Deferred Adaptive Compute Shading

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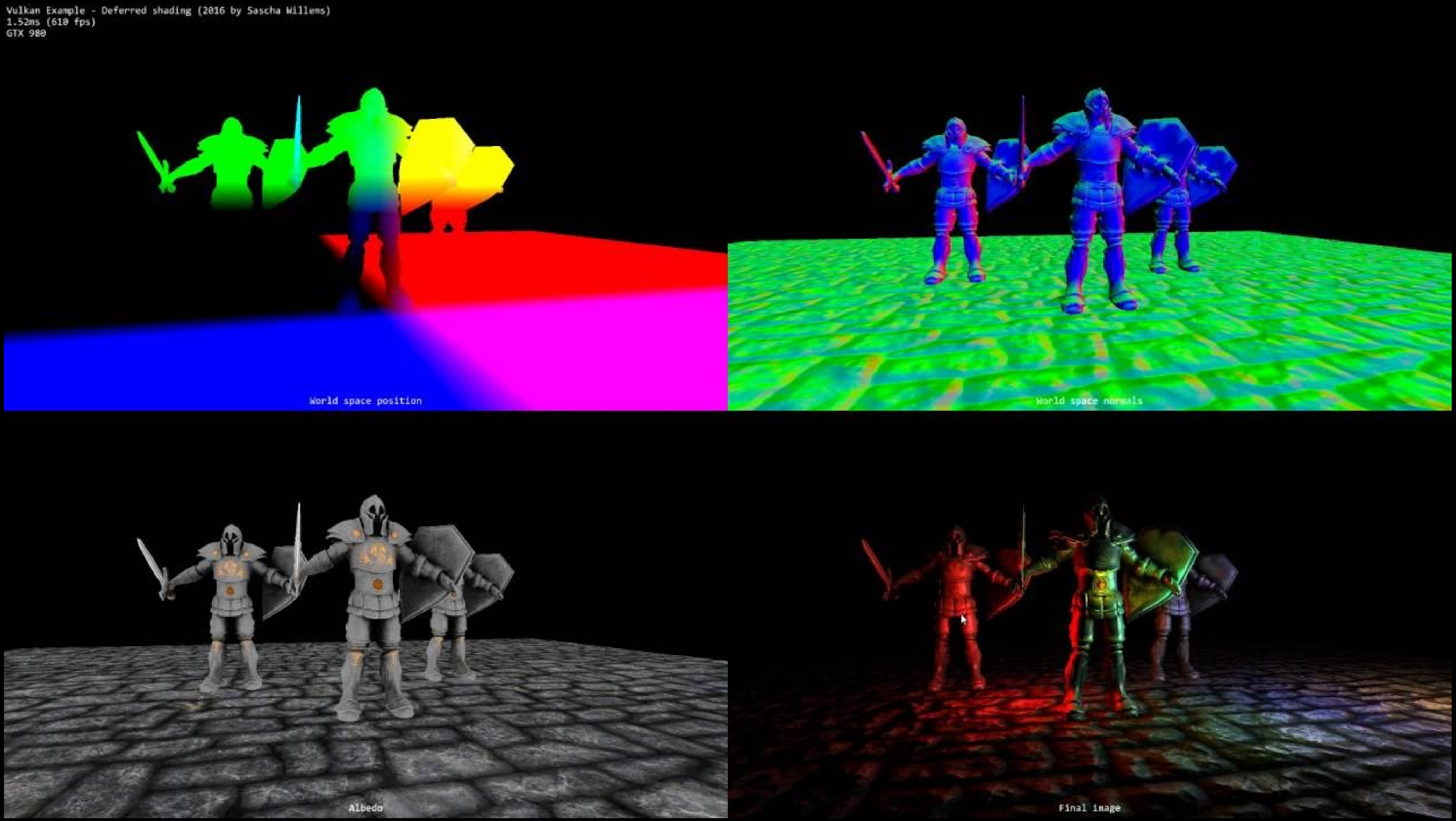
Utah Graphics

2018

Fragments Are Expensive

- Deferred shading: reduces expensive overdraw



```
Vulkan Example - Deferred shading (2016 by Sascha Willems)
1.52ms (610 fps)
GTX 980
```

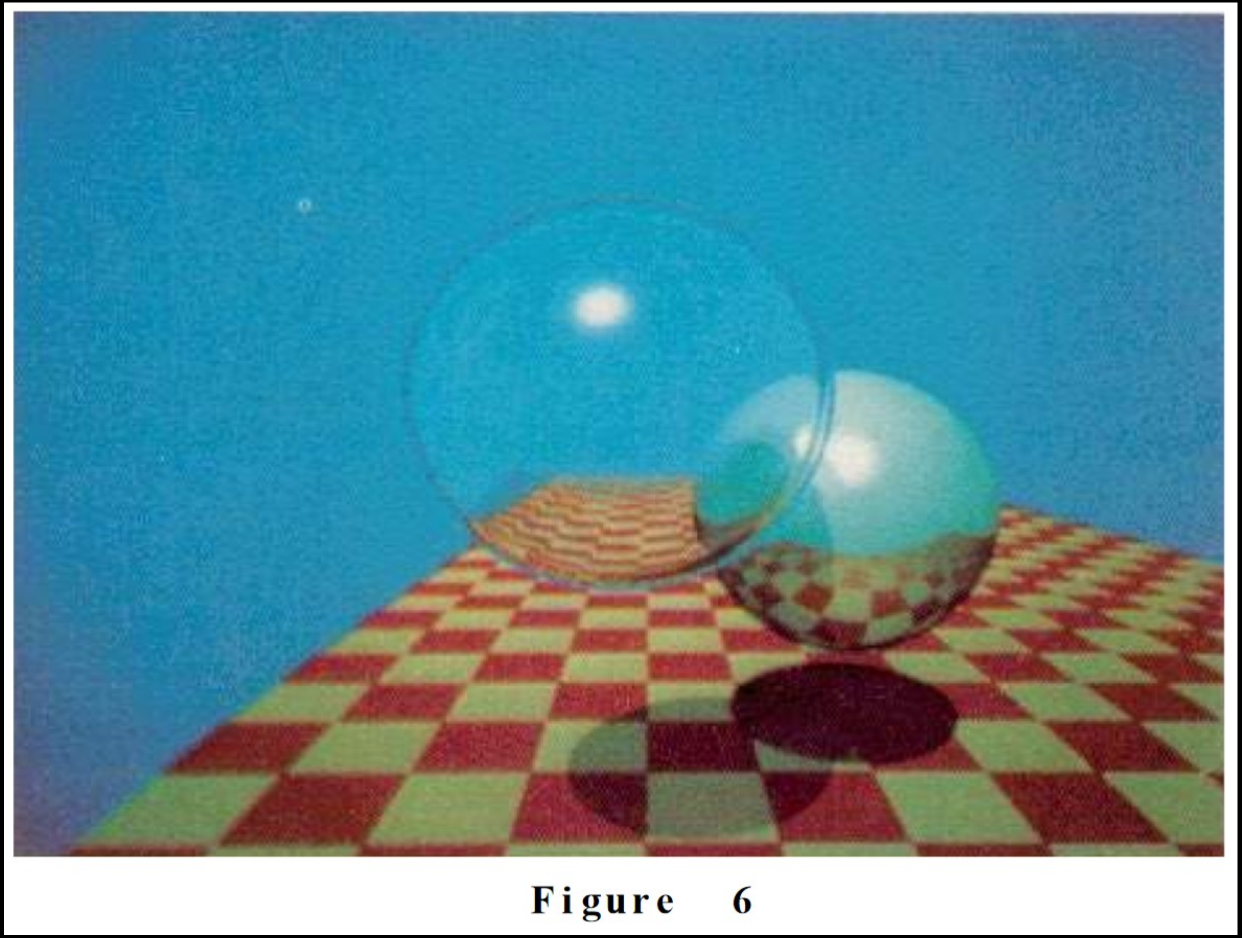
(image by Sascha Willems)

Fragments Are Expensive

- **Many** adaptive sampling algorithms in raytracing
  - With us since the beginning!

"I had written a draft of a SIGGRAPH conference submission and was rendering illustrations to be included in the paper. The submission deadline was near, but with 16x super-sampling, the estimated rendering times extended beyond the submission deadline. The spontaneous idea of ***adaptively super-sampling was a life saver*** *because it only added additional samples where needed. It was implemented within a couple of hours and the paper was edited to include this new idea while the illustrations were being rendered."*

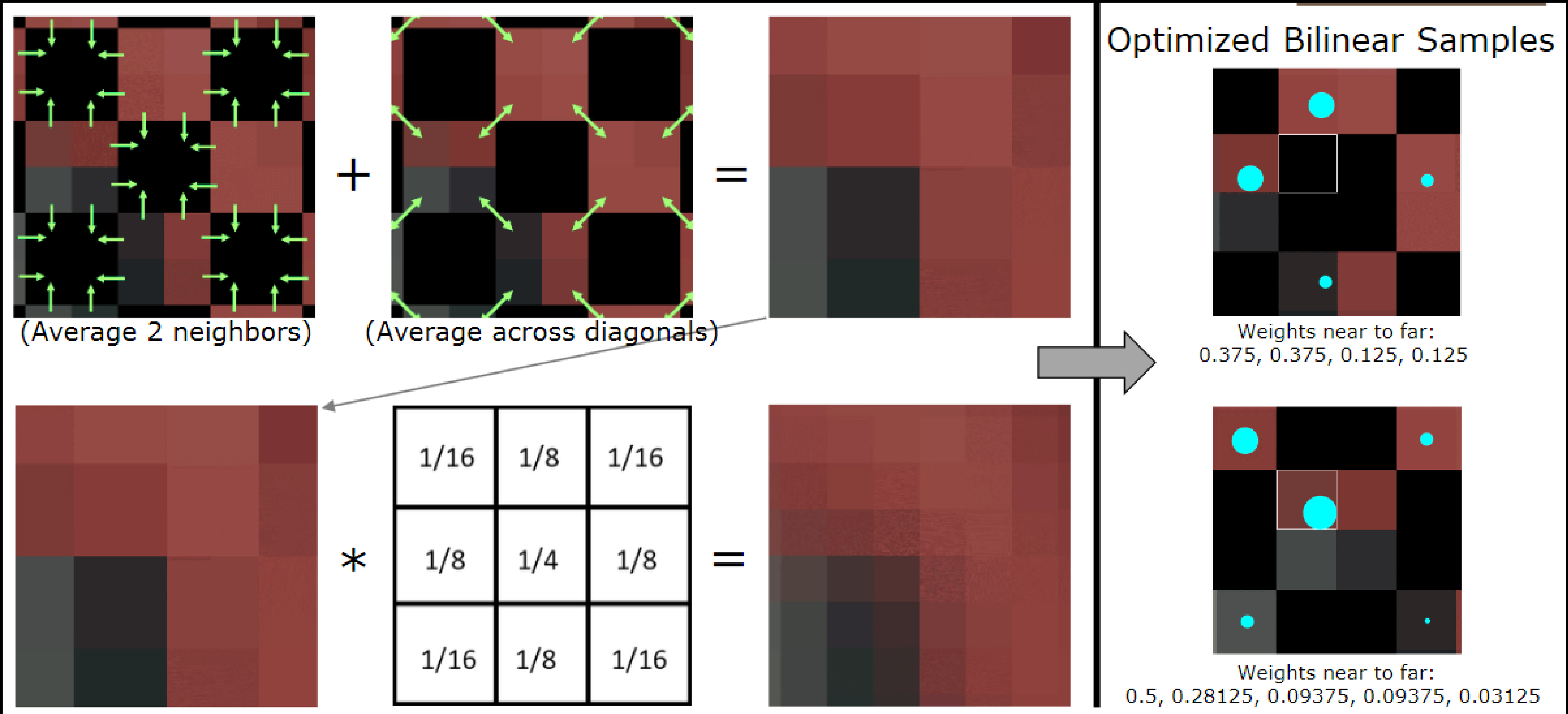
-J. Turner Whitted



(image by J. Turner Whitted)

Fragments Are Expensive

- Checkerboard rendering: reduce shades to < 1 / pixel. Adaptive sampling doesn’t map well to GPU!



1/16	1/8	1/16
1/8	1/4	1/8
1/16	1/8	1/16

(slide by Alex Vlachos)

Deferred Adaptive Compute Shading

- Replacement for checkerboard rendering
  - (one-fewer pass, simple, provided code)

- Reduces shading adaptively

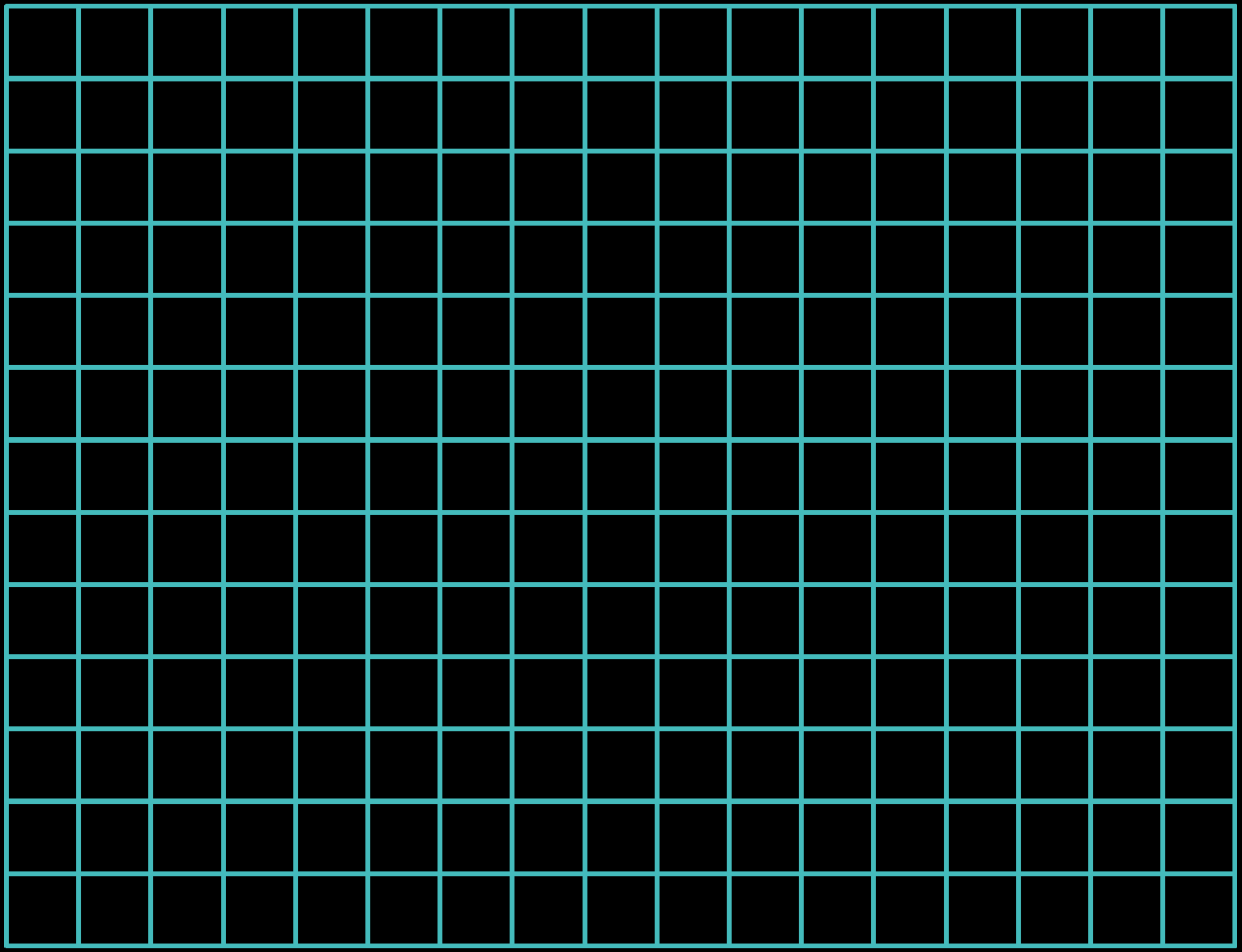
- Still GPU-friendly:
  - Typical results: 2–4× better quality/perf

Adaptive Subdivision

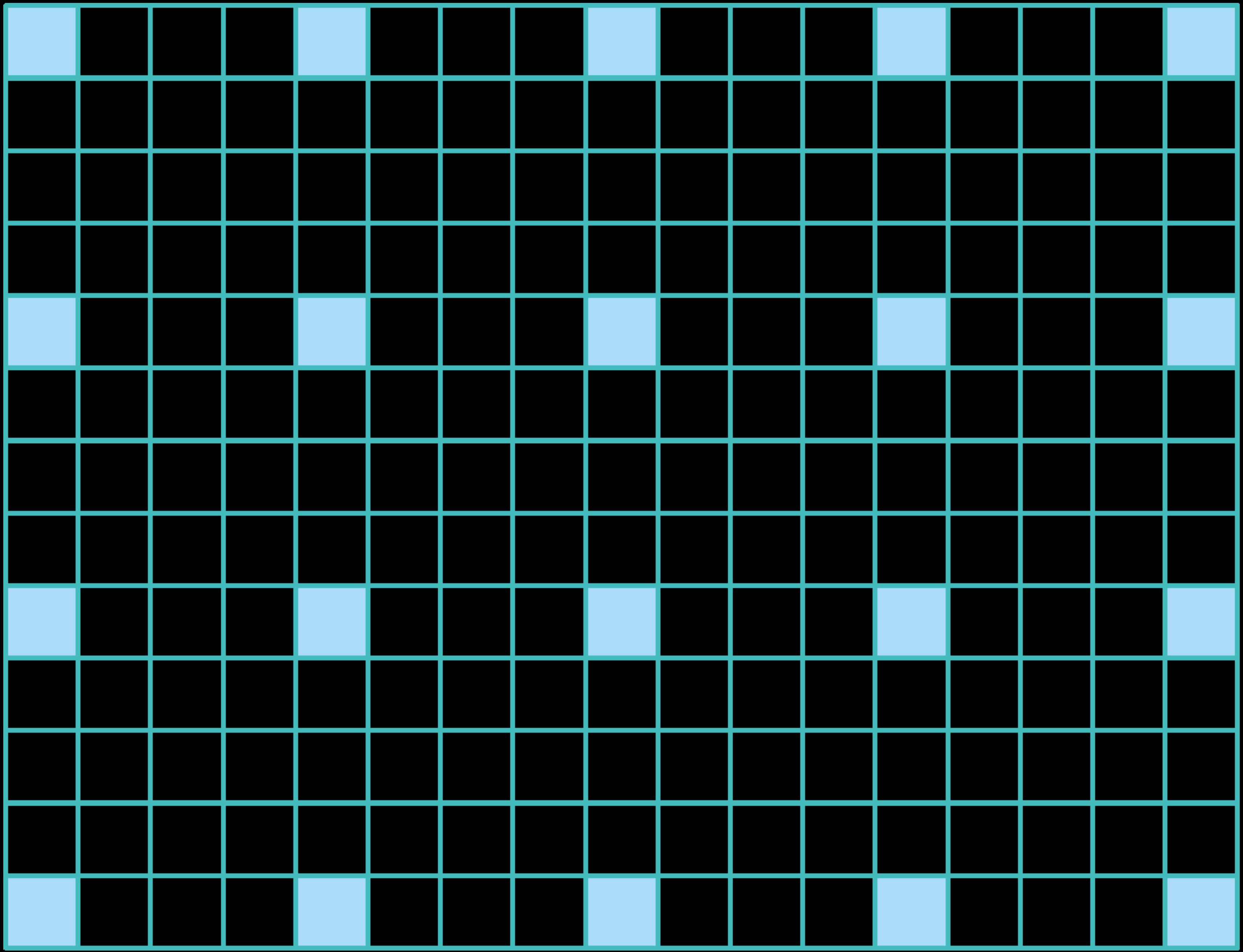
- Simple but proven adaptive subdivision scheme (inspired by V-Ray)
  - (Tried some others, but this one works best)

- Elegant rotational pattern

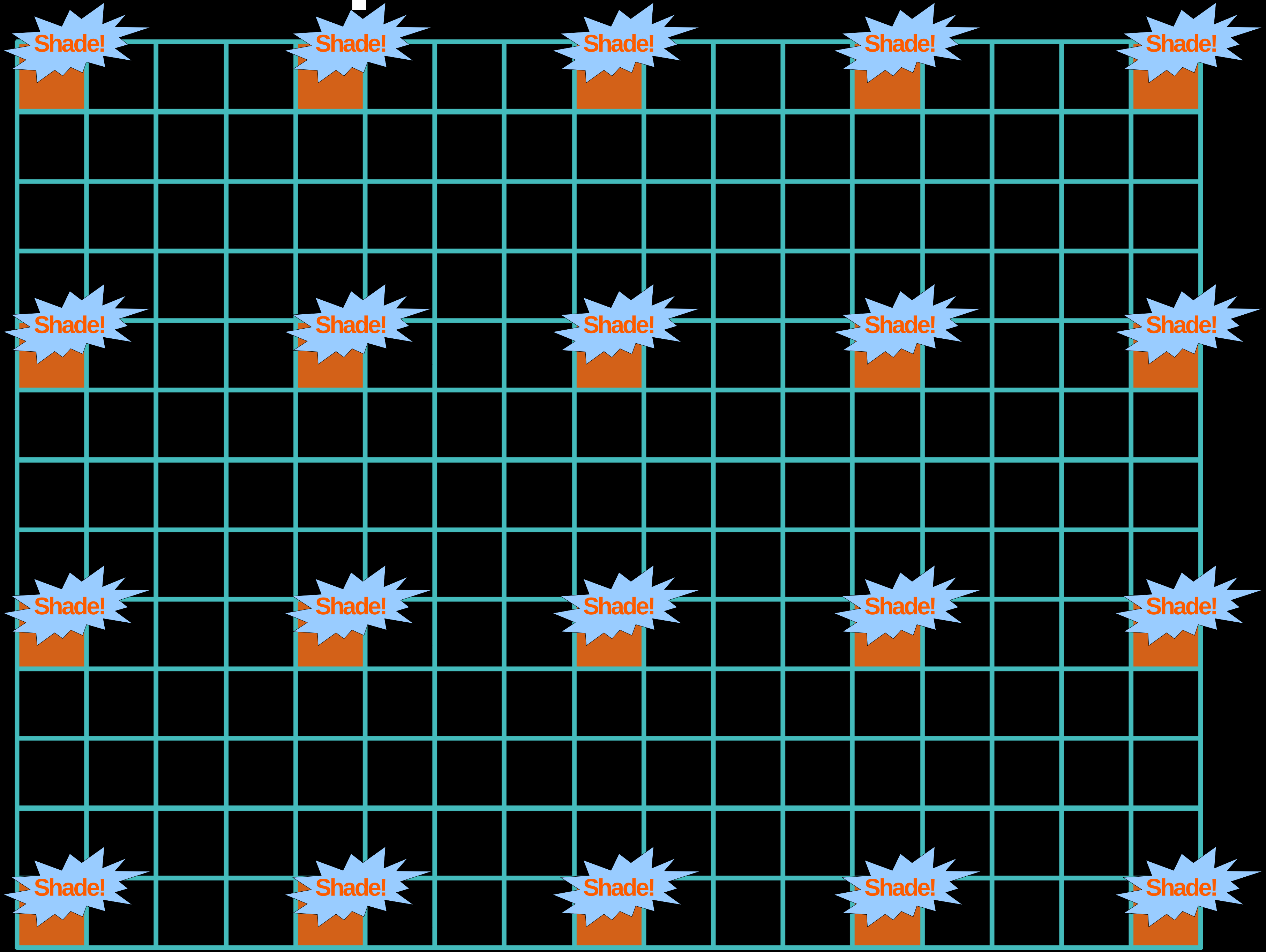
Adaptive Subdivision



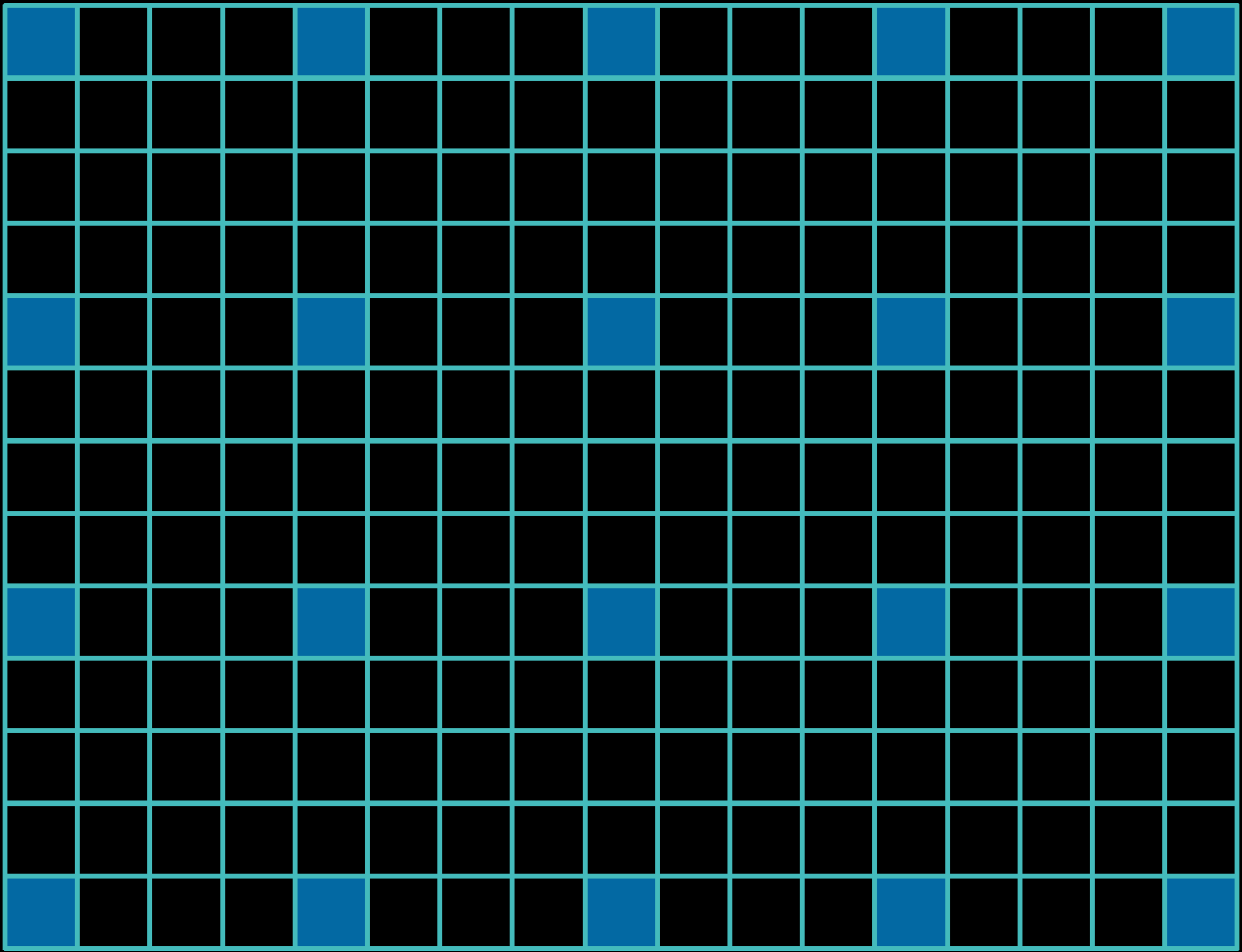
Adaptive Subdivision



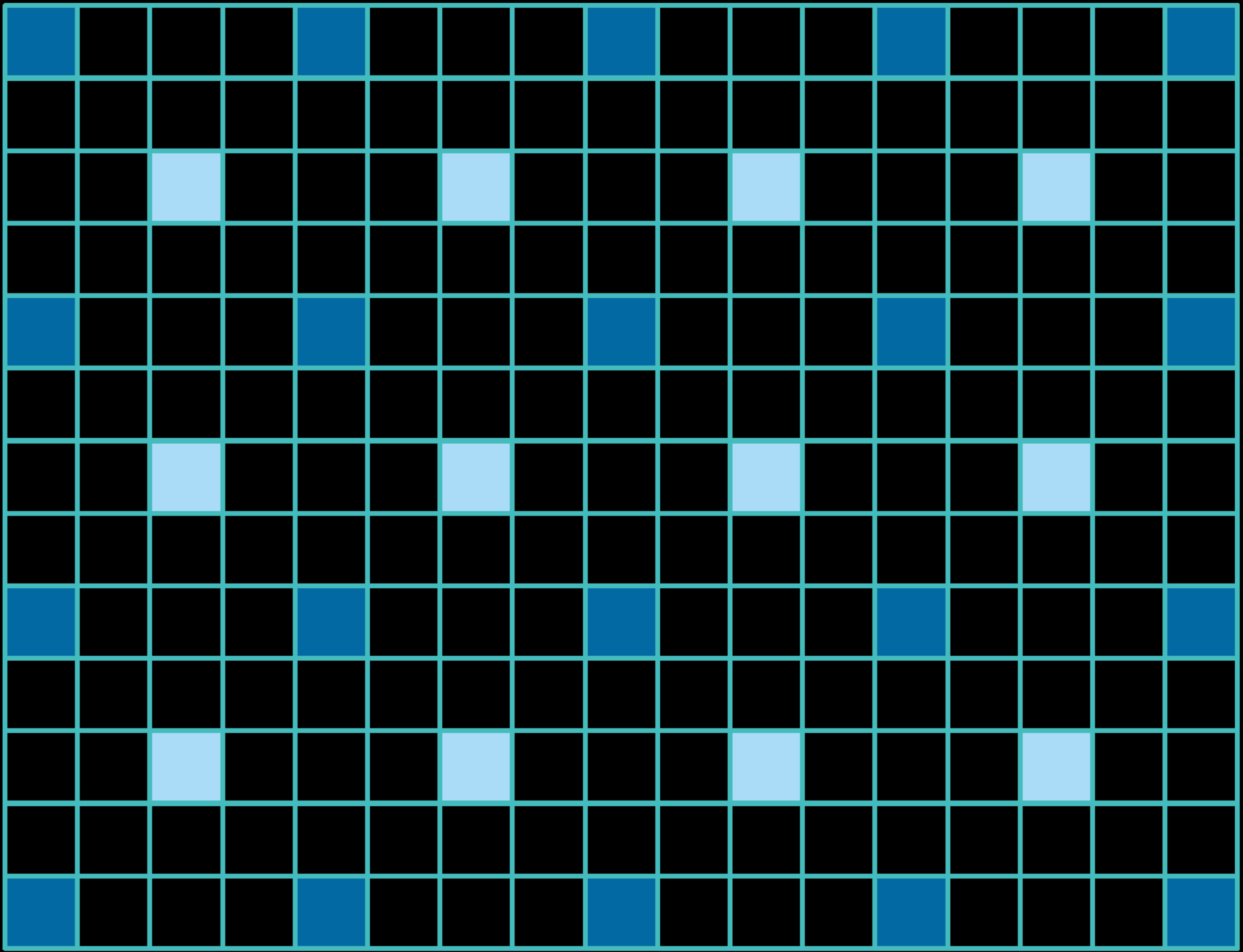
Adaptive Subdivision



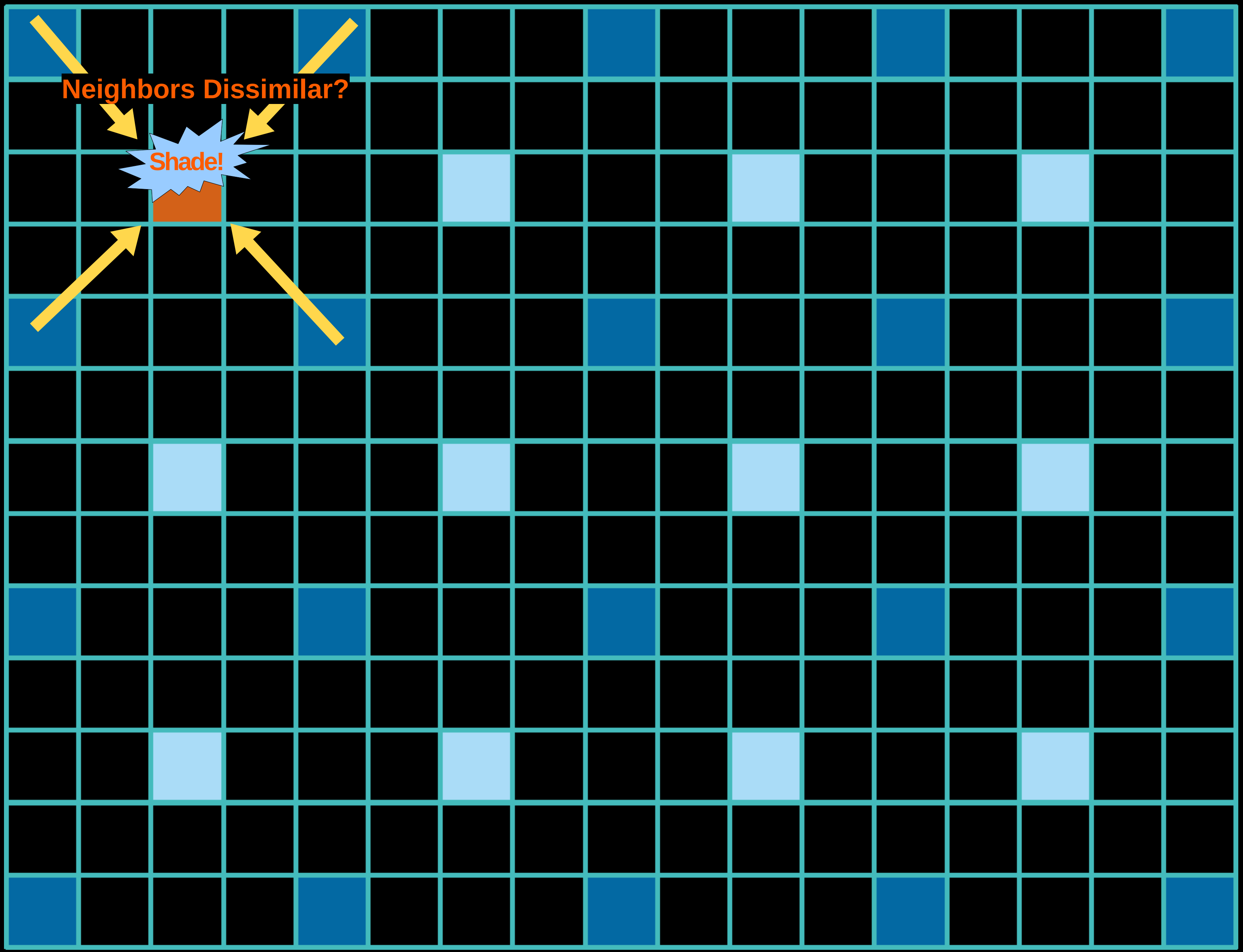
Adaptive Subdivision



Adaptive Subdivision



Adaptive Subdivision

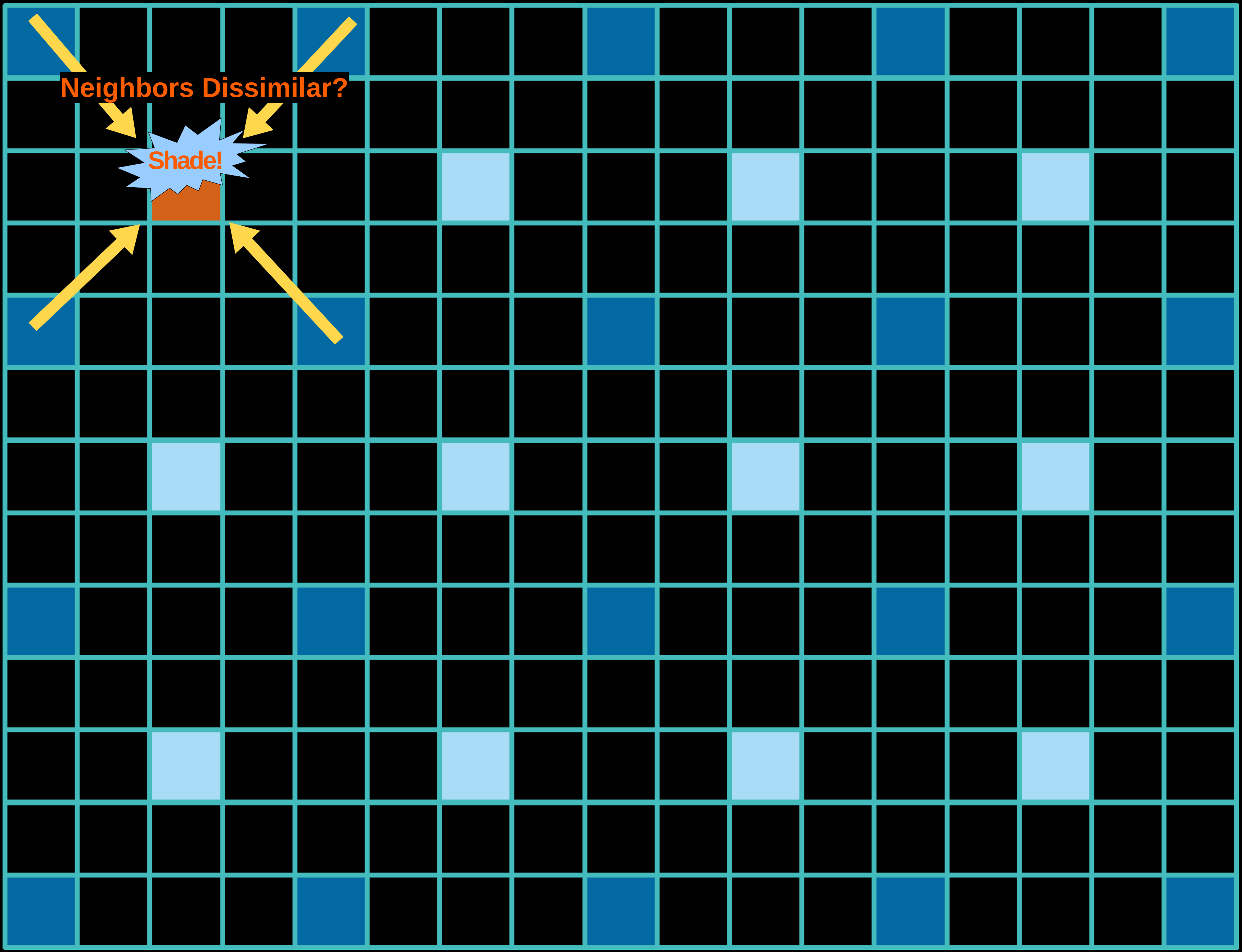


Adaptive Subdivision

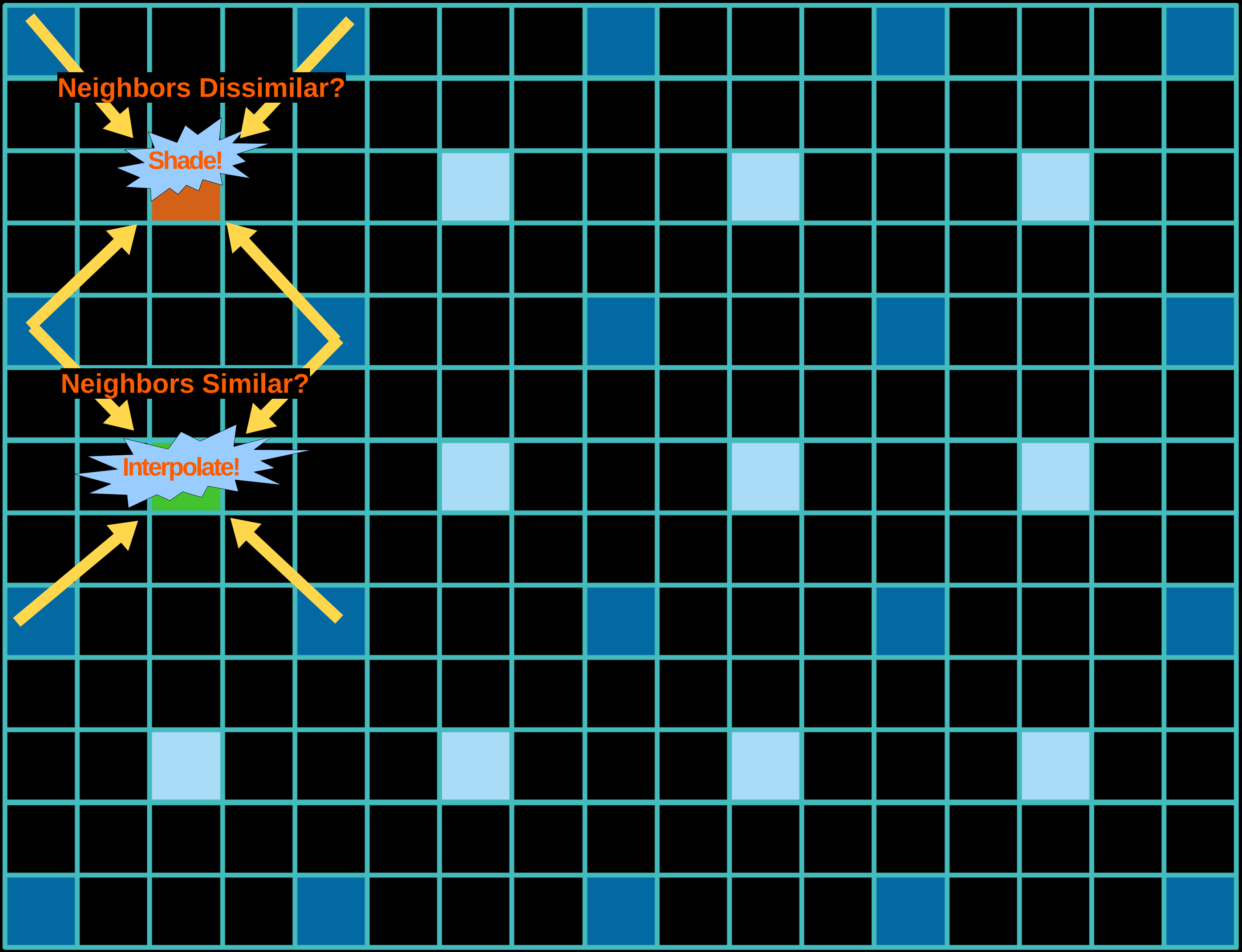
- “Similarity” given by user-defined metric

- We suggest:
  - “Dissimilar” if material IDs different
  - “Dissimilar” if final colors differ by threshold or more
  - Look at other G-buffer features?

Adaptive Subdivision



Adaptive Subdivision



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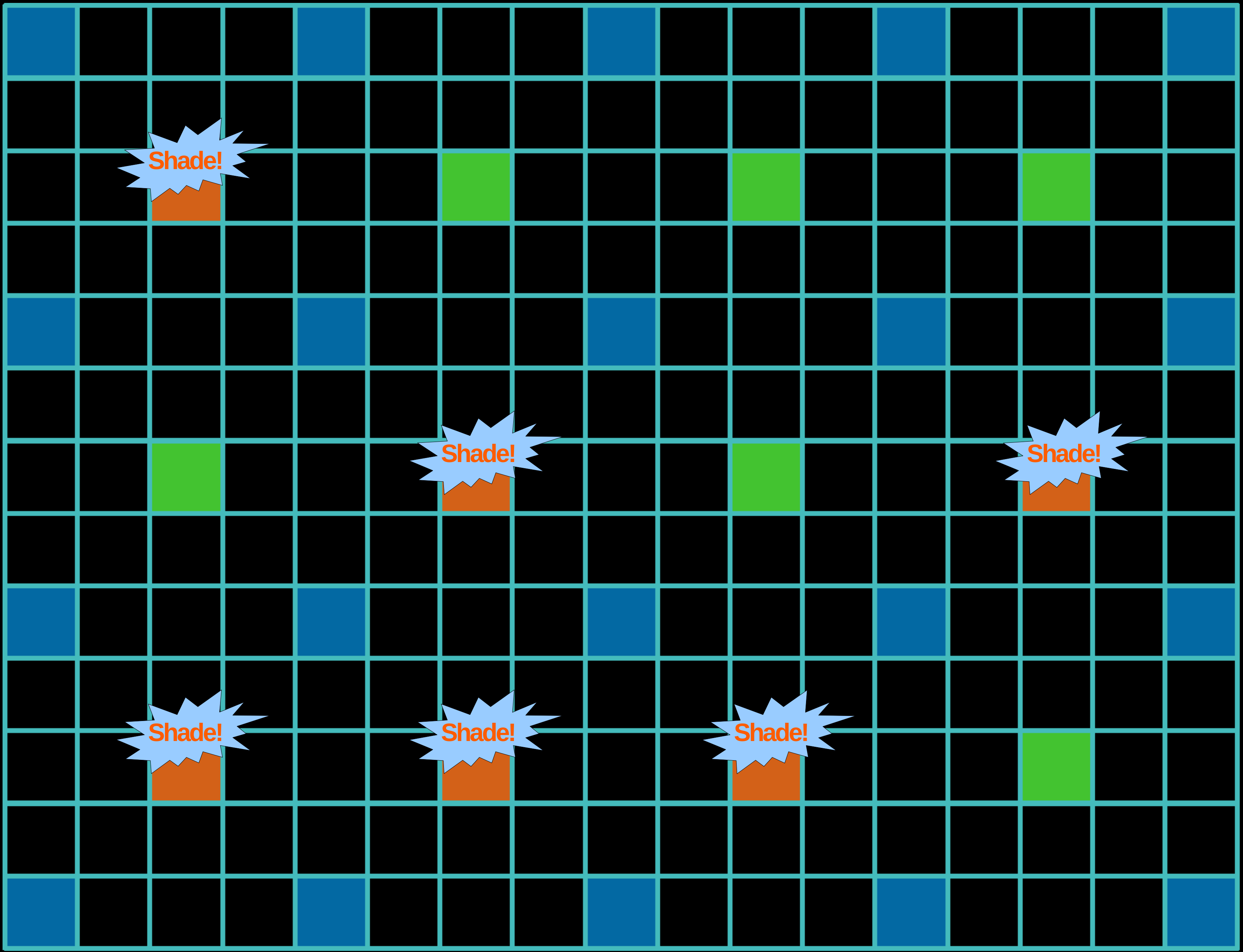
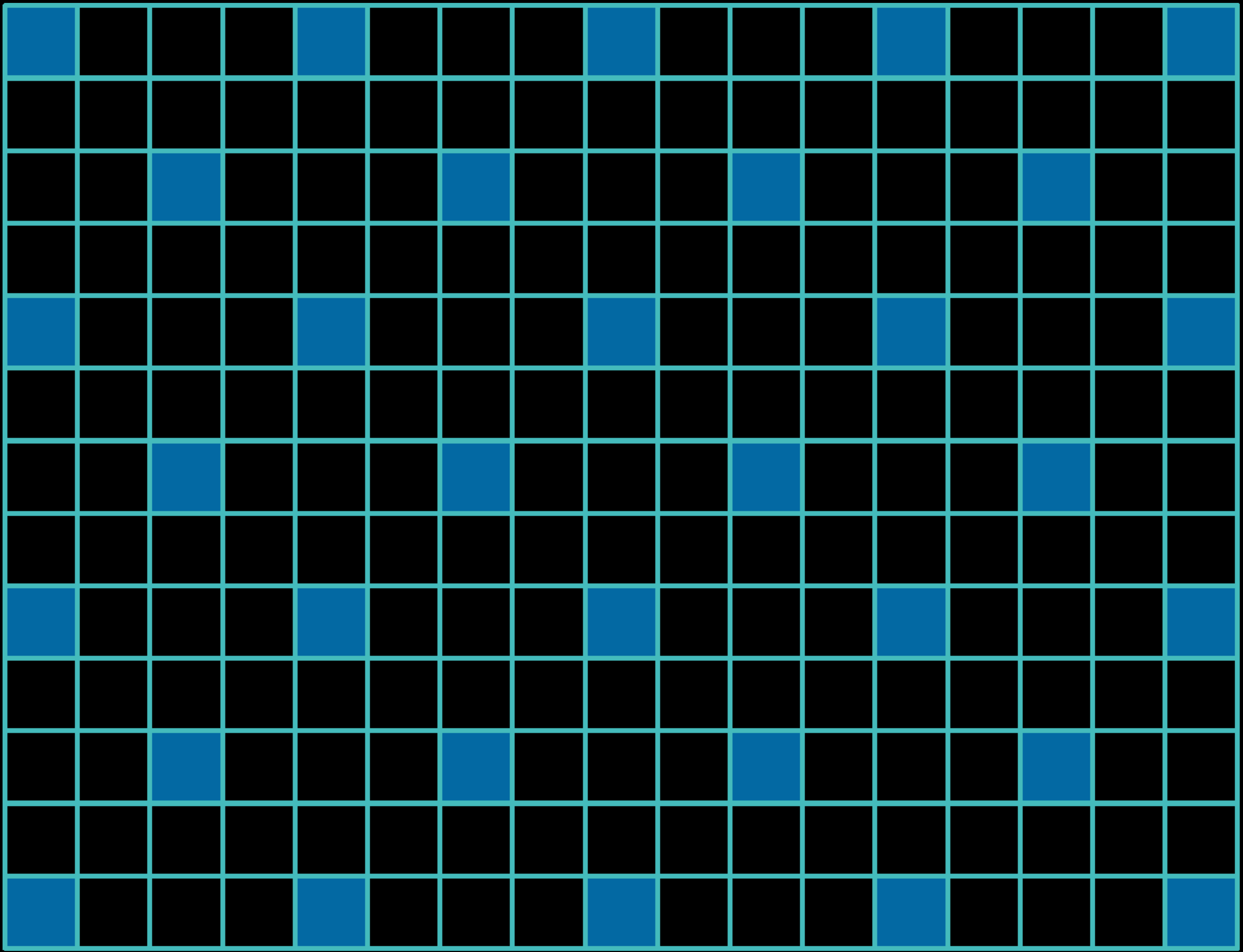


Adaptive Subdivision



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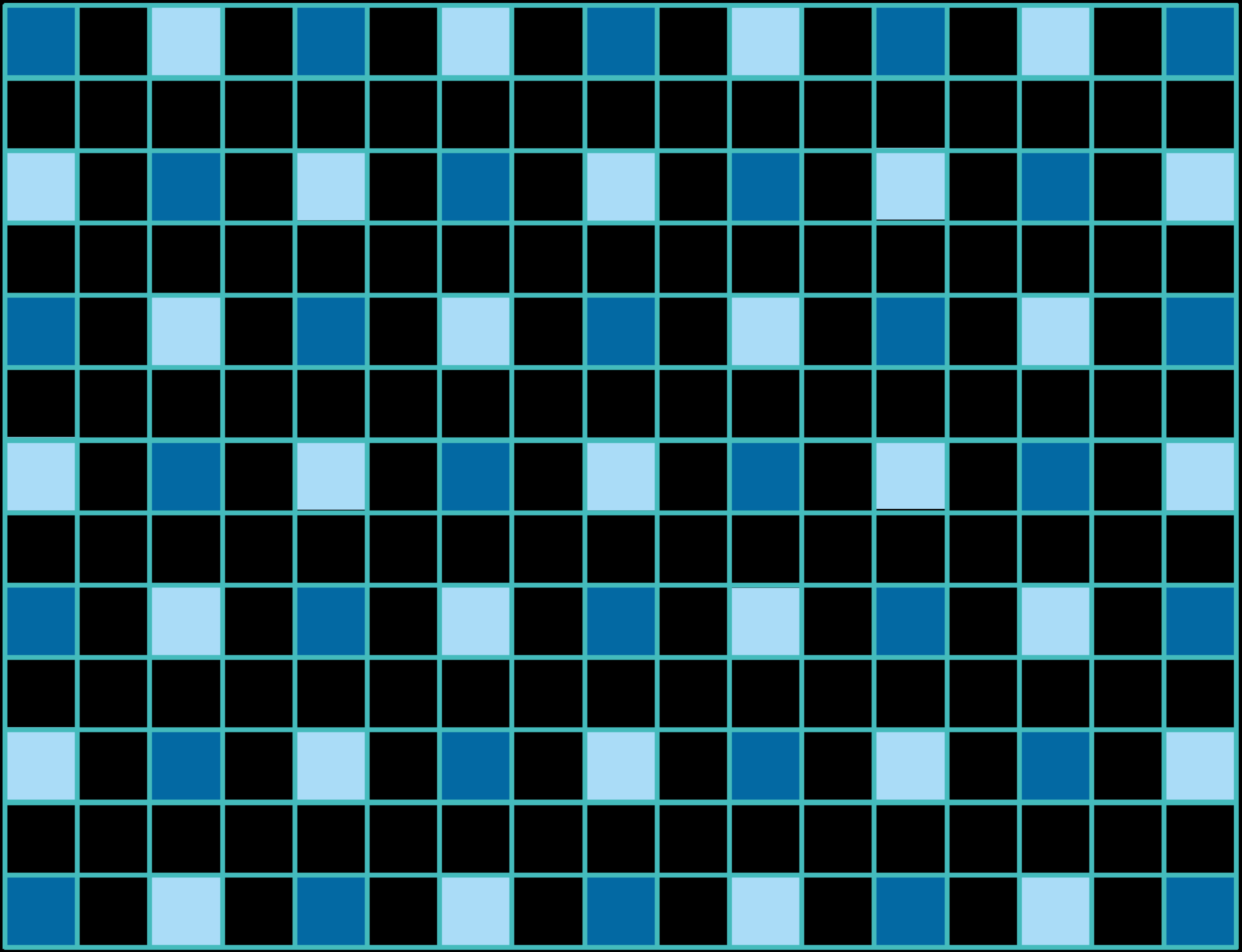
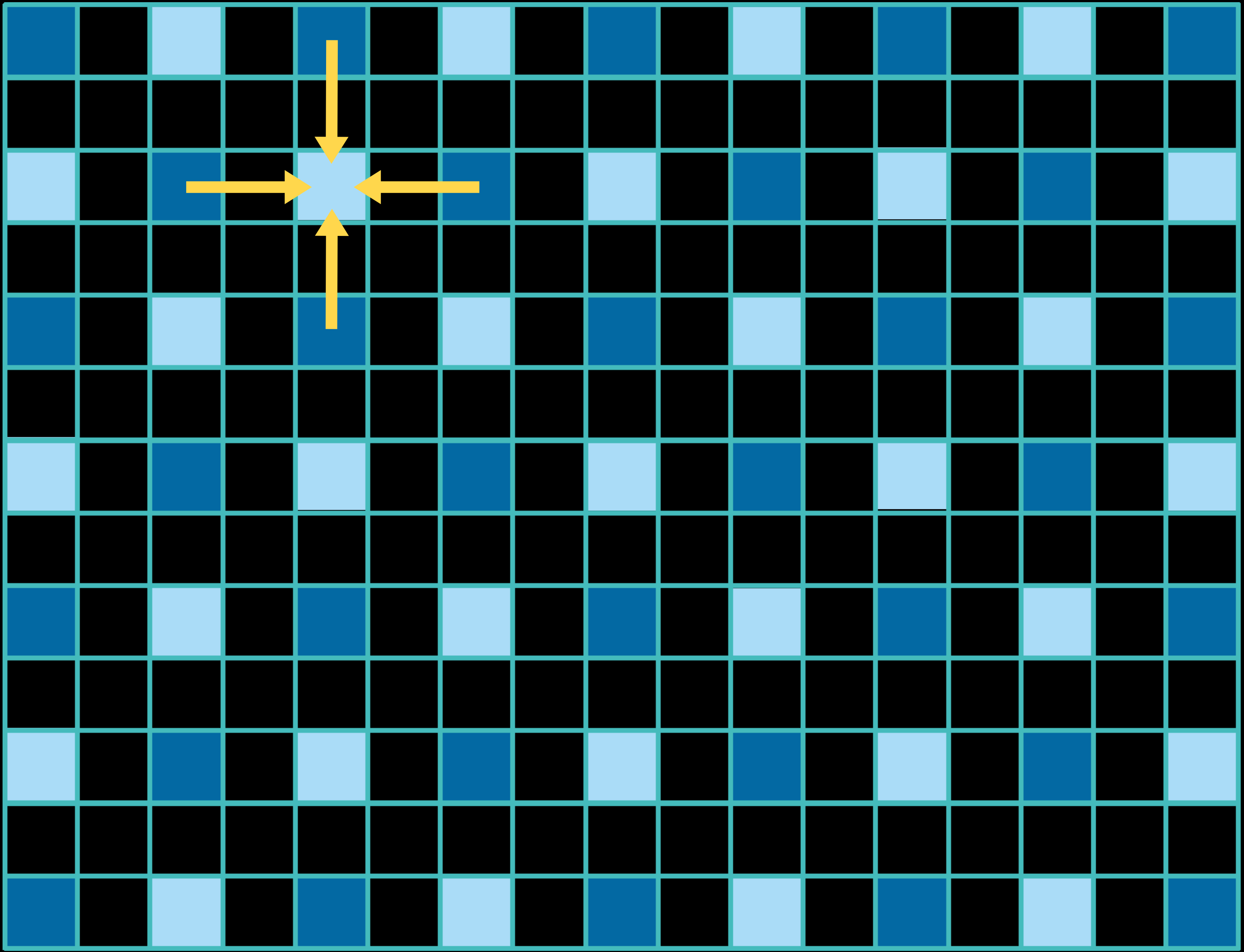


Adaptive Subdivision



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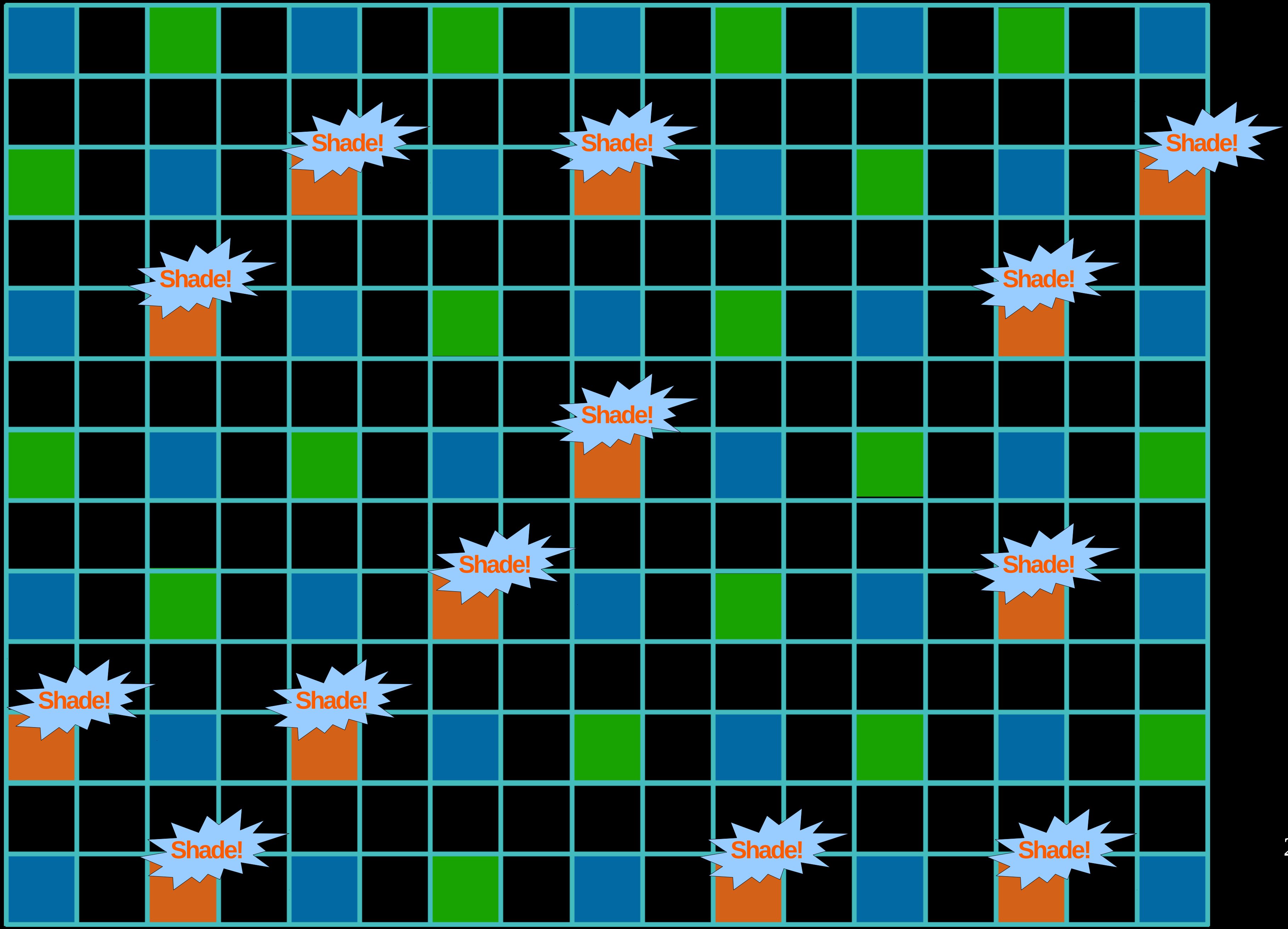

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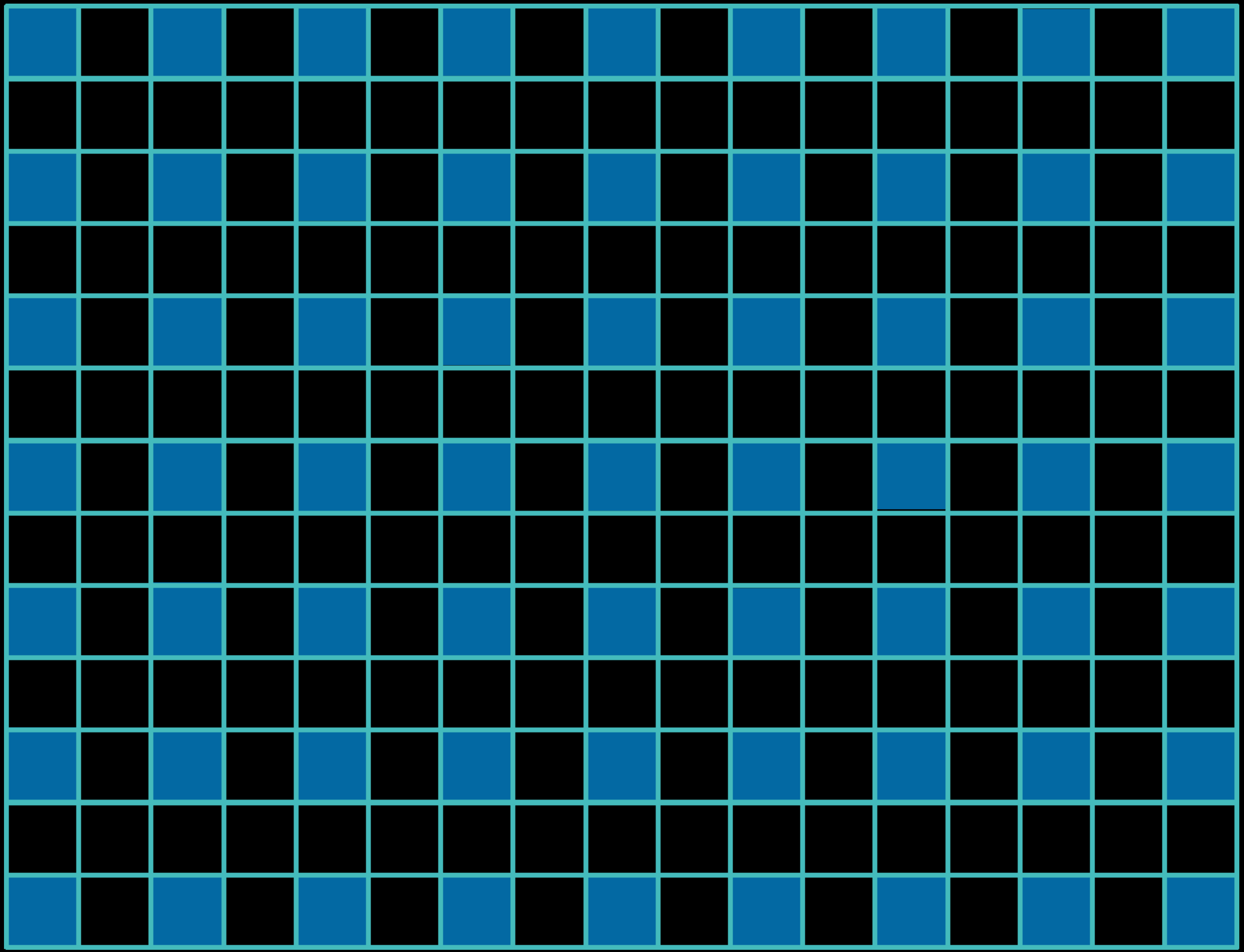
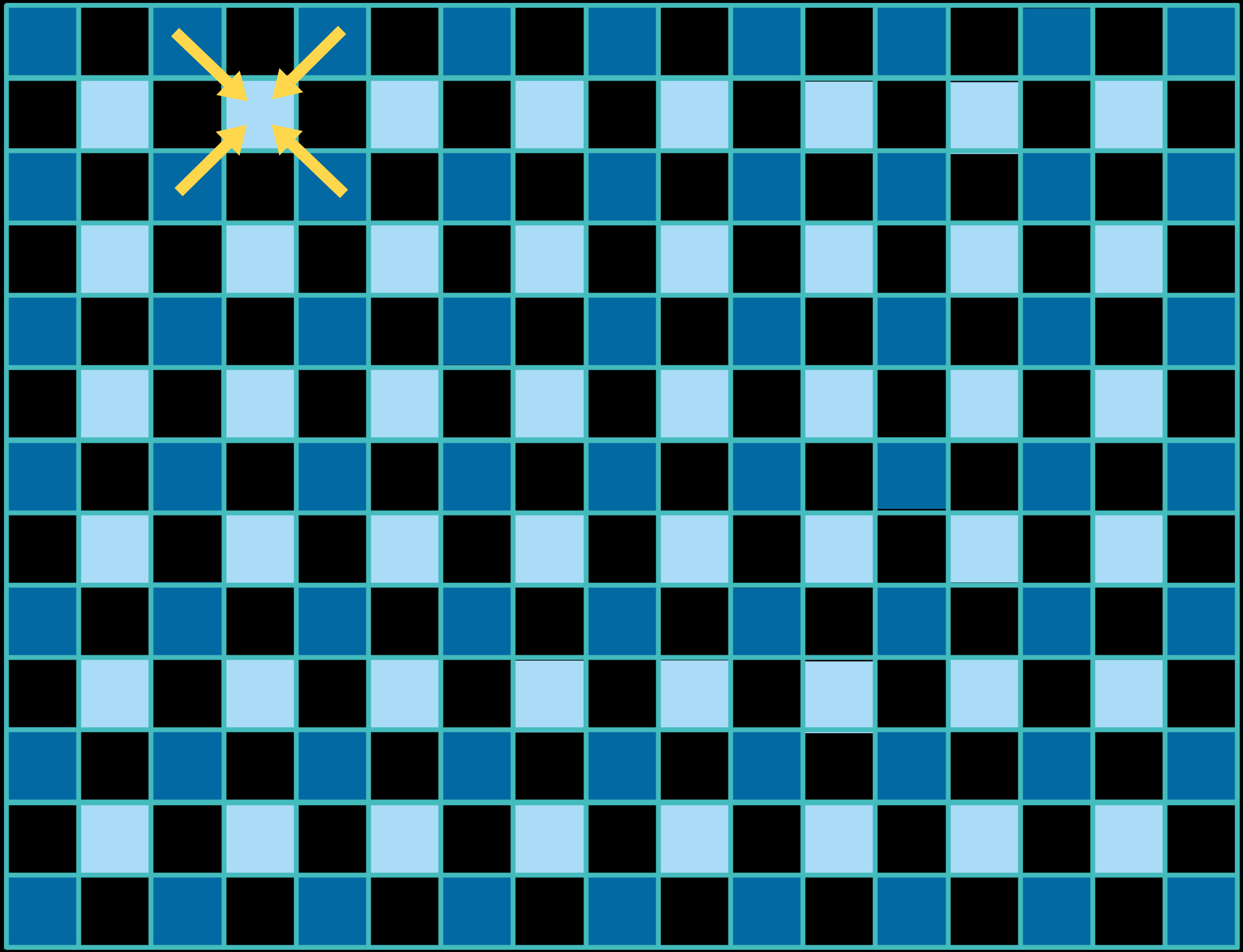
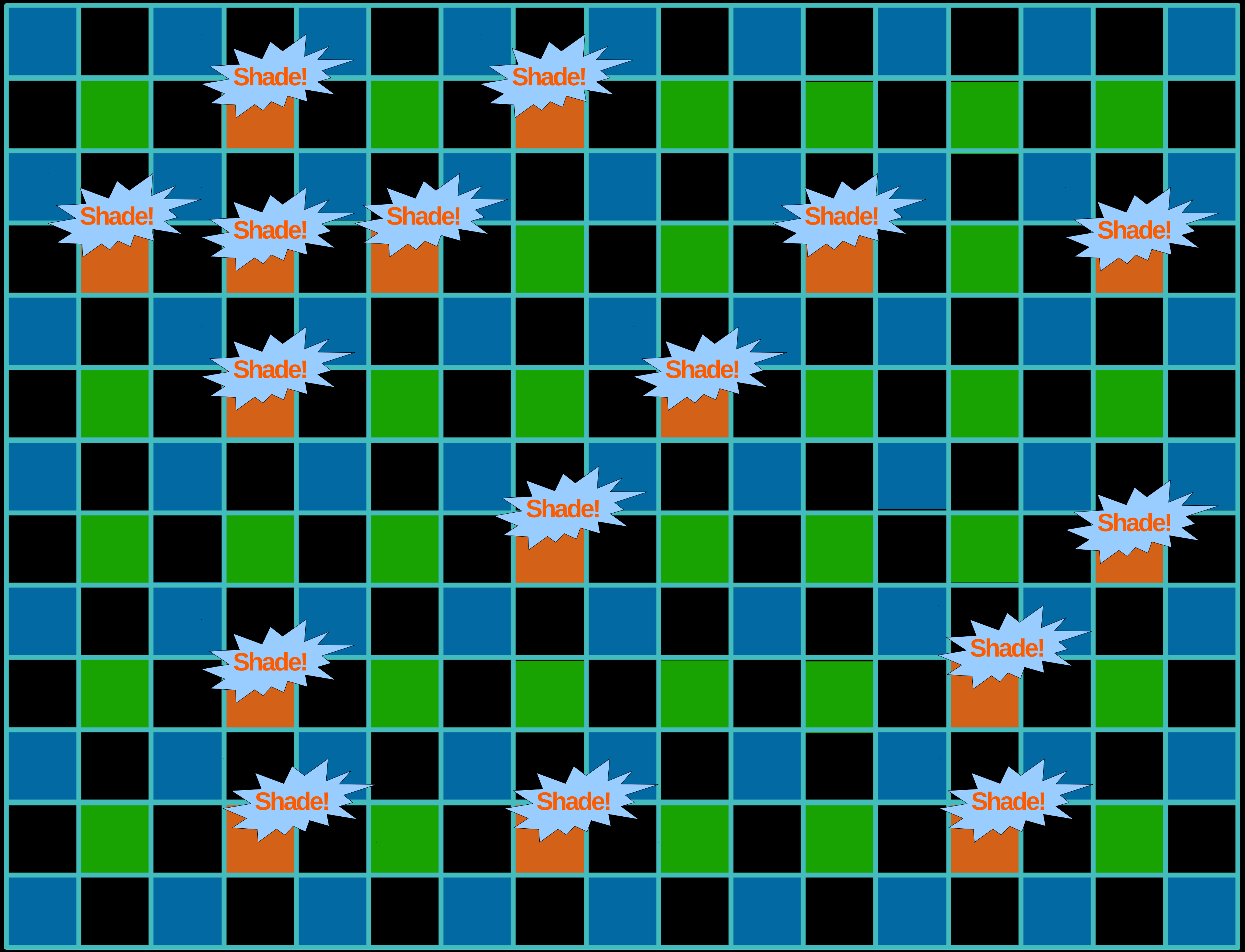


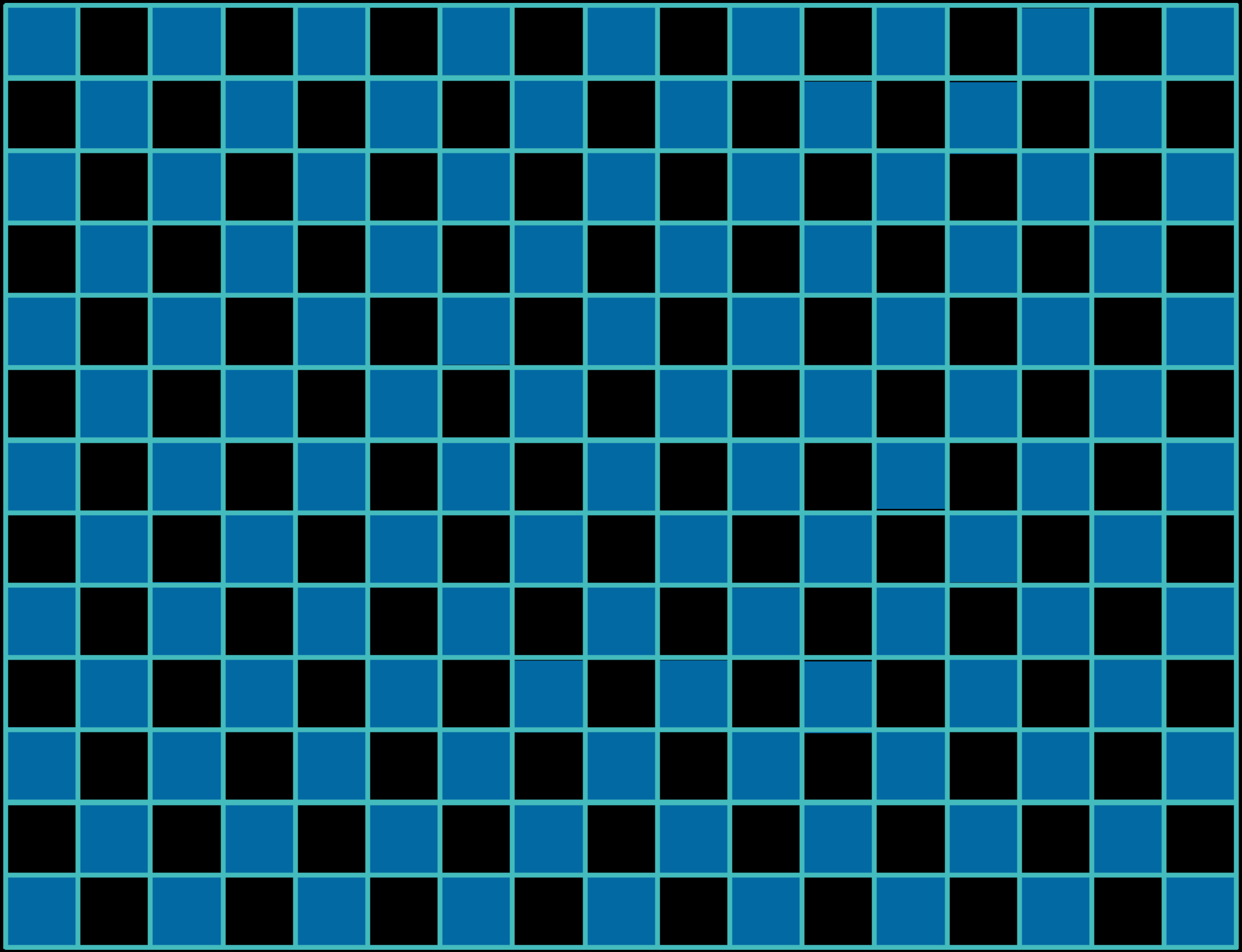
Adaptive Subdivision



Adaptive Subdivision



Adaptive Subdivision



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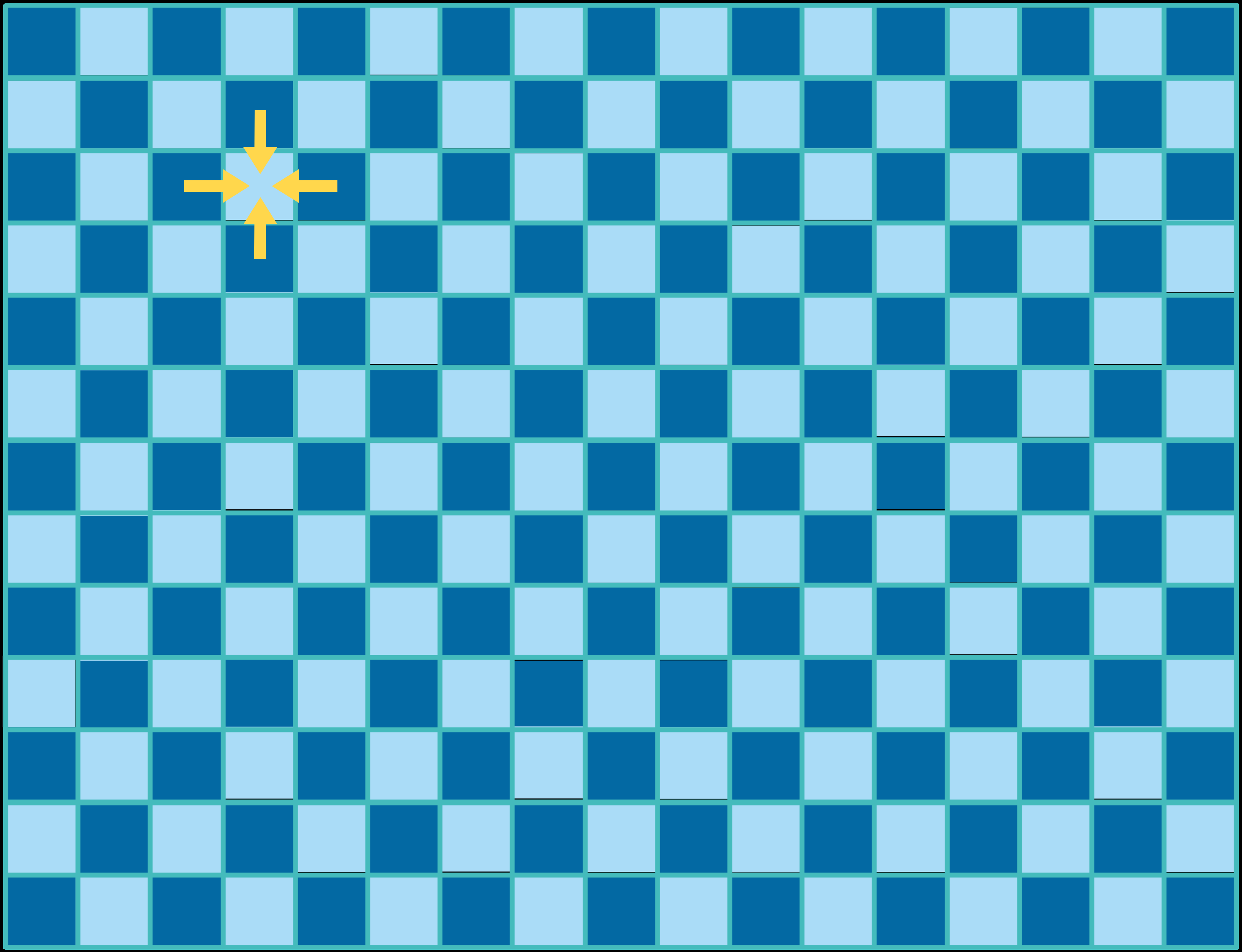
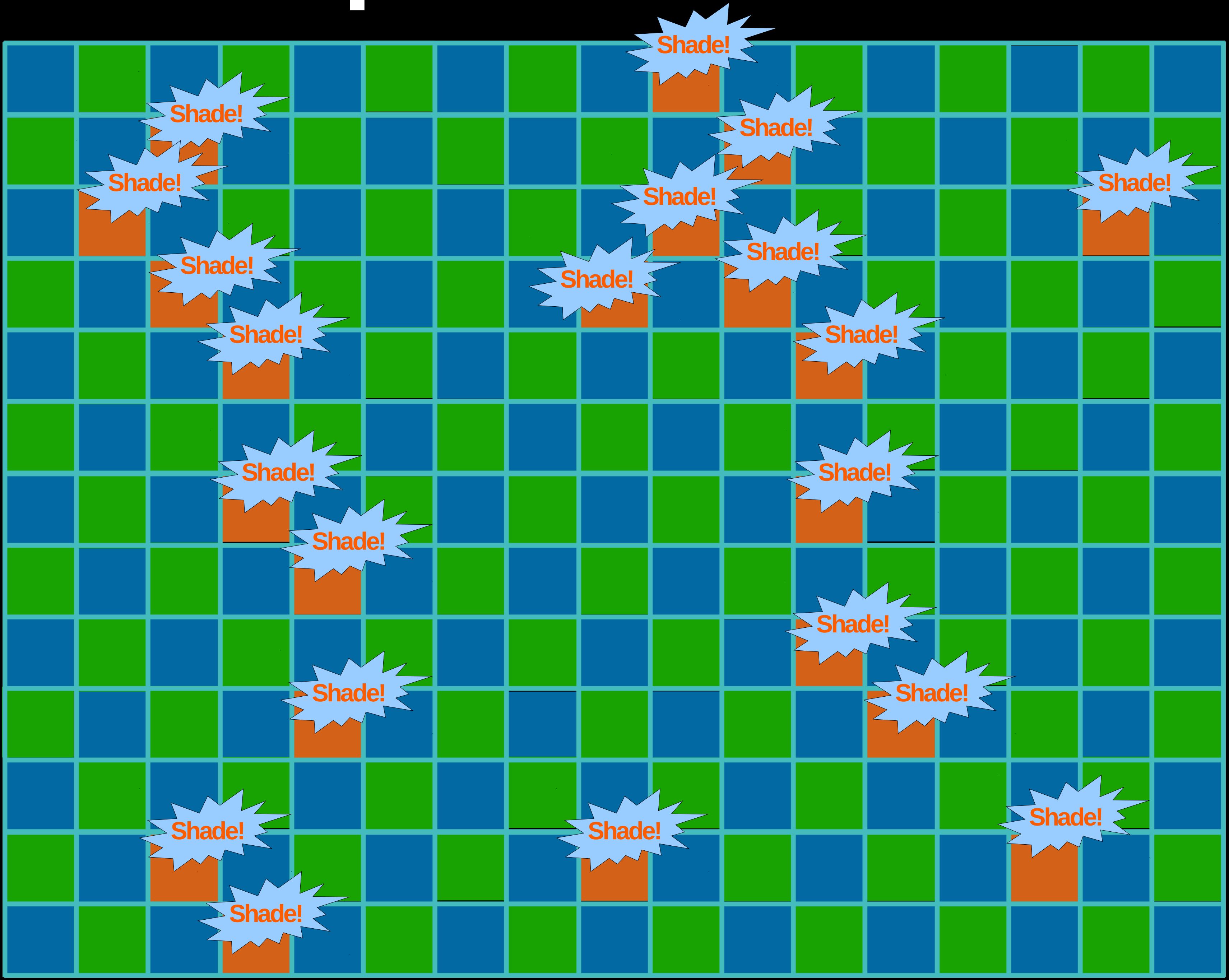


Adaptive Subdivision



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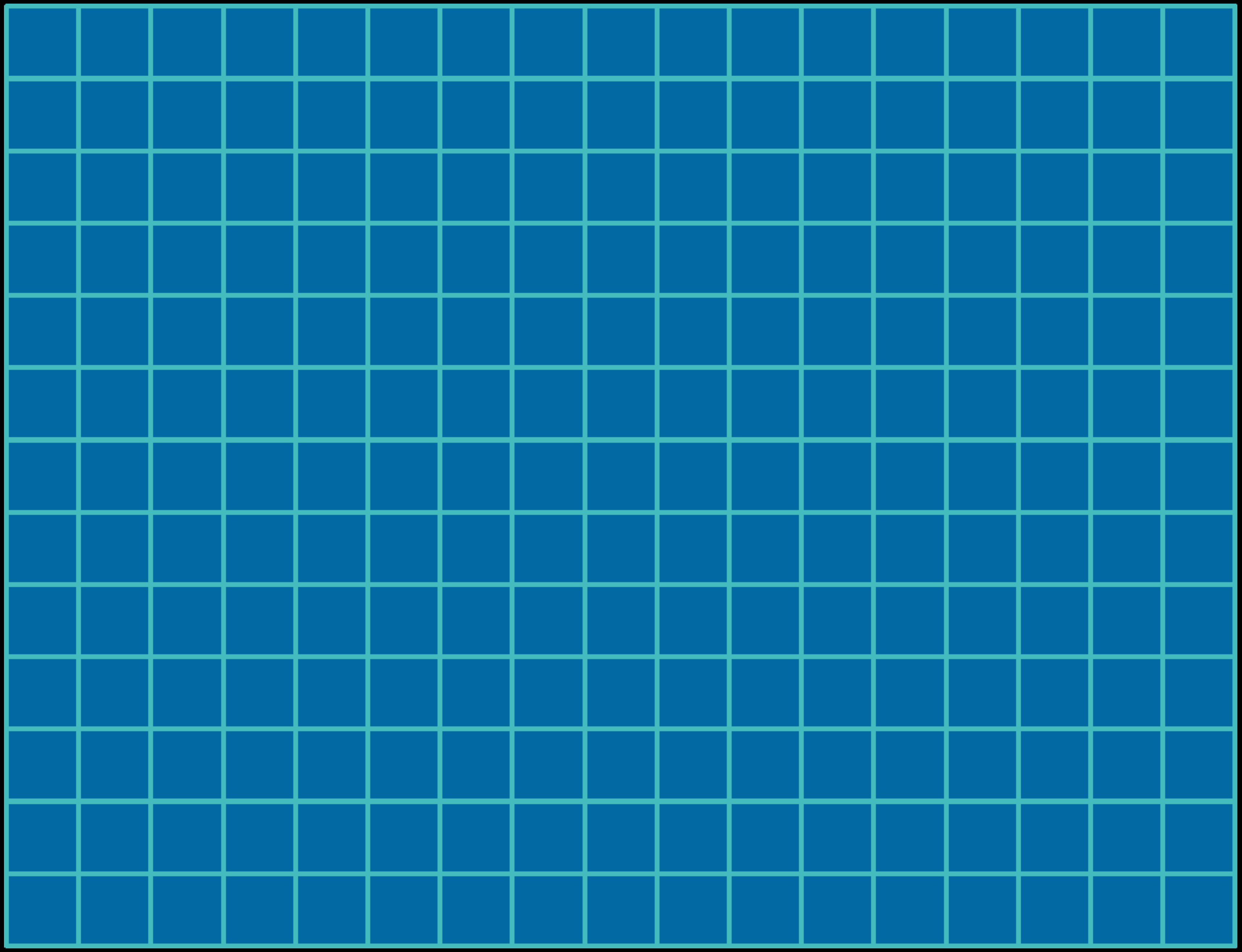
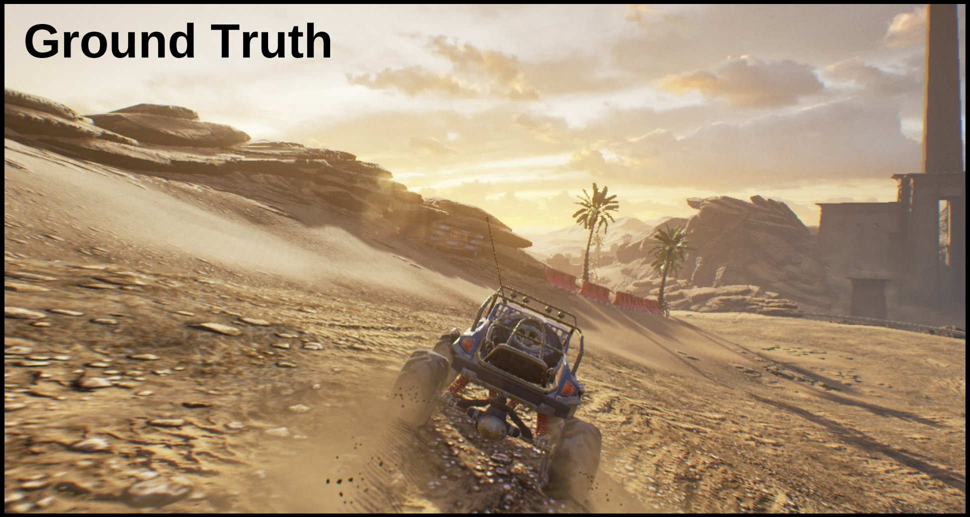
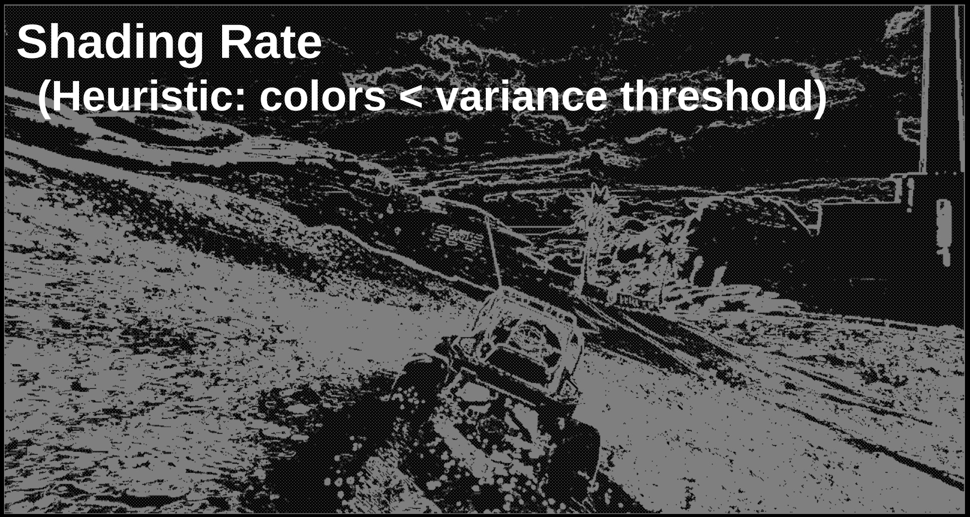


Adaptive Subdivision

Adaptive Subdivision





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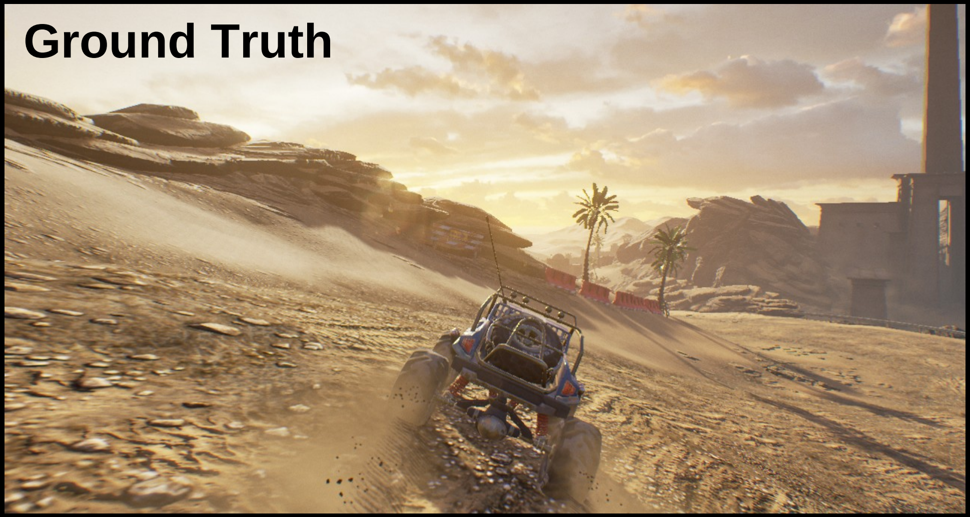
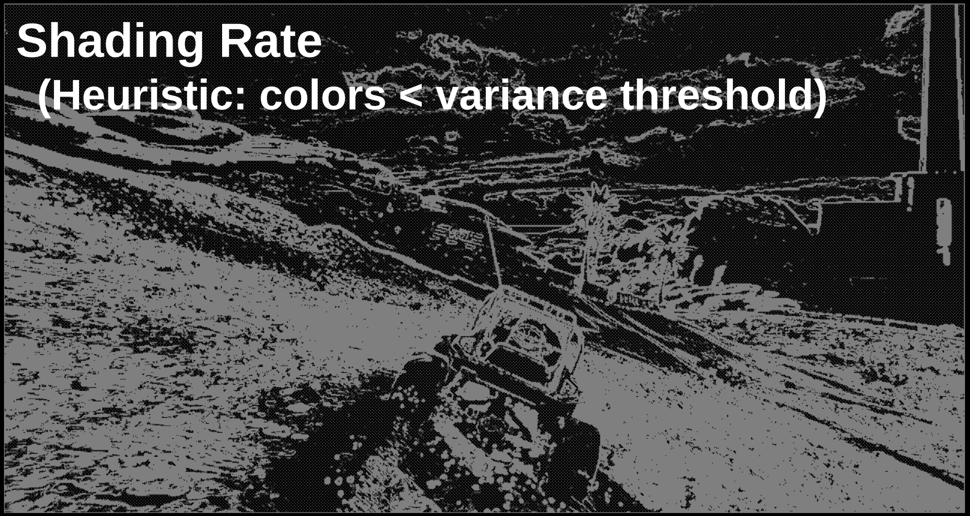
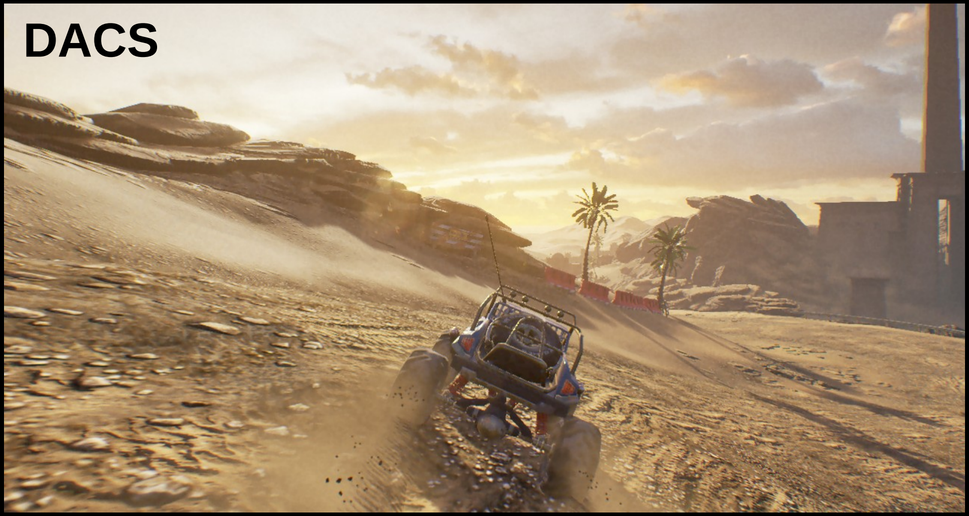
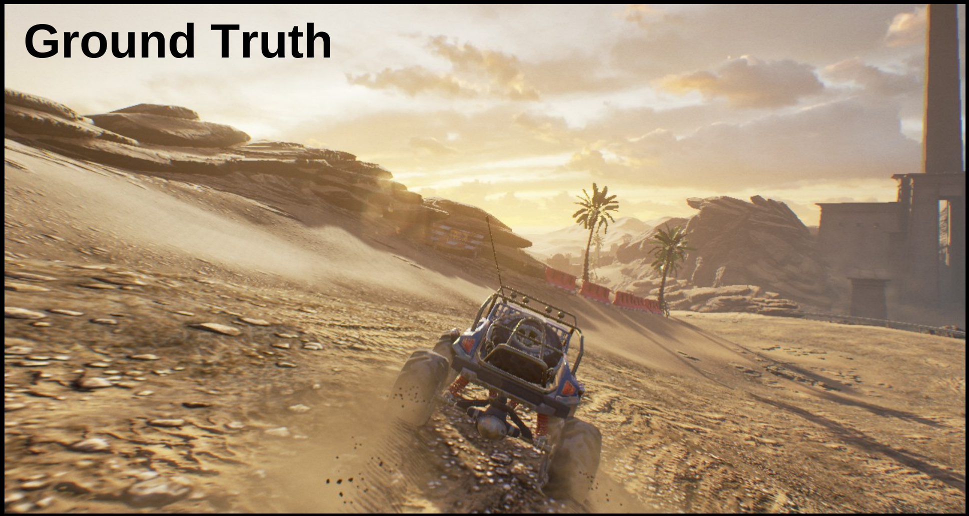
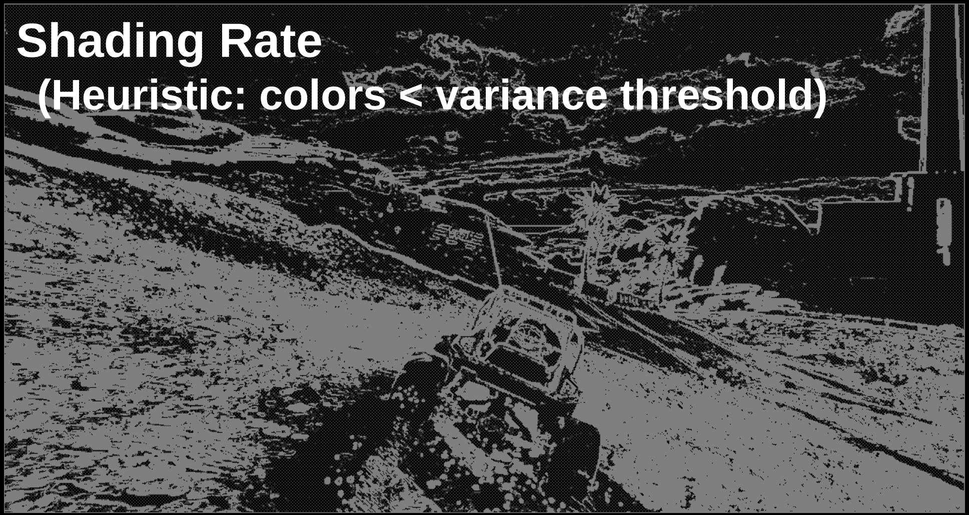


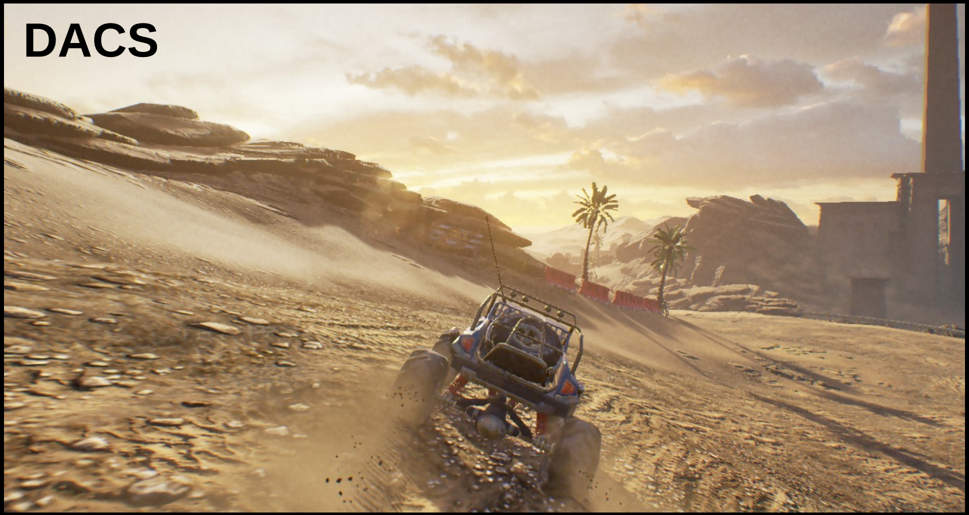


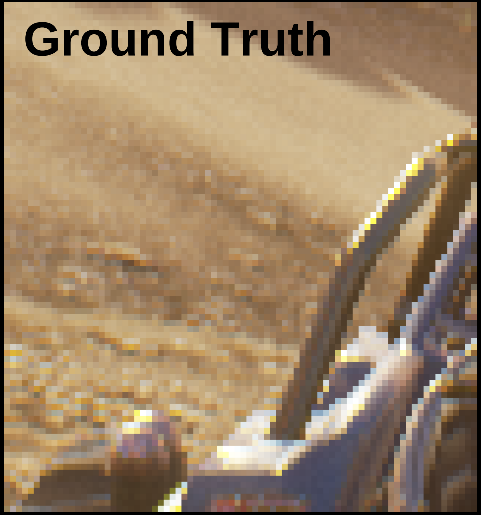


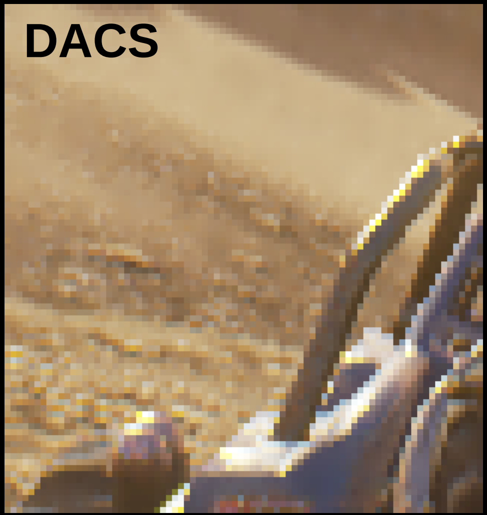
Adaptive Subdivision


Ground Truth


Shading Rate
(Heuristic: colors < variance threshold)


DACS


Ground Truth


DACS

Deferred Adaptive Compute Shading

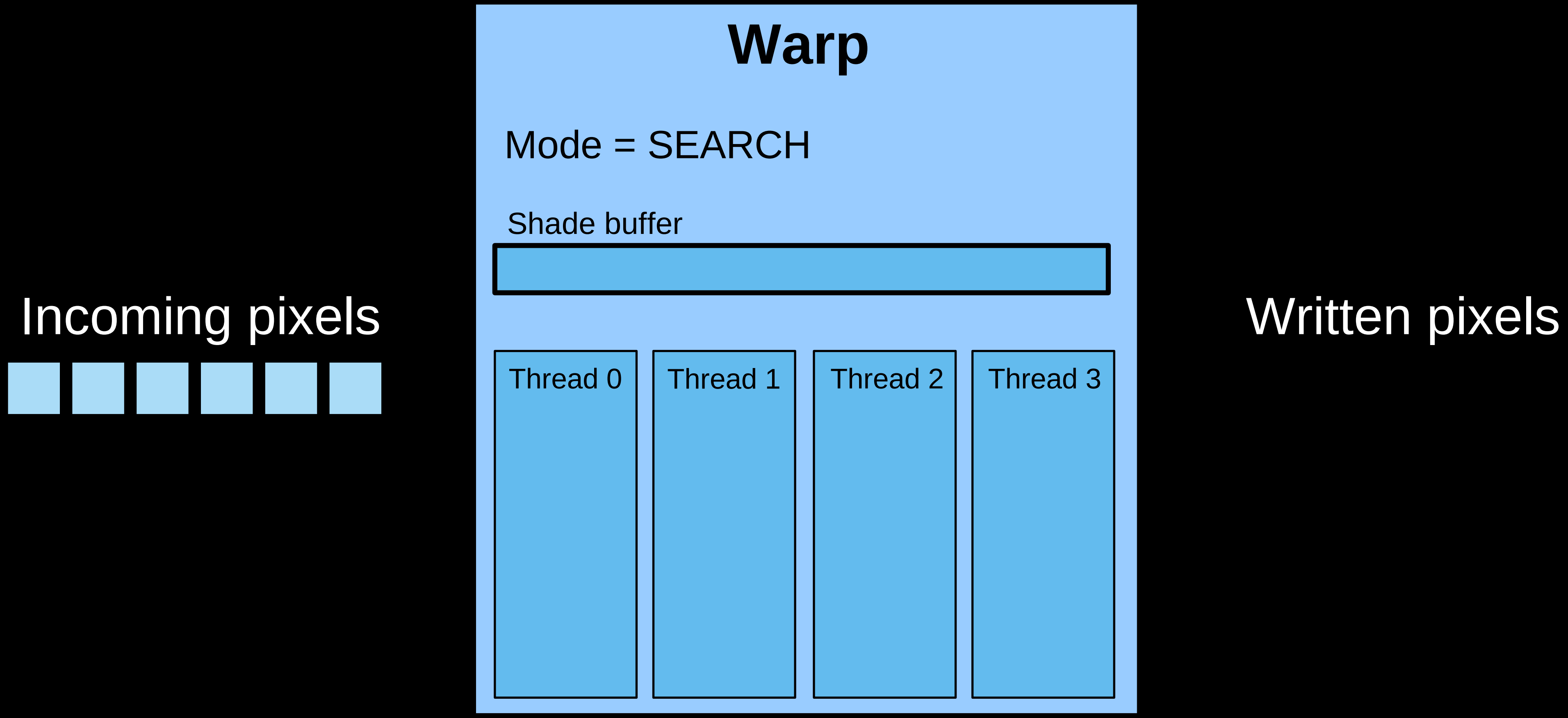
Implementation on Current GPUs

Warp Divergence

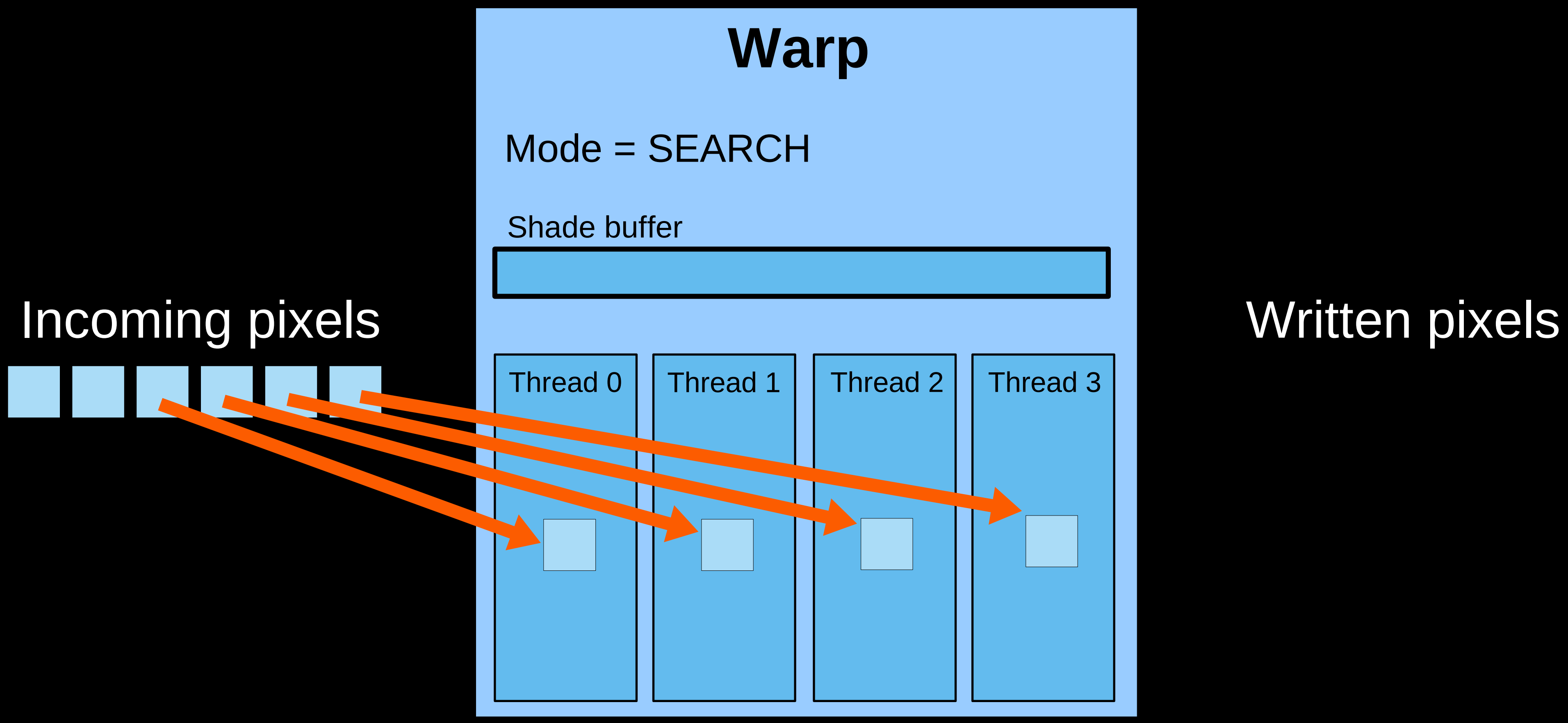
- Cannot skip pixels like this!
  - GPU still does the work (it’s just wasted)!

- Solution: warps switch between “search/interpolate” mode and “shade” mode

Mode Switching



Mode Switching



Warp

Mode = SEARCH

Shade buffer

Incoming pixels

Thread 0

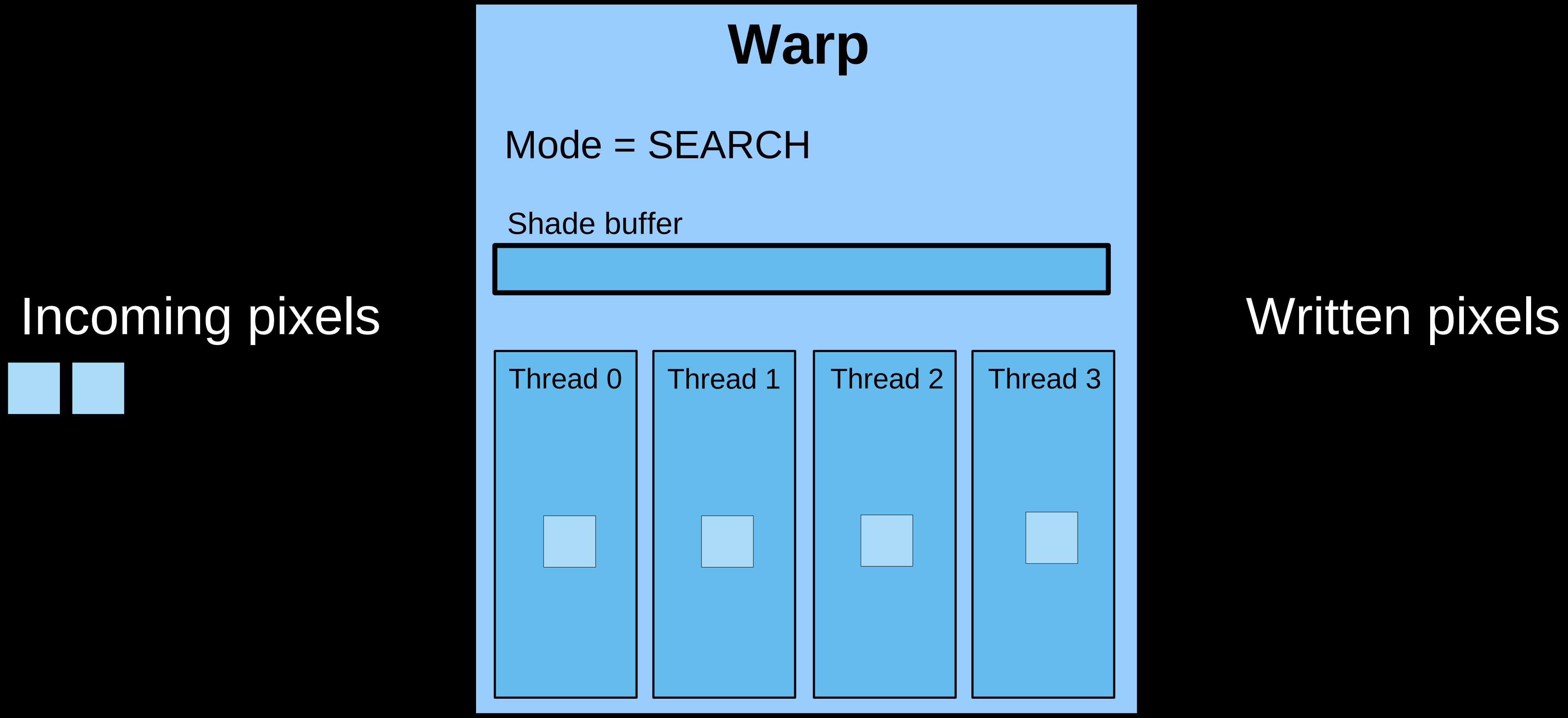
Thread 1

Thread 2

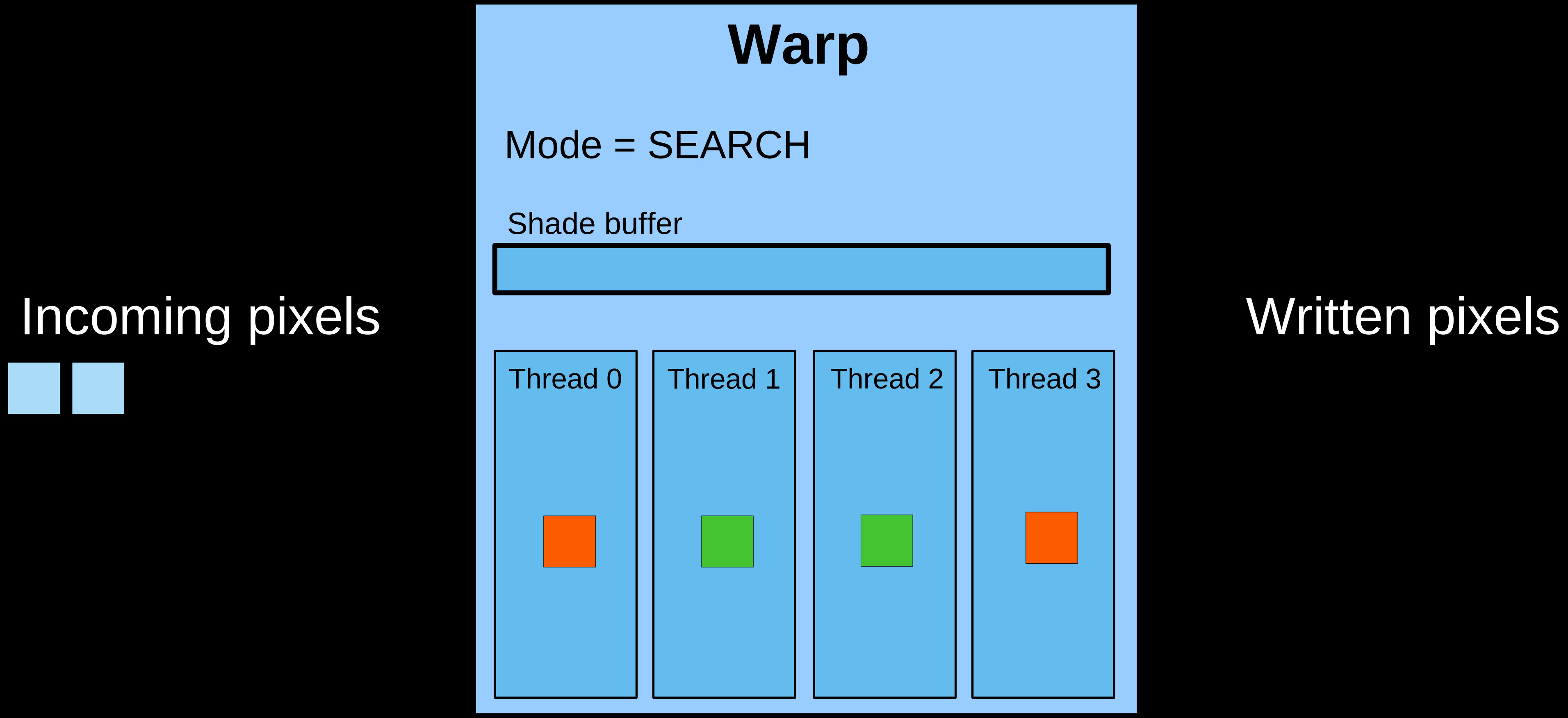
Thread 3

Written pixels

Mode Switching



Mode Switching



Warp

Mode = SEARCH

Shade buffer

Incoming pixels

Written pixels

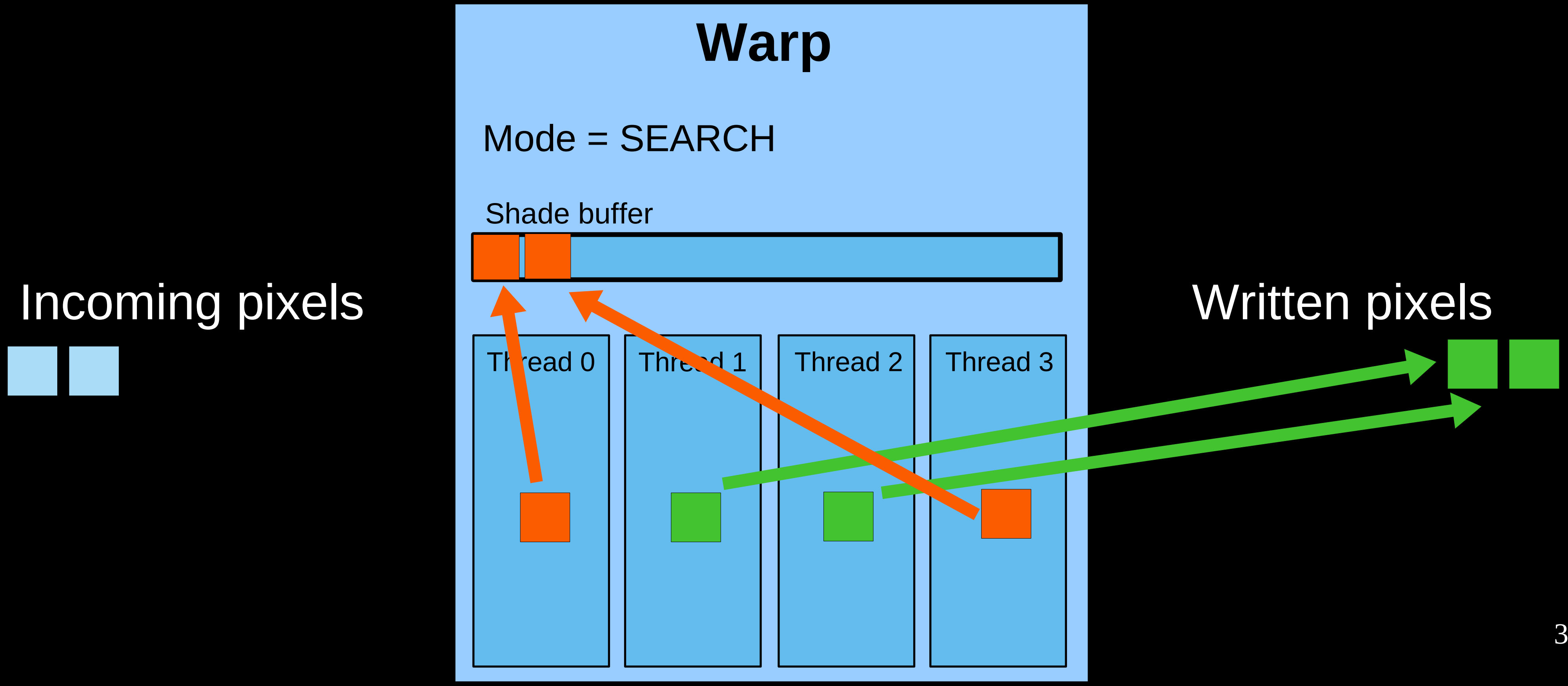
Thread 0

Thread 1

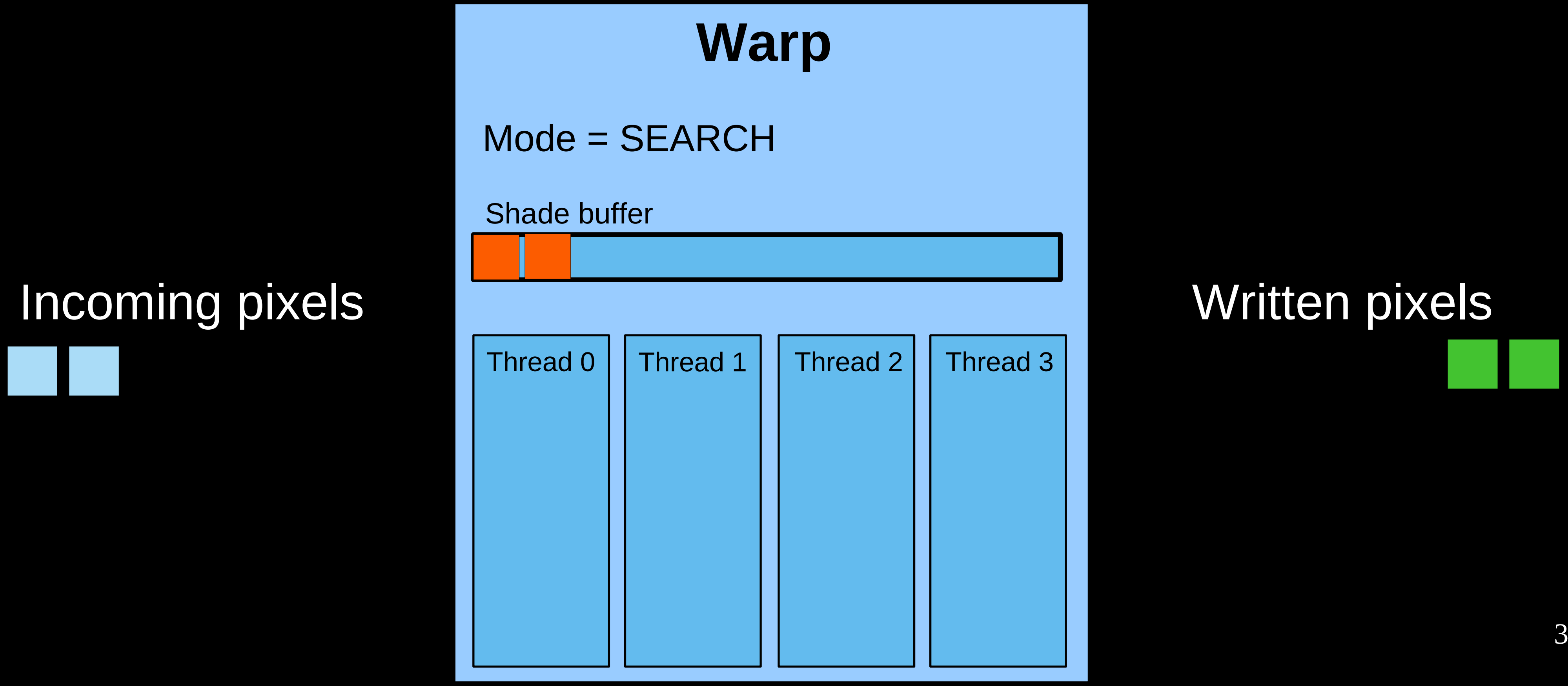
Thread 2

Thread 3

Mode Switching



Mode Switching



Warp

Mode = SEARCH

Shade buffer

Incoming pixels

Written pixels

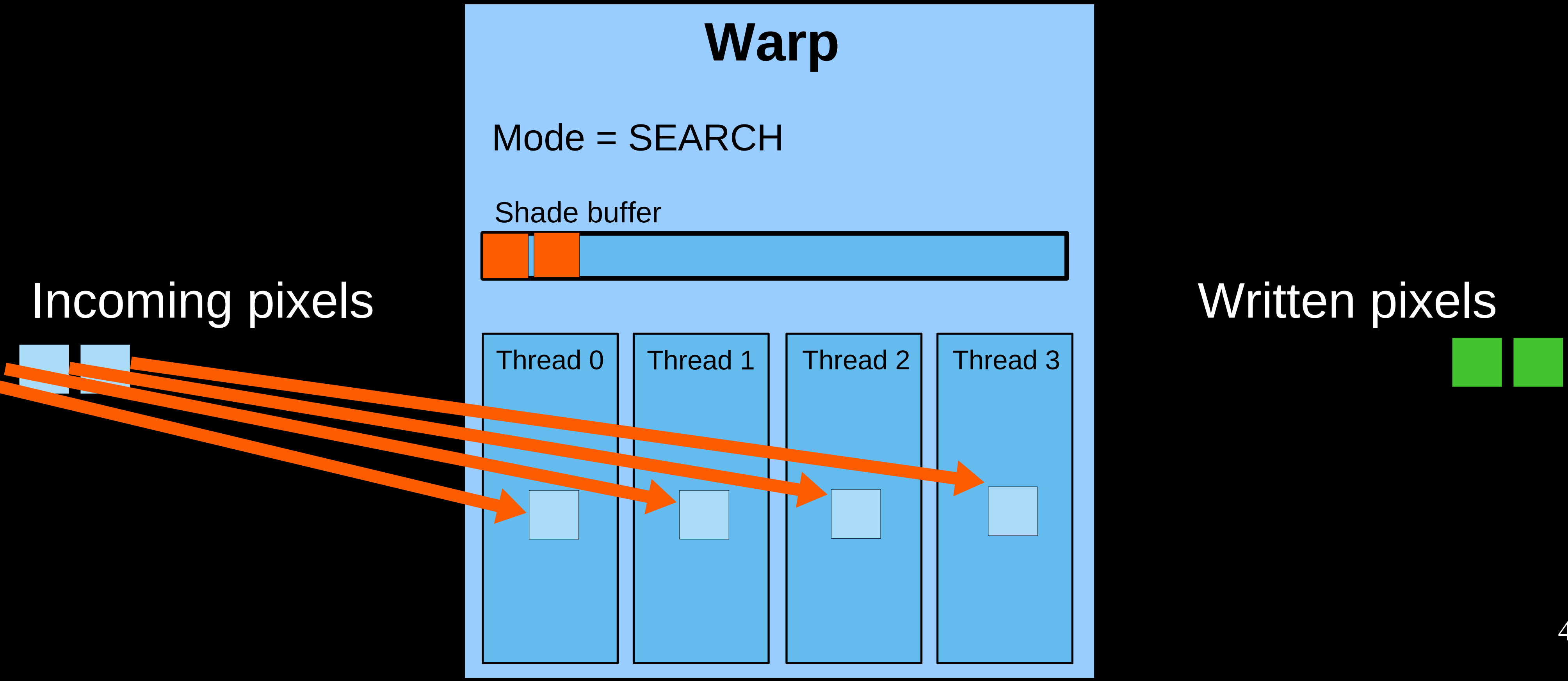
Thread 0

Thread 1

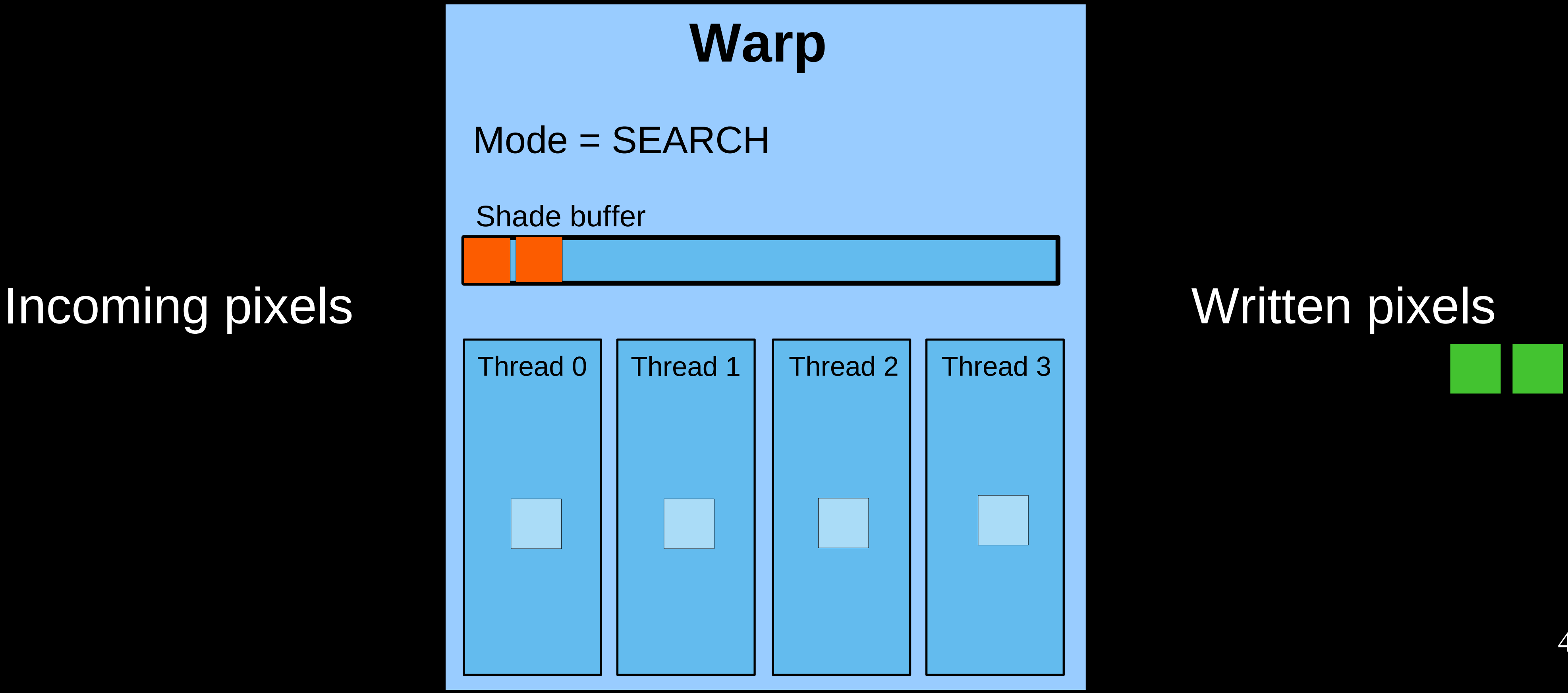
Thread 2

Thread 3

Mode Switching



Mode Switching



Incoming pixels

Warp

Mode = SEARCH

Shade buffer

Thread 0

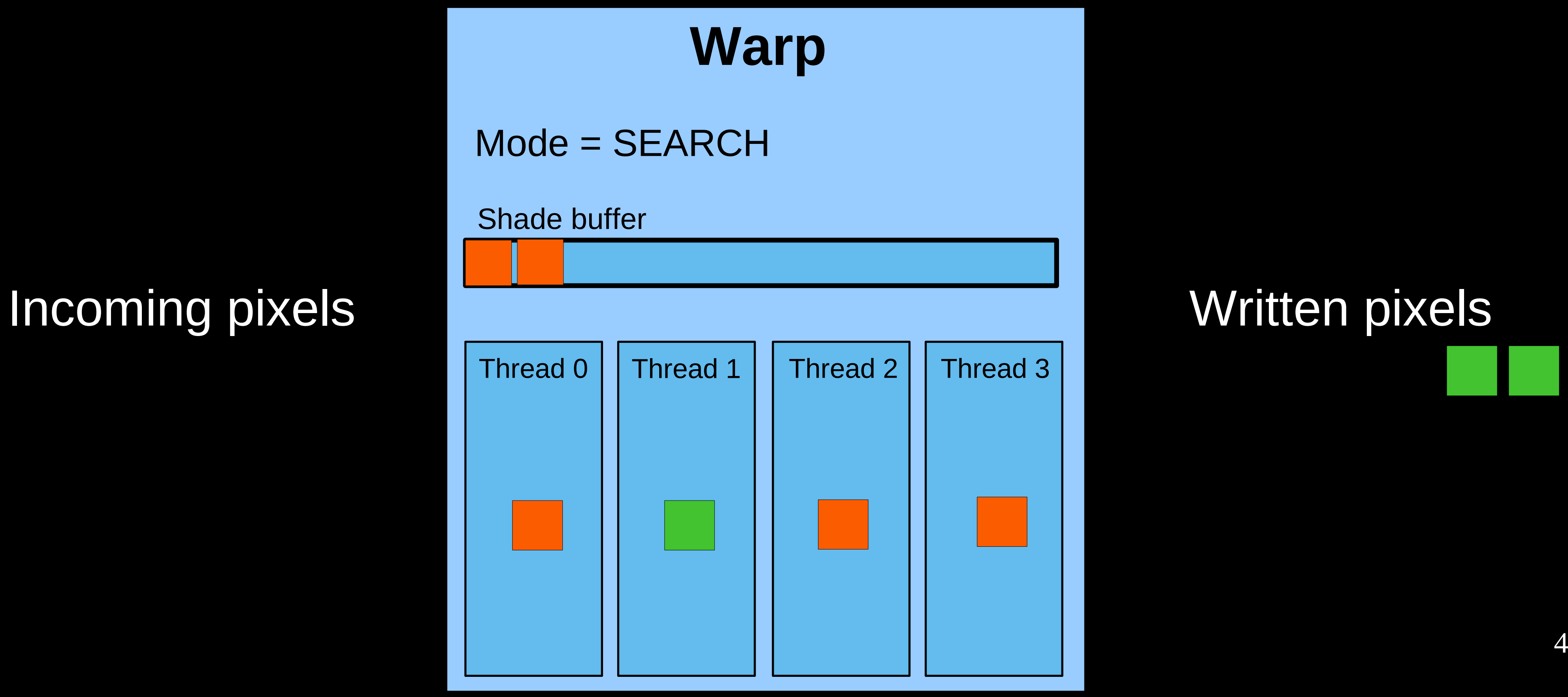
Thread 1

Thread 2

Thread 3

Written pixels

Mode Switching



Incoming pixels

Warp

Mode = SEARCH

Shade buffer

Thread 0

Thread 1

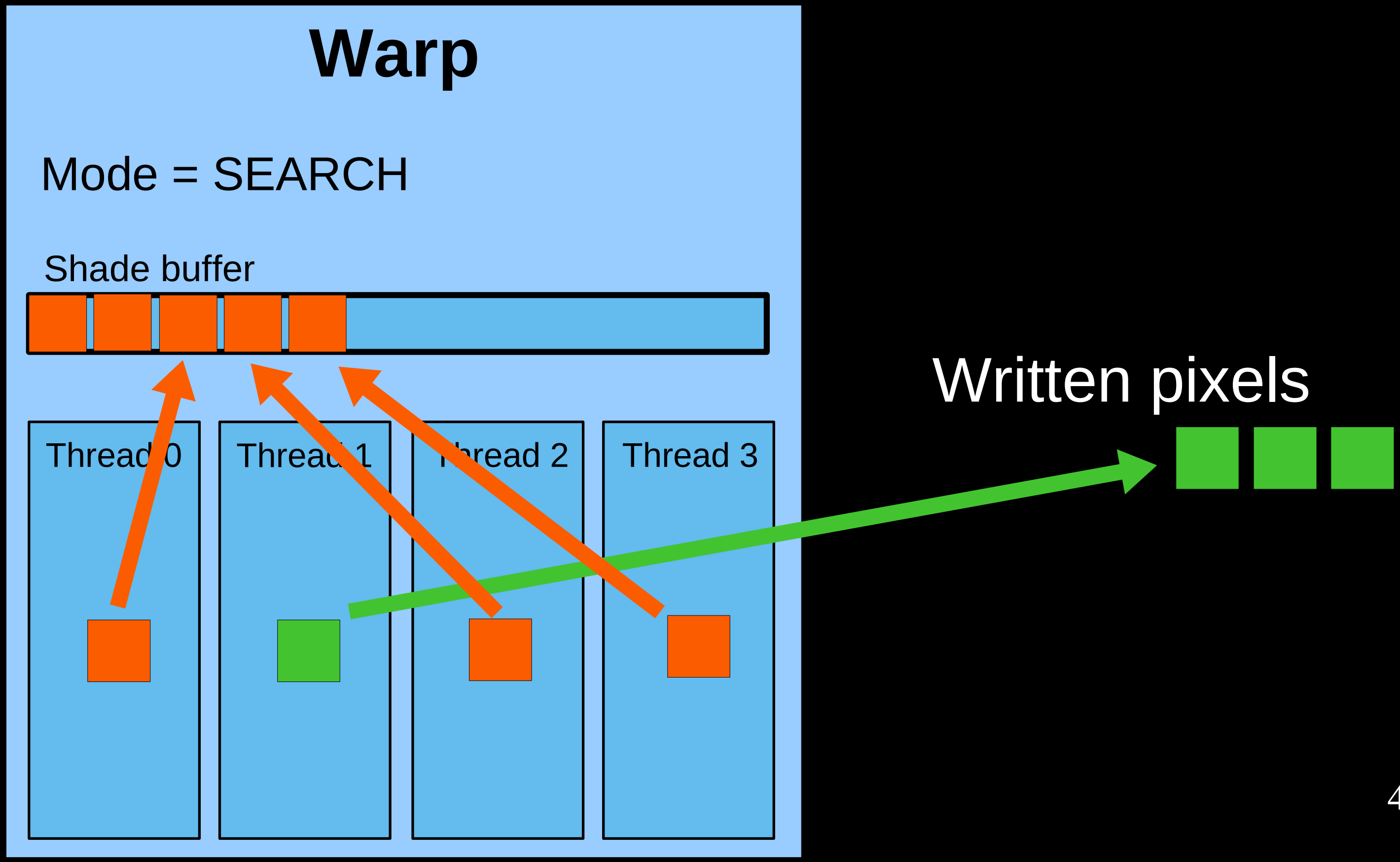
Thread 2

Thread 3

Written pixels

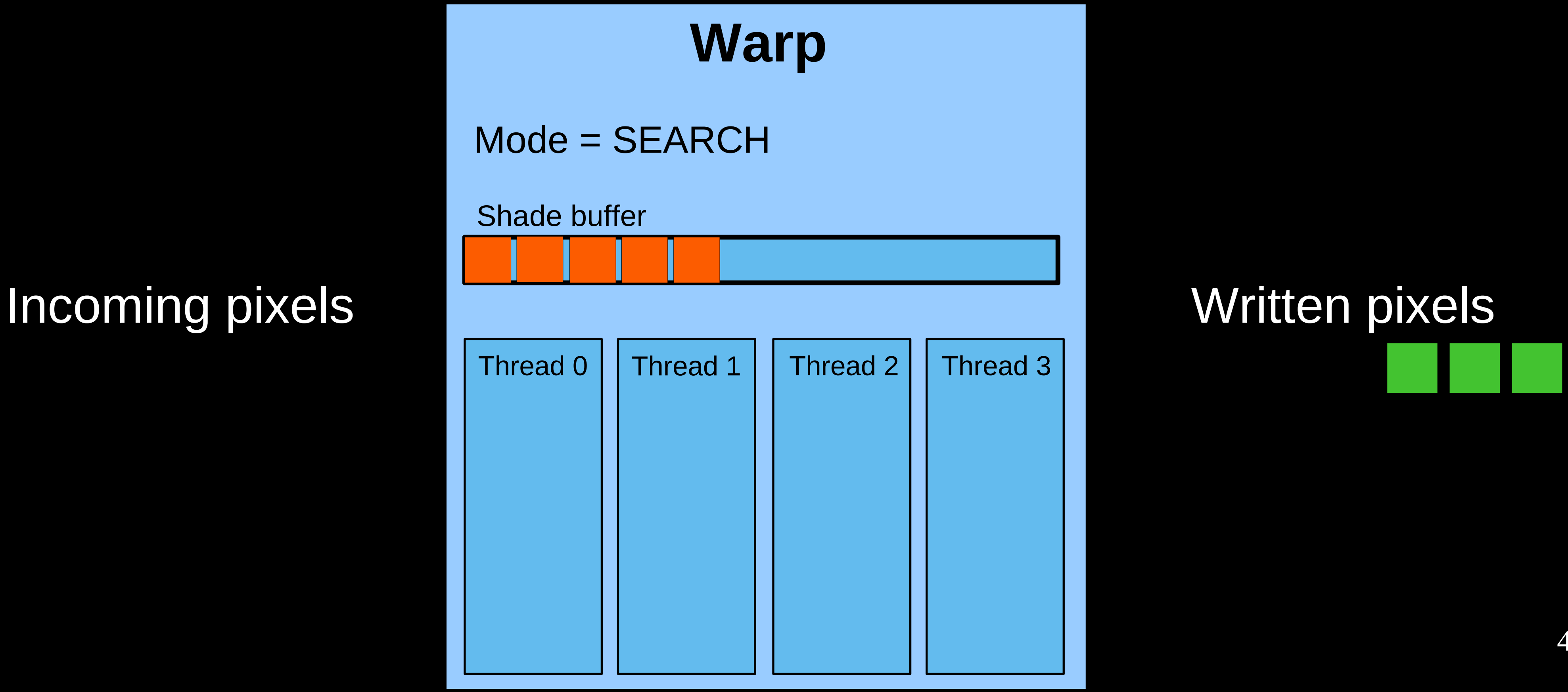
Mode Switching

Incoming pixels



Written pixels

Mode Switching



Incoming pixels

Warp

Mode = SEARCH

Shade buffer

Thread 0

Thread 1

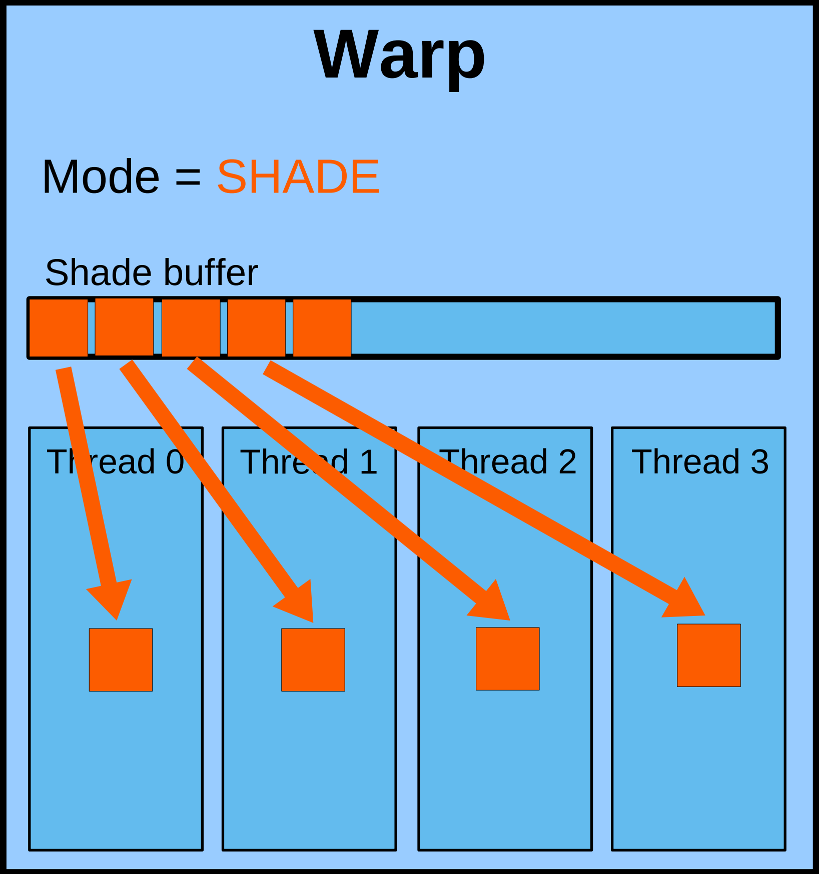
Thread 2

Thread 3

Written pixels

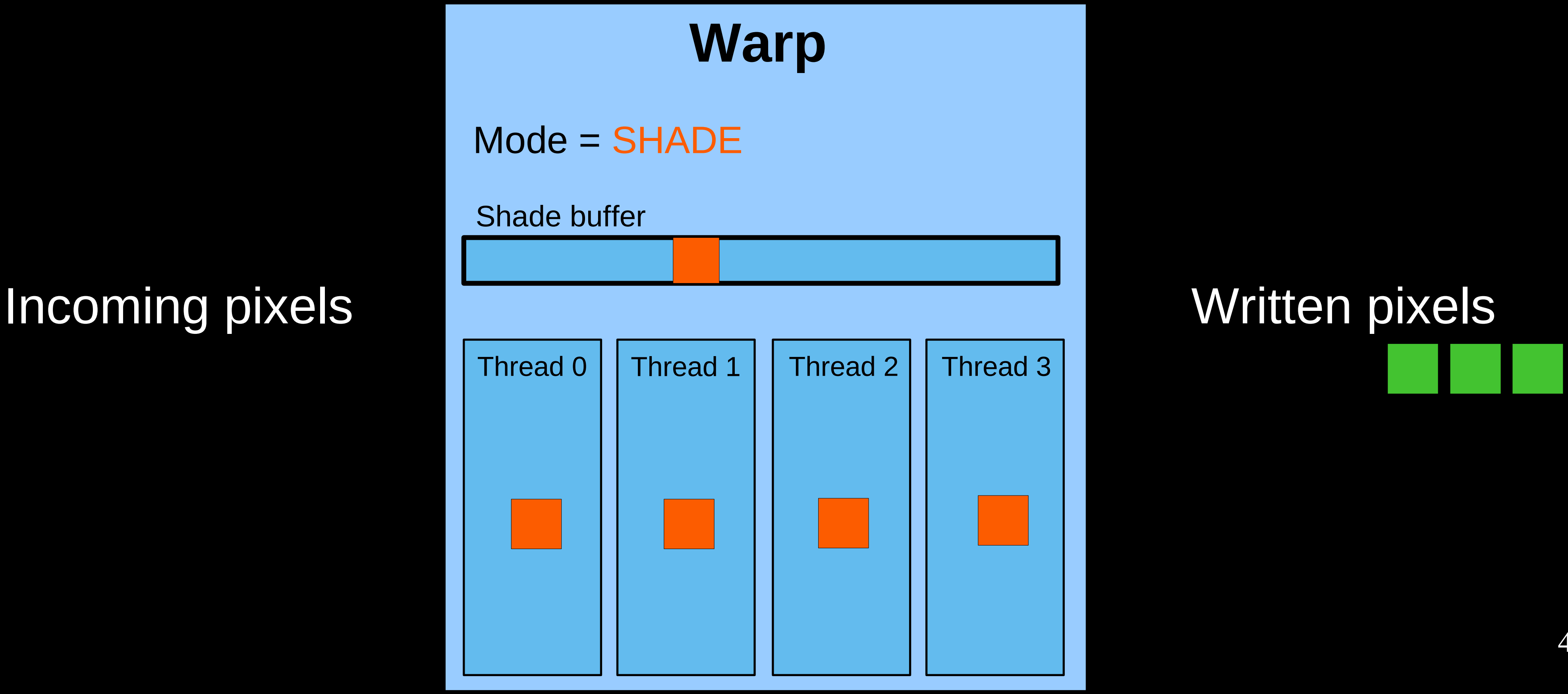
Mode Switching

Incoming pixels



Written pixels

Mode Switching



Warp

Mode = SHADE

Shade buffer

Incoming pixels

Thread 0

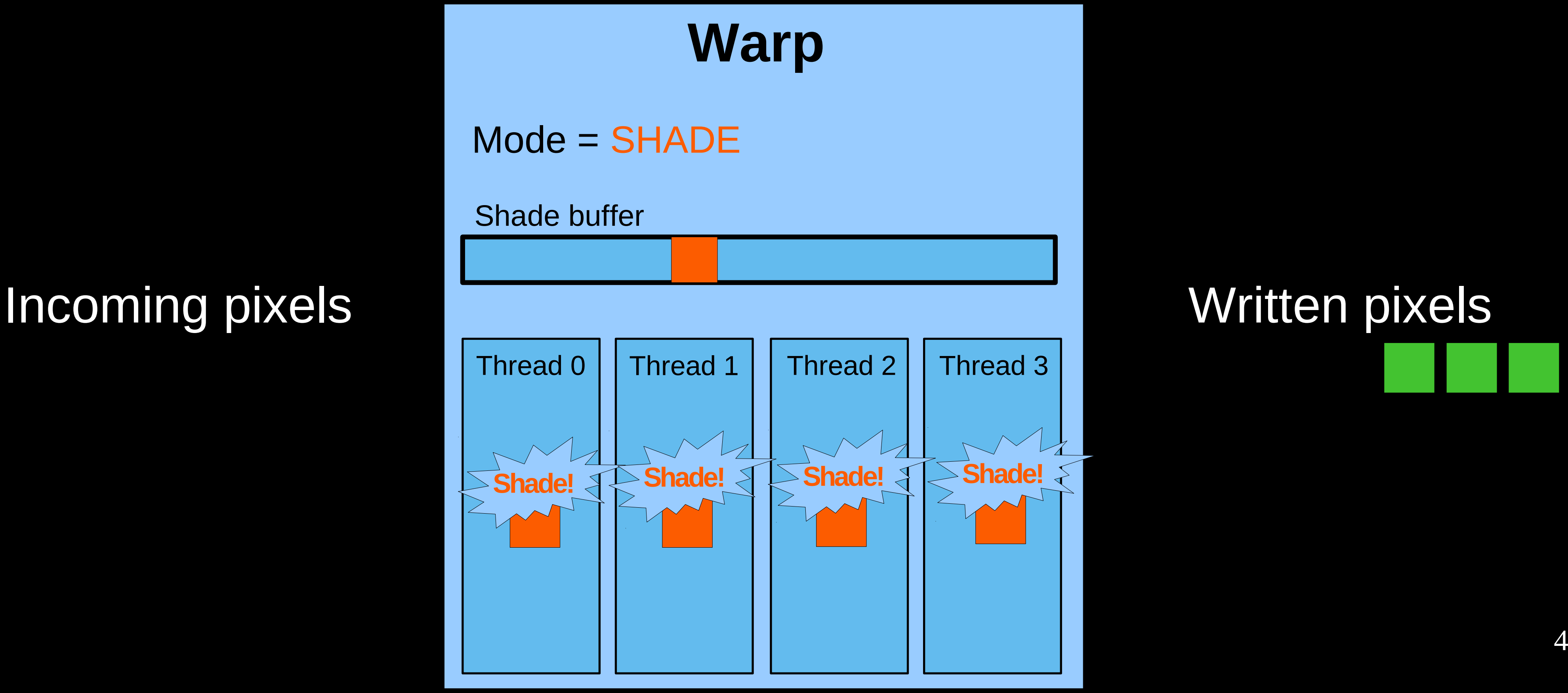
Thread 1

Thread 2

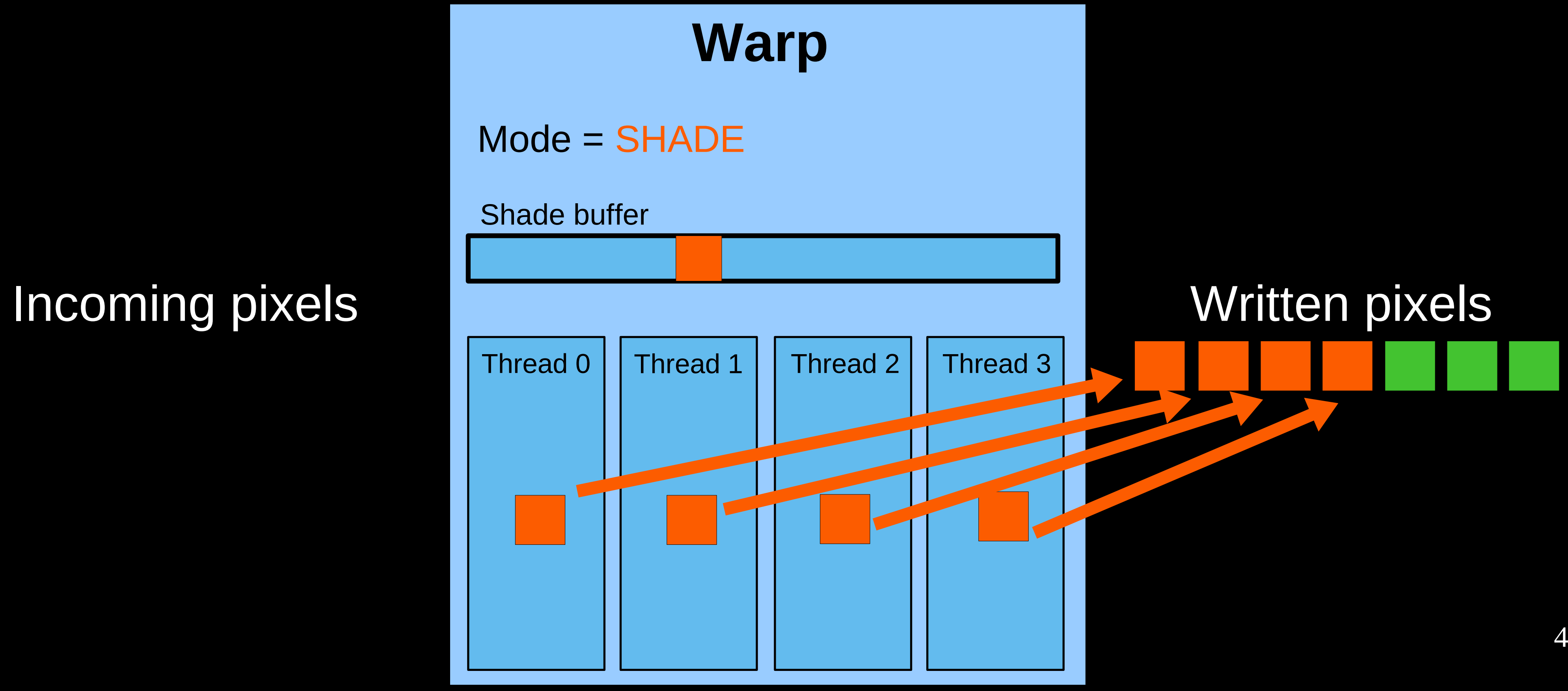
Thread 3

Written pixels

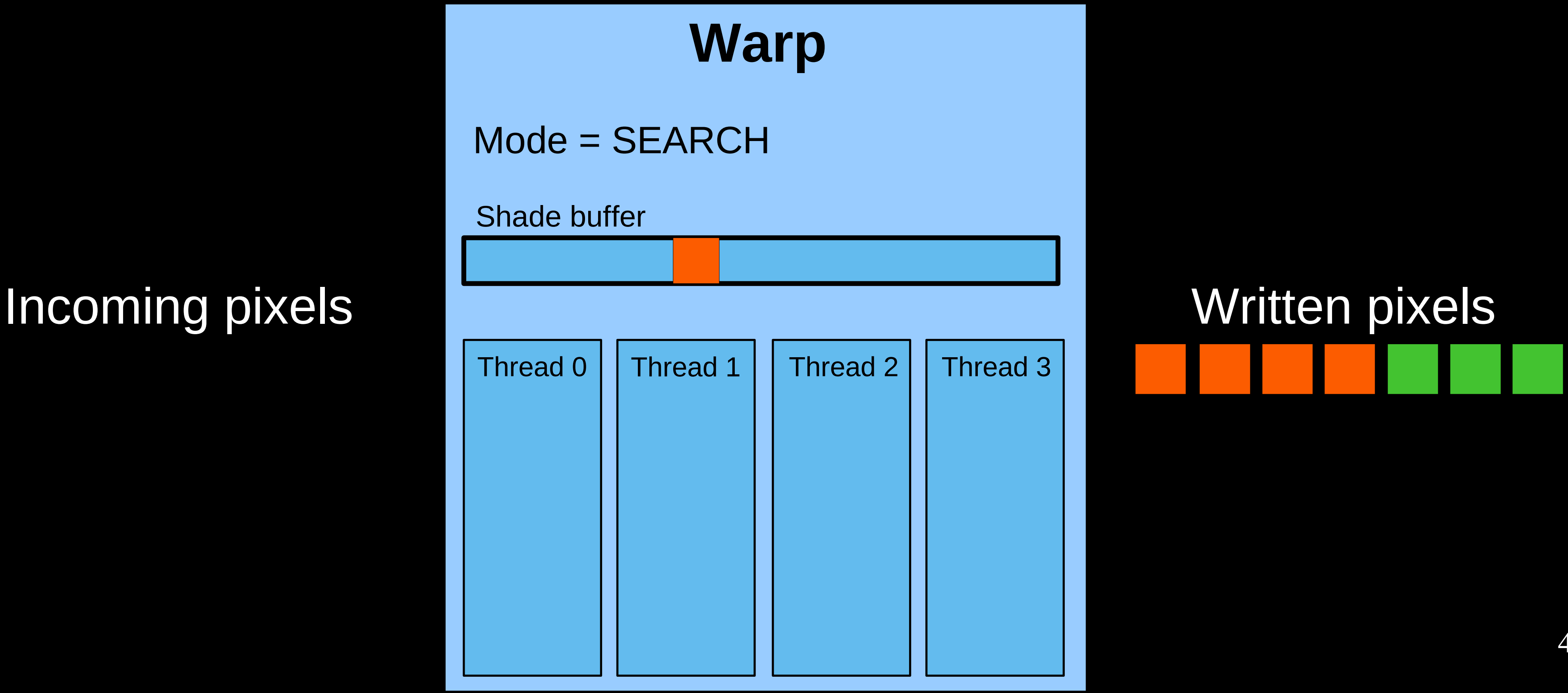
Mode Switching



Mode Switching



Mode Switching



Incoming pixels

Warp

Mode = SEARCH

Shade buffer

Thread 0

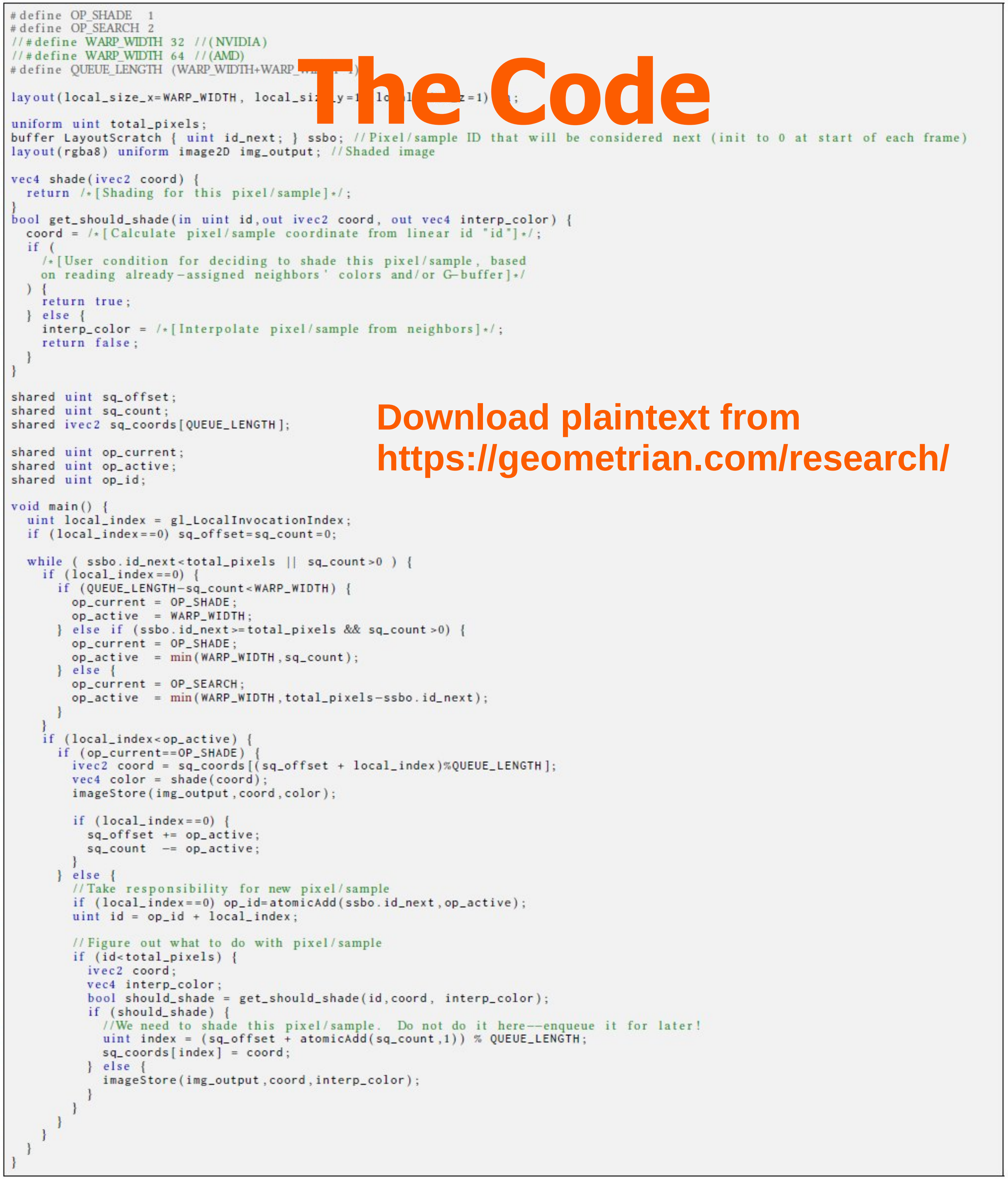
Thread 1

Thread 2

Thread 3

Written pixels

The Code



```
#define OP_SHADE  1
#define OP_SEARCH 2
//#define WARP_WIDTH 32 //(NVIDIA)
//#define WARP_WIDTH 64 //(AMD)
#define QUEUE_LENGTH (WARP_WIDTH+WARP_WIDTH-1)

layout(local_size_x=WARP_WIDTH, local_size_y=1, local_size_z=1) in;

uniform uint total_pixels;
buffer LayoutScratch { uint id_next; } ssbo; //Pixel/sample ID that will be considered next (init to 0 at start of each frame)
layout(rgba8) uniform image2D img_output; //Shaded image

vec4 shade(ivec2 coord) {
  return /*[Shading for this pixel/sample]*/;
}
bool get_should_shade(in uint id,out ivec2 coord, out vec4 interp_color) {
  coord = /*[Calculate pixel/sample coordinate from linear id "id"]*/;
  if (
    /*[User condition for deciding to shade this pixel/sample, based
    on reading already-assigned neighbors' colors and/or G-buffer]*/
  ) {
    return true;
  } else {
    interp_color = /*[Interpolate pixel/sample from neighbors]*/;
    return false;
  }
}

shared uint sq_offset;
shared uint sq_count;
shared ivec2 sq_coords[QUEUE_LENGTH];

shared uint op_current;
shared uint op_active;
shared uint op_id;

void main() {
  uint local_index = gl_LocalInvocationIndex;
  if (local_index==0) sq_offset=sq_count=0;

  while ( ssbo.id_next<total_pixels || sq_count>0 ) {
    if (local_index==0) {
      if (QUEUE_LENGTH-sq_count<WARP_WIDTH) {
        op_current = OP_SHADE;
        op_active  = WARP_WIDTH;
      } else if (ssbo.id_next>=total_pixels && sq_count>0) {
        op_current = OP_SHADE;
        op_active  = min(WARP_WIDTH,sq_count);
      } else {
        op_current = OP_SEARCH;
        op_active  = min(WARP_WIDTH,total_pixels-ssbo.id_next);
      }
    }
    if (local_index<op_active) {
      if (op_current==OP_SHADE) {
        ivec2 coord = sq_coords[(sq_offset + local_index)%QUEUE_LENGTH];
        vec4 color = shade(coord);
        imageStore(img_output,coord,color);

        if (local_index==0) {
          sq_offset += op_active;
          sq_count  -= op_active;
        }
      } else {
        //Take responsibility for new pixel/sample
        if (local_index==0) op_id=atomicAdd(ssbo.id_next,op_active);
        uint id = op_id + local_index;

        //Figure out what to do with pixel/sample
        if (id<total_pixels) {
          ivec2 coord;
          vec4 interp_color;
          bool should_shade = get_should_shade(id,coord, interp_color);
          if (should_shade) {
            //We need to shade this pixel/sample. Do not do it here--enqueue it for later!
            uint index = (sq_offset + atomicAdd(sq_count,1)) % QUEUE_LENGTH;
            sq_coords[index] = coord;
          } else {
            imageStore(img_output,coord,interp_color);
          }
        }
      }
    }
  }
}
```

Download plaintext from https://geometrian.com/research/

Results

- Ran color-only simulated results on synthetic images

- Implemented in my deferred renderer
  - Comparison to simple checkerboard implementation
  - Note: no temporal filtering in any algorithm!

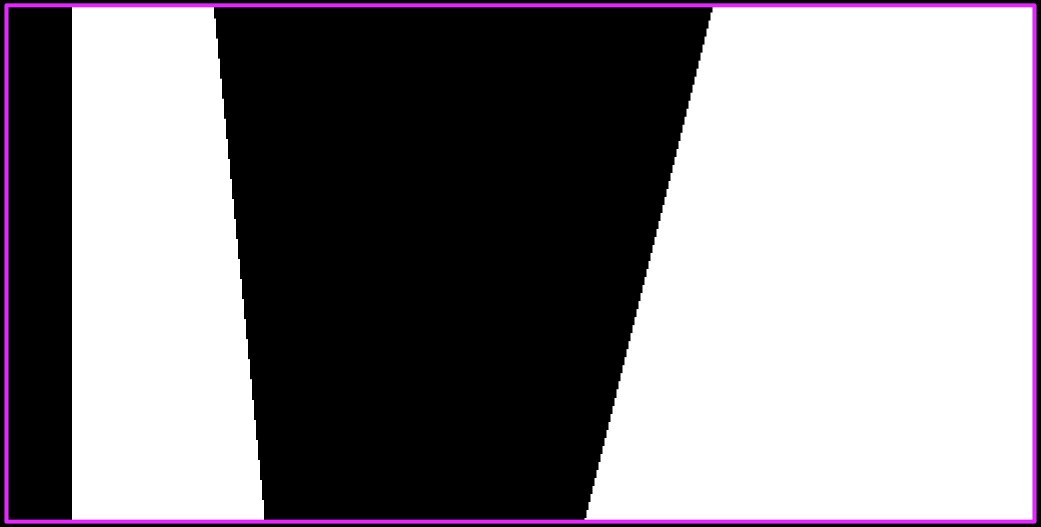
- Ran color-only simulated results on Unreal Engine frames (see video).
  - Timing not meaningful

Results: Synthetic Images

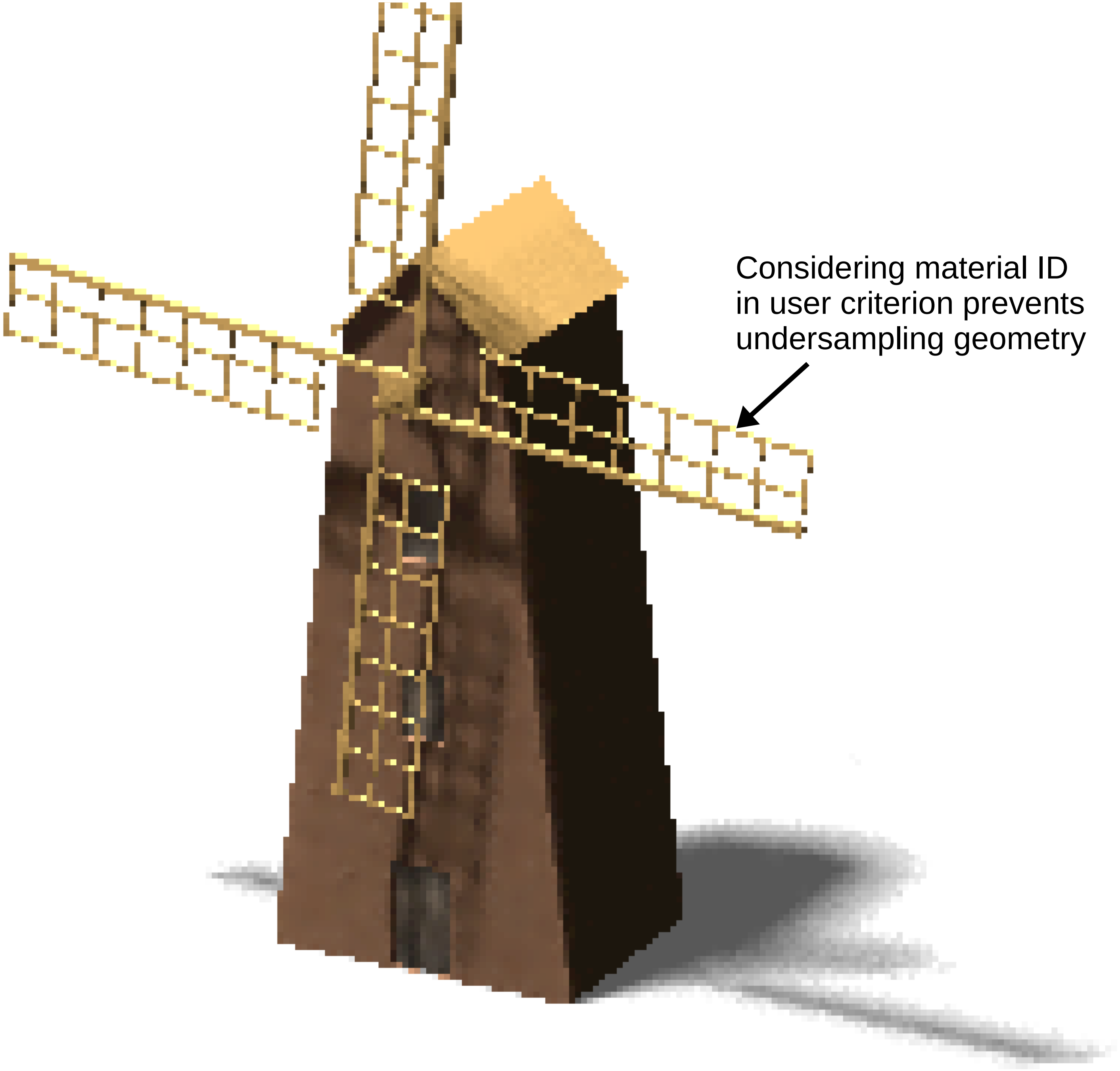
- Perfectly reconstructs gradient and step functions

- Gradient: characteristic of soft shadows, shaded regions

- Step: texture features, depth discontinuities

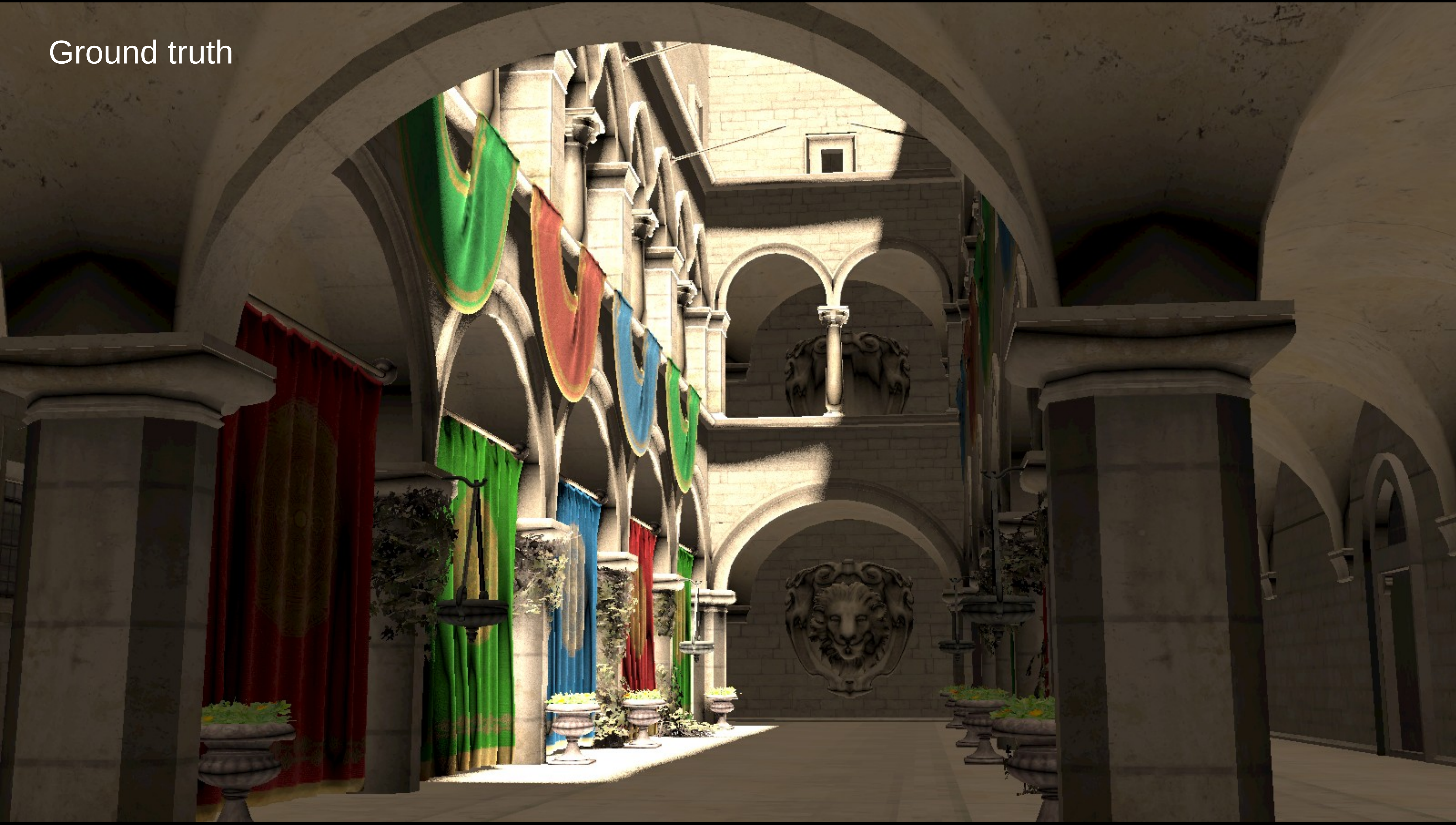


Results: Thin Features

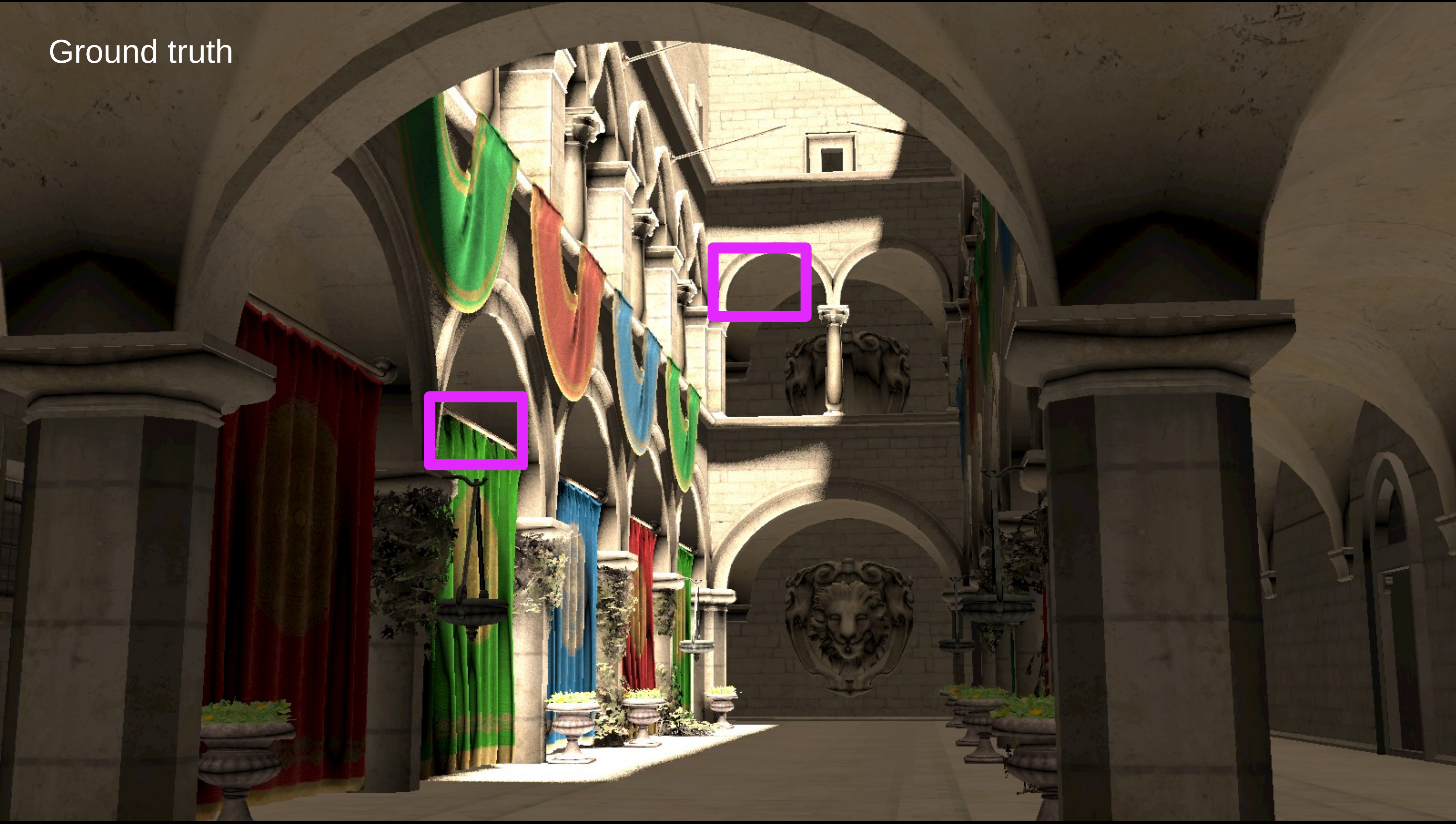


Considering material ID in user criterion prevents undersampling geometry

Results: Deferred Renderer

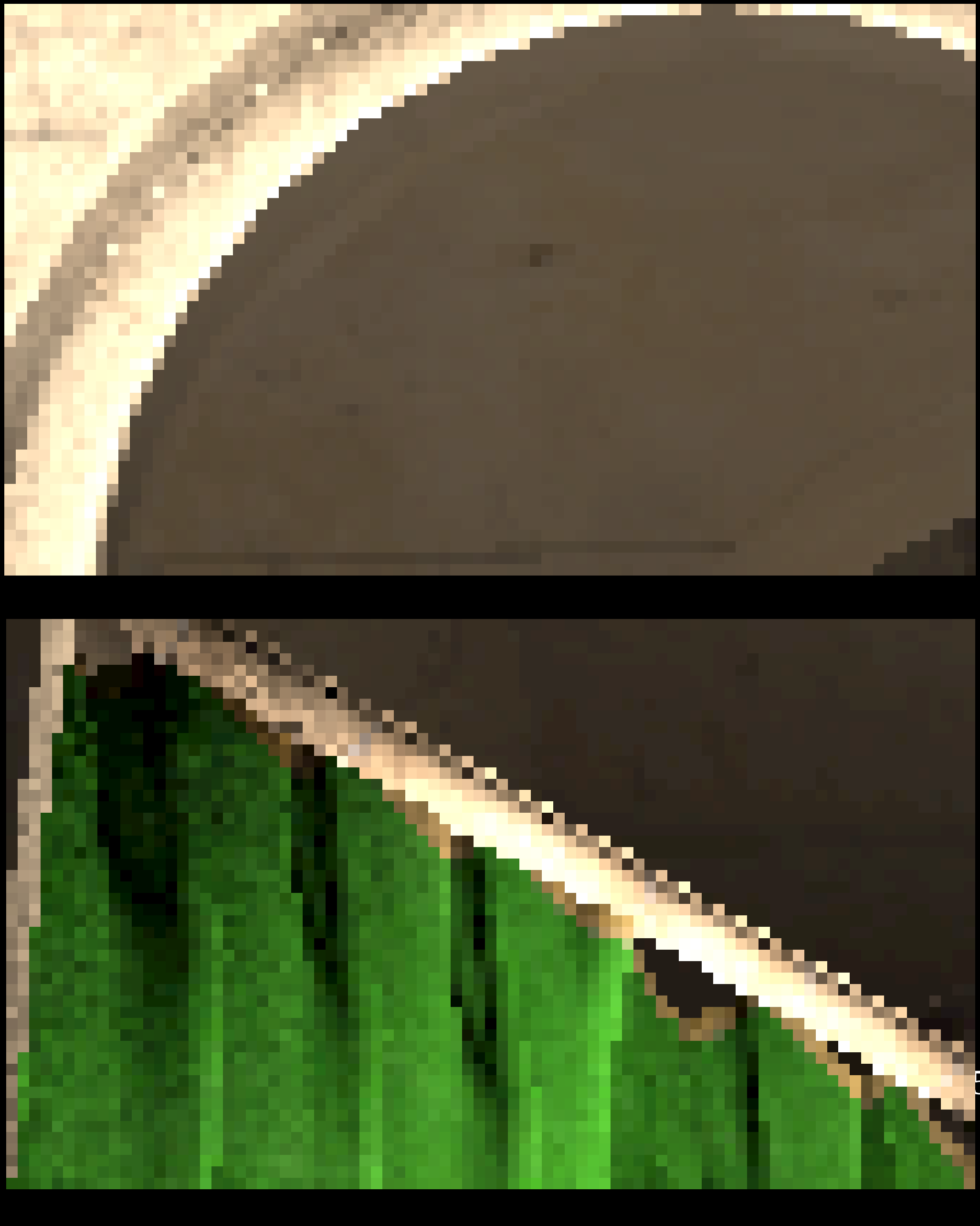


Results: Deferred Renderer



Results: Deferred Renderer

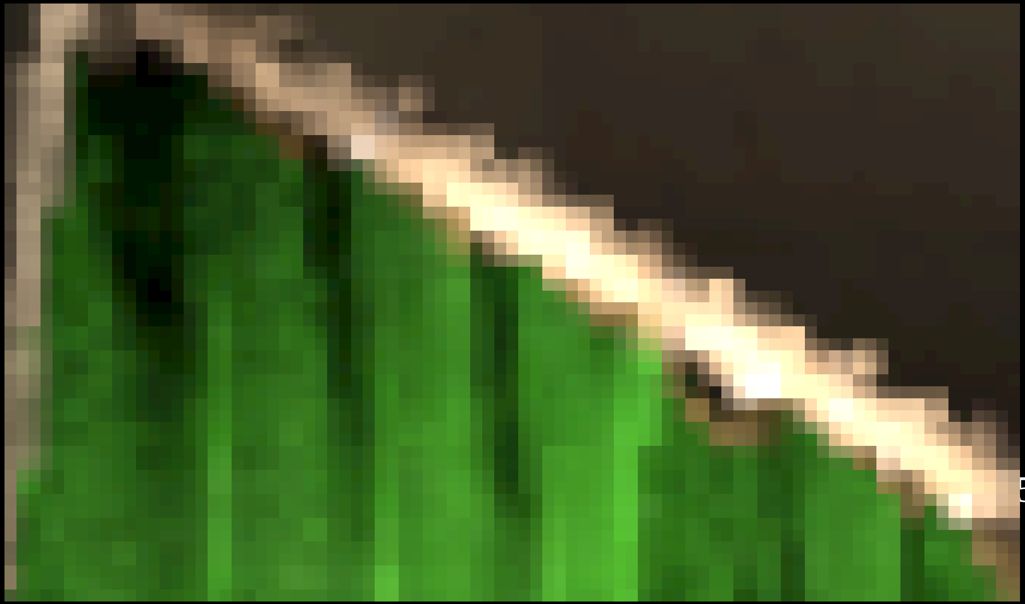
Ground Truth



Results: Deferred Renderer

Checkerboard

- Loss of detail in a single frame
- 1.89× speedup



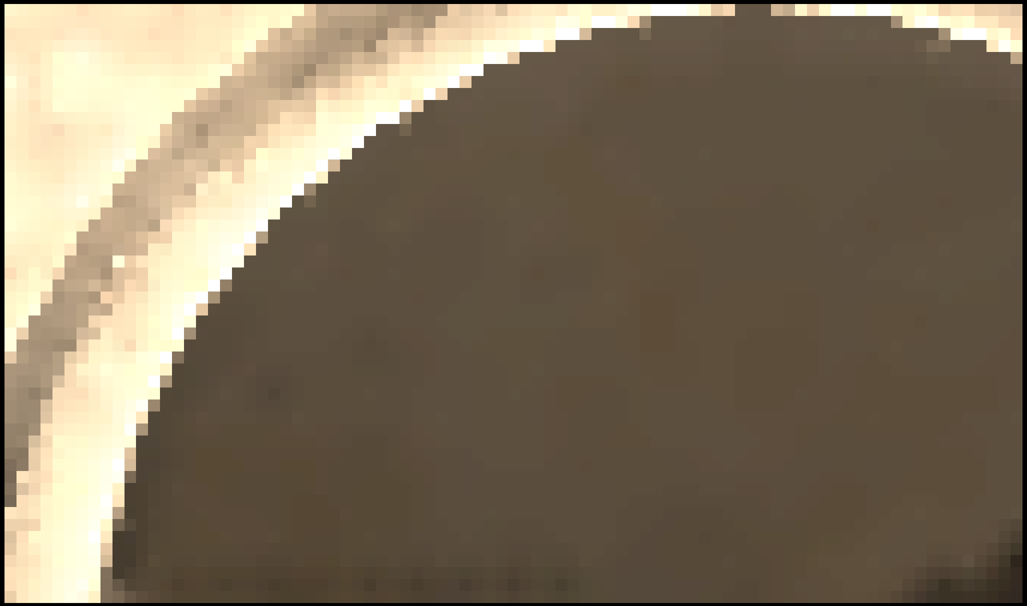
RMSE: 0.04218
PSNR: 27.53
MSSIM: 0.8954

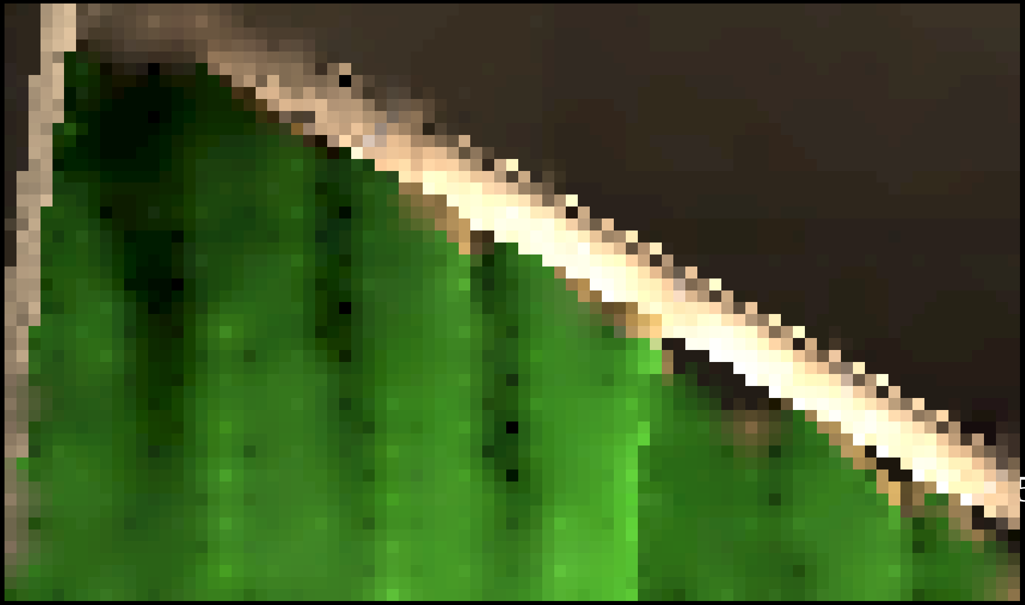
Speedup: 1.89× to GT

Results: Deferred Renderer

DACS

- “Equal” quality to checkerboard (same MSSIM)
- Better edge resolution
- 4.22× speedup!





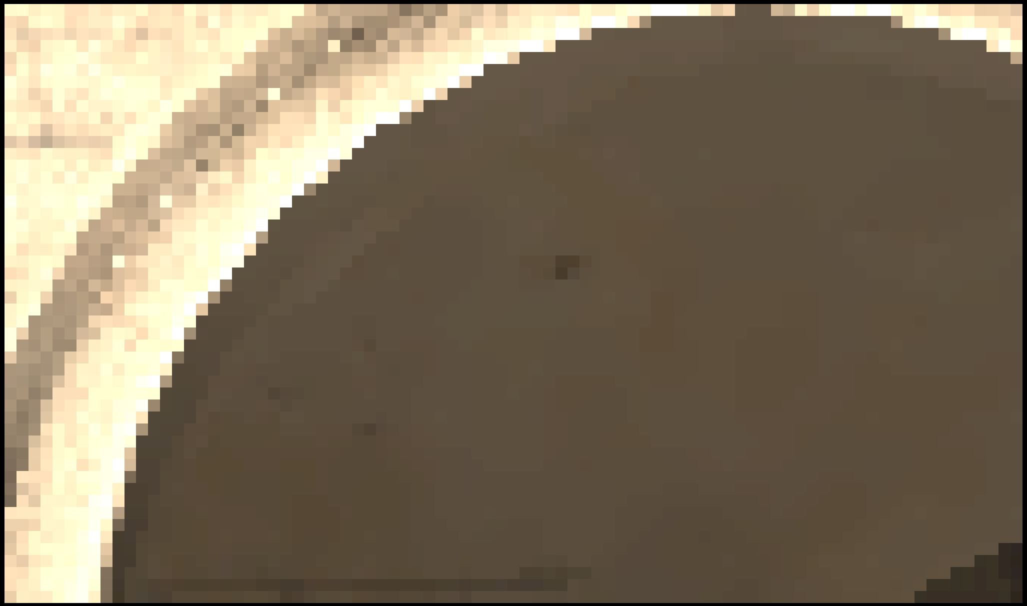
RMSE: 0.02647
PSNR: 31.57
MSSIM: 0.8881

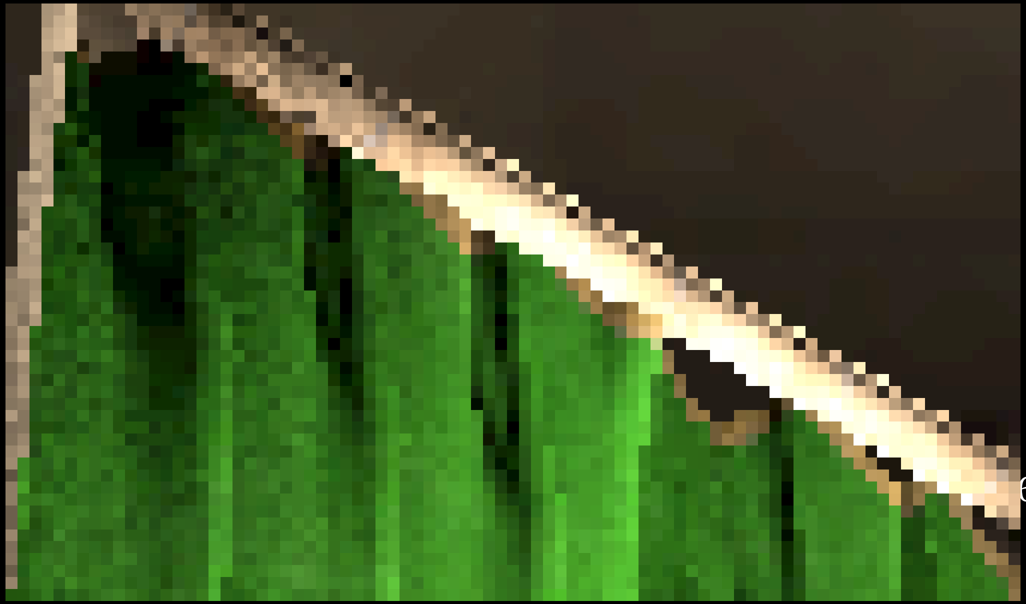
Speedup: 4.22× to GT
Speedup: 2.24× to checkerboard

Results: Deferred Renderer

DACS

- Equal time to checkerboard
- Far better quality



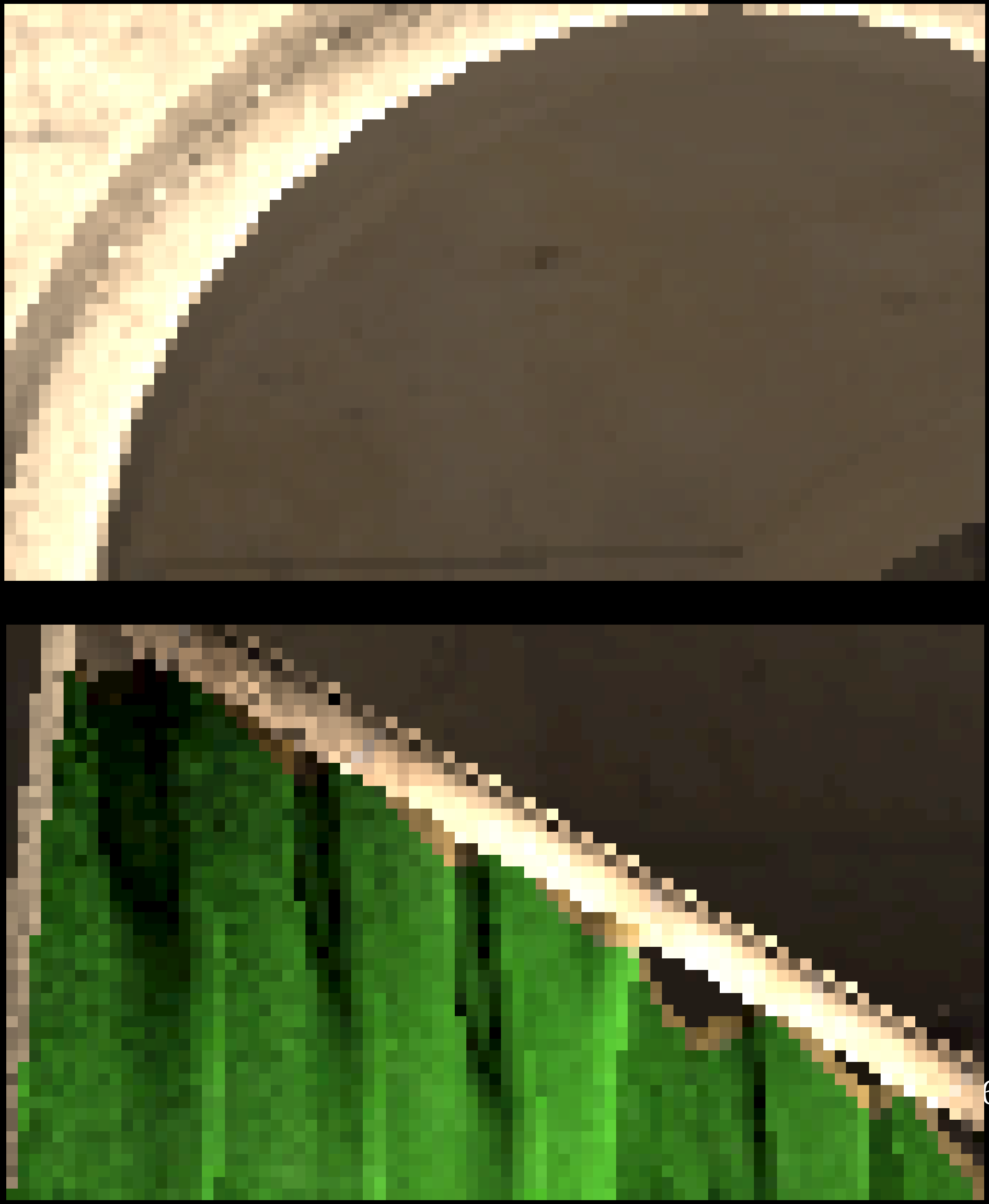


RMSE: 0.009076
PSNR: 40.85
MSSIM: 0.9620

Speedup: 1.89× to GT
Speedup: 1.00× to checkerboard

Results: Deferred Renderer

Ground Truth



Extensions and Applications

Adaptive Supersampling

Foveated Rendering

- Temporal Filtering
- Framerate stabilization
- More G-Buffer Features
- Perceptual Heuristics
- Energy Tradeoff for Mobile

Conclusion

- Significantly reduces shading complexity
- Adaptive, yet runs efficiently on GPUs
- Simple implementation

Questions

(and video)