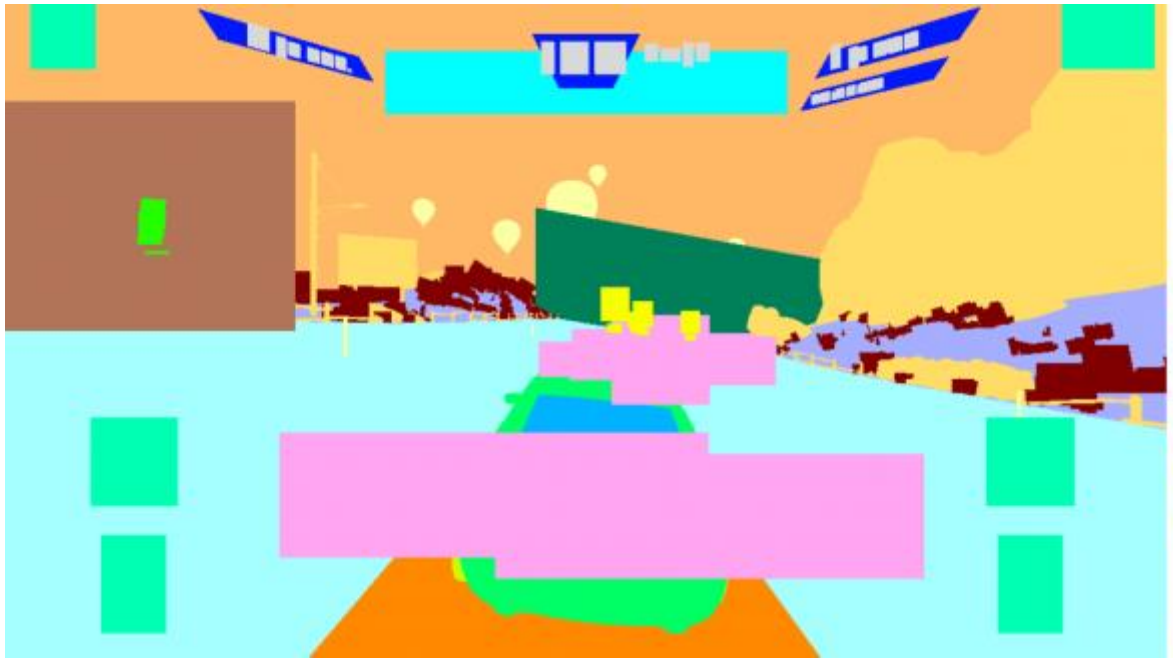
Statistics

Total number of API function calls	624902
Average vert/frame	323250,00
Average instanced vert/frame	0,00
Average draw/frame	138,00
Frame #	419
Number of API calls in current frame	2757
Number of draw calls in current frame	139
Number of vertices submitted in current frame	323658
API call #	619473
Number of vertices in current draw call	n/a

- 300k vertices
- 140 draw calls
- Not much overdraw
  - Stop lights
  - HUD

ARM

ARM® Mali™ Graphics Debugger (on a Samsung Galaxy SIII)



Fragment Shaders

Program	Name	Instructions	Shortest path	Longes...	Instances run	Total cycles
129	Shader 128	14	14	14	272330	3812620
60	Shader 59	7	7	7	145816	1020712
108	Shader 107	18	18	18	49211	885798
159	Shader 158	1	1	1	665856	665856
9	Shader 8	6	6	6	99483	596898
177	Shader 176	9	7	9	58480	467840
105	Shader 104	17	17	17	23389	397613
132	Shader 131	9	9	9	30708	276372
36	Shader 35	2	2	2	136553	273106
138	Shader 137	5	5	5	45264	226320
174	Shader 173	3	2	2	68854	137708
147	Shader 146	4	4	4	24442	97768
210	Shader 209	3	3	3	27593	82779
21	Shader 20	5	5	5	16384	81920
123	Shader 122	9	9	9	7617	68553
102	Shader 101	2	2	2	28038	56076
213	Shader 212	3	3	3	12493	37479
198	Shader 197	3	3	3	11470	34410
111	Shader 110	4	4	4	7311	29244
207	Shader 206	10	8	10	2896	26064
24	Shader 23	5	5	5	4096	20480
114	Shader 113	3	3	3	4542	13626
204	Shader 203	3	3	3	2466	7398
135	Shader 134	11	11	11	210	2310
192	Shader 191	2	2	2	851	1702
153	Shader 152	4	4	4	324	1296
117	Shader 116	1	1	1	537	537
195	Shader 194	4	4	4	76	304

- Post FXs disabled here
- Shaders covering large screen areas must be cheap :
  - `Road => 14 cycles (specular / normal map)`
  - `Rocks => 7 cycles`
  - `Sky => 1 cycle`
  - `Cars => 18 cycles`
  - `Lights/Smoke => 2/4 cycles`

ARM

ETC1 and Alpha

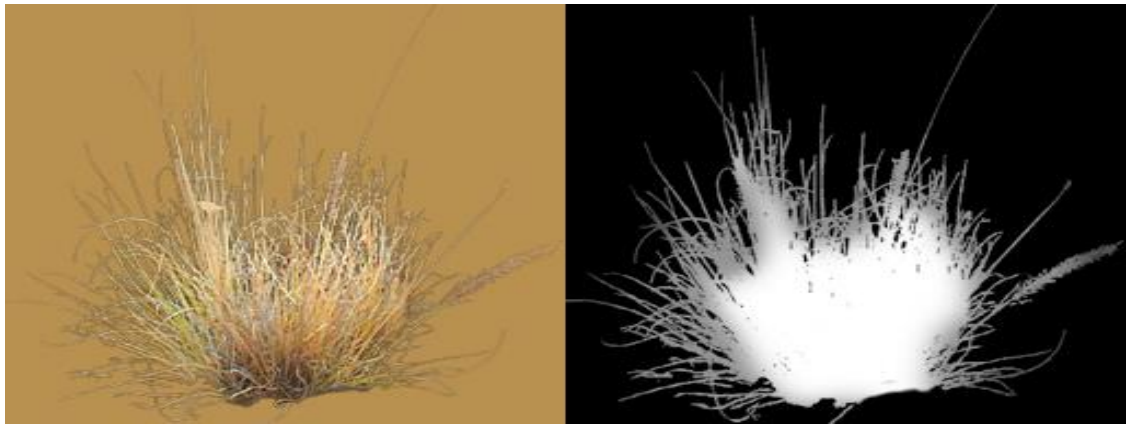
- ~80% of the textures are ETC1 compressed
  - We keep uncompressed :
    - Splash / loading screens
    - Cars & tracks illustrations
    - Lens flare textures, LUTs…
- ~20% of the textures need alpha:
  - Menus, HUD
  - Billboards
  - Specular maps …

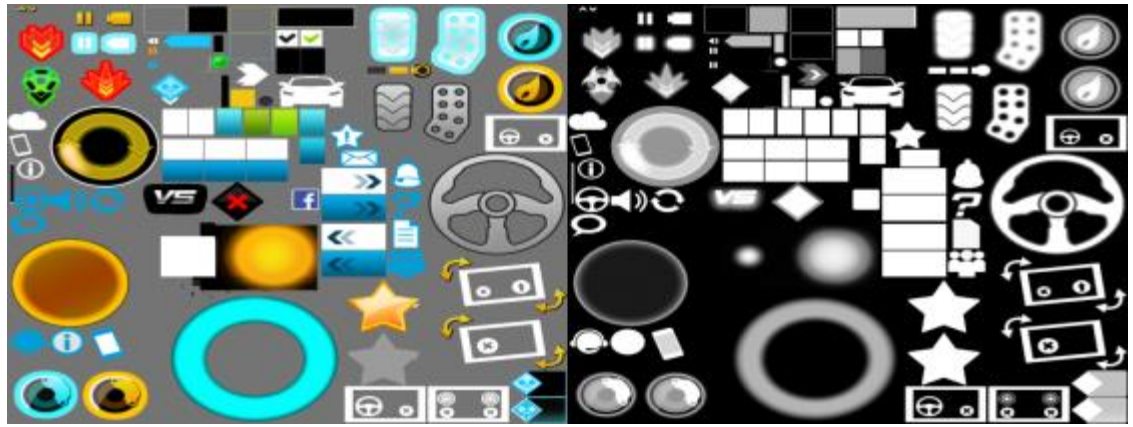
Split Alpha on Android™

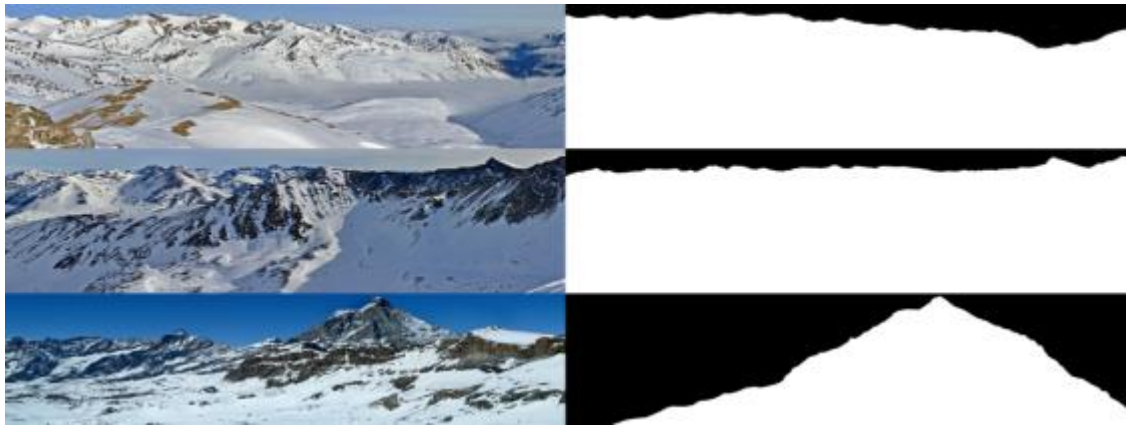
- Using two ETC1 compressed textures
  - One for Alpha
  - One for RGB
- ETC1 compression ratio: 4bpp (24bits)
  - RGB: 6x
  - RGBA: 3x

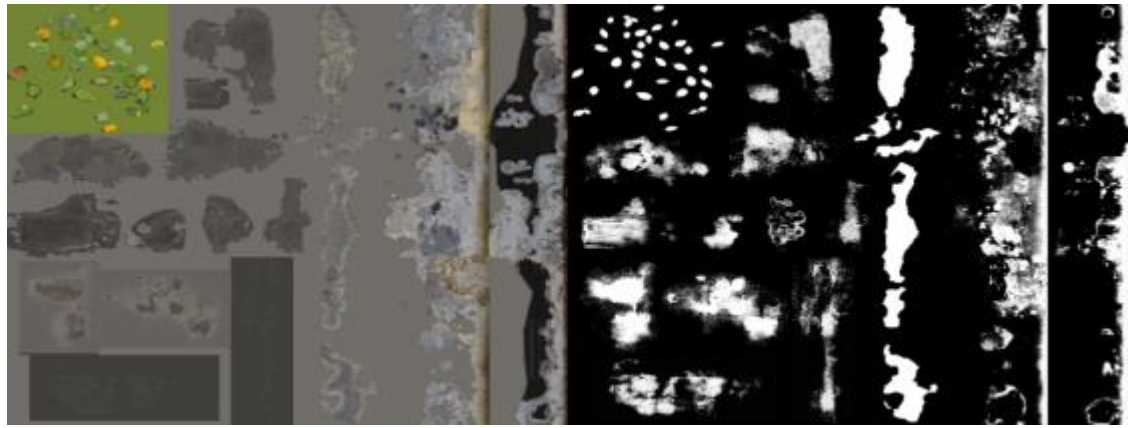
ARM

Billboards / HUD



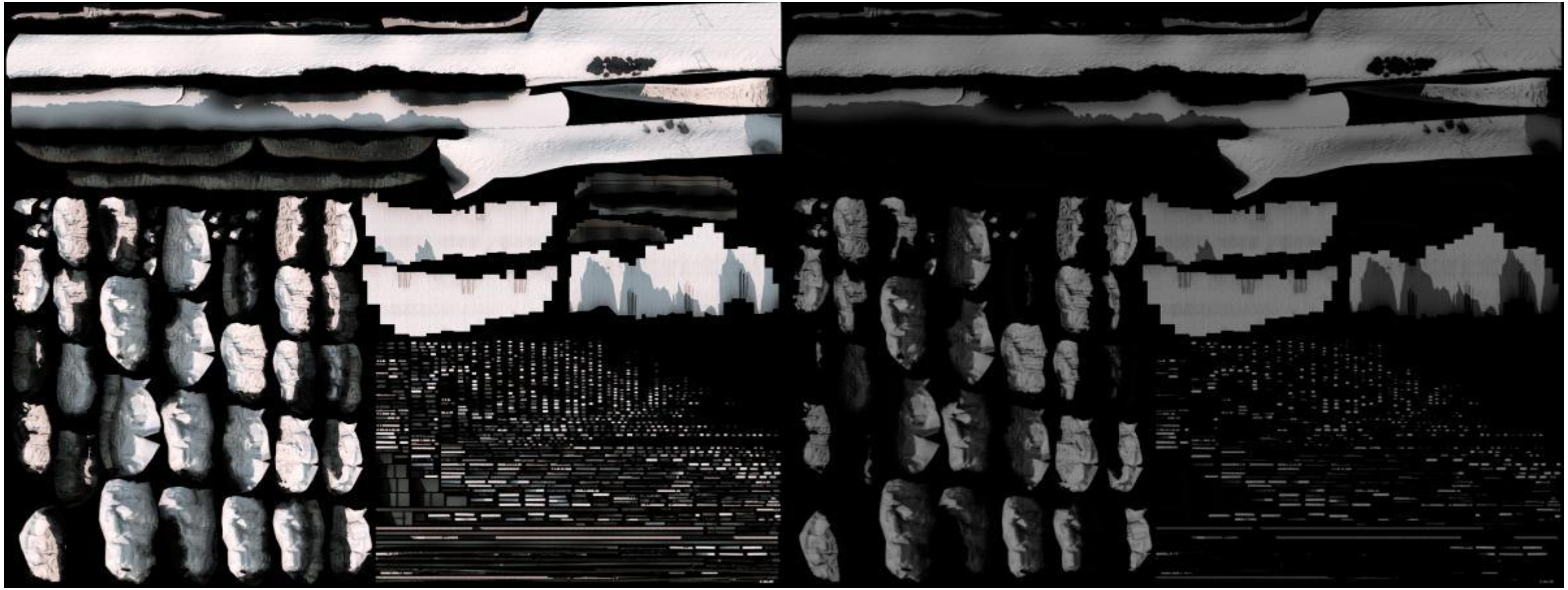






Additive particles / lens flare textures do not need alpha !

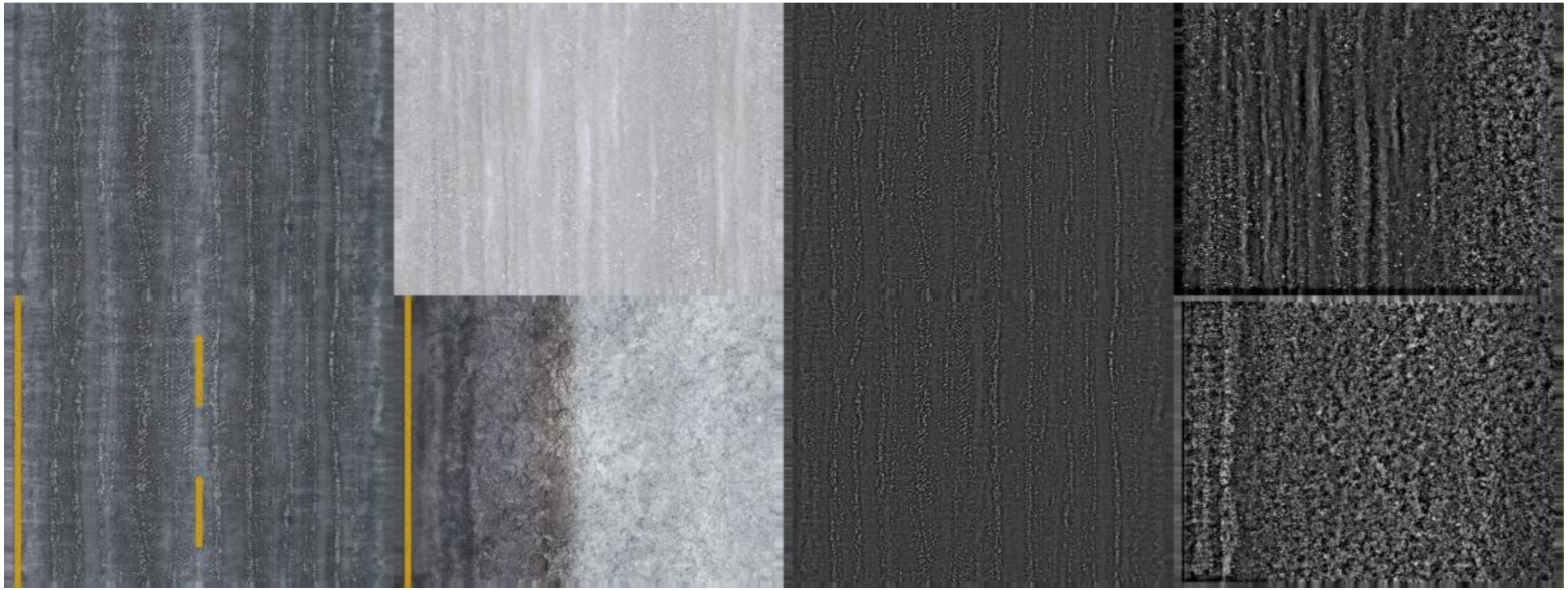
Light Maps



```
Complete = DF * (LM + (LM * LM.a * brightBurn)) * overbright;
```


ARM

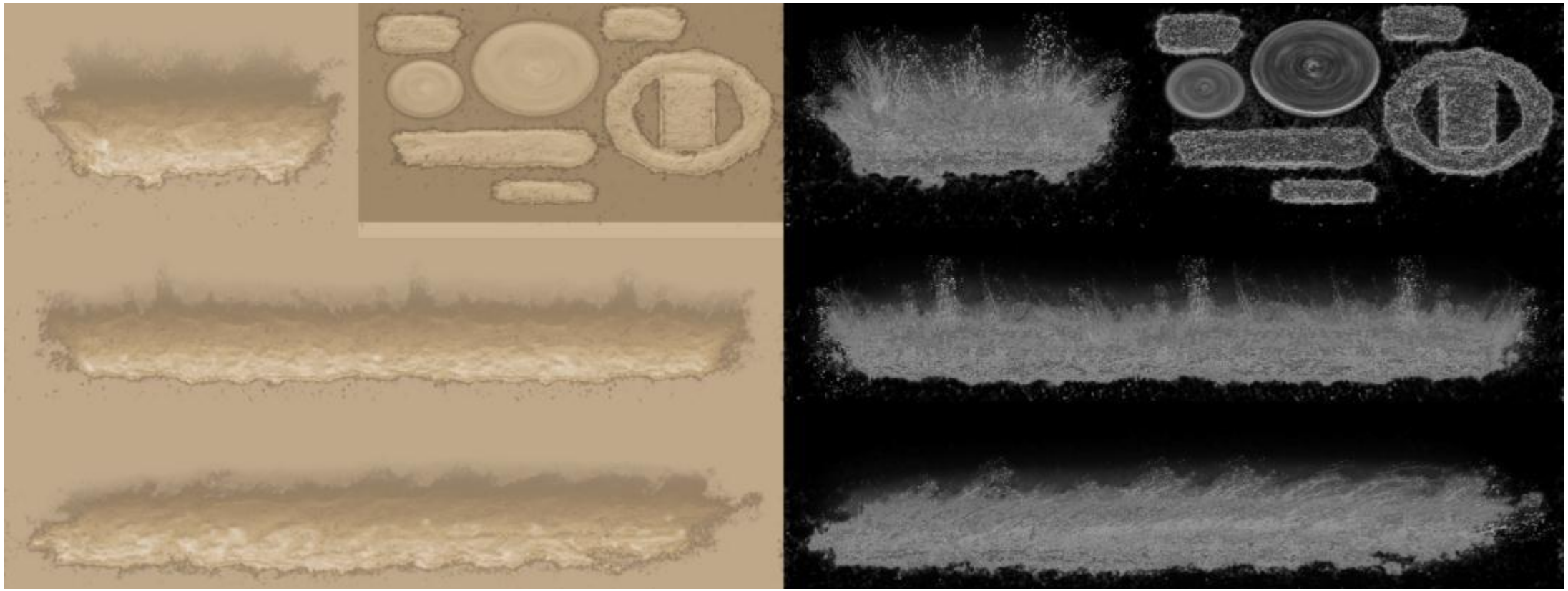
Road Specular Map



Alpha = AO + Specular Intensity

ARM

Dirt Map



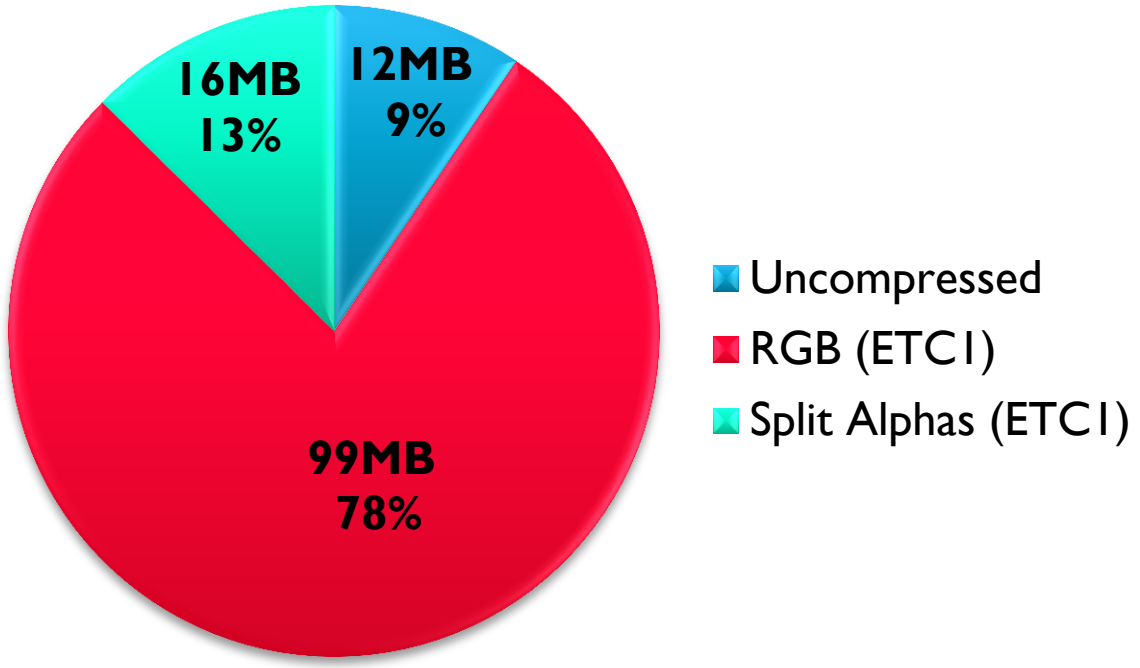
```
vec3 dirt = aoFactor * light * DIRT.rgb;
float dirtFactor = min(dirtAmount * DIRT.a, 1.0);
color = mix(color, dirt, dirtFactor);
```

Textures in Iceland Track

ARM

Iceland Track: Memory Usage

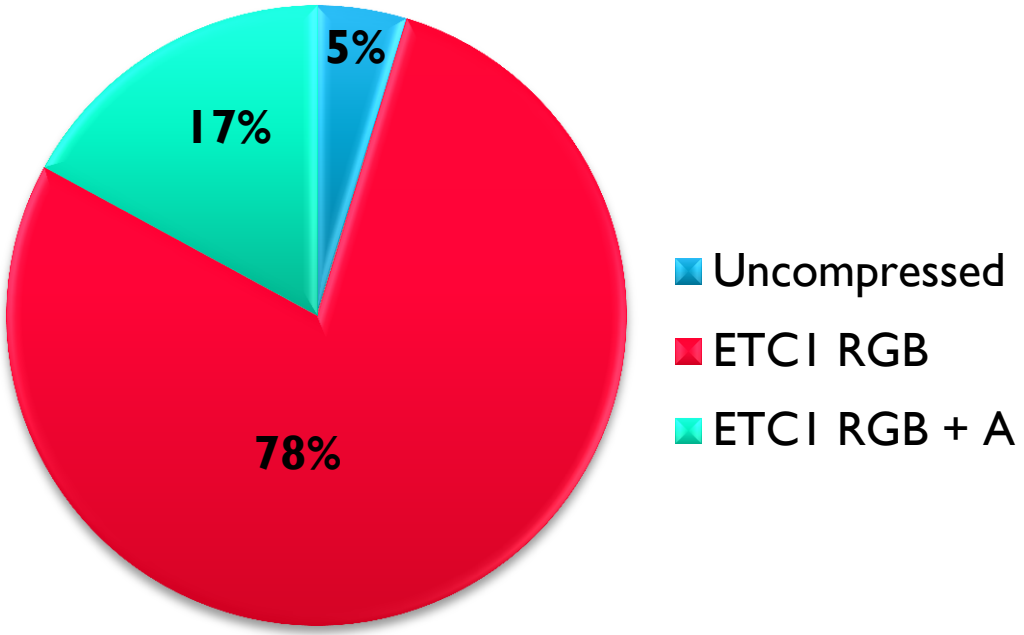
- Total : 127 MB
  - mipmaps not counted
- 13% of texture data is used for alphas (16MB)



ARM

Iceland Track: Texture Repartition

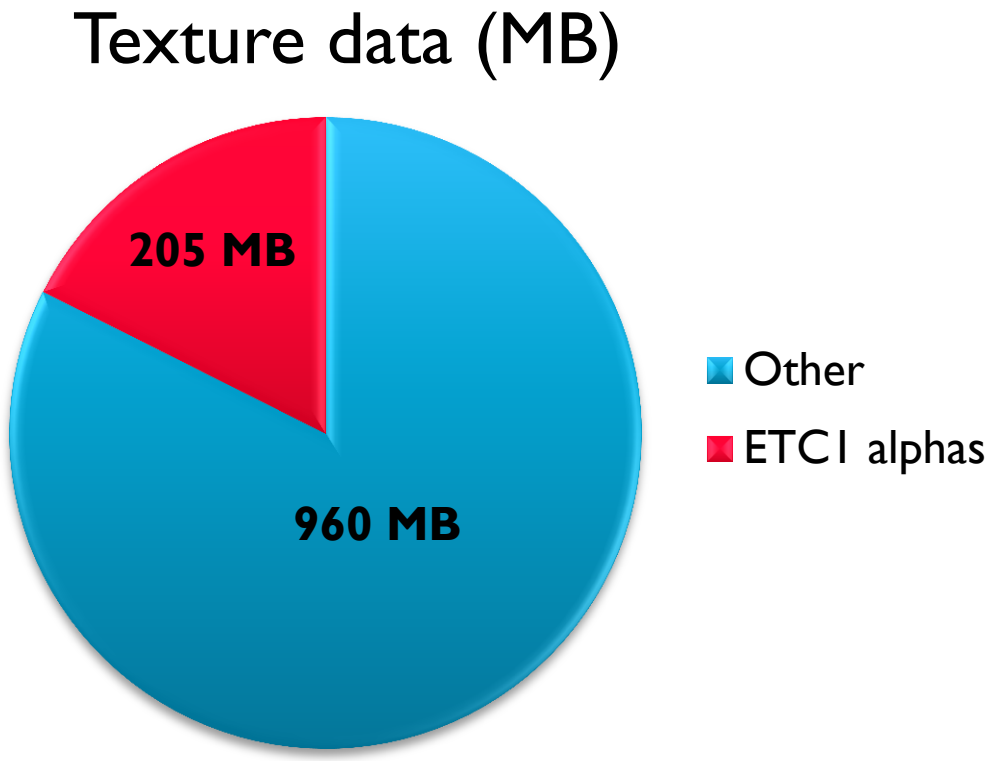
- Things to take care of with ETC1 split alpha technique :
  - More bandwidth usage
  - One extra sampling operation in shaders:
    - More fragment instructions
    - Still better cache efficiency than uncompressed, but not as good as ETC1 RGB



ARM

Total Texture Size on Disk

- Total texture size in game package: 1165 MB
- 17.5% of package (205MB) is ETC1 alphas data



ARM

Texture Compression

ARM

Texture Compression Formats

- ETC – ARM® Mali™-400 GPU
  - 4bpp
  - RGB No alpha channel
- ETC2 – ARM Mali-T604 GPU
  - 4bpp
  - Backward compatible
  - RGB also handles alpha & punch through
- ASTC – ARM Mali-T624 GPU and beyond
  - 0.8bpp to 8bpp
  - Supports RGB, RGB alpha, luminance, luminance alpha, normal maps
  - Also supports HDR
  - Also supports 3D textures

ARM

ETC

- Khronos standard
- Most widely supported
- Doesn't support alpha channels
- If you need alpha, the ARM® Mali™ Texture Compression Tool has options to store a separate alpha image

ARM

ETC 2

- Extension of ETC
- Less widely supported
- More block modes
- Alpha / punch through
- Punch through tip:
  - Use `discard` and sort front to back

ARM

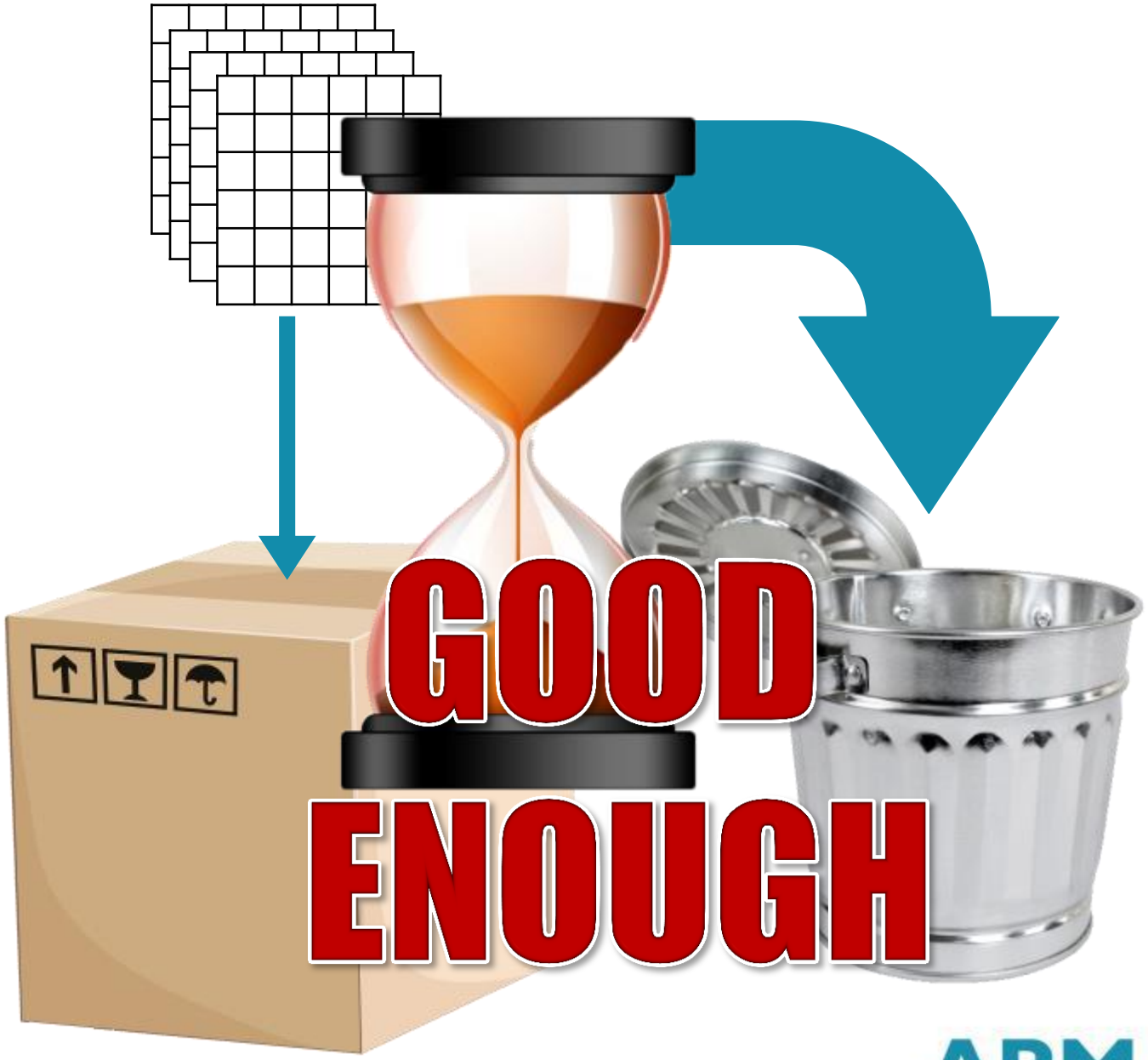
ASTC

- Developed by ARM, now a Khronos Standard
- Variable bit rate 8bpp to 0.8bpp
- ASTC is on the cutting edge so only the most up to date hardware supports it
- This time next year ASTC will be everywhere

ARM

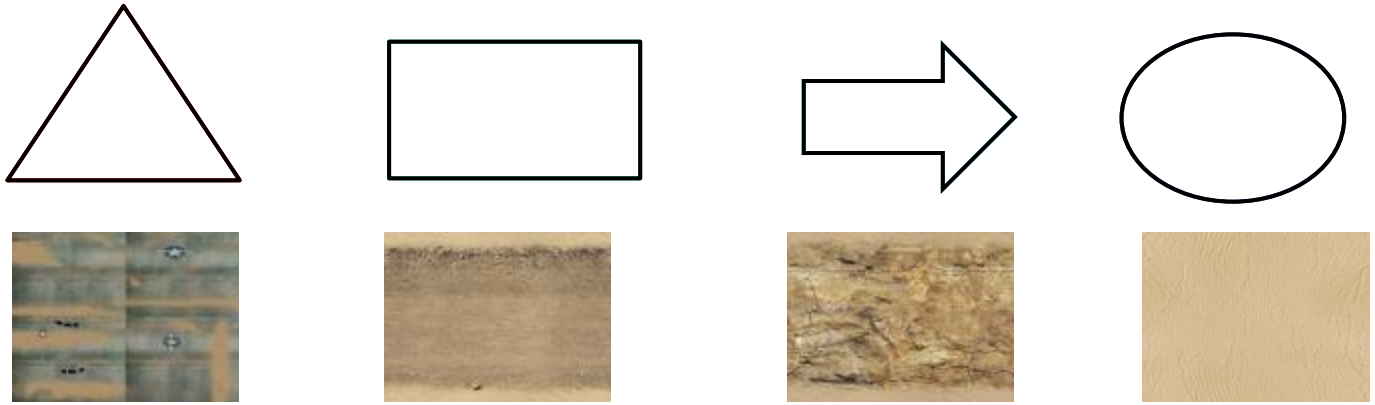
General Tips

- Quality setting is a time trade off
- Iterate low quality, ship high quality
- Compress in the asset pipeline
- Familiarize artists with the tools



ARM

Atlassing?

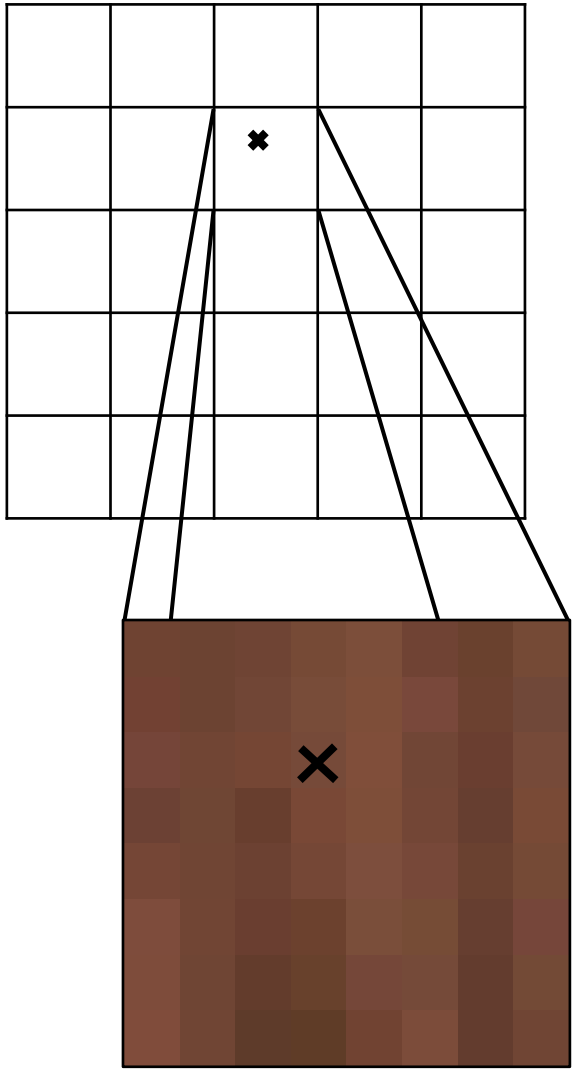


Atlassing Compressed Textures

- The conventional wisdom is that compressed textures cannot be altered
- If you change the content it has to be recompressed
- This isn't *entirely* true

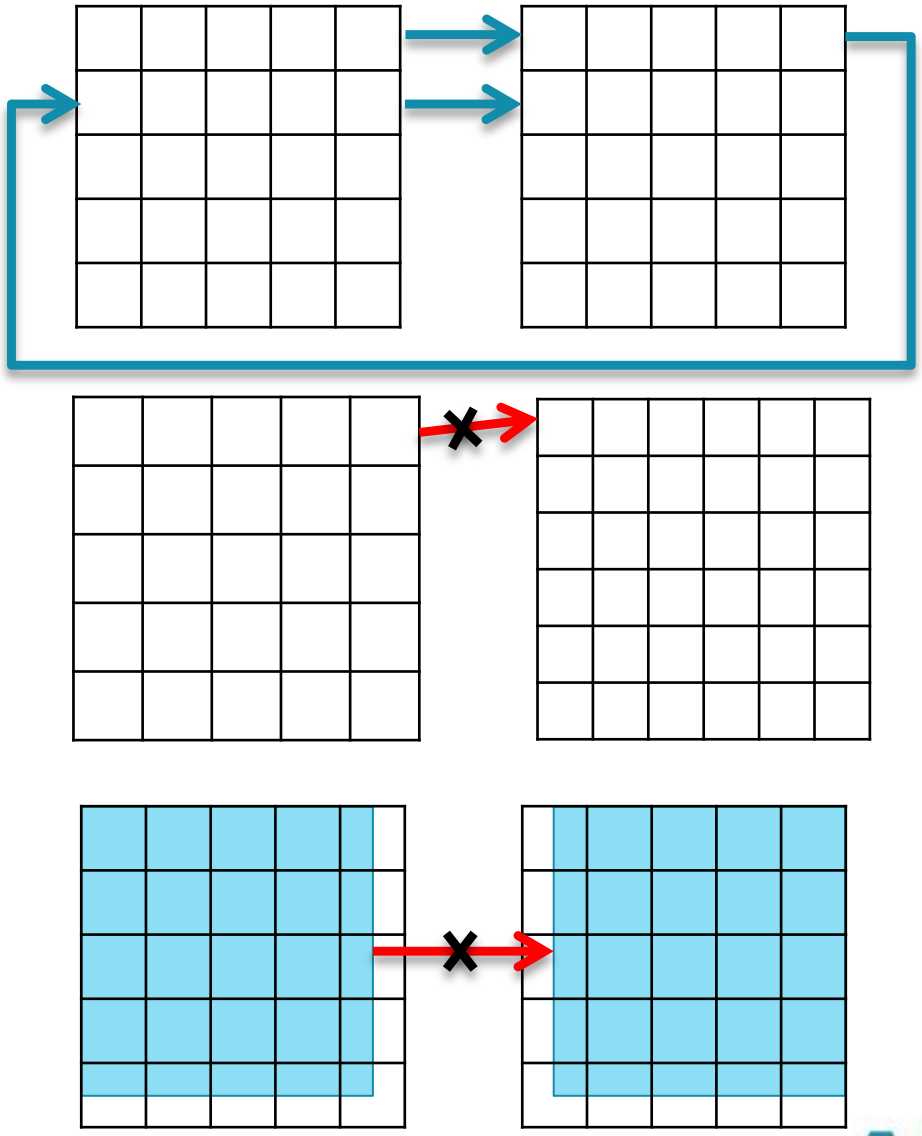
Atlassing Compressed Textures

- Compressed textures are block based
- Hardware decompression uses this
  - Use coords to look up block
  - Decompress block
  - Use relevant pixels
- Blocks are wholly independent
- Textures with the same block size can be stuck together



Atlassing Compressed Textures

- Combined textures must be in the same format, with the same global settings
  - Encoding
  - Block size
- Quality settings can differ
  - Purely an argument of the compression
- Textures must stitch at block boundaries



ARM

malideveloper.arm.com

community.arm.com

Thank You

Any questions?