Large Ray Packets for Real-time Whitted Ray Tracing

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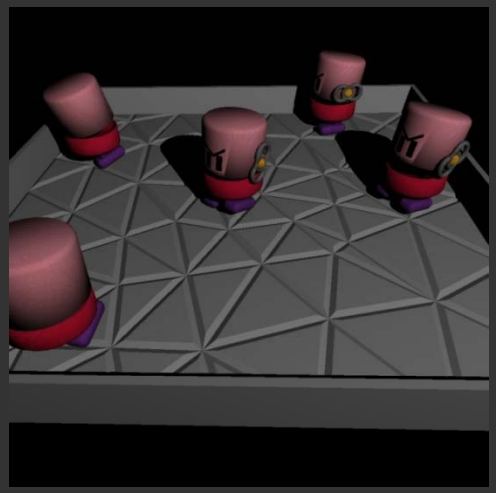
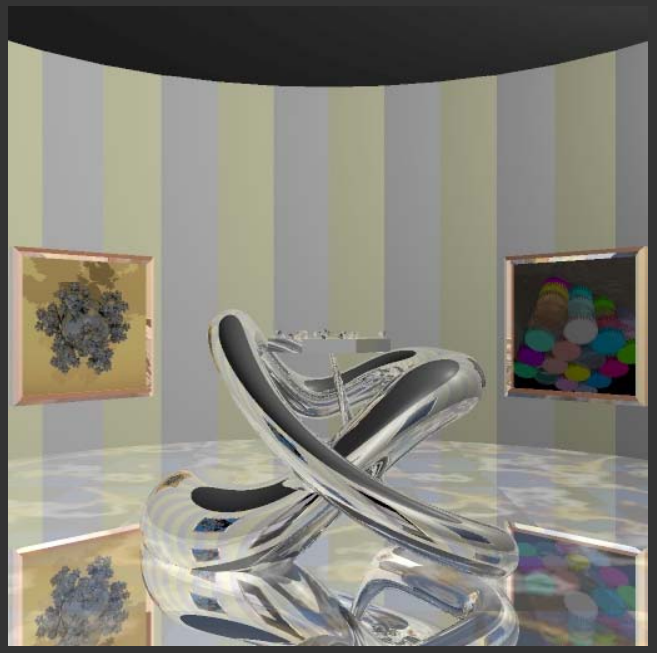
Current Real-time Ray Tracing

- Use large ray packets (16-256 rays)
- Focused on primary visibility and point-light shadows
- Images somewhat dull
- Easily generated using rasterization algorithms



This Work: Whitted Ray Tracing

- Whitted Ray tracing:
  - Primary Visibility
  - Point-light Shadows
  - Reflections
  - Refractions



Mission

- Study large ray packets for Whitted ray tracing
  - Scene traversal (BVH)
    - Partition Traversal: *New!*
  - Frustum Culling
    - General secondary ray packets: *New!*

Mission

- Evaluation of old and new algorithms
  - Ray packet size
  - Scene complexity
  - Ray Recursion Complexity

Result: Real-time Whitted RT

Outline

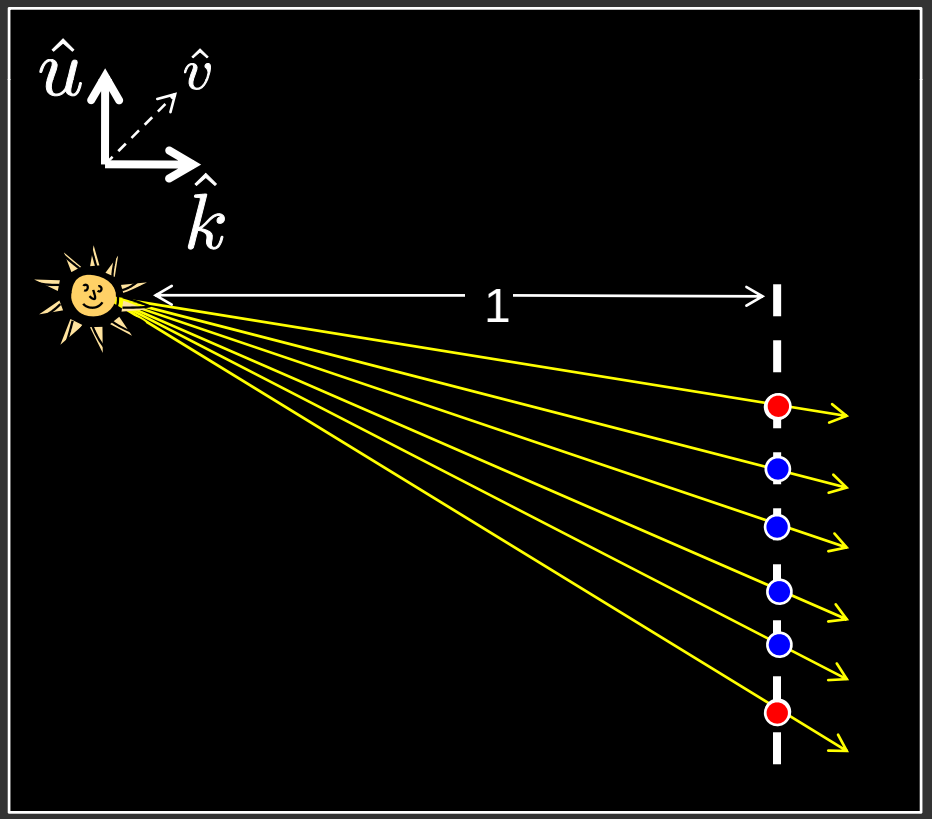
- Motivation
- Frustum Culling for Secondary Rays
- Scene Traversal with Large Ray Packets
- Results

Frustum Culling

- Primary Rays
  - Reshetov et al. 2005
- Point-Light Shadow Rays
  - Boulos et al. 2006 , Wald et al. 2007
- Reflection + Refraction Rays
  - *New!*

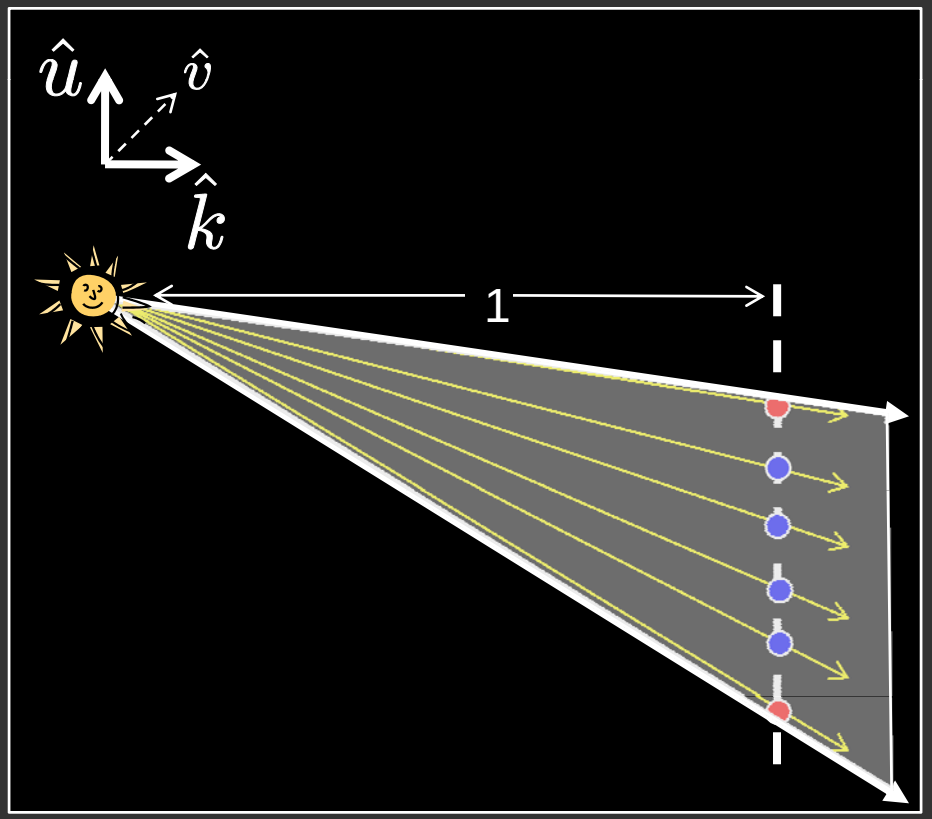
Frustum Culling: Point Light

1. Choose dominant axis: $\hat{k}$
2. Find (u, v) intersection points at $k = 1$.
3. Get min/max (u, v) coords.

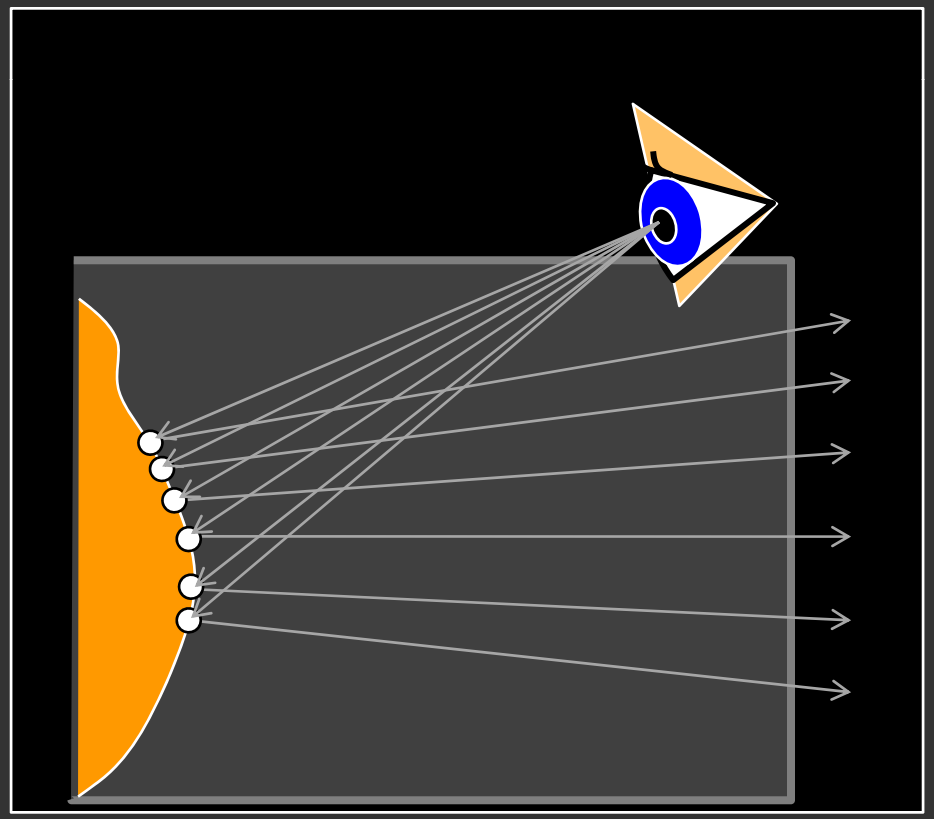


Frustum Culling: Point Light

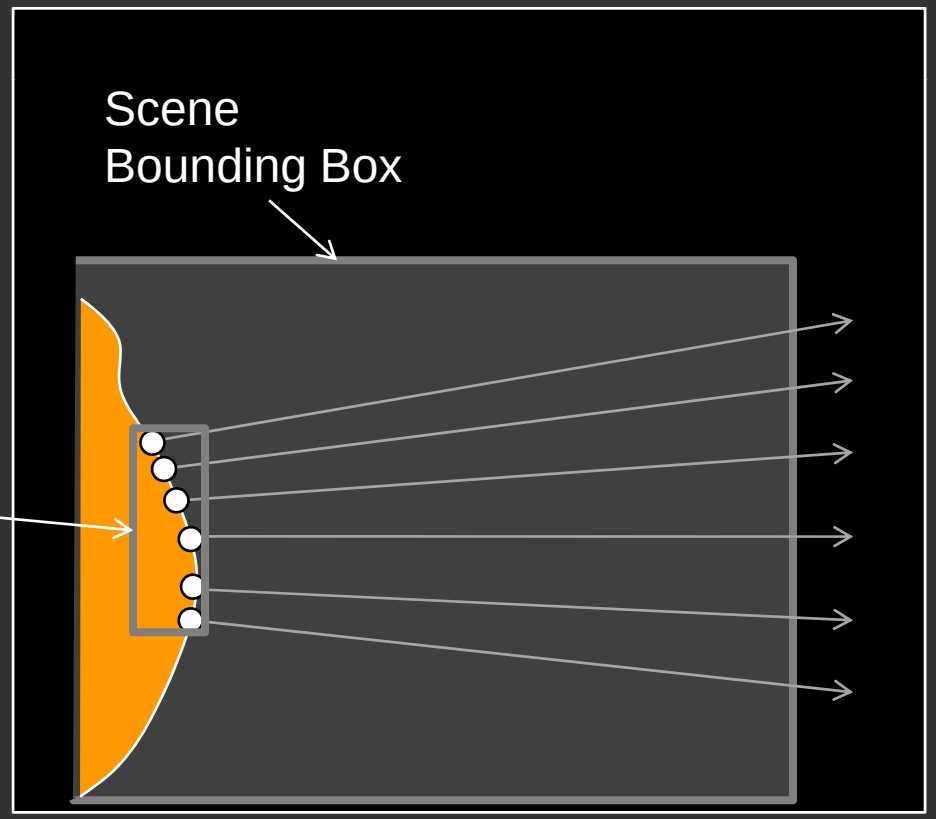
1. Choose dominant axis: $\hat{k}$
2. Find (u, v) intersection points at $k = 1$.
3. Get min/max (u, v) coords.
4. Create 4 corner rays.
5. Compute plane normals.



Frustum Culling: Reflection

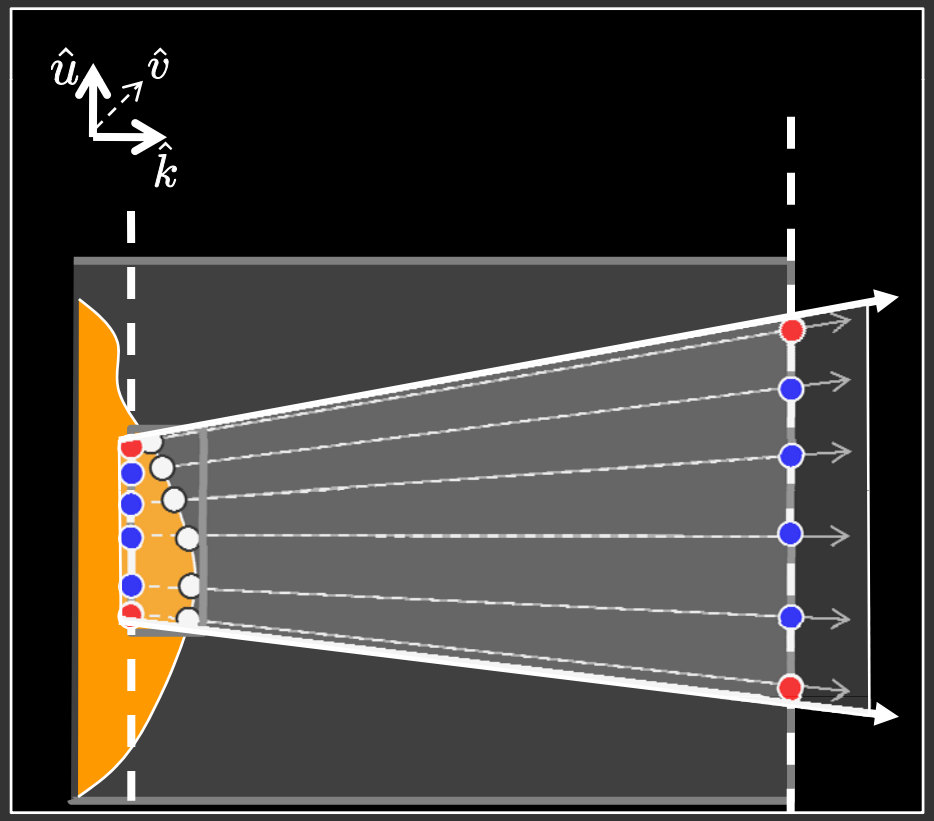


Frustum Culling: Reflection



Frustum Culling: Reflection

1. Choose dominant axis: $\hat{k}$
2. Find (u, v) intersections with 2 planes:
   1. $+\hat{k}$ from scene AABB.
   2. $-\hat{k}$ from samples' AABB.
3. Get min/max (u, v) coords.
4. Create 4 corner rays.
5. Compute plane normals.



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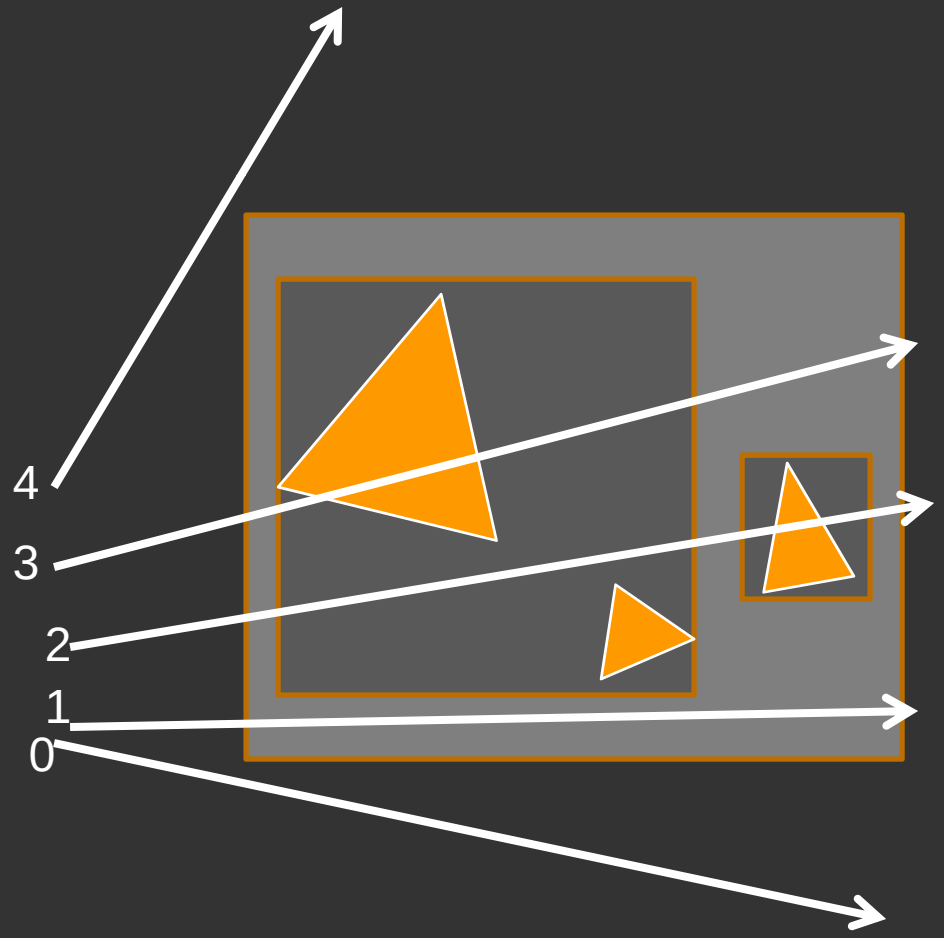
3 Algorithms for Scene Traversal

- Masked Traversal – Control Method
  - Based on Wald 2001, Reshetov 2005 (MLRT)
  - Only good for small packets
- Ranged Traversal – State-of-the-art
  - Wald et al. 2007
  - Degrades performance for incoherent rays!
- Partition Traversal: *New!*
  - Robust to incoherent rays and large packets

Masked Traversal



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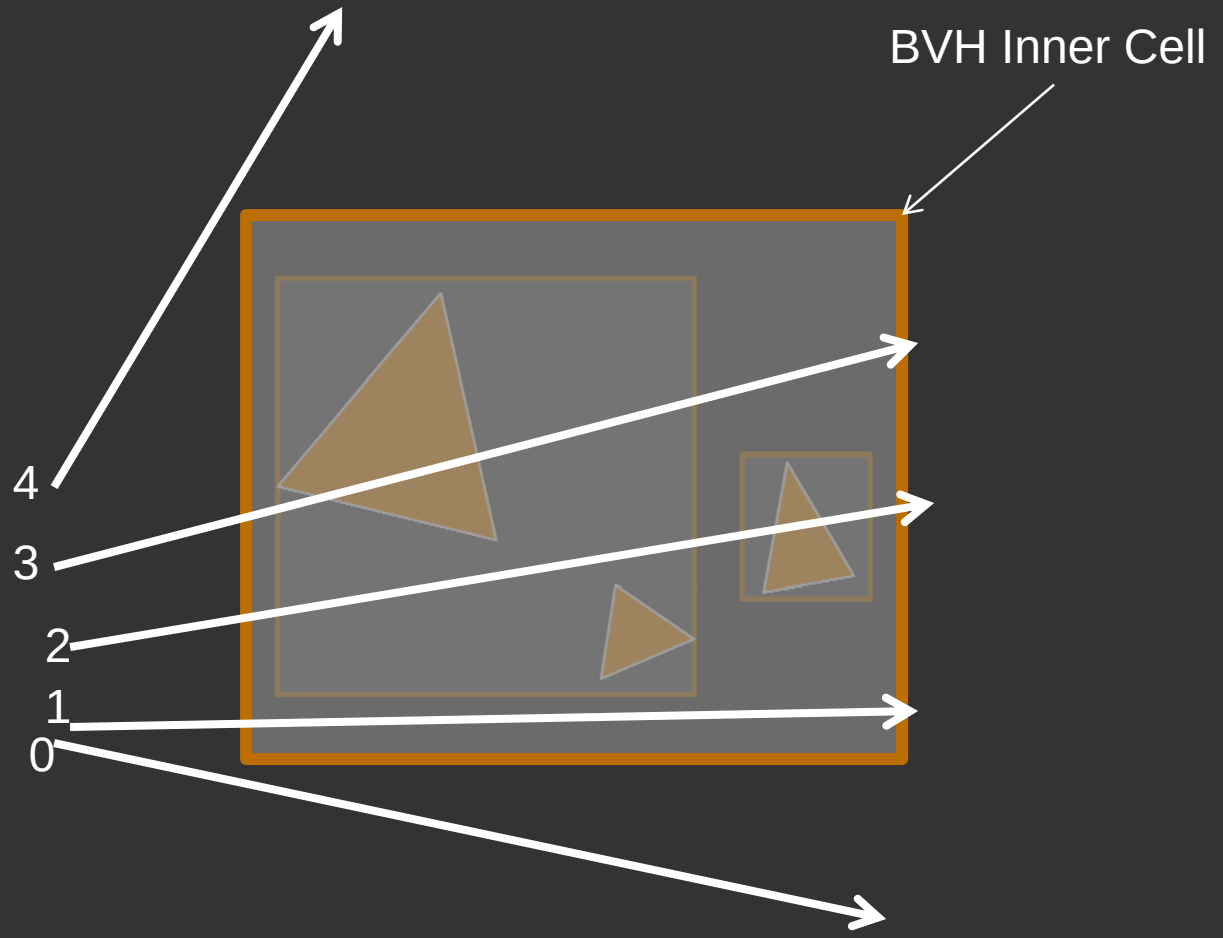

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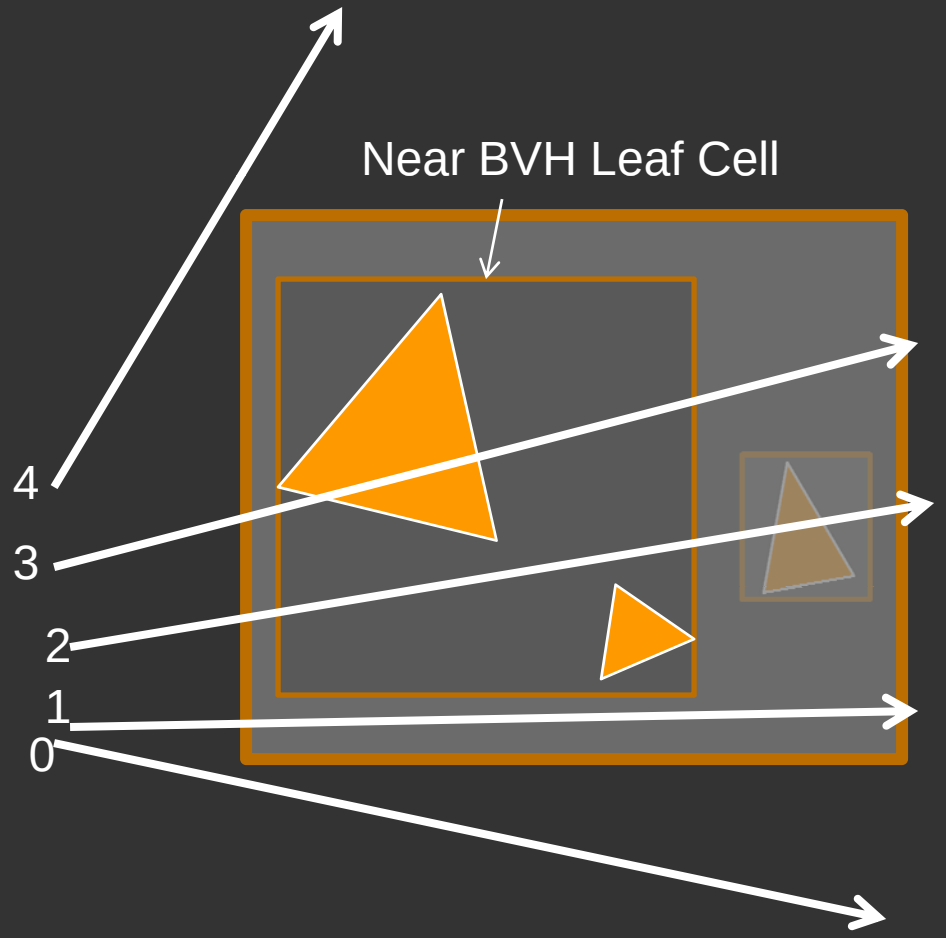

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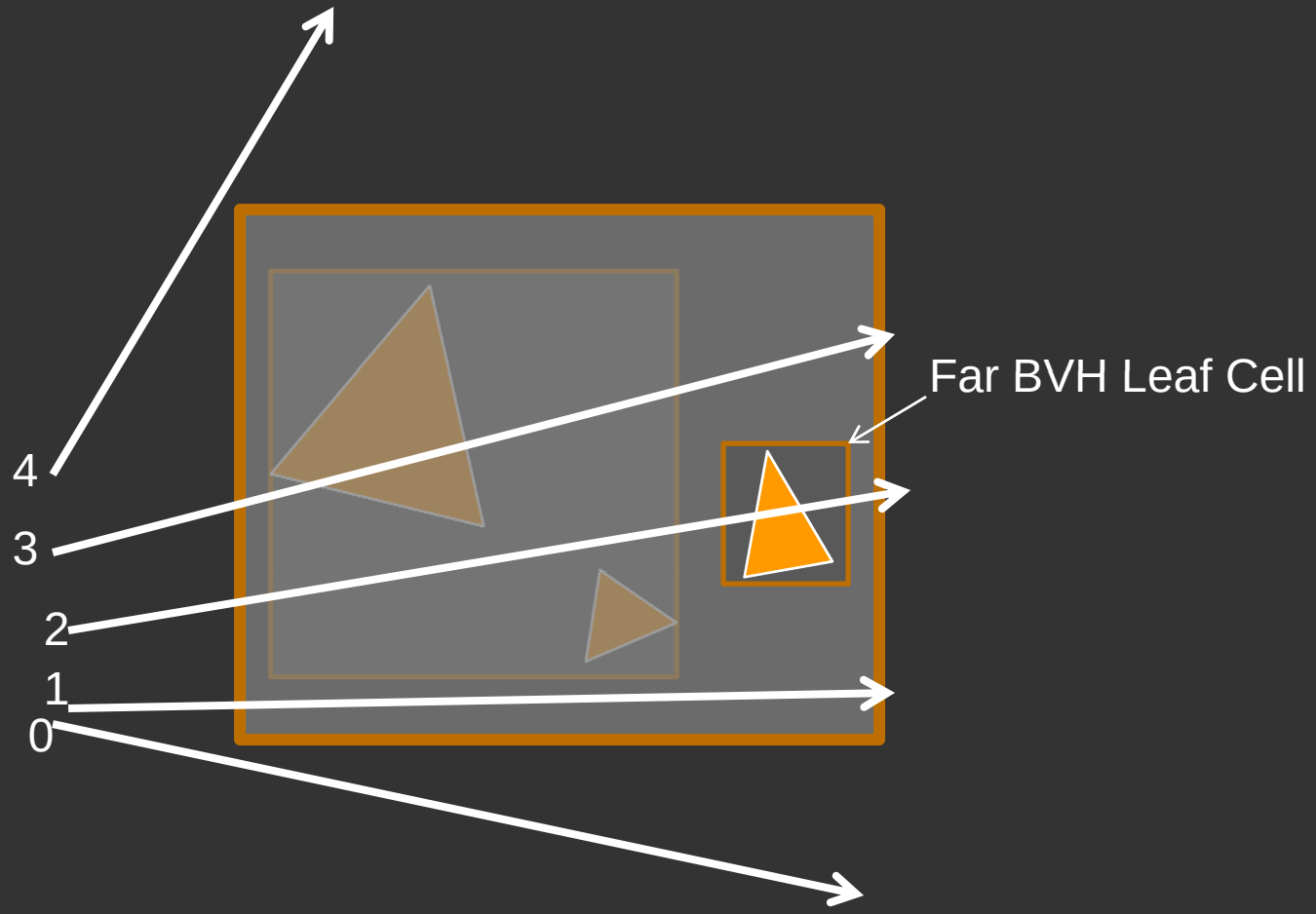

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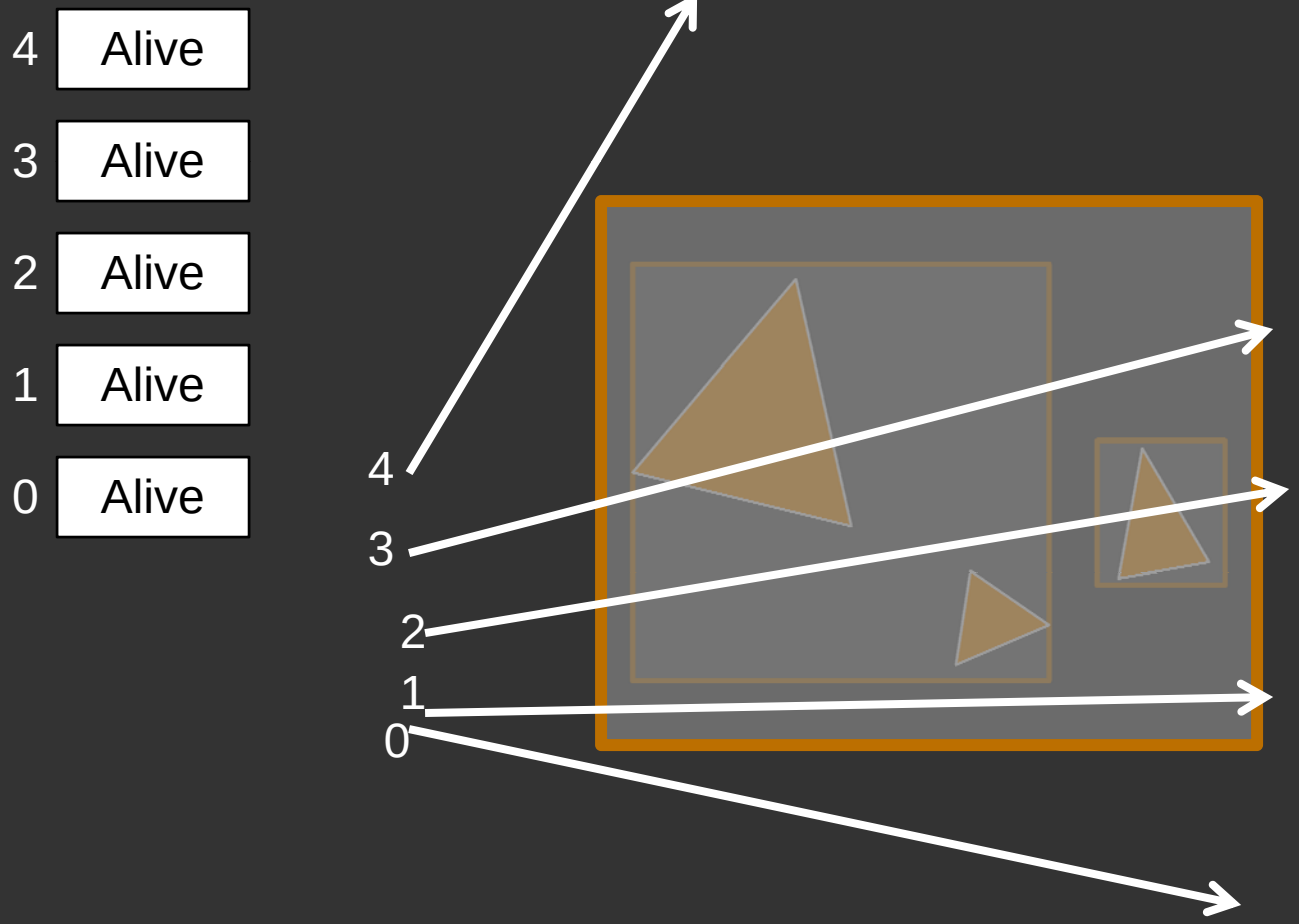

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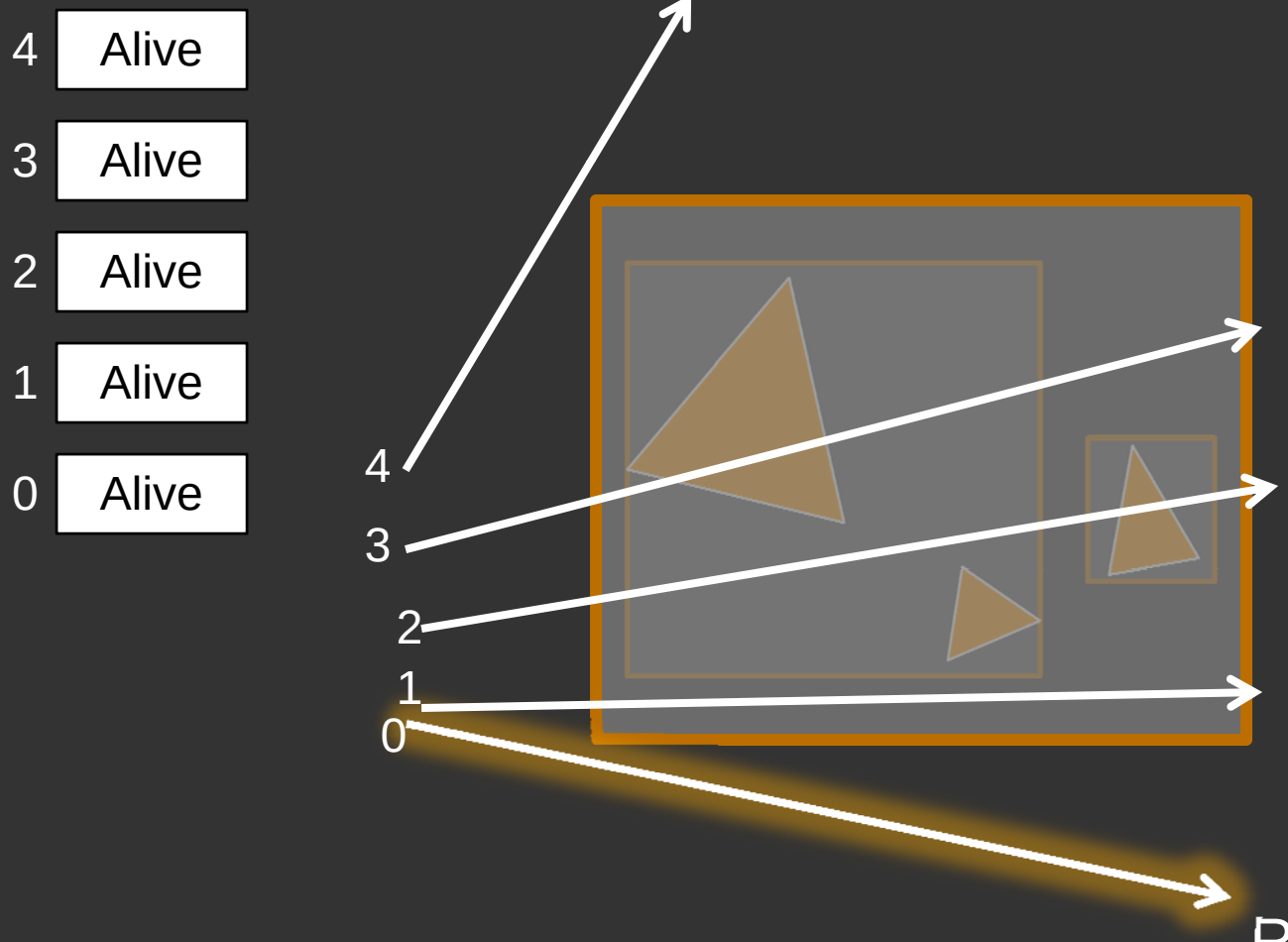

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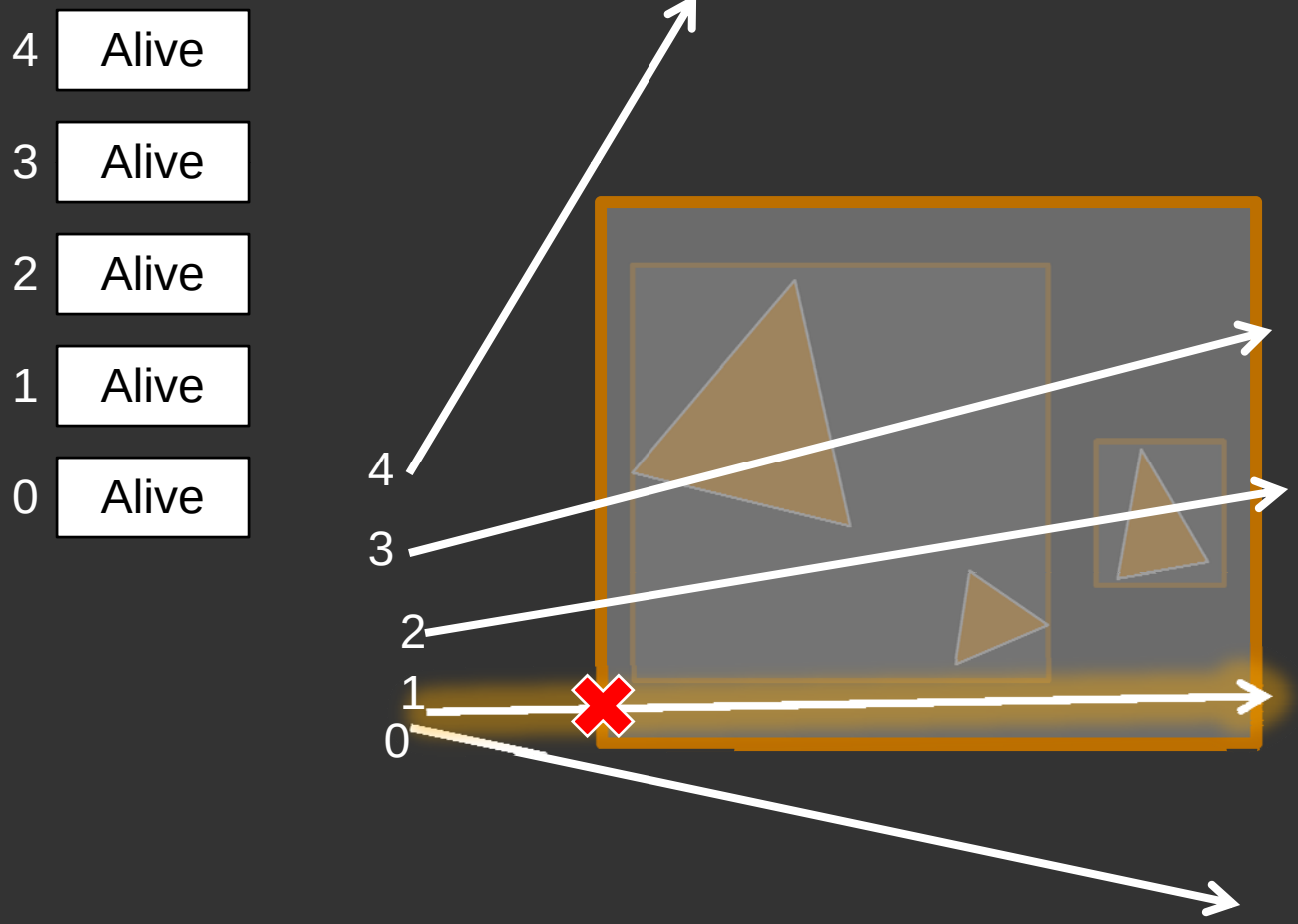

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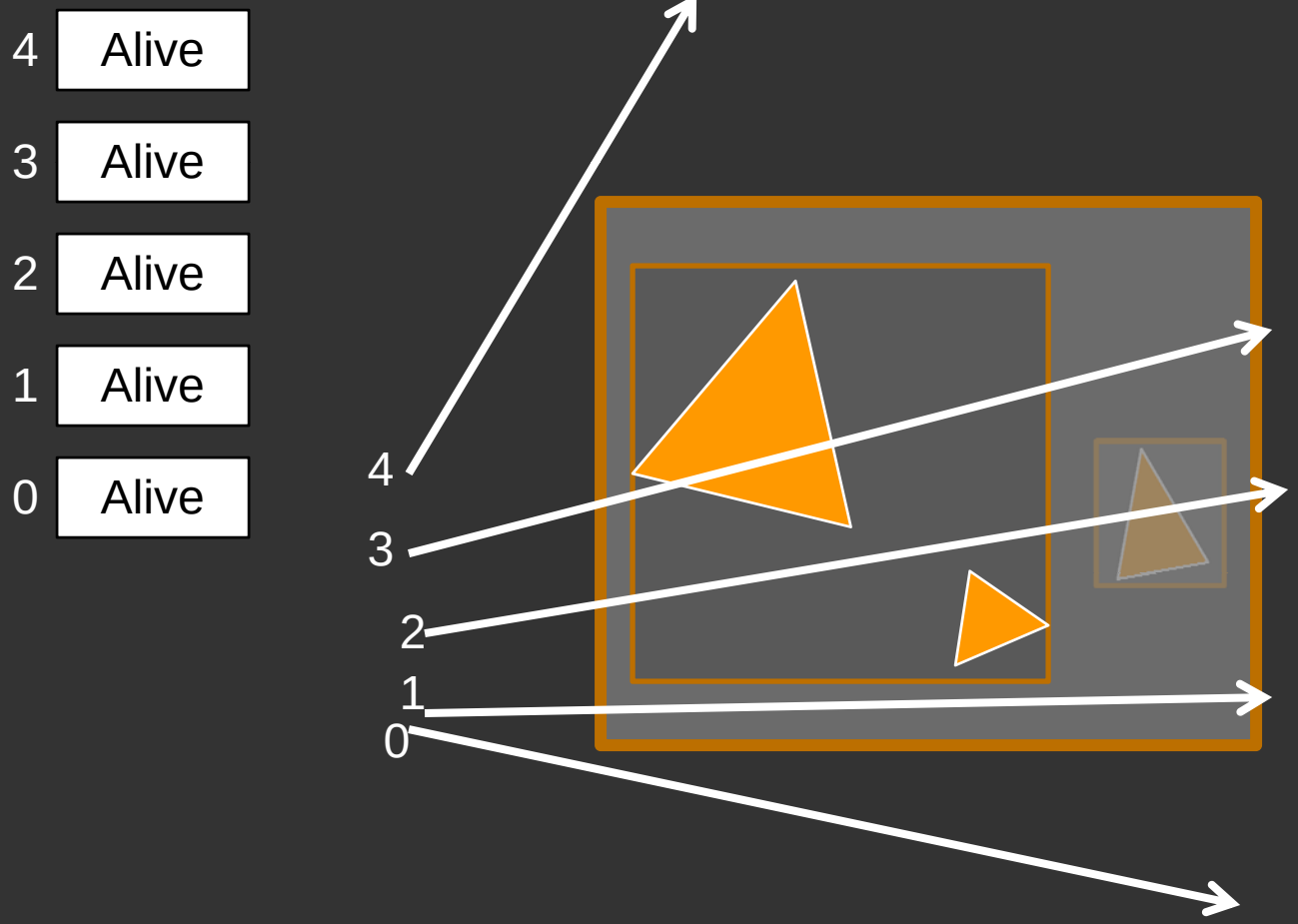

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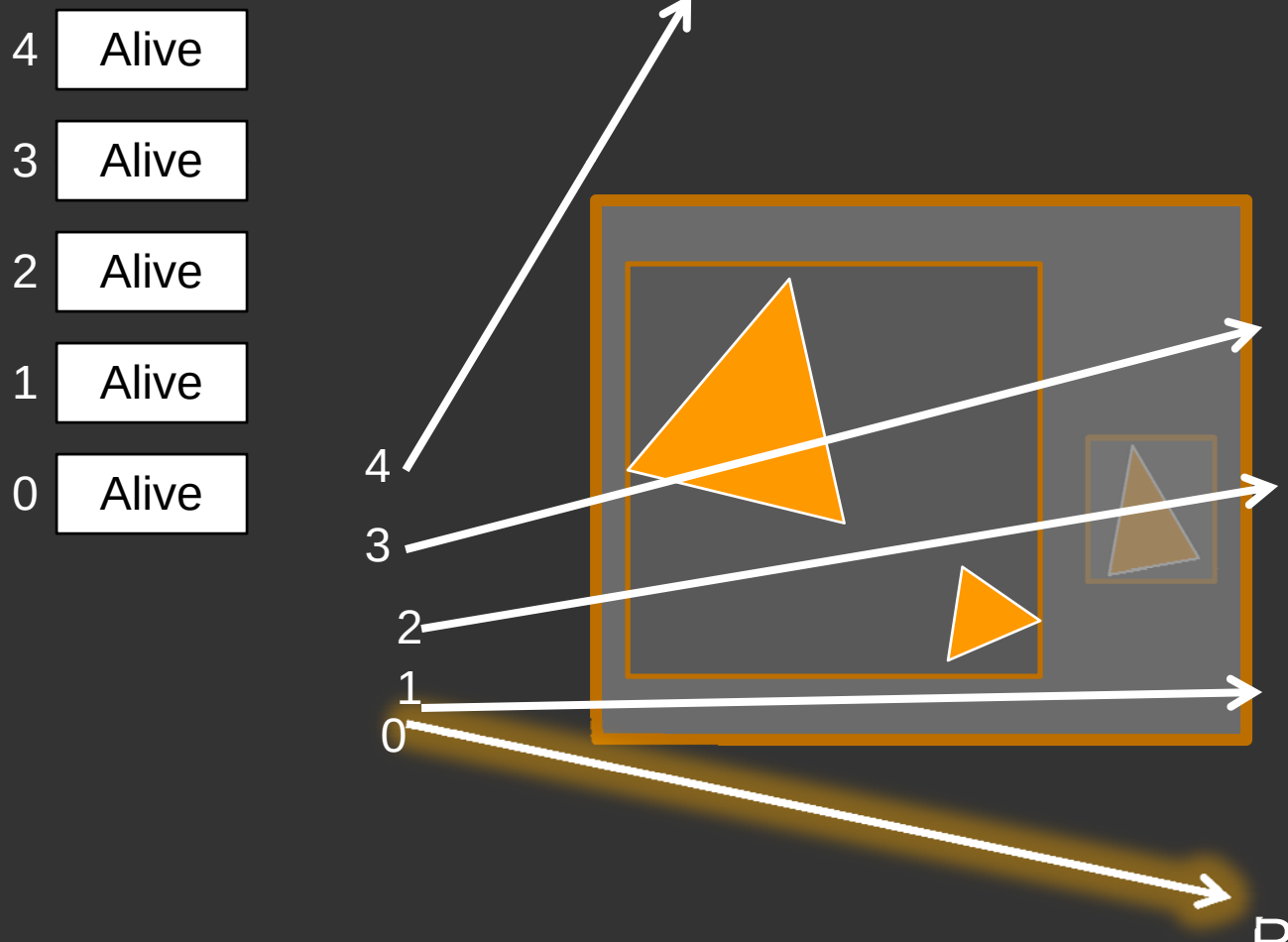

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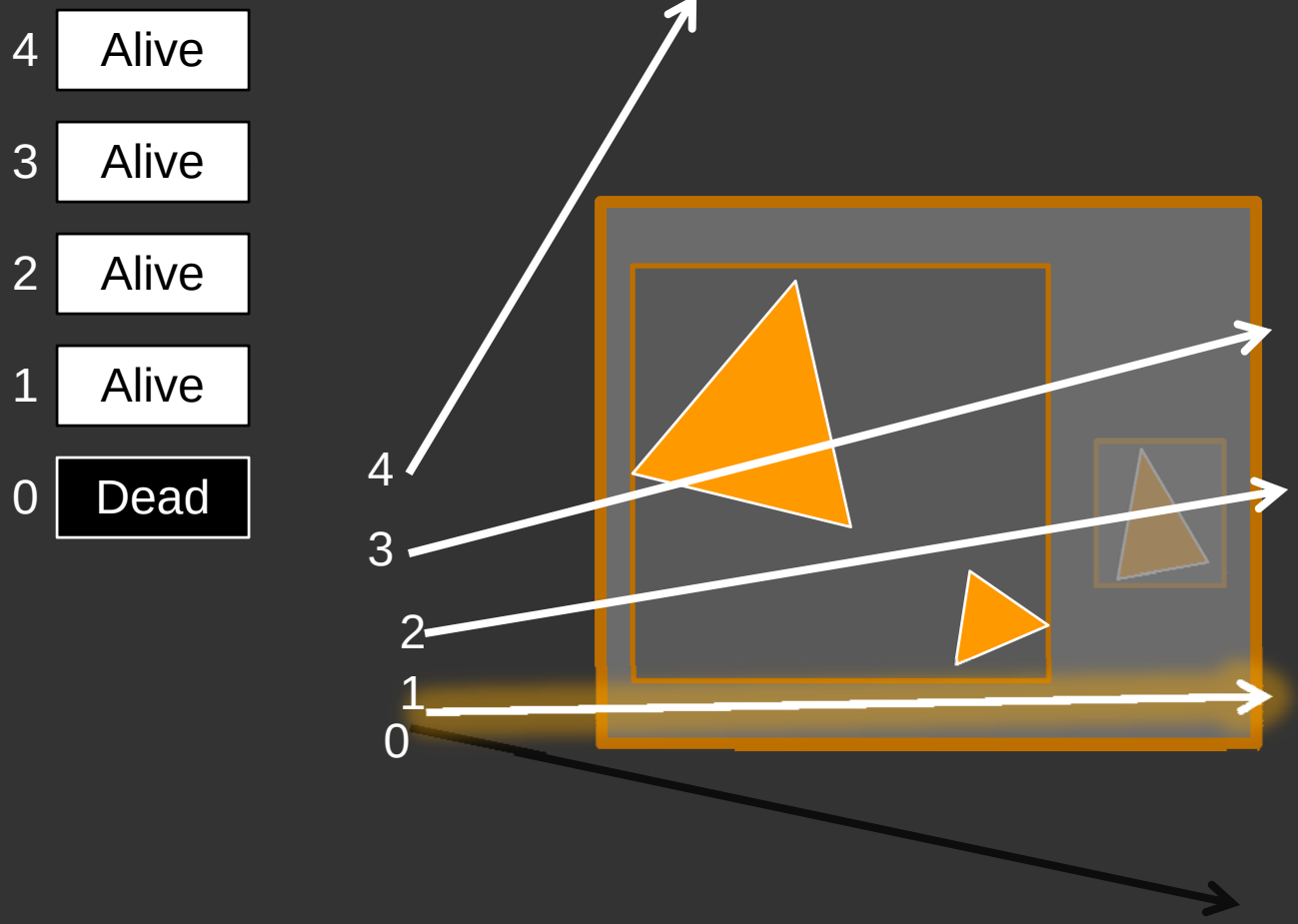

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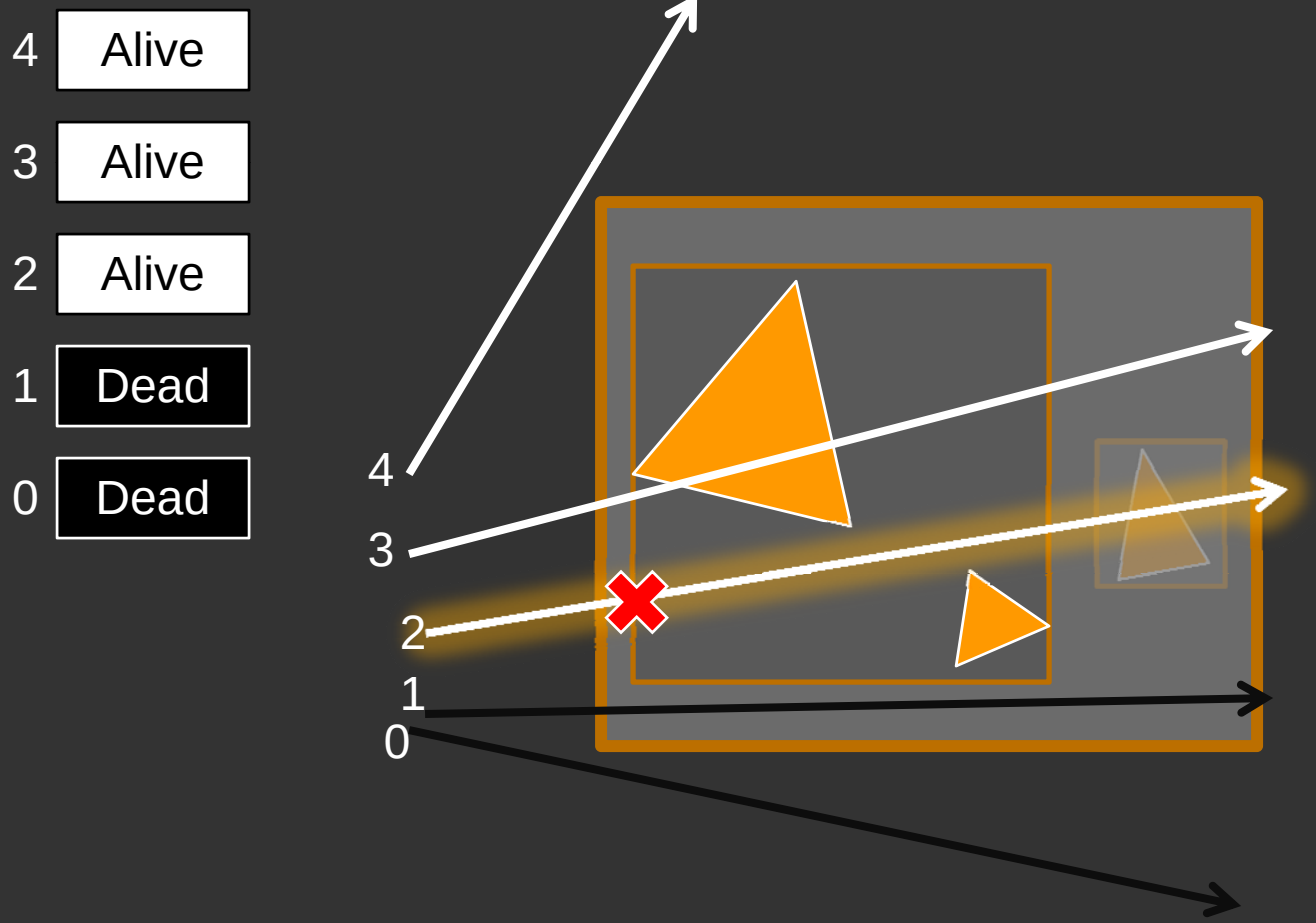

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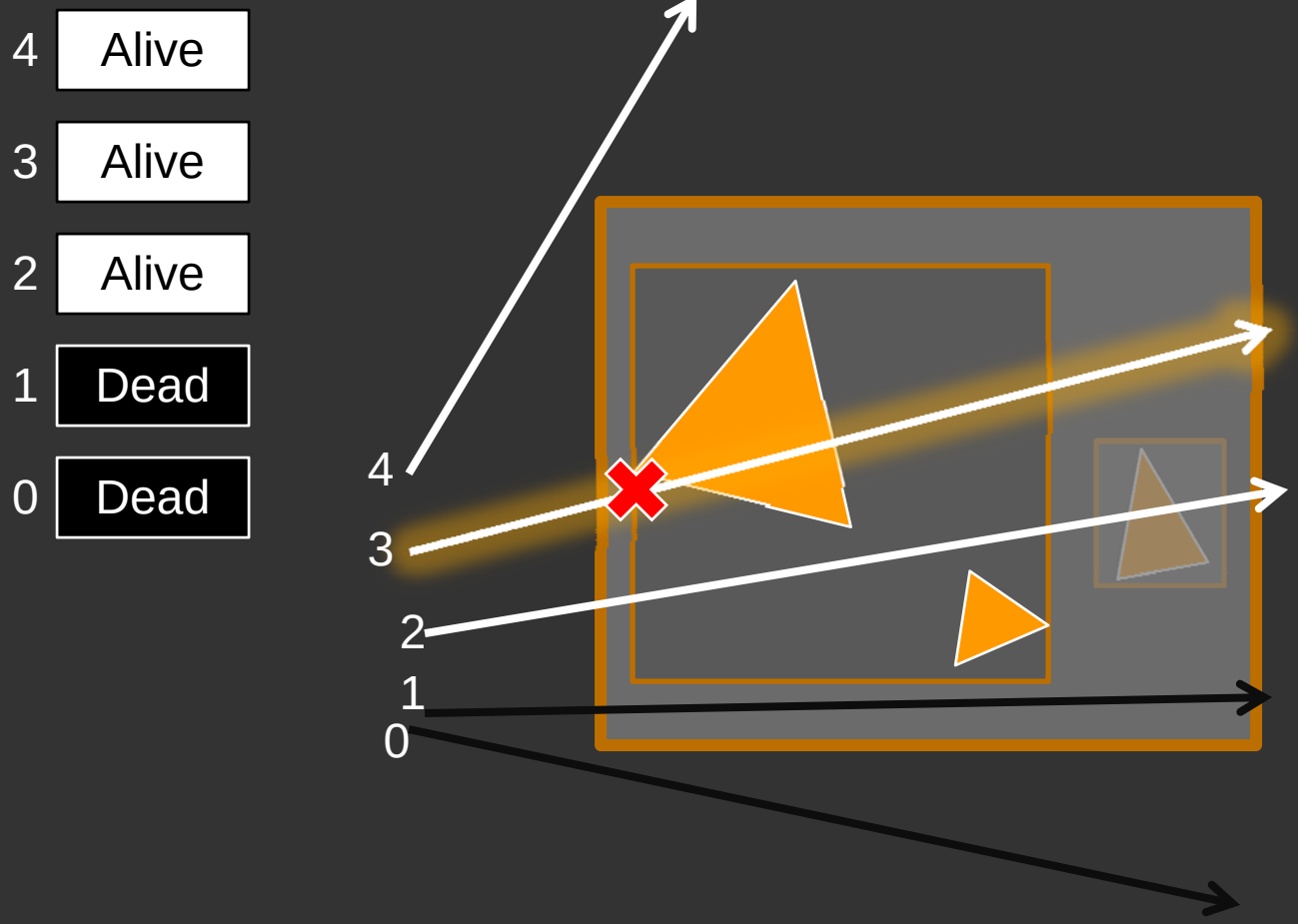

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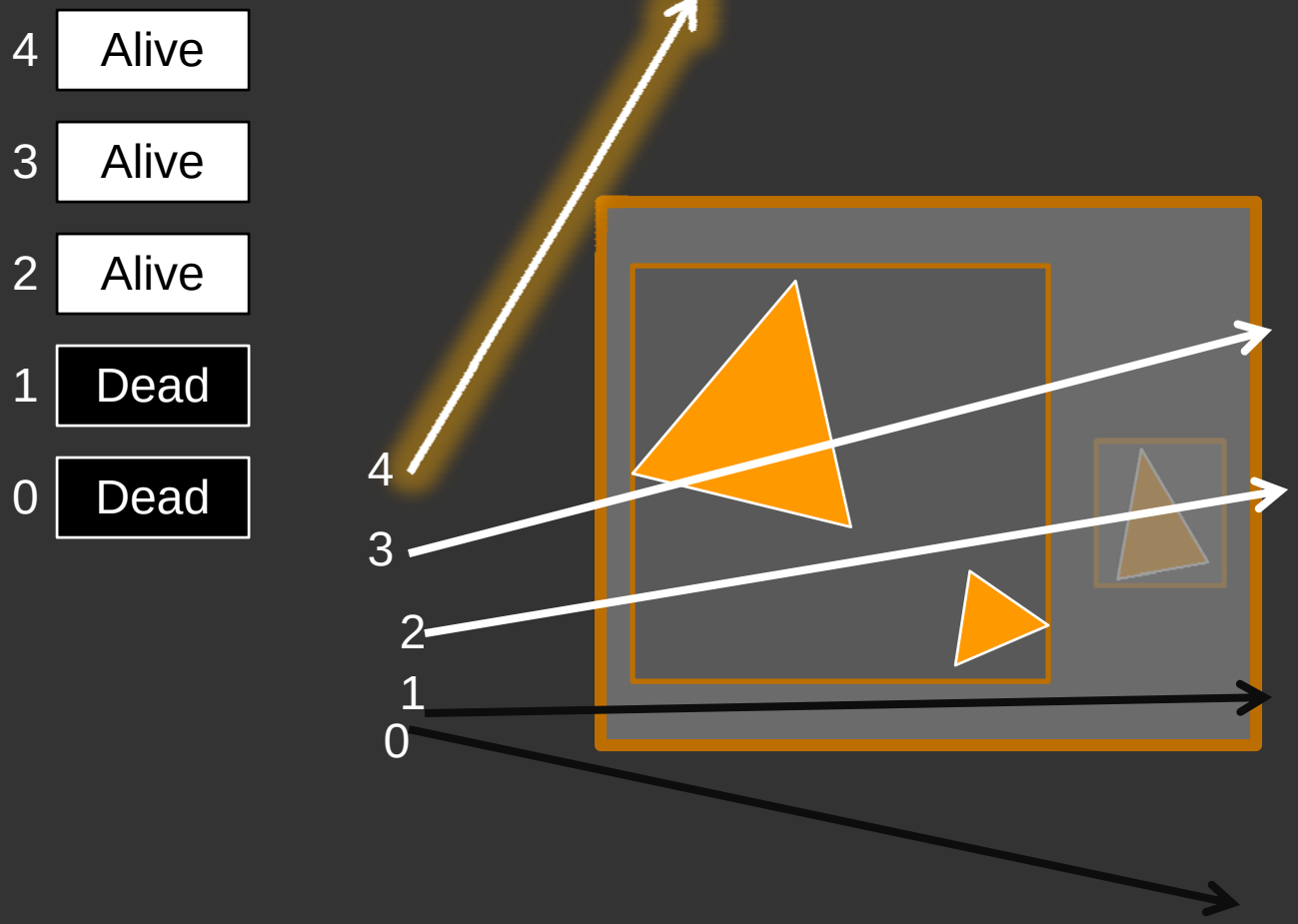

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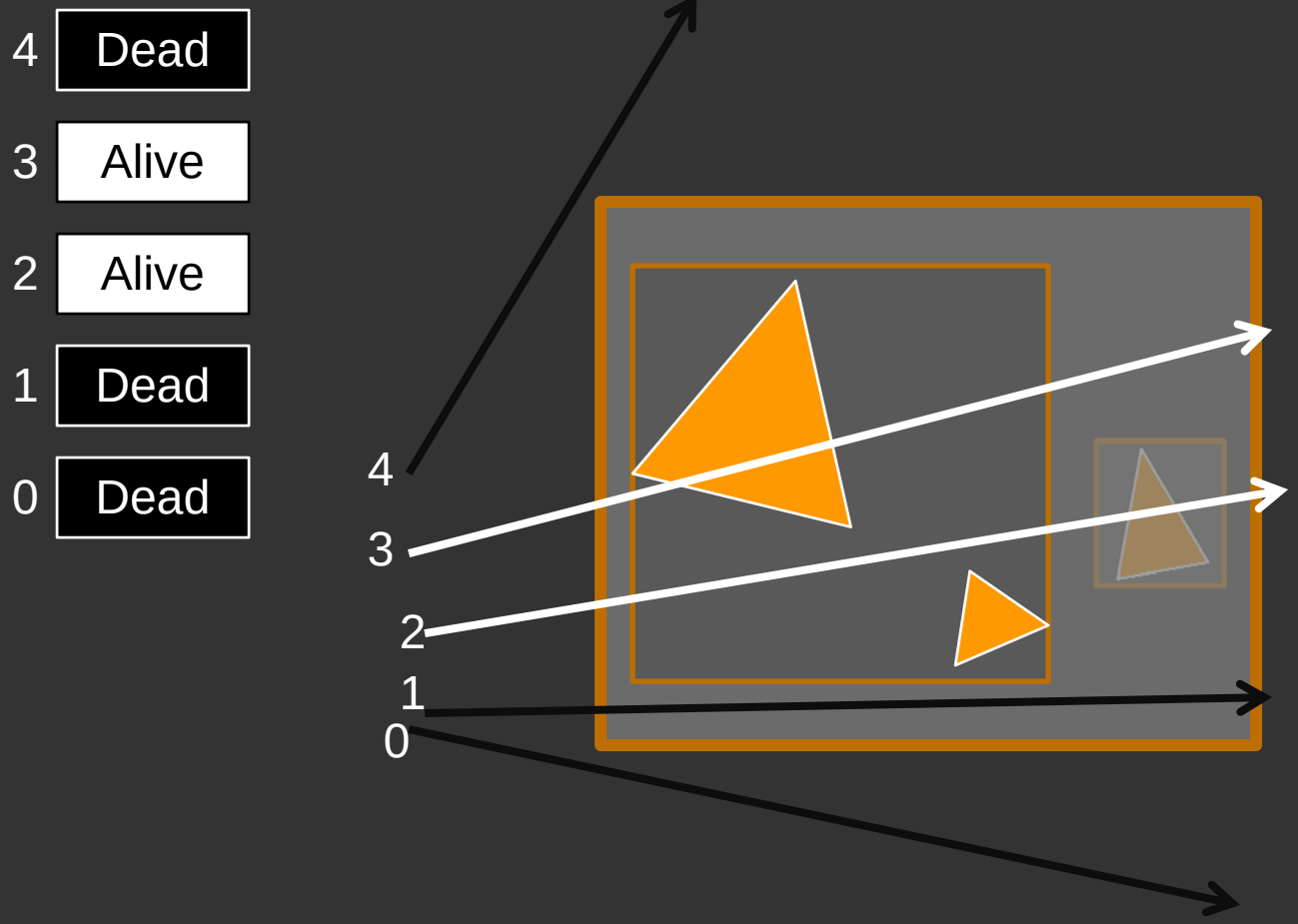

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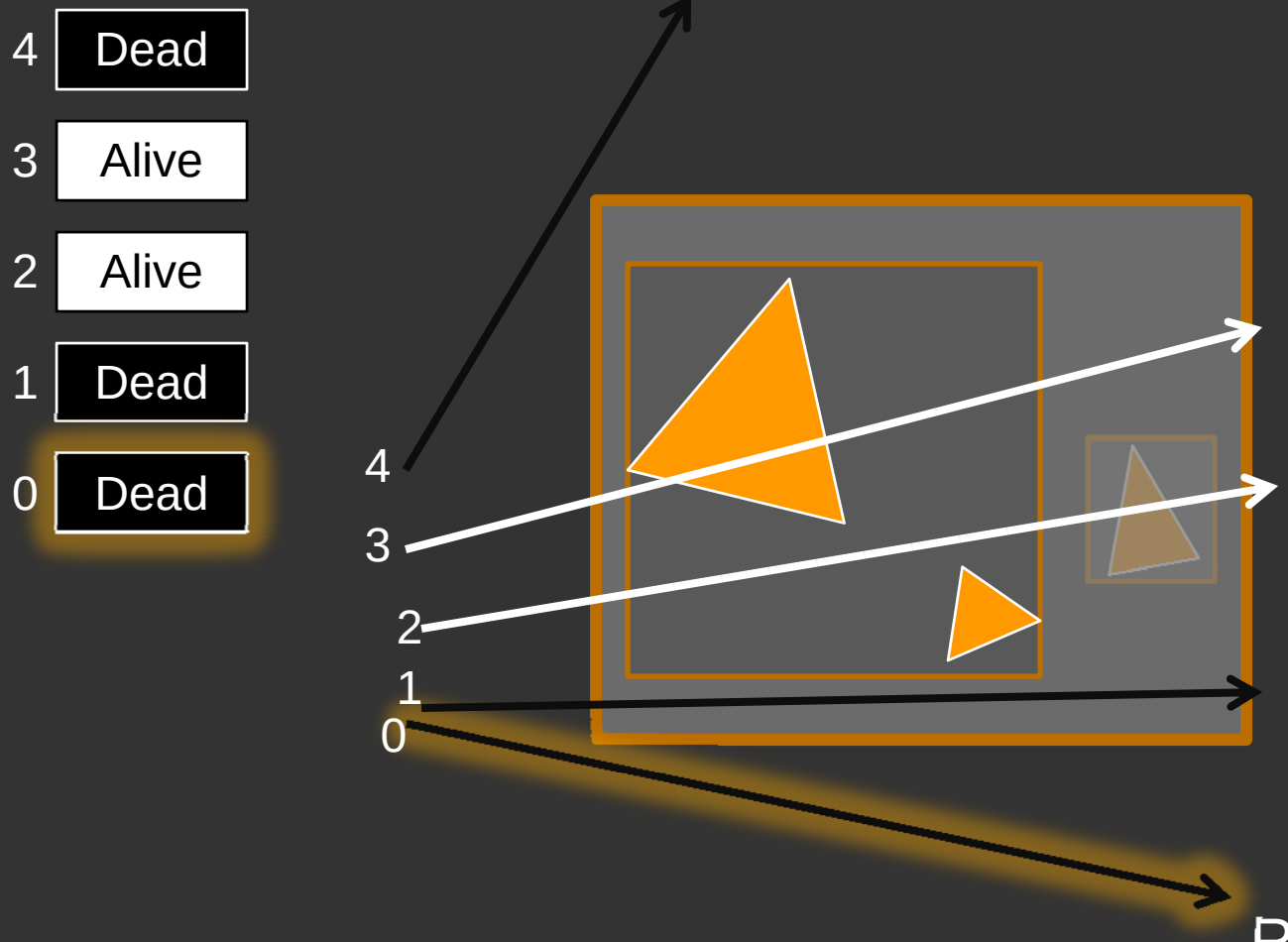

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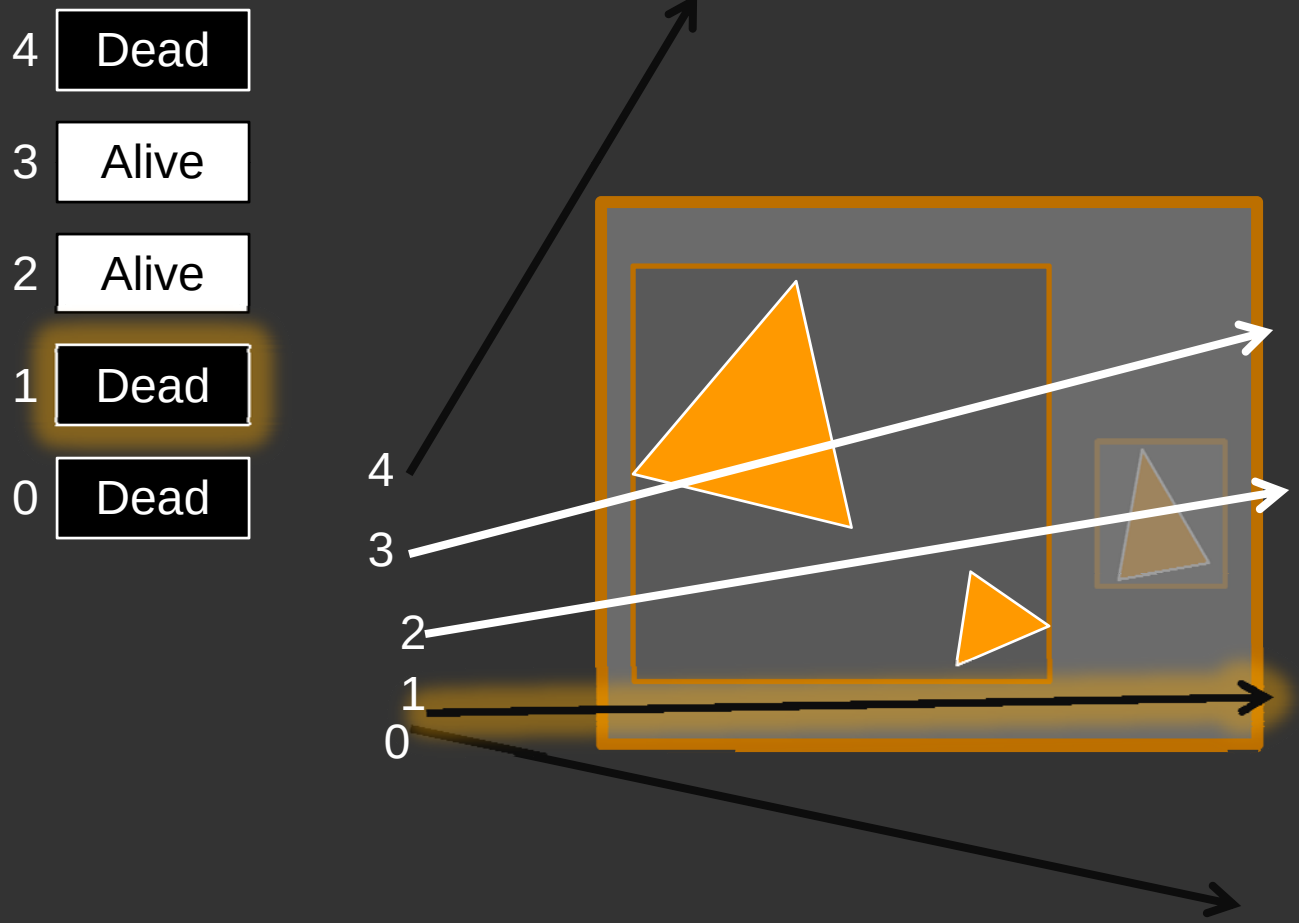

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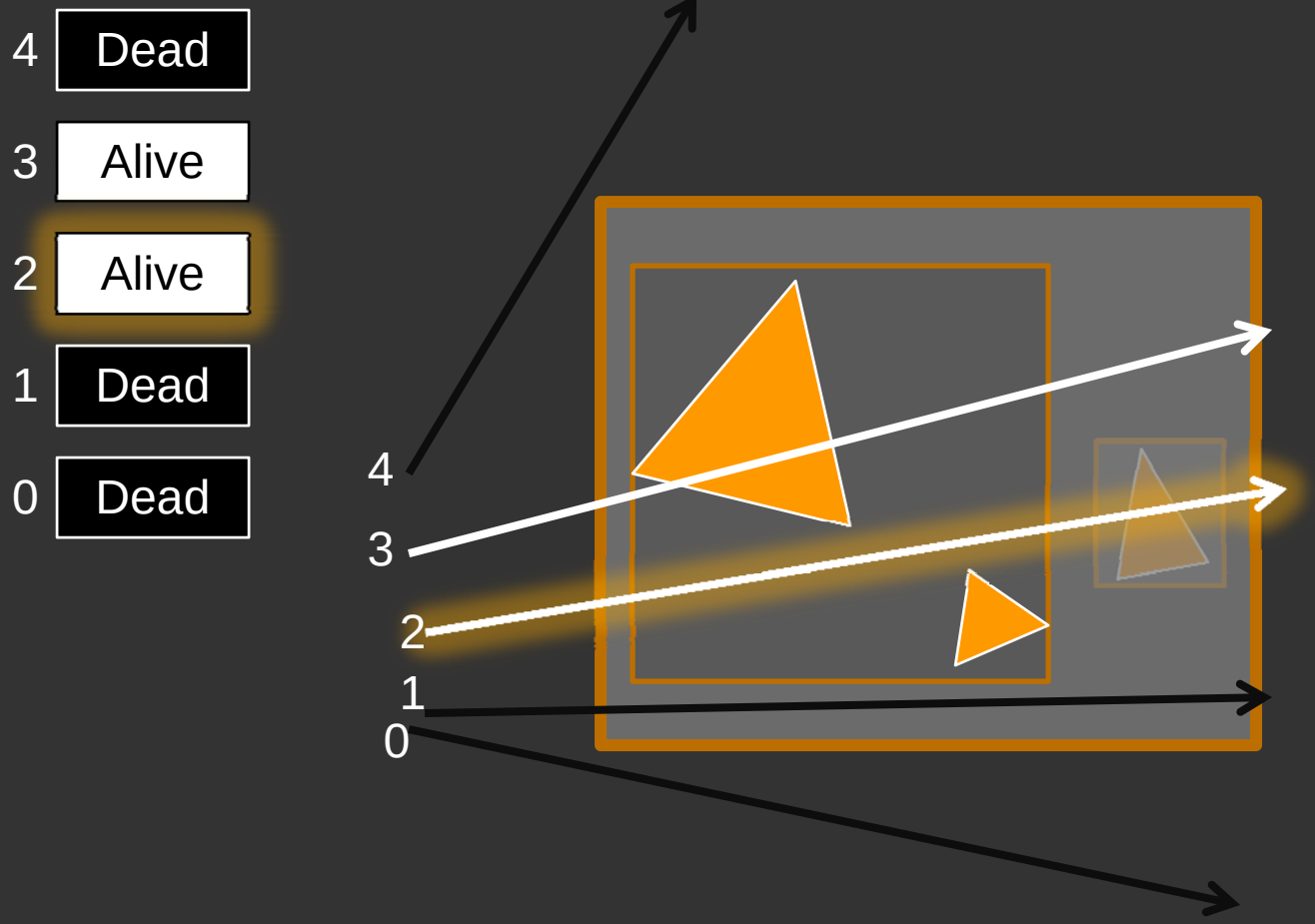

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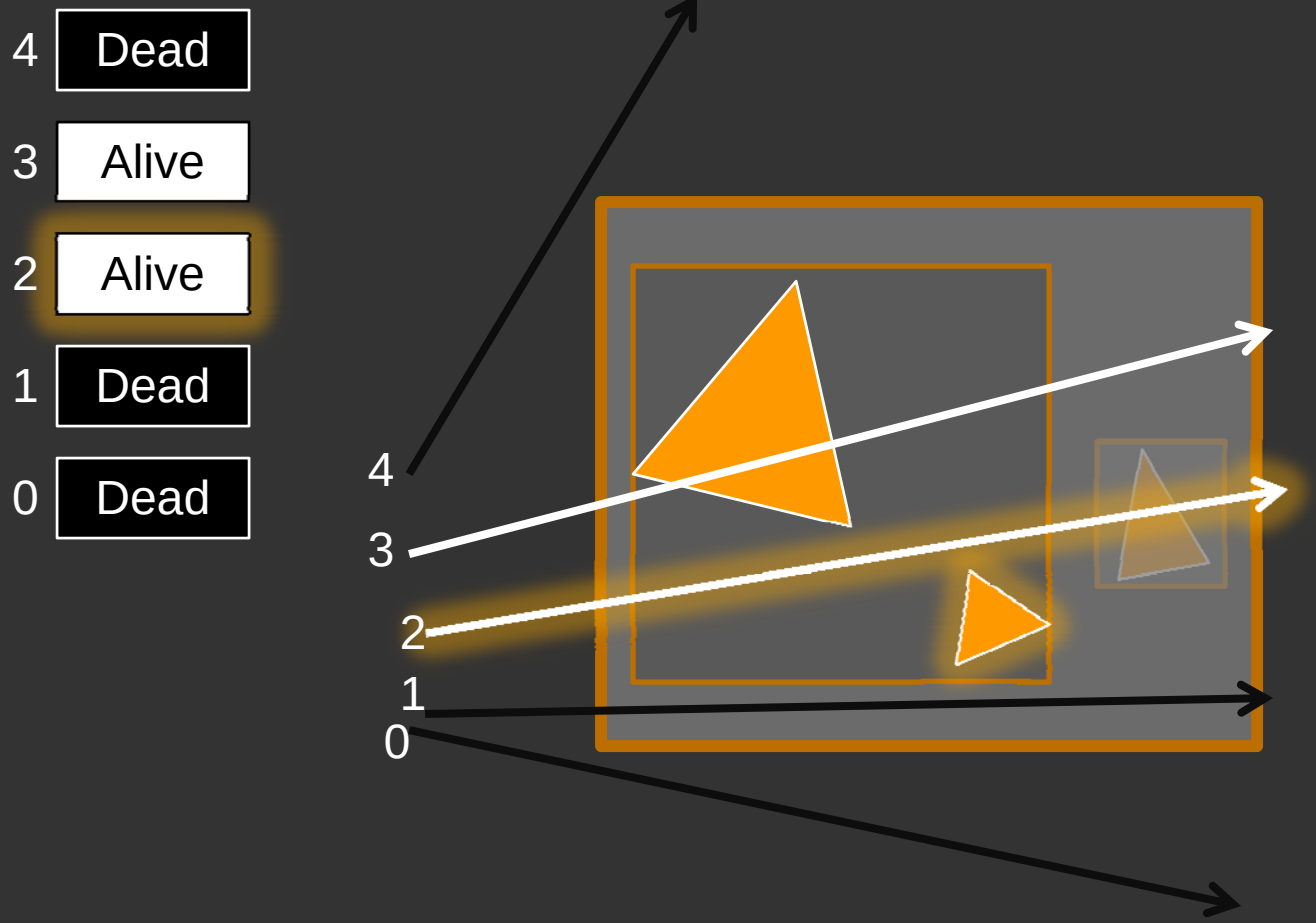

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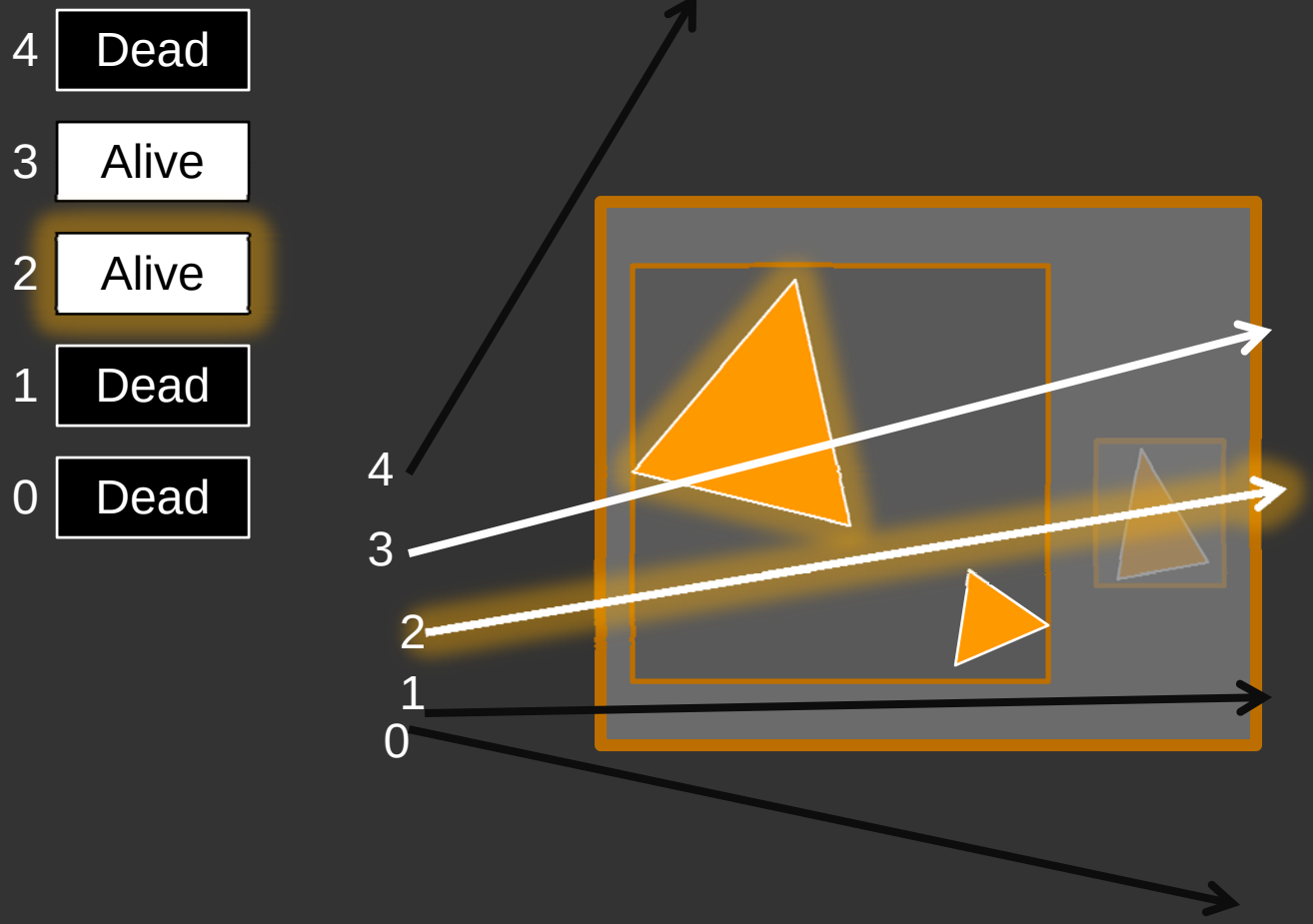

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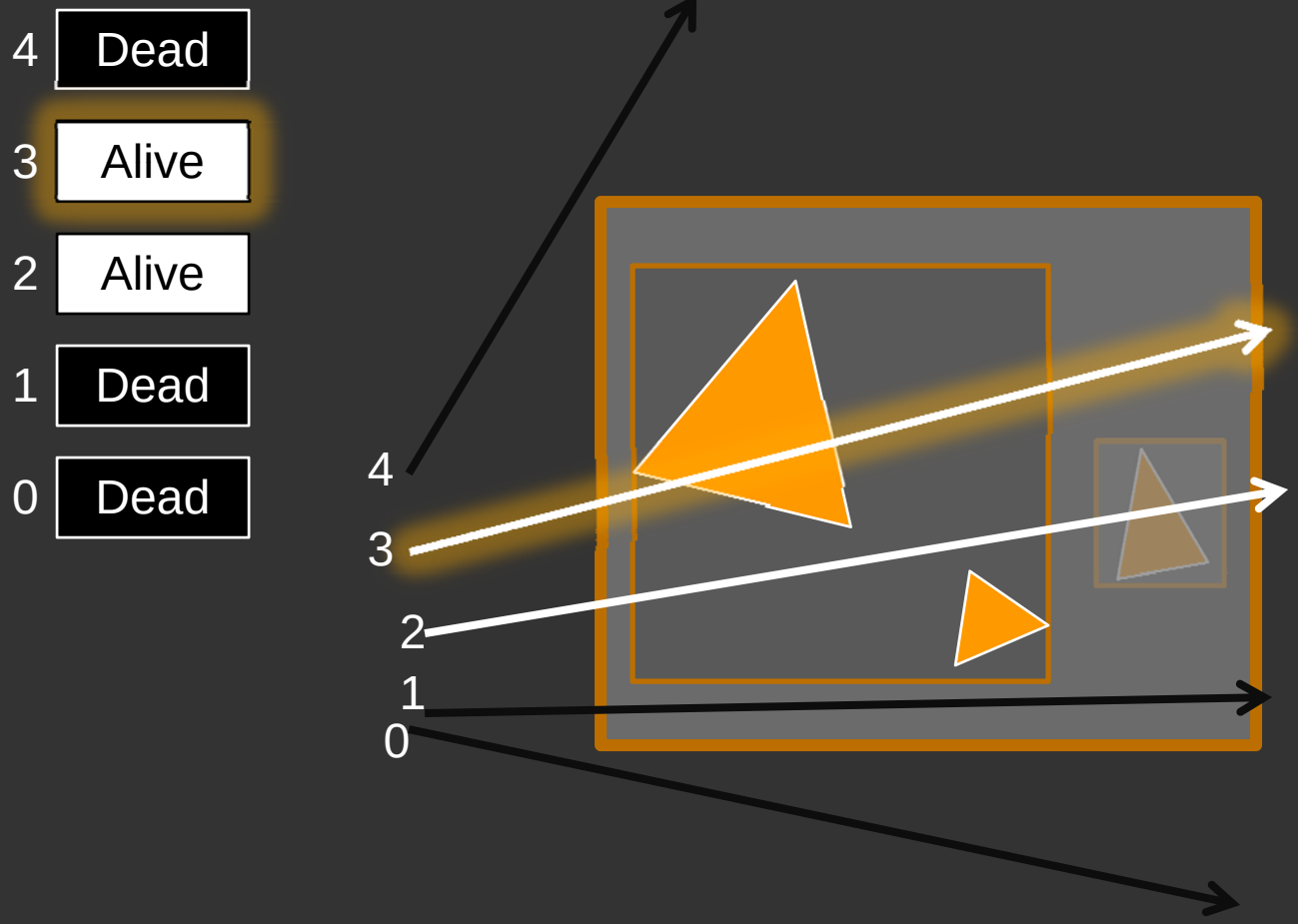

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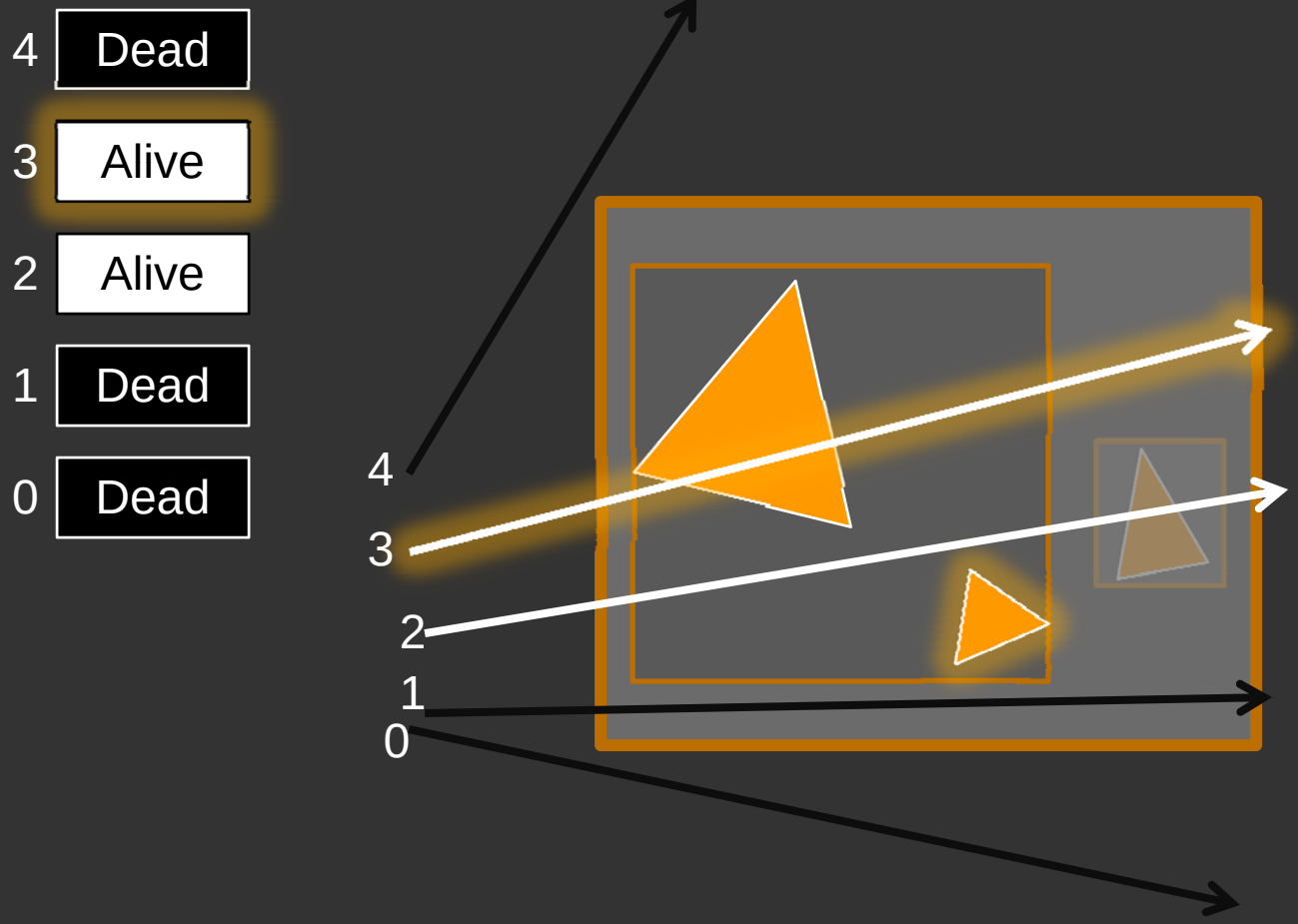

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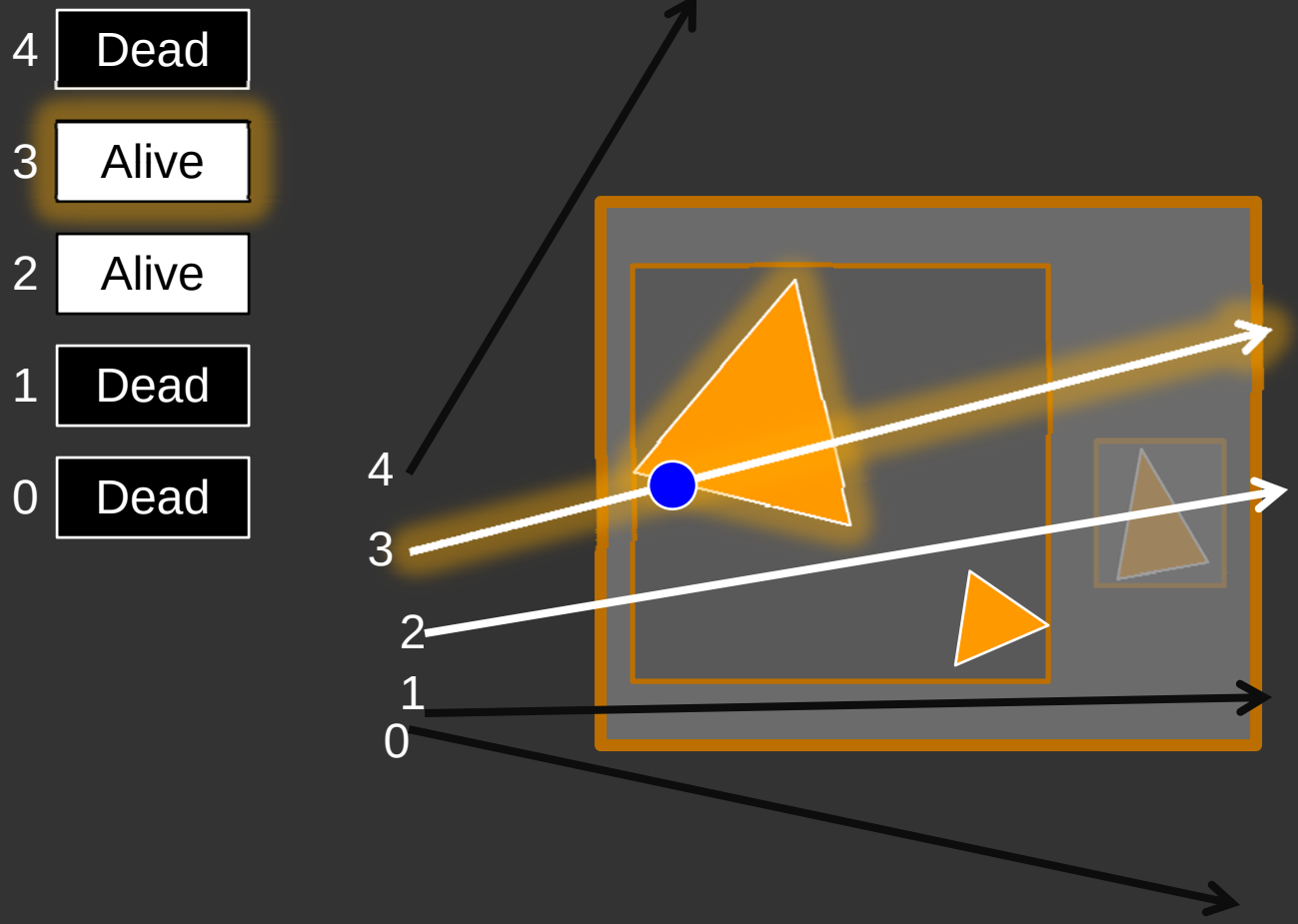

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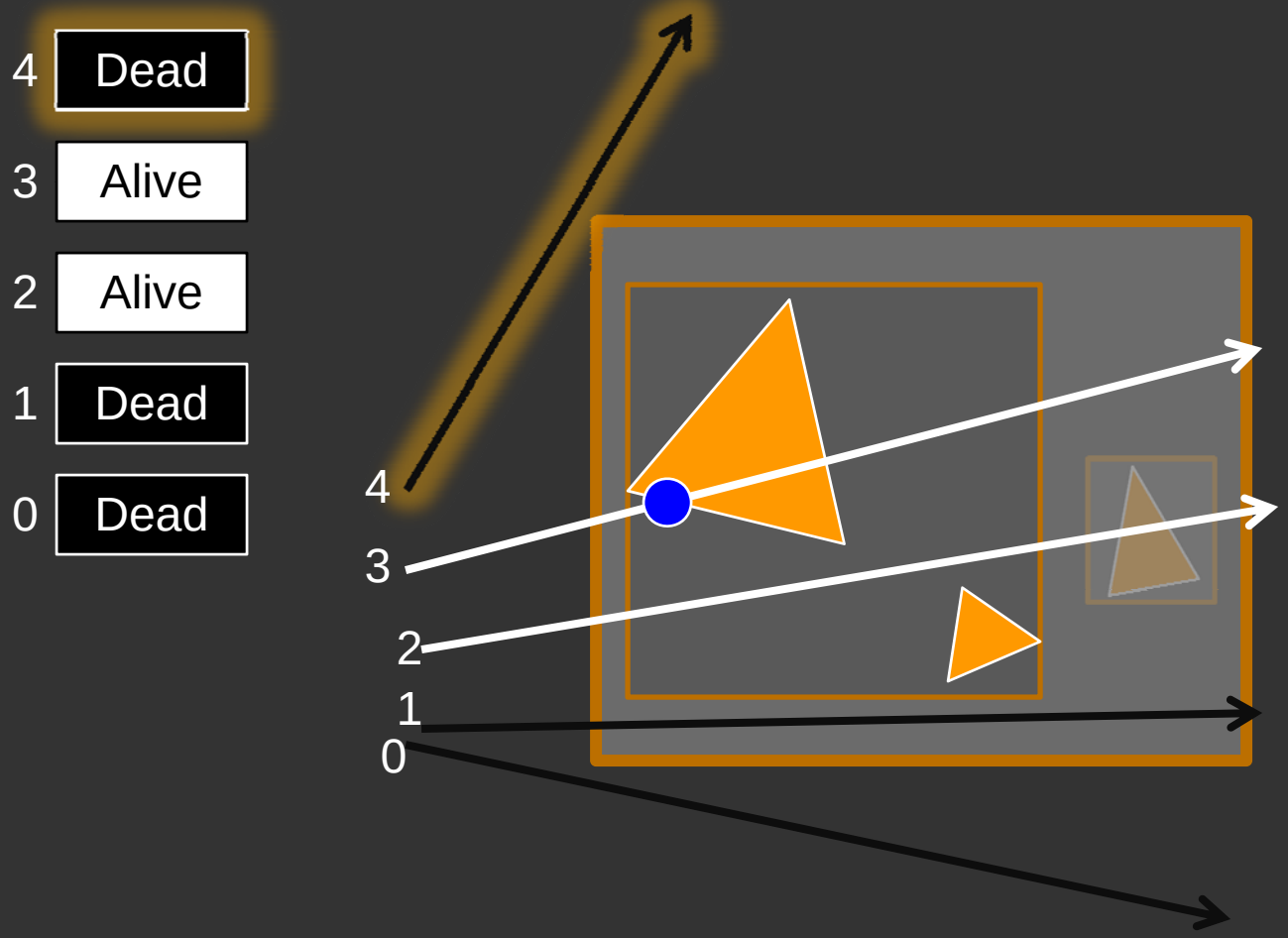

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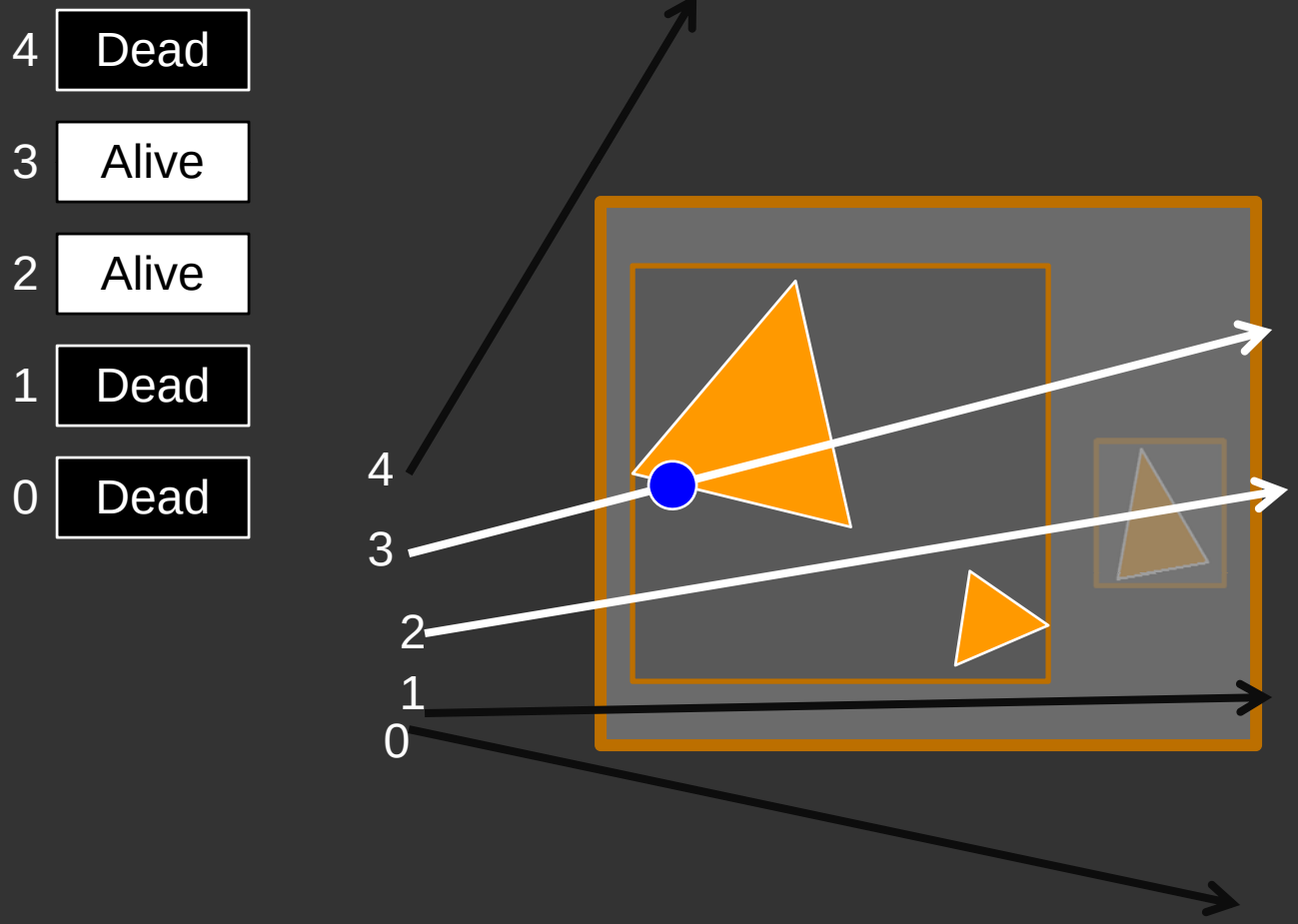
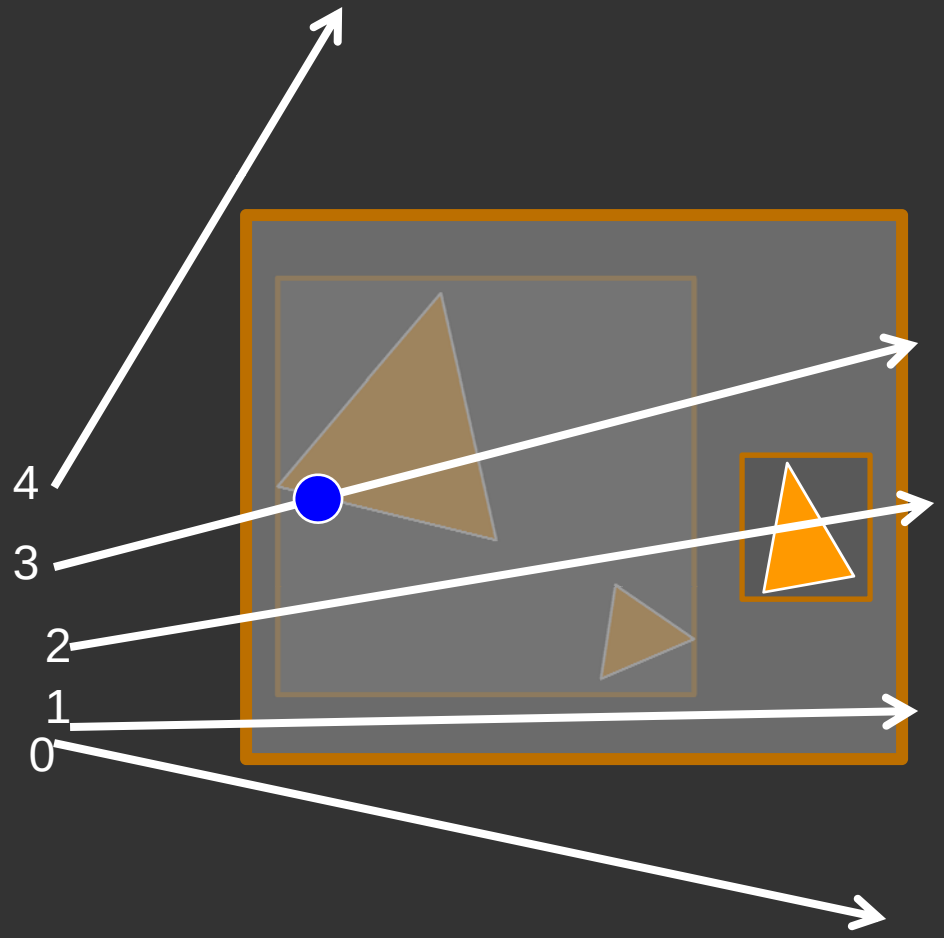


Masked Traversal

4	Alive
3	Alive
2	Alive
1	Alive
0	Alive



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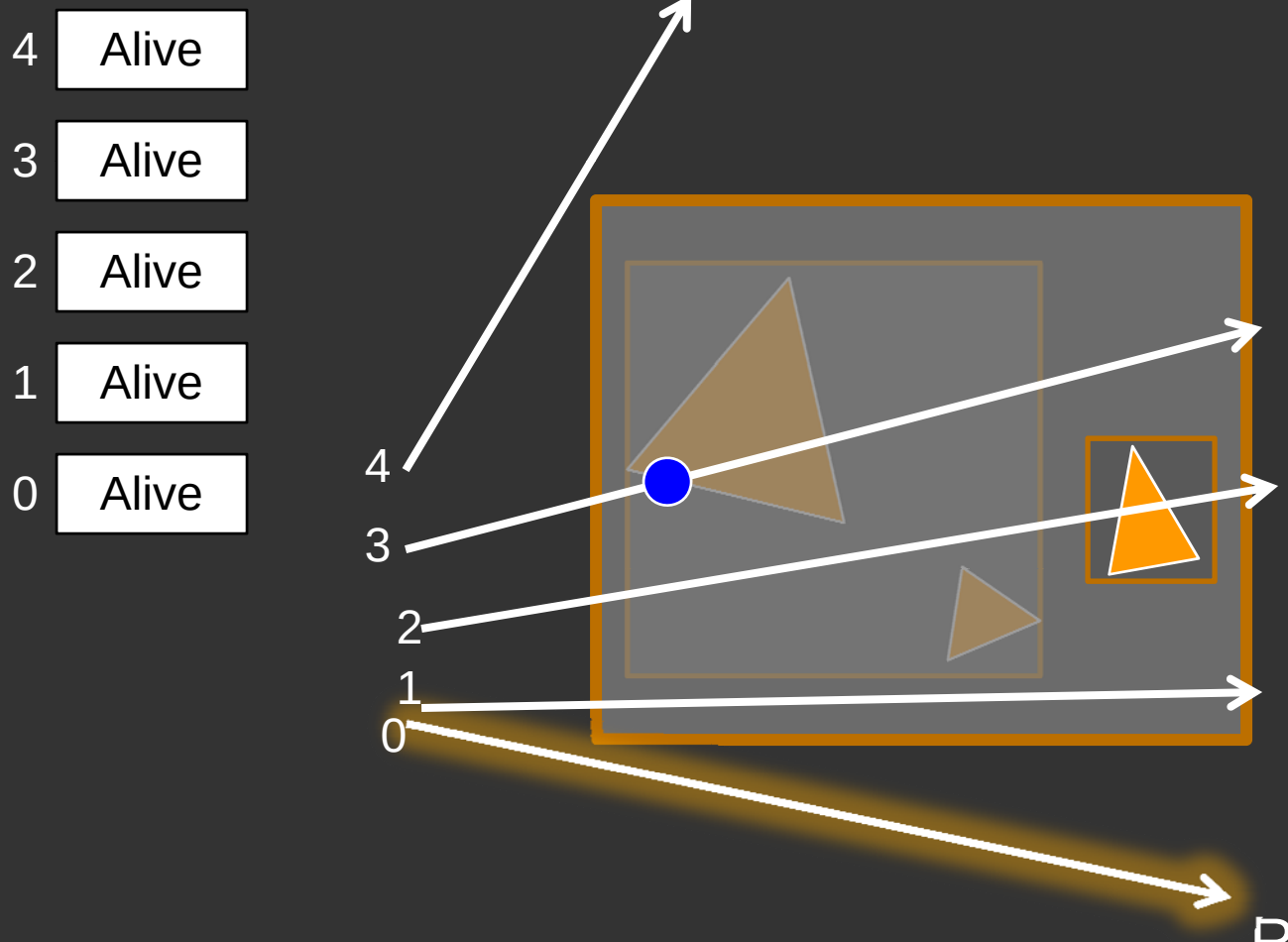

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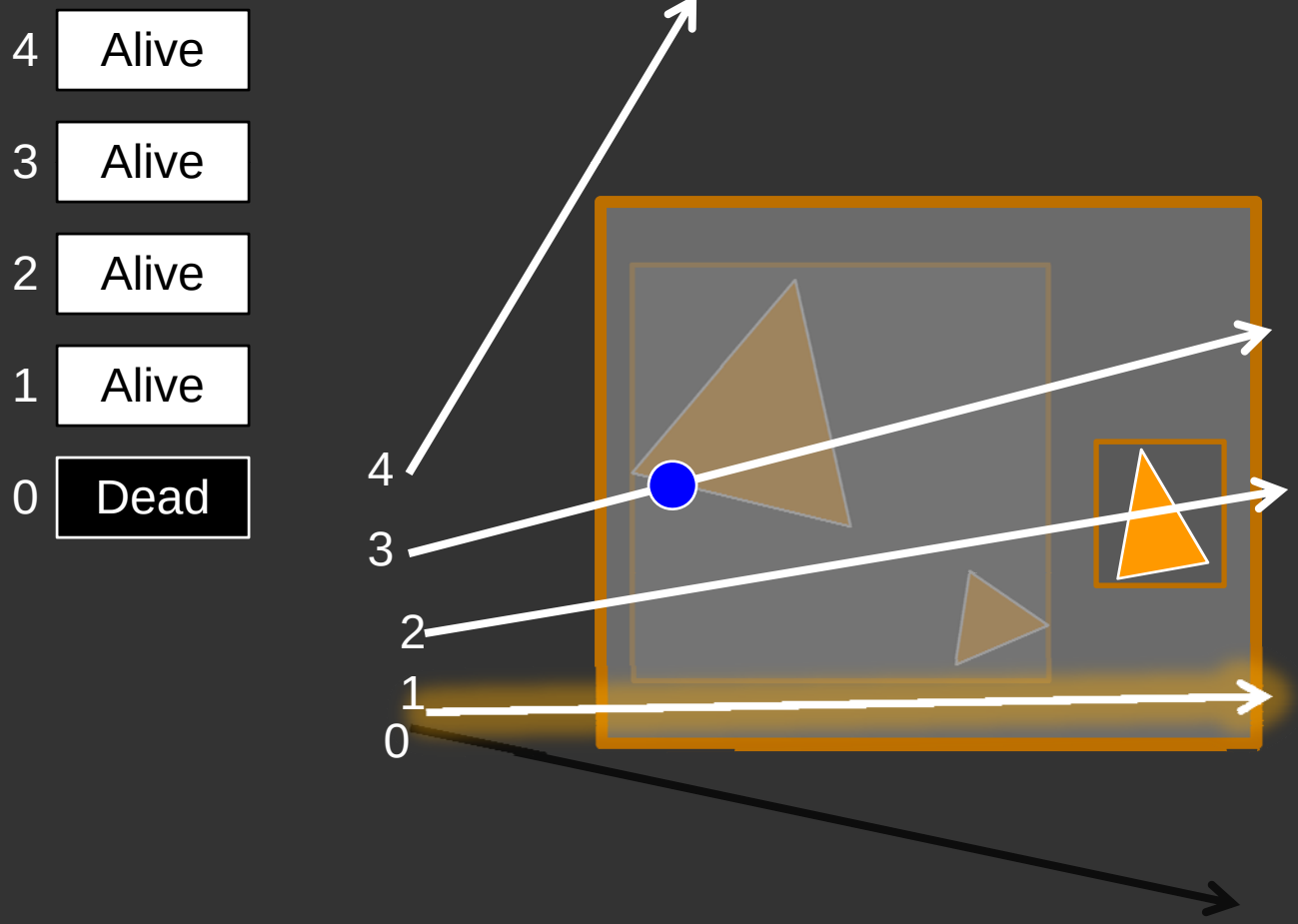

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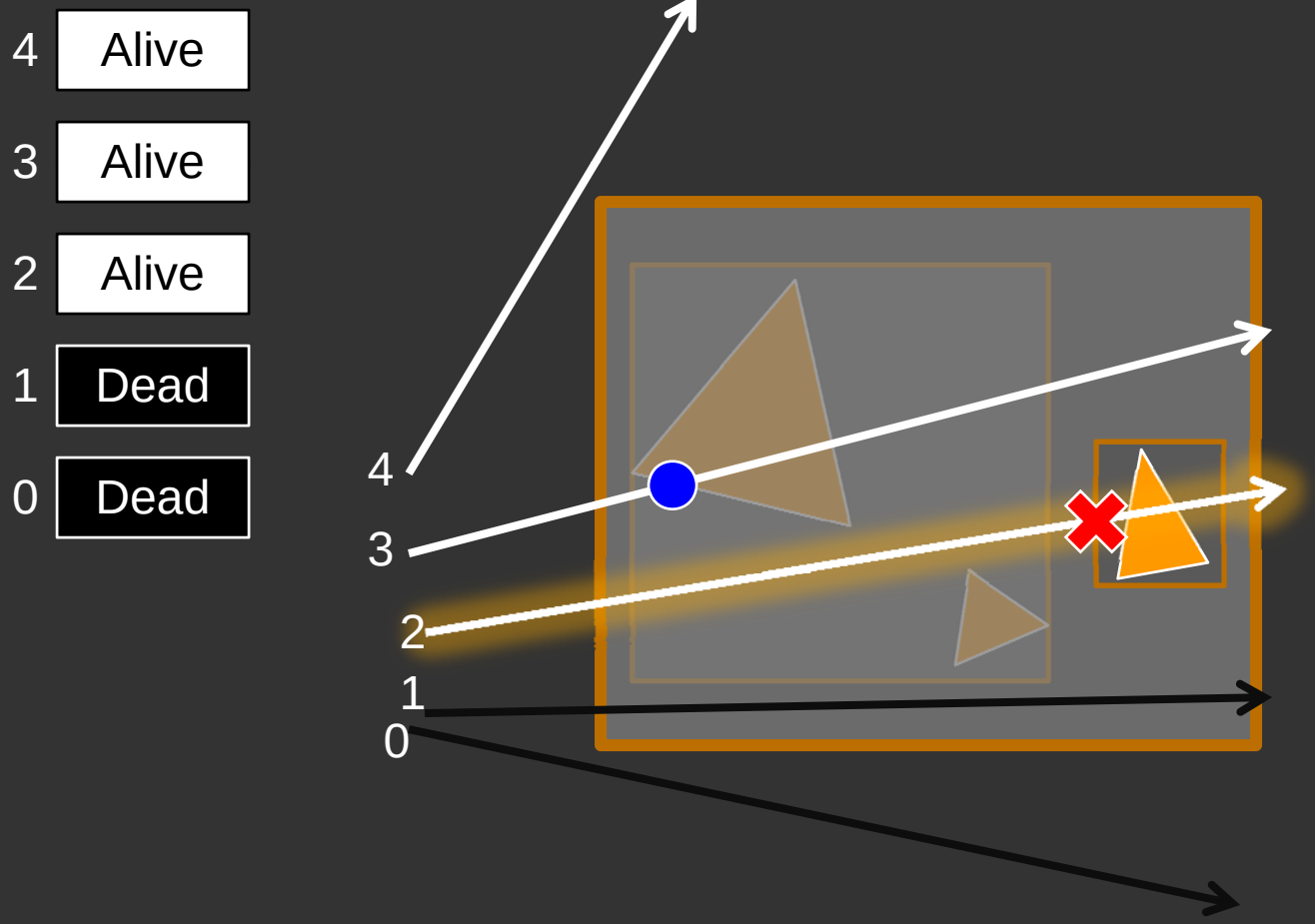

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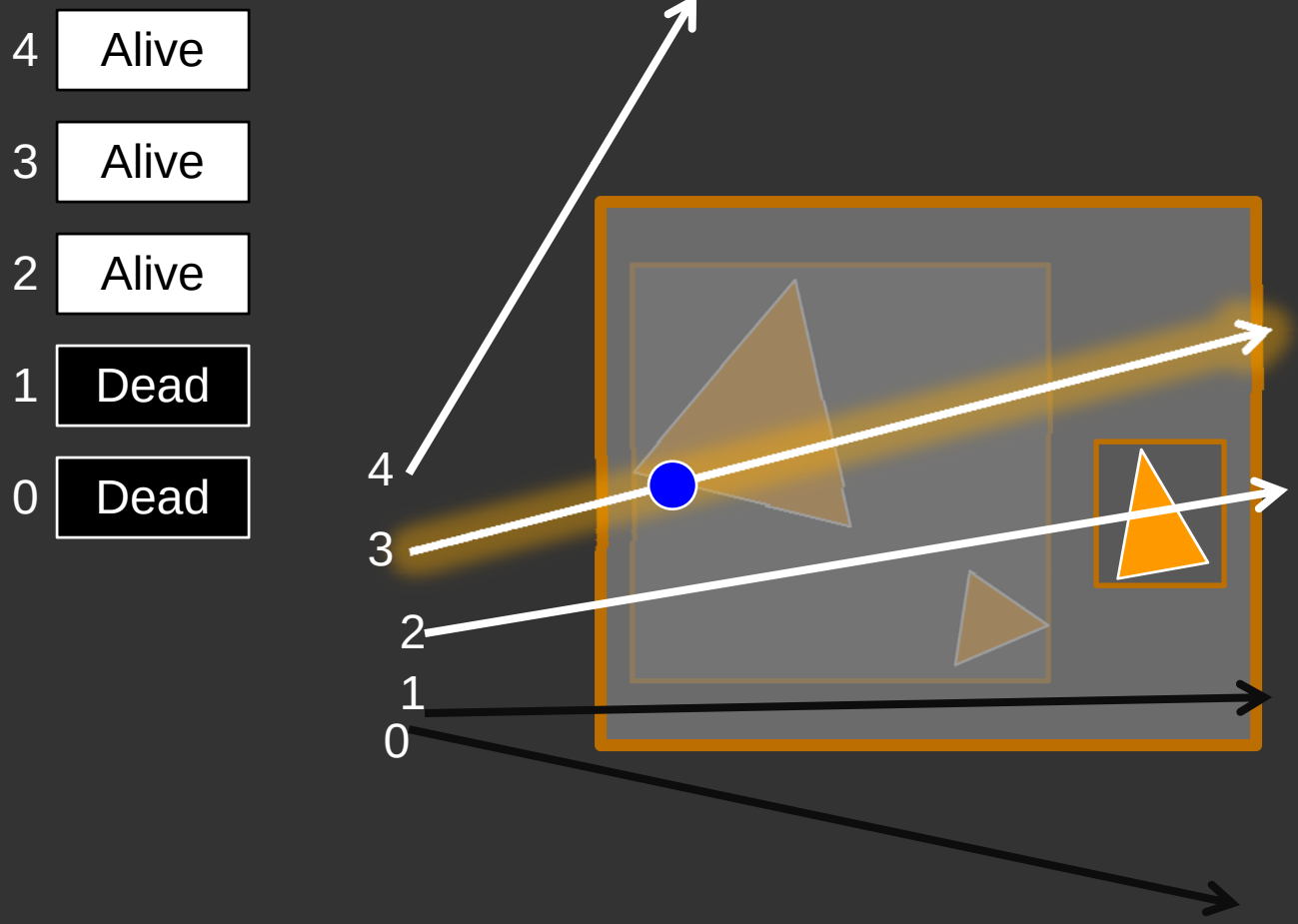

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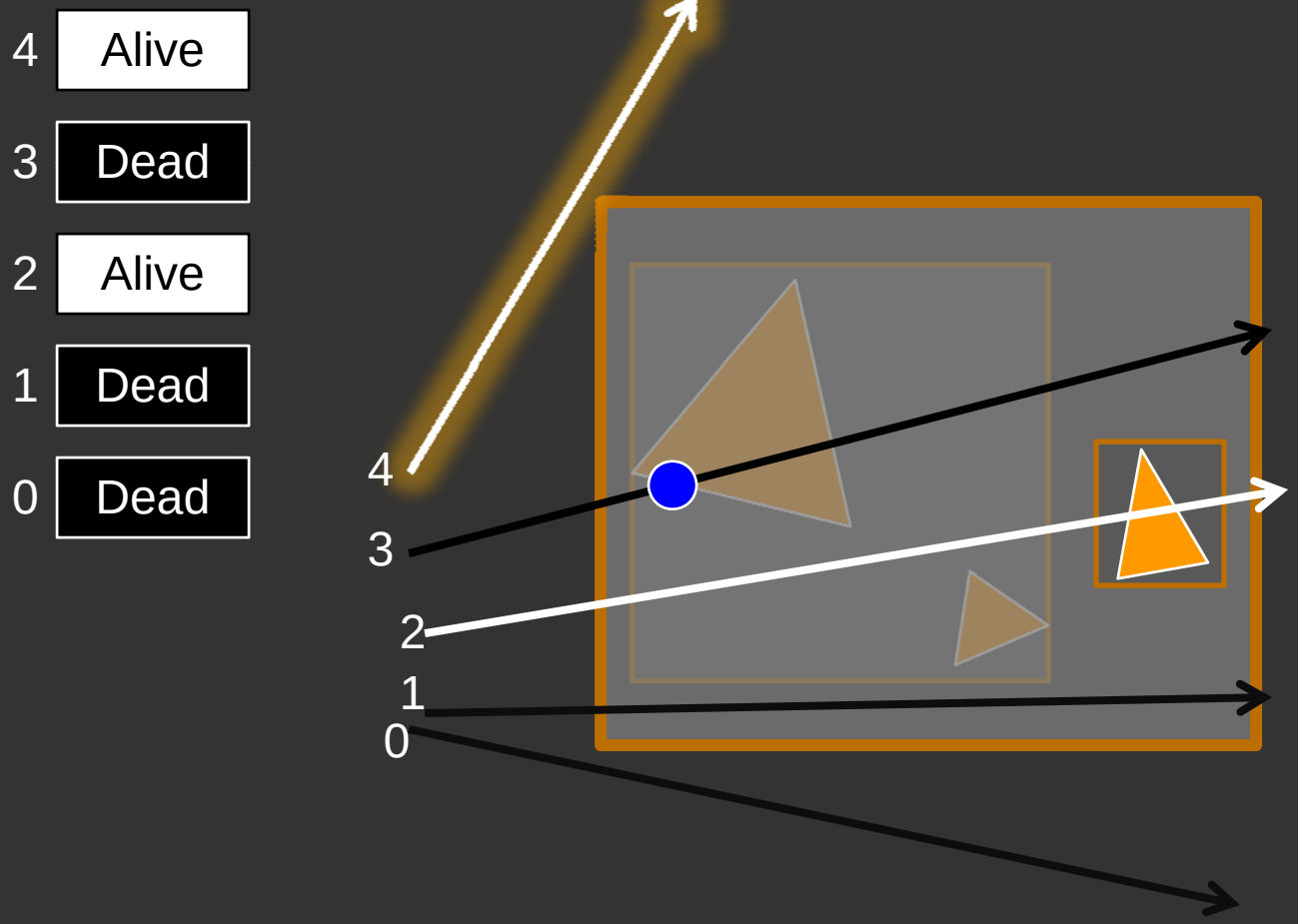
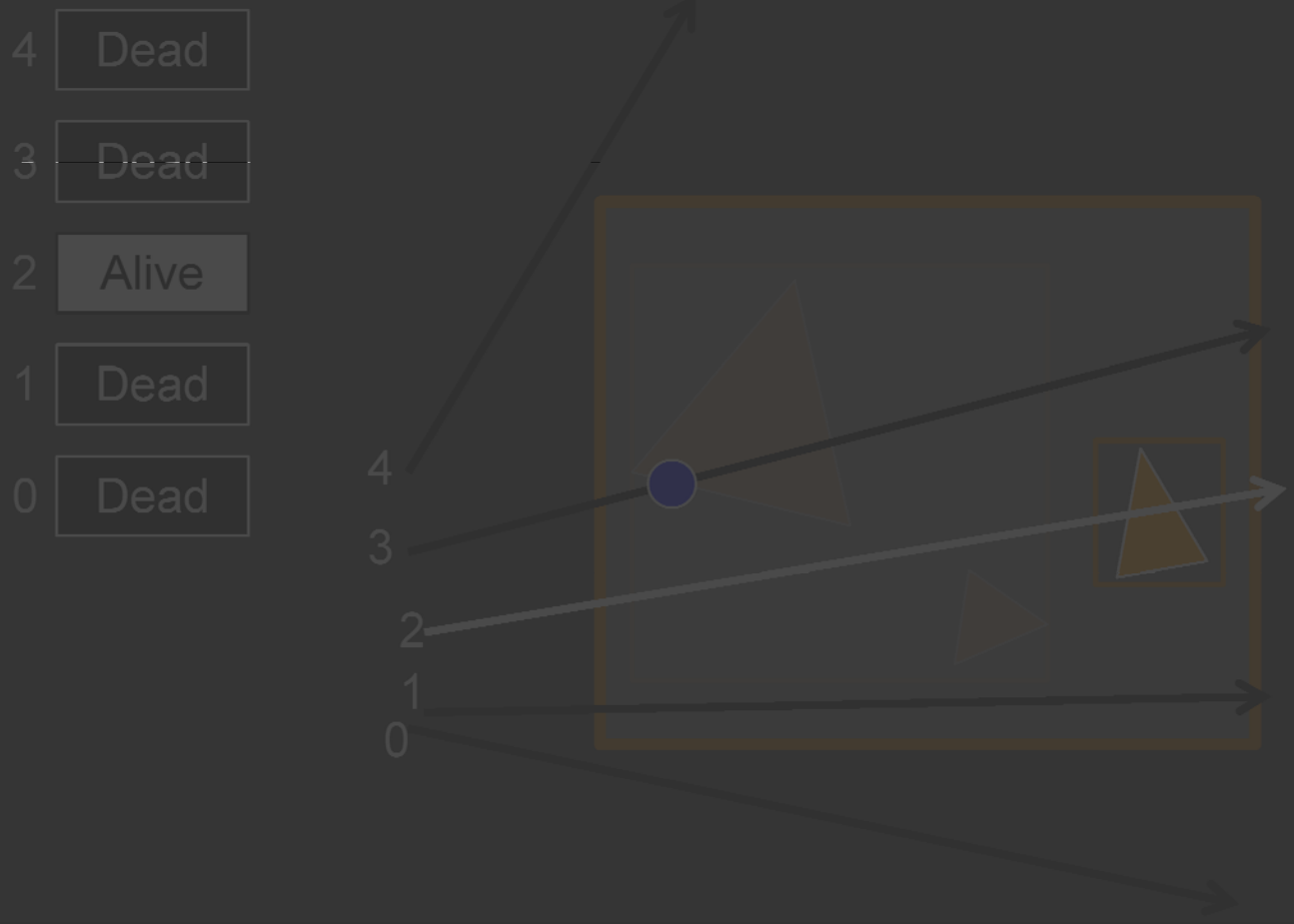
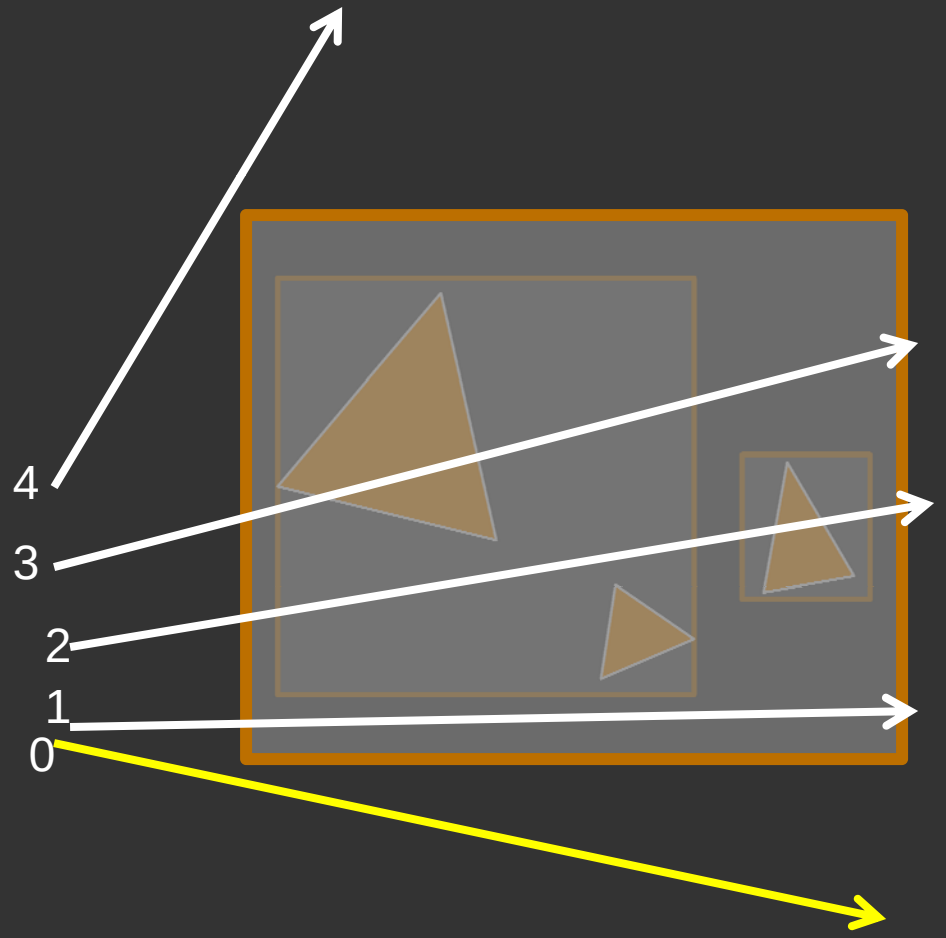


Masked Traversal

- Causes extra ray—cell tests



Ranged Traversal



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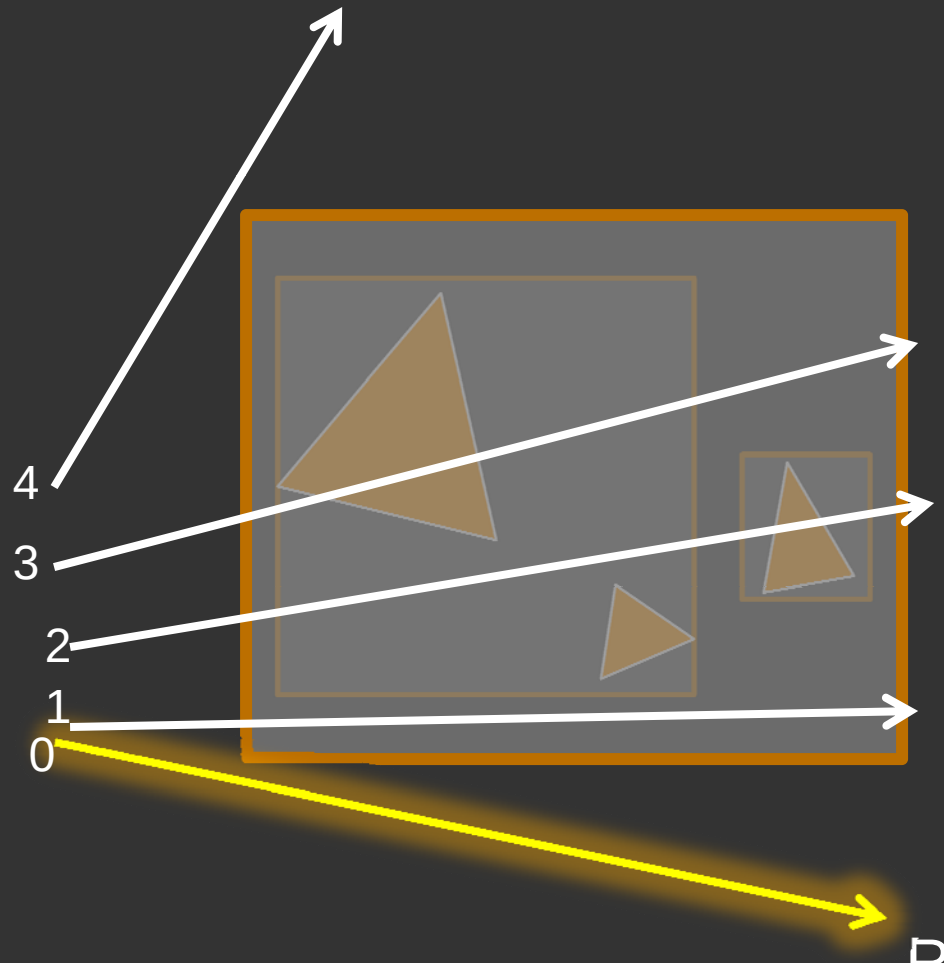

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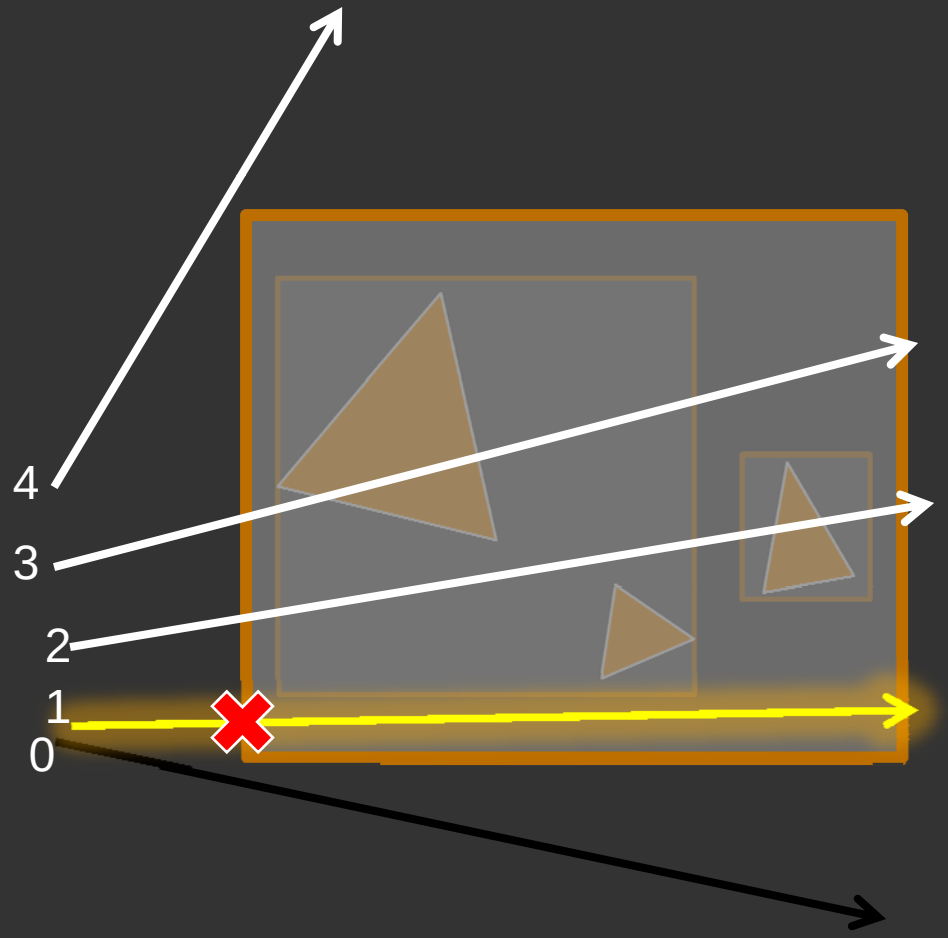

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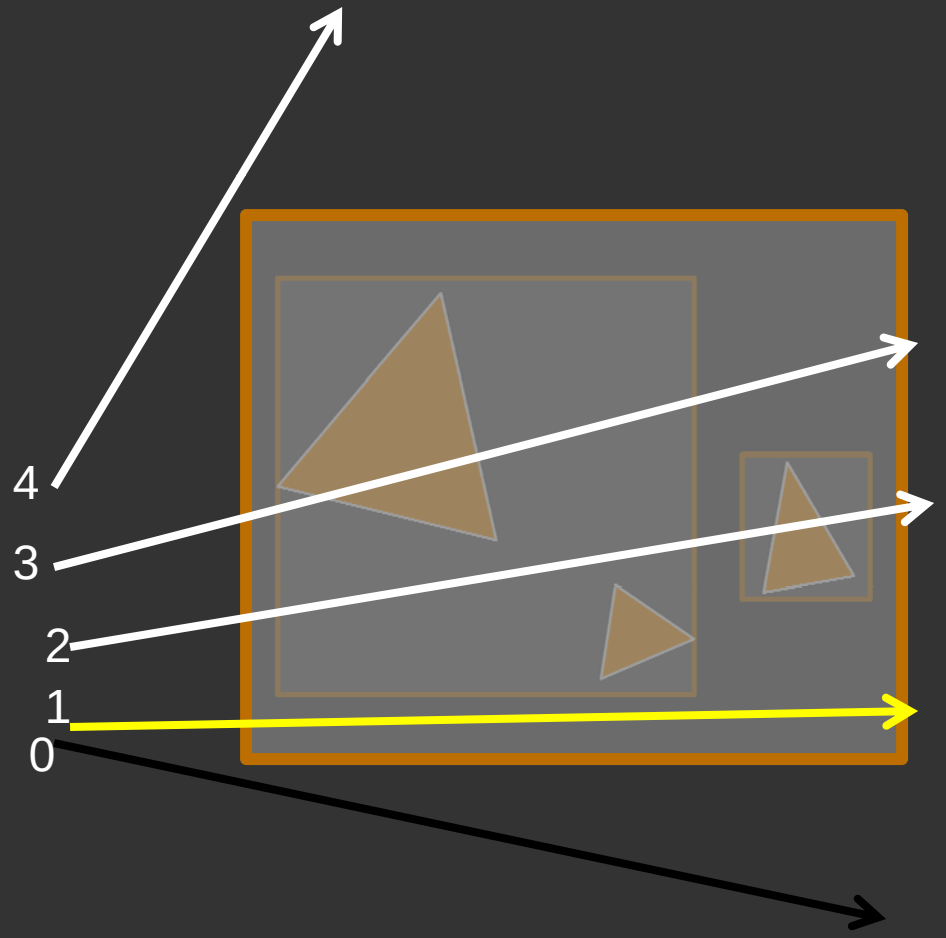

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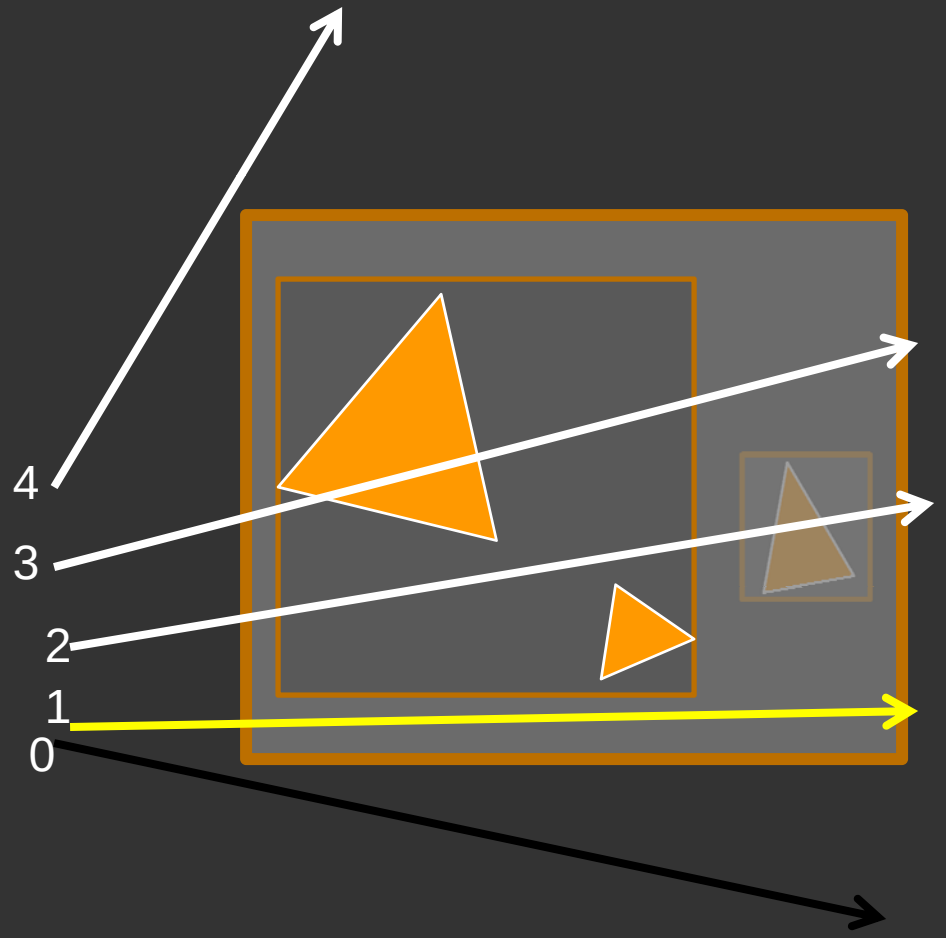

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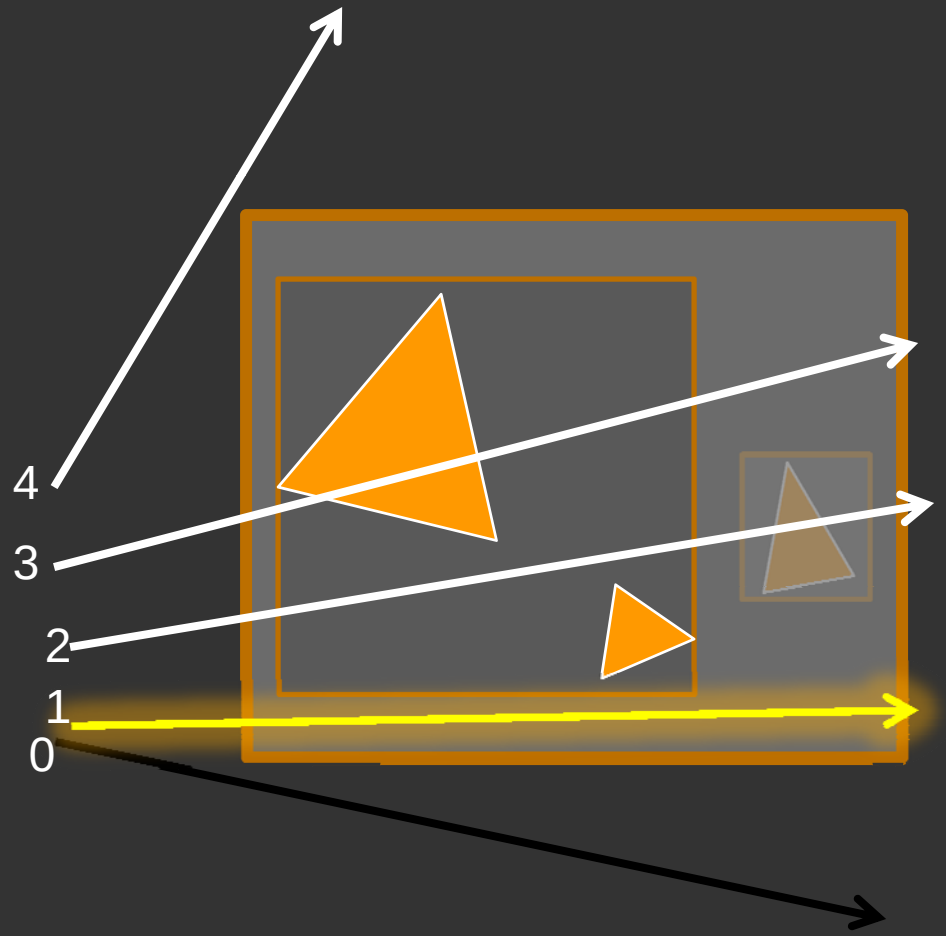

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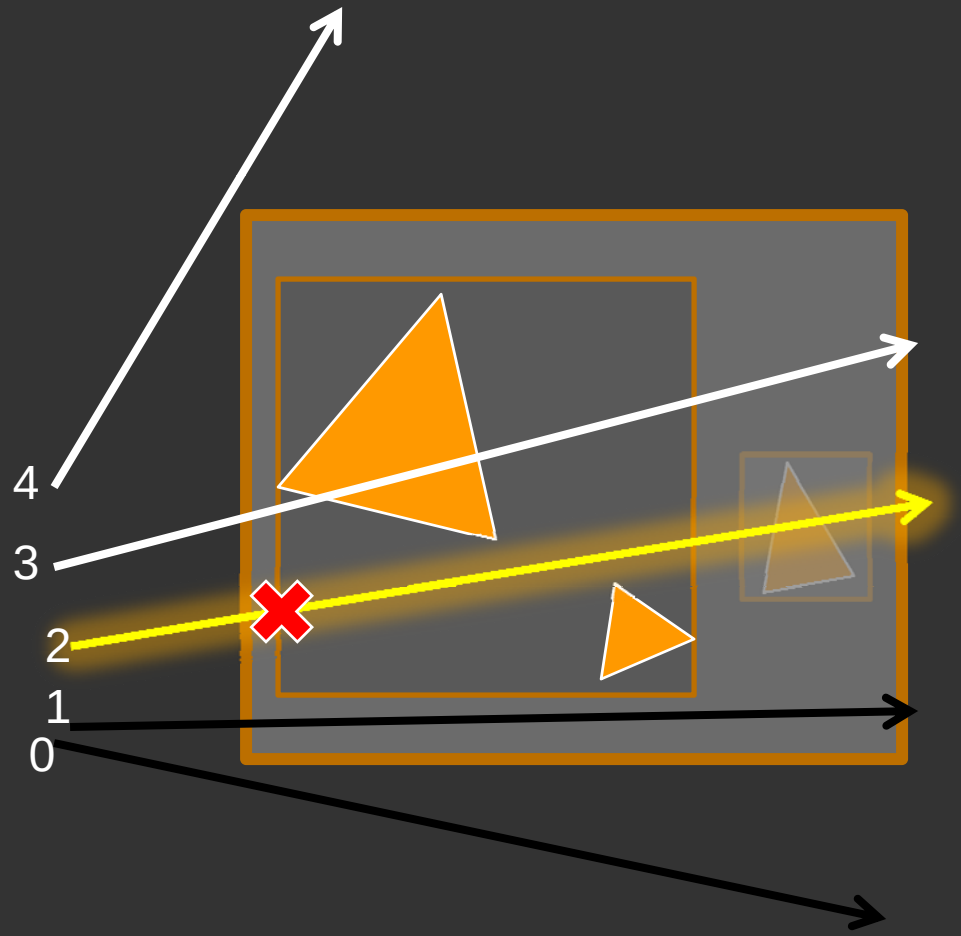

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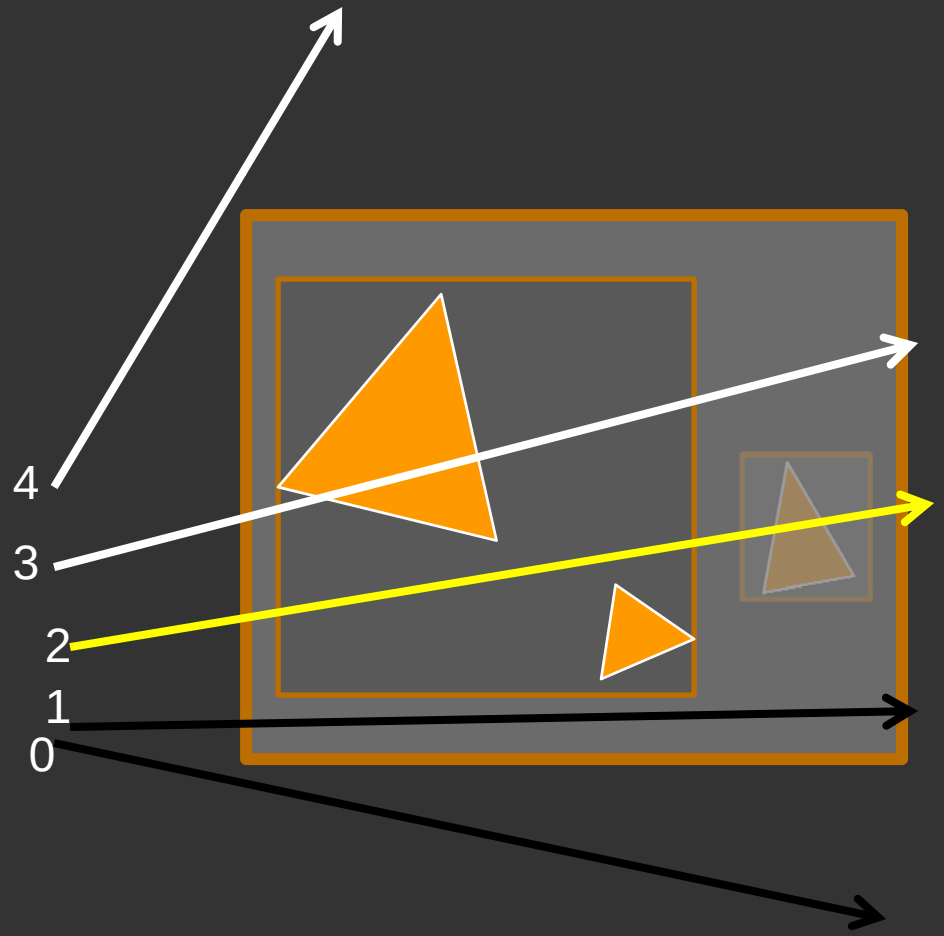

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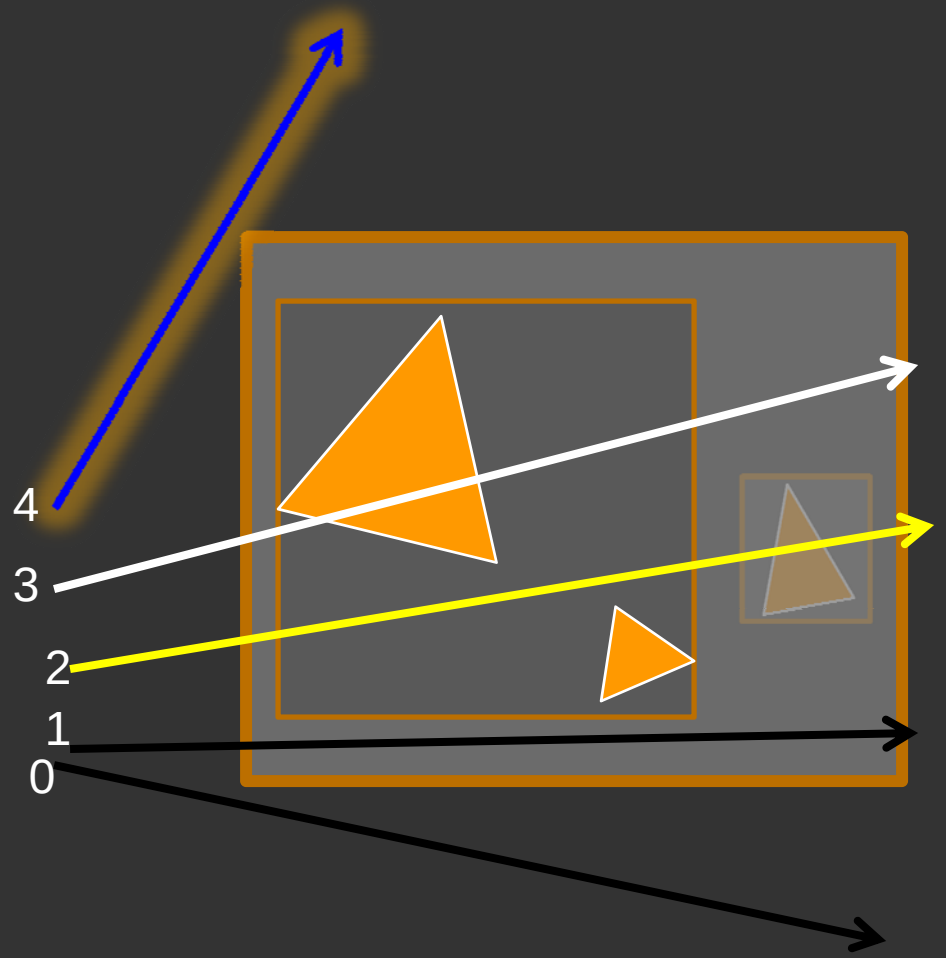

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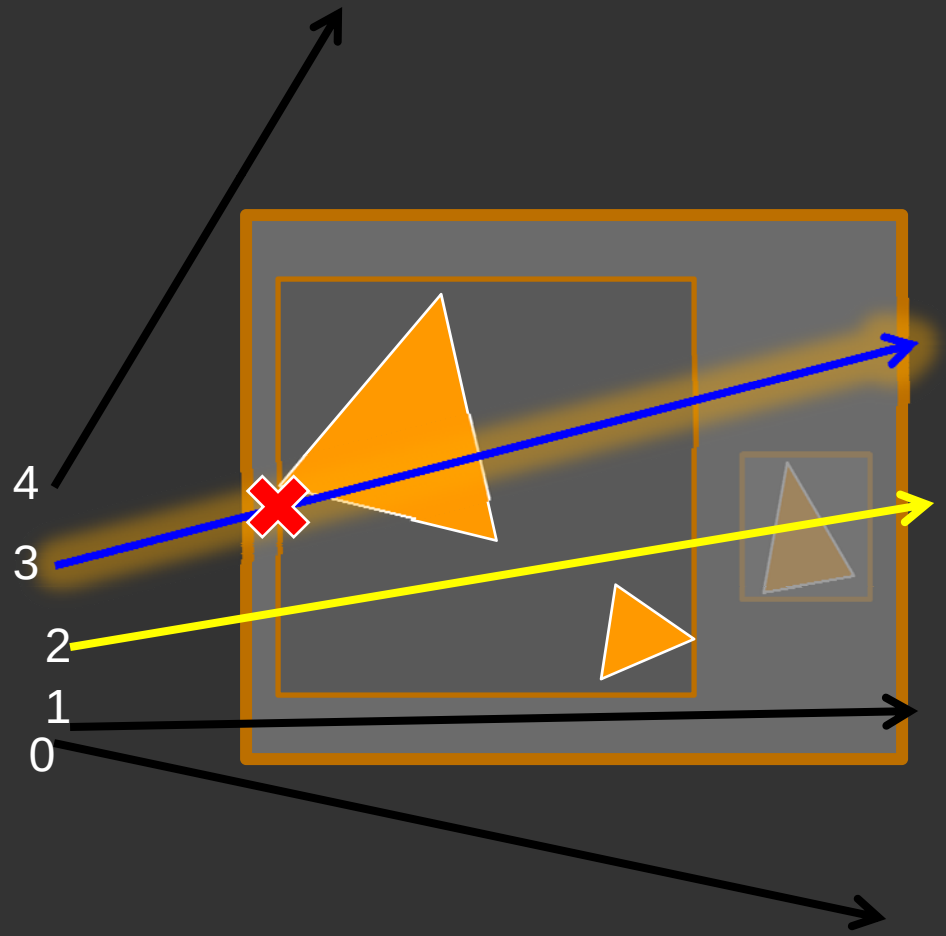

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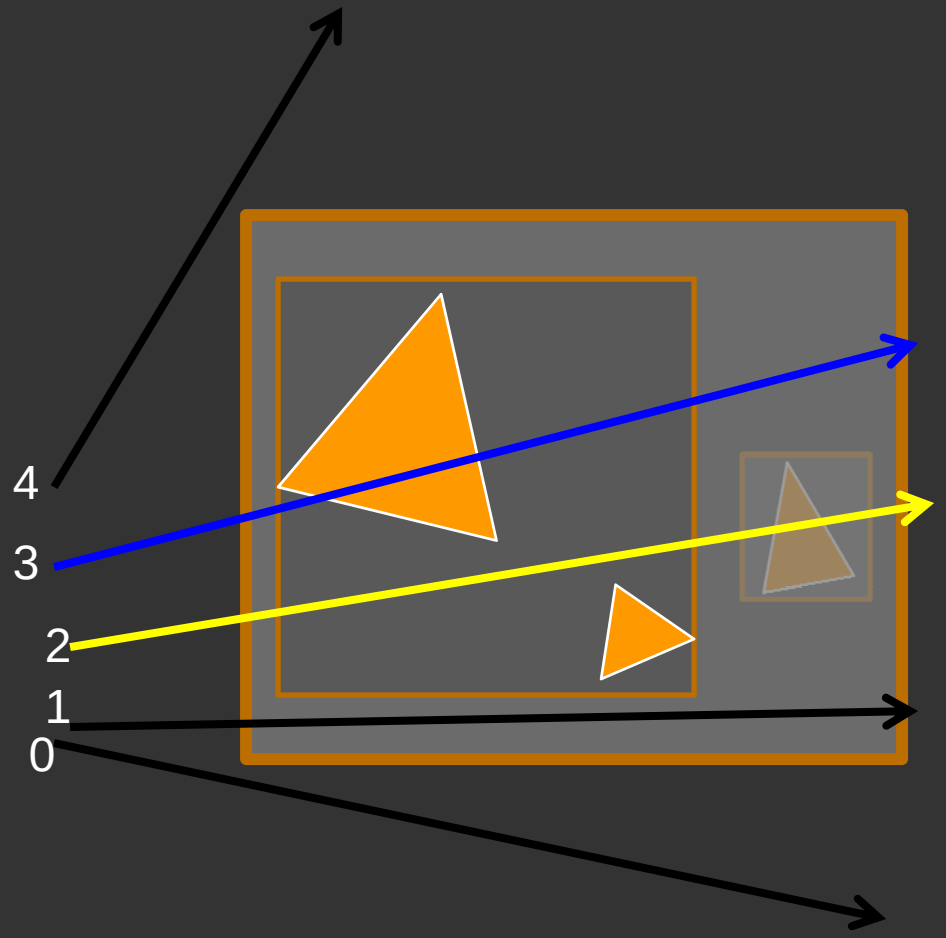

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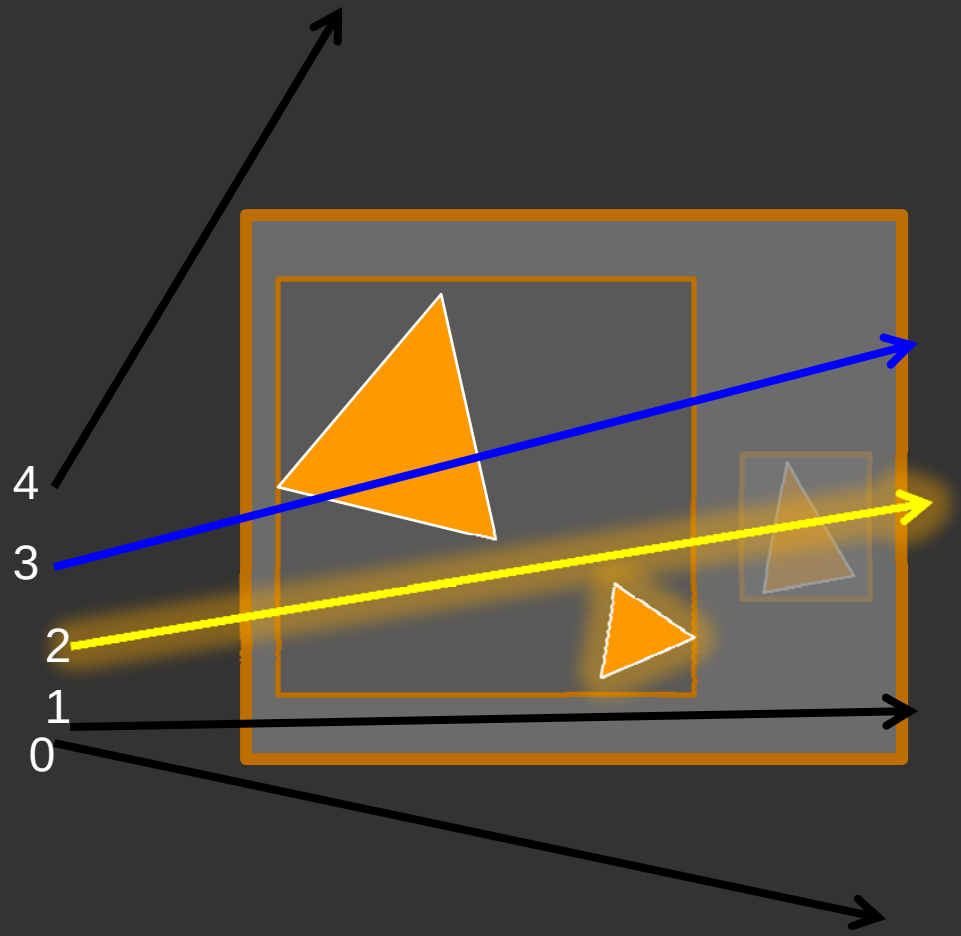
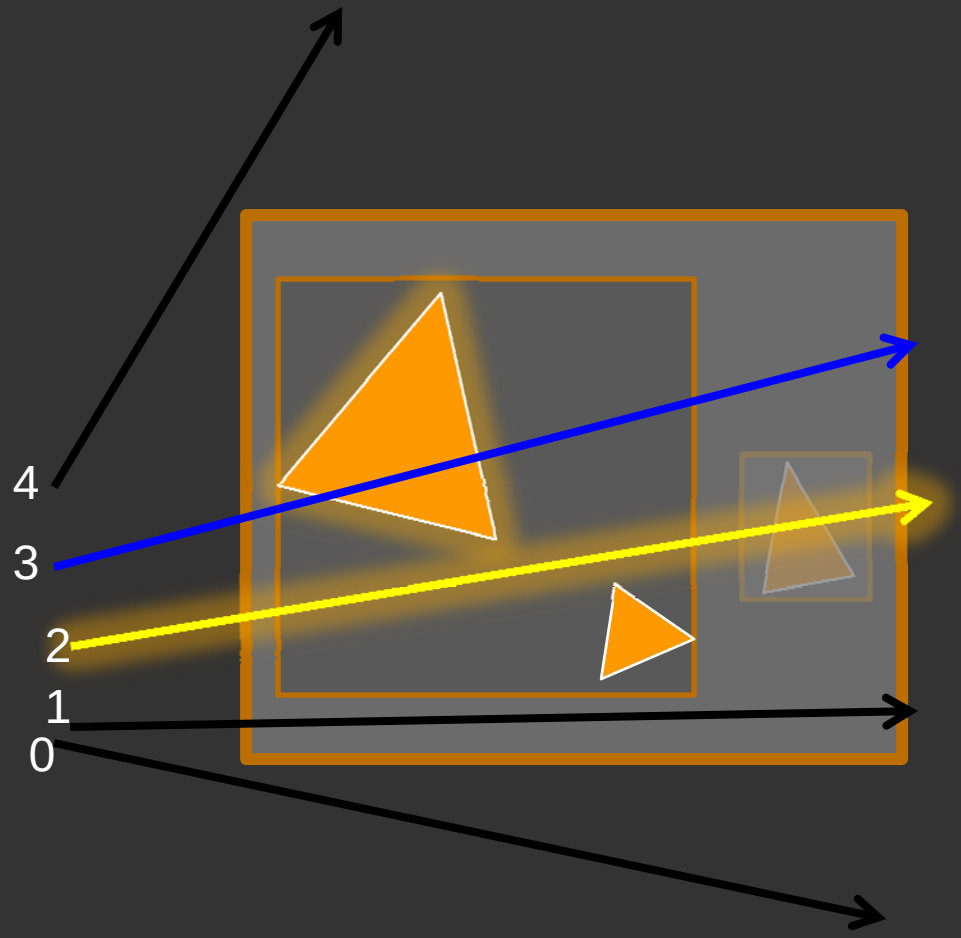
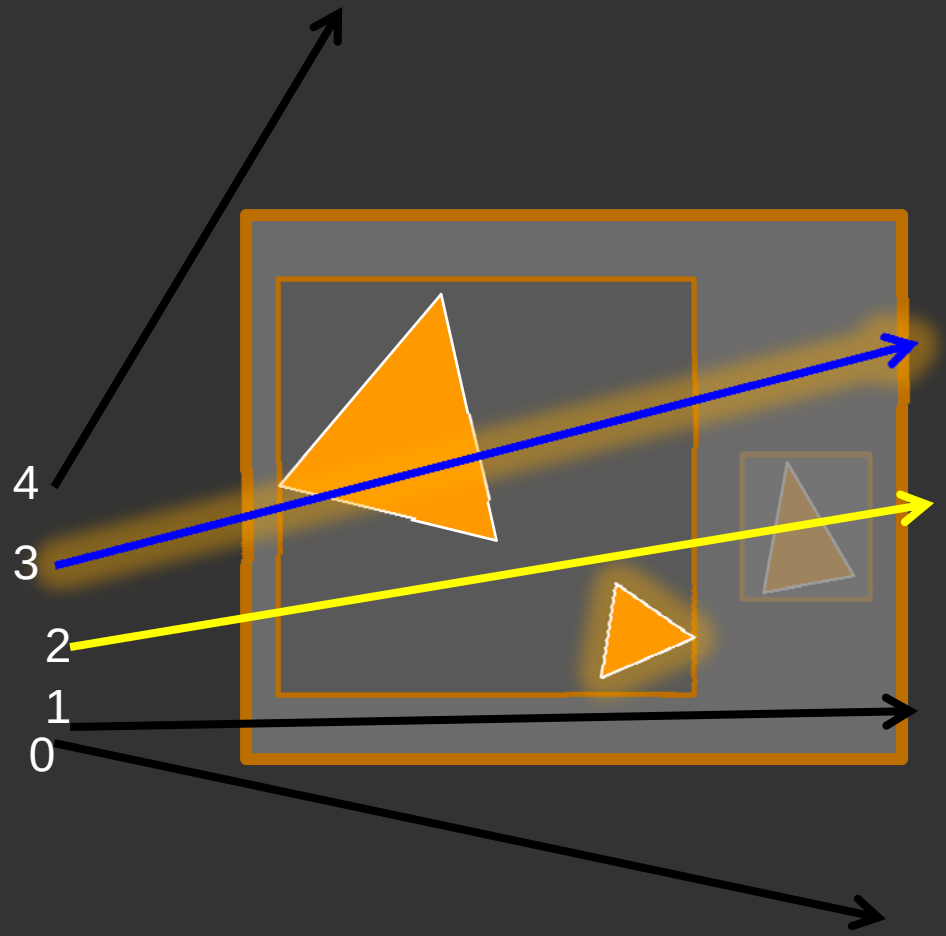


Ranged Traversal



Ranged Traversal



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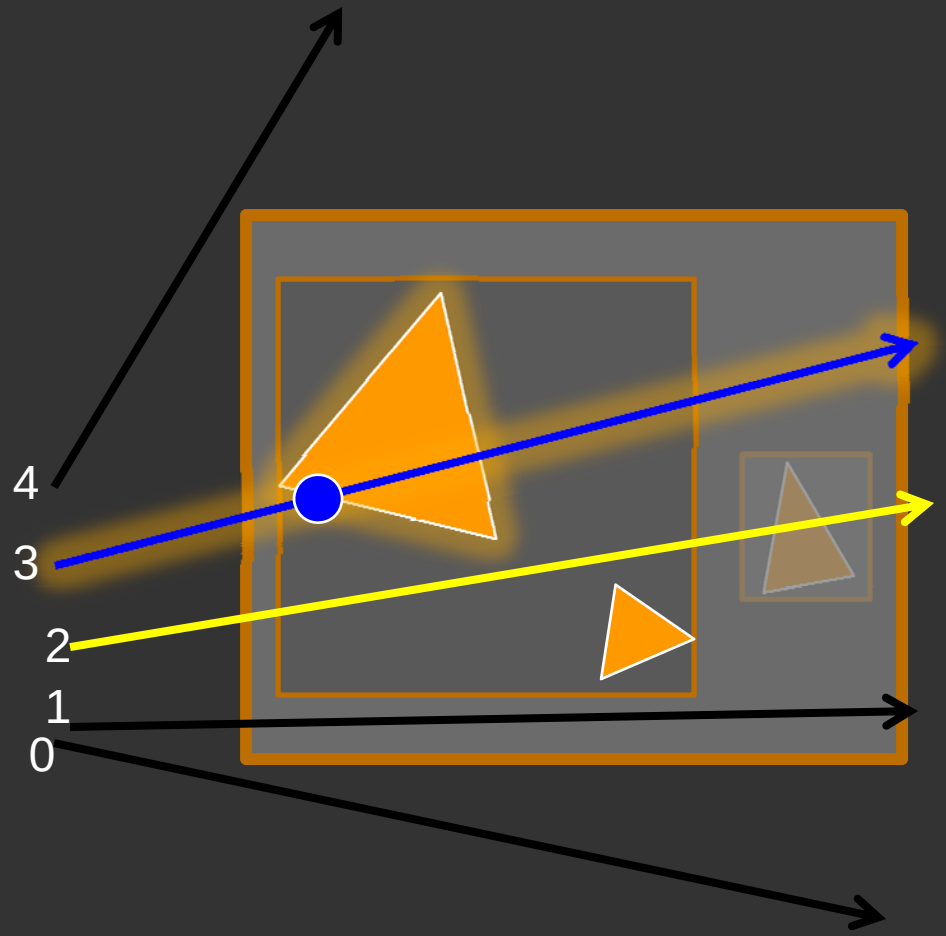

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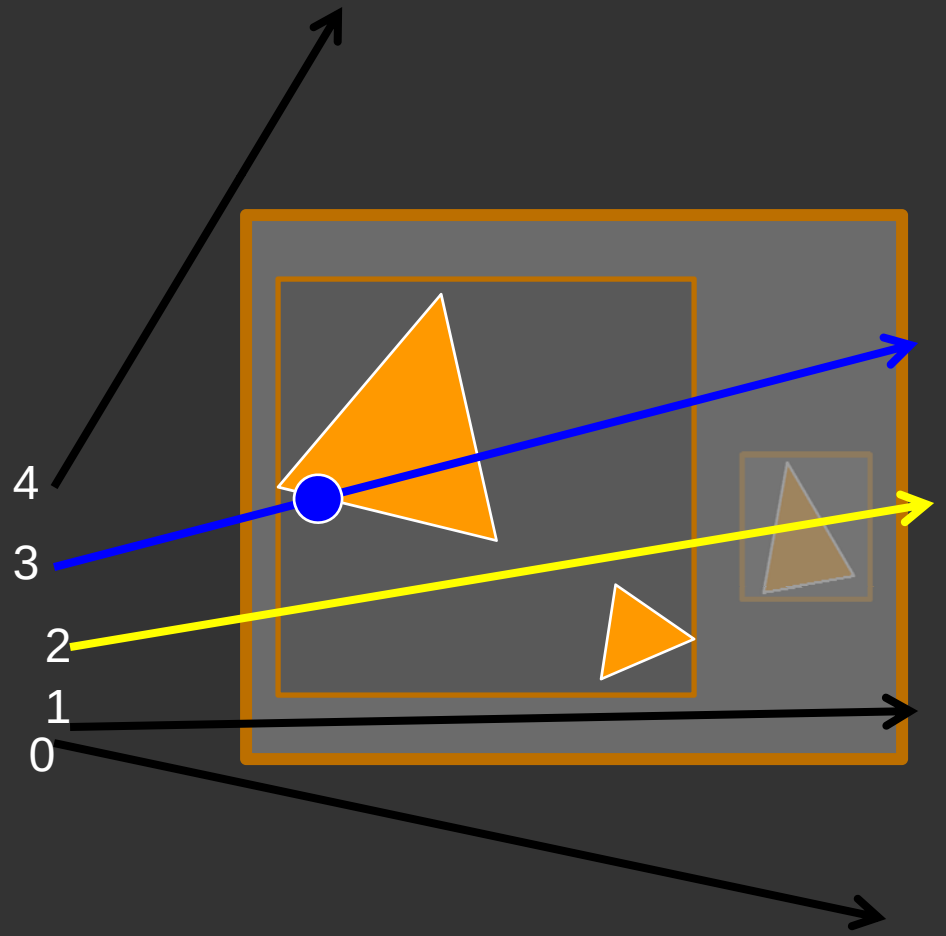

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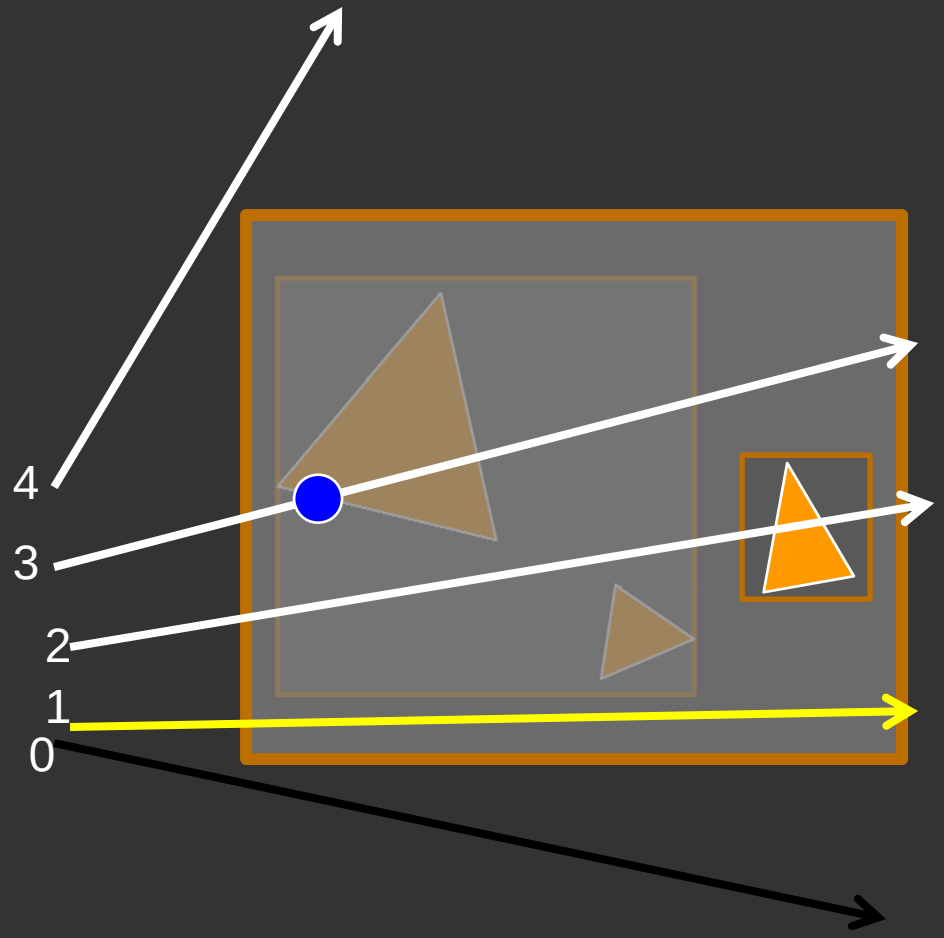

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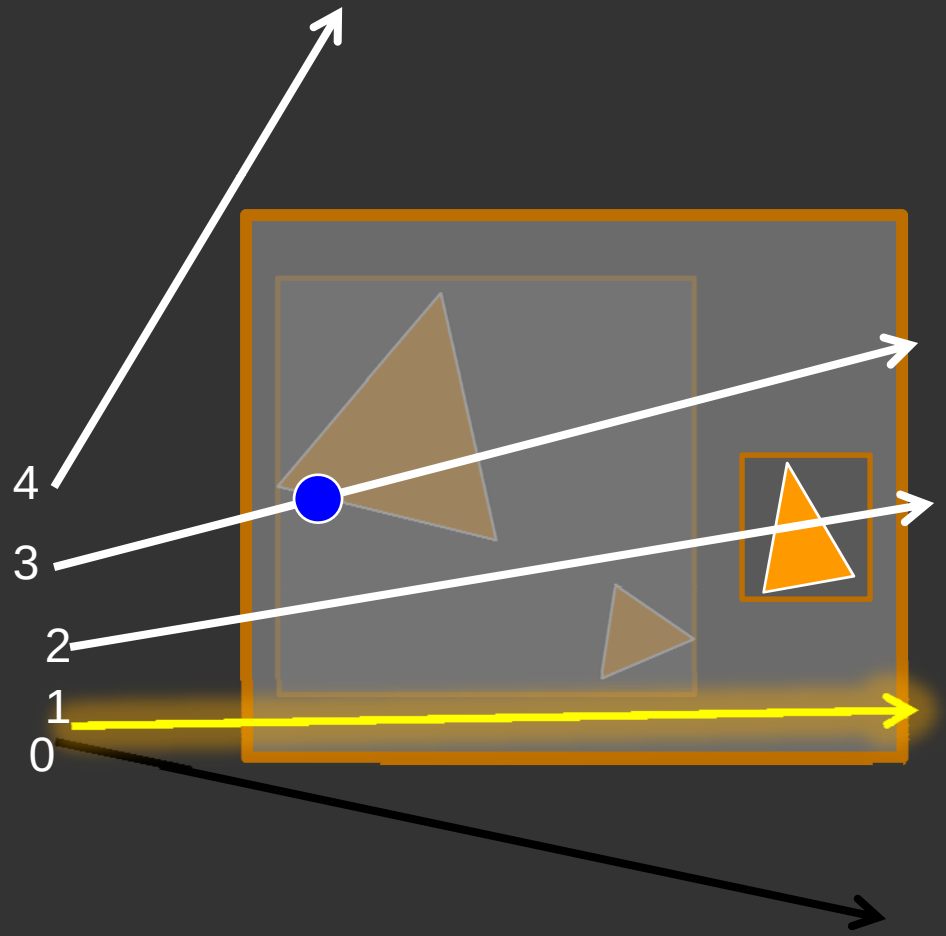

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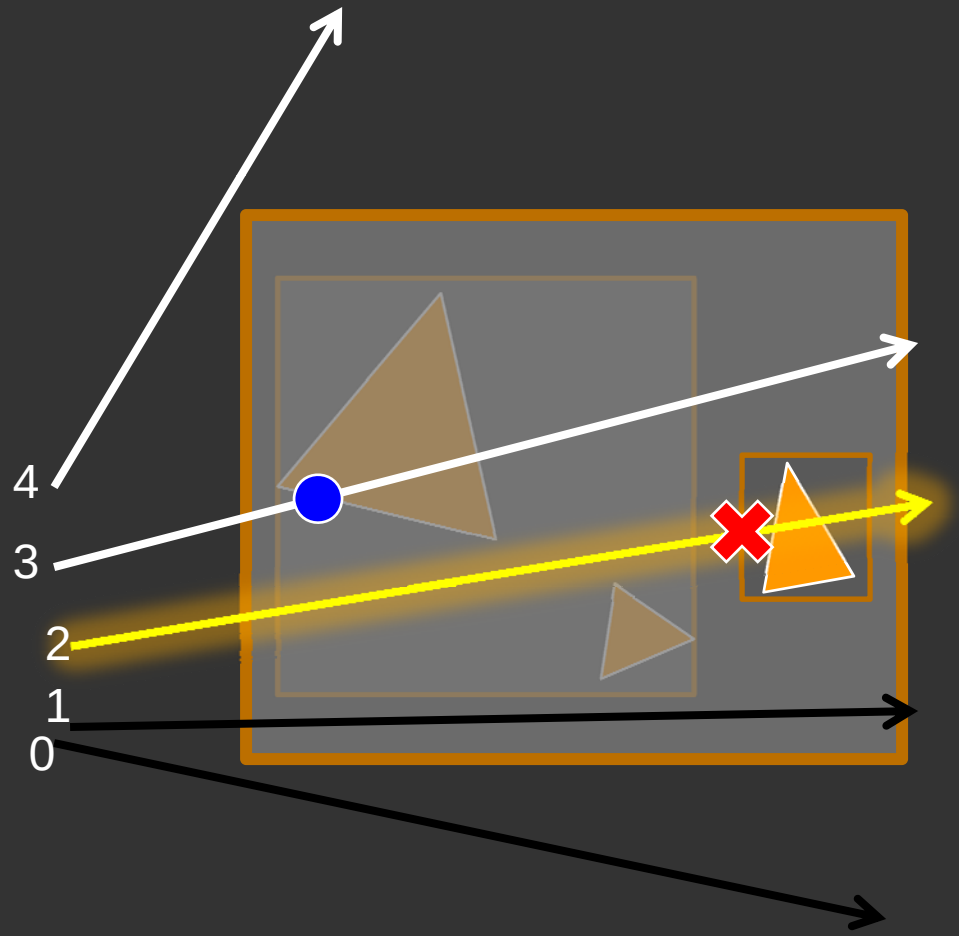

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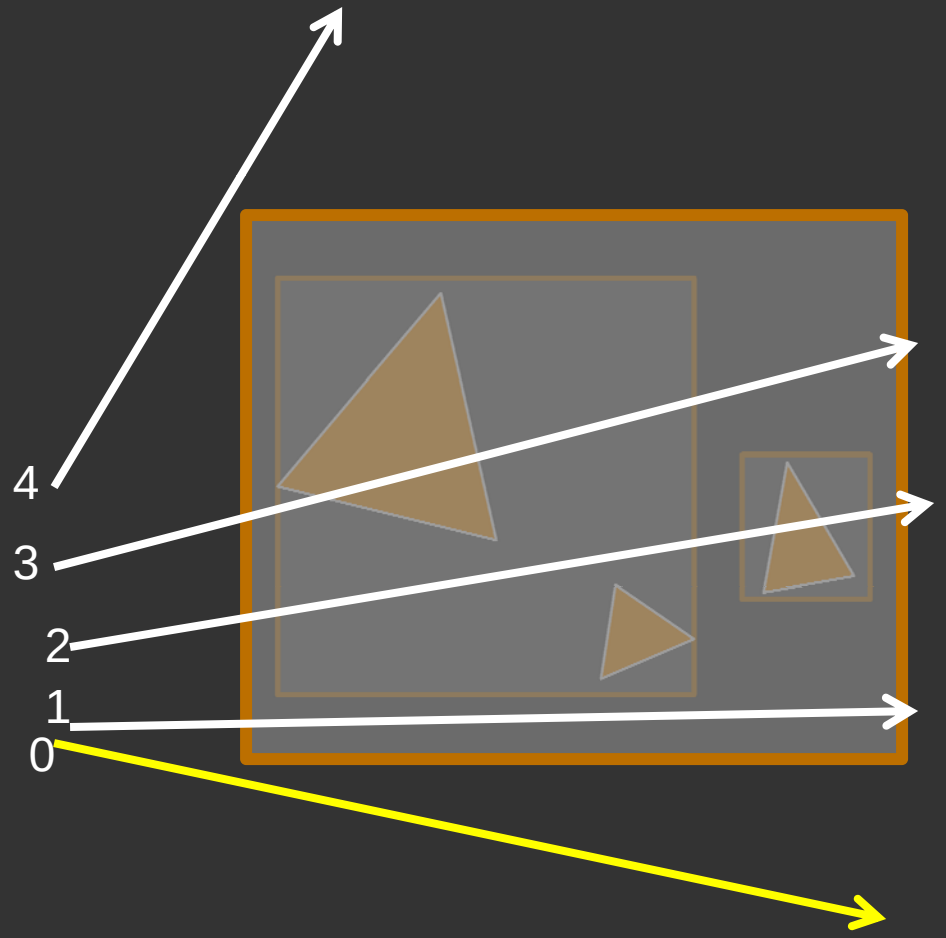

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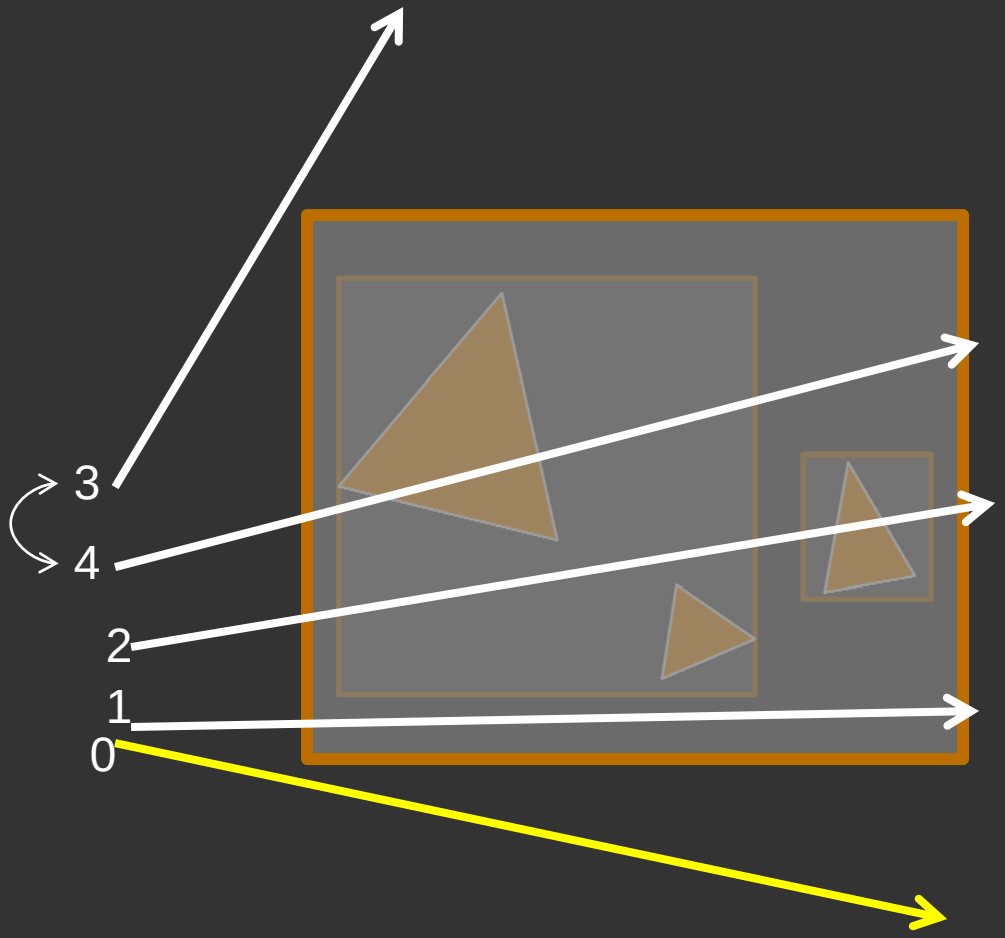

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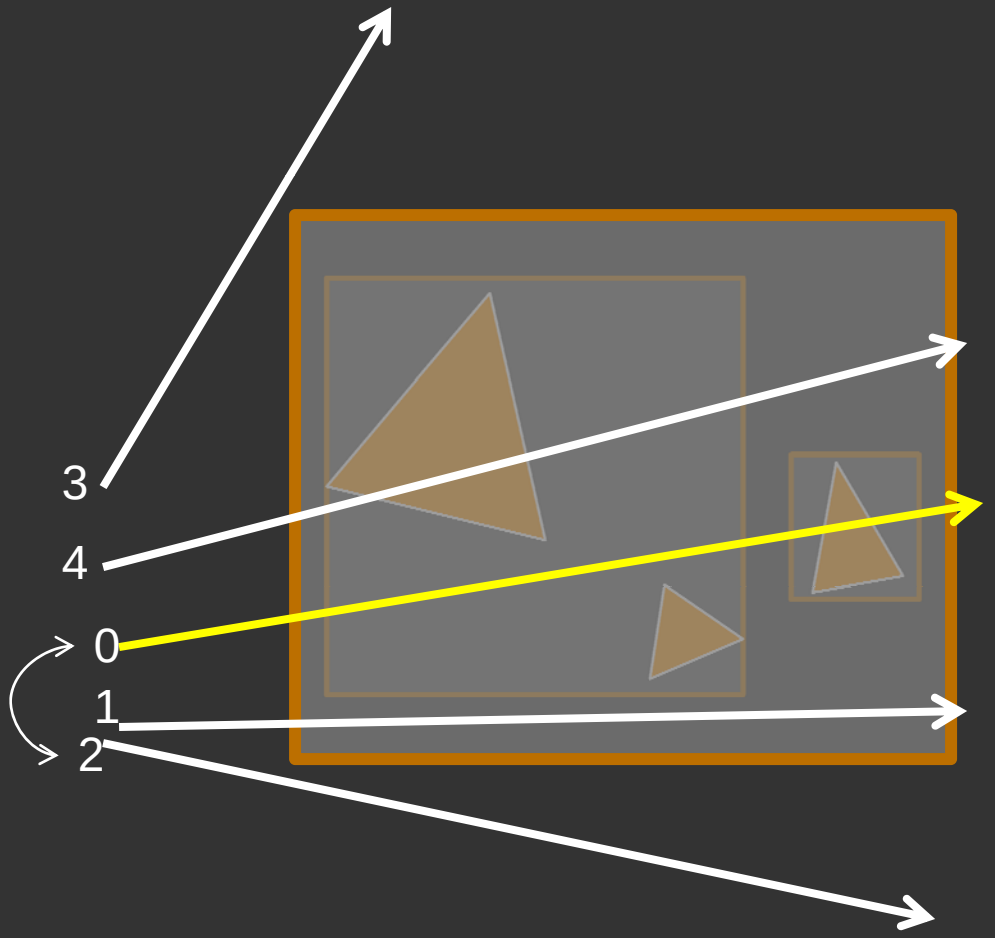

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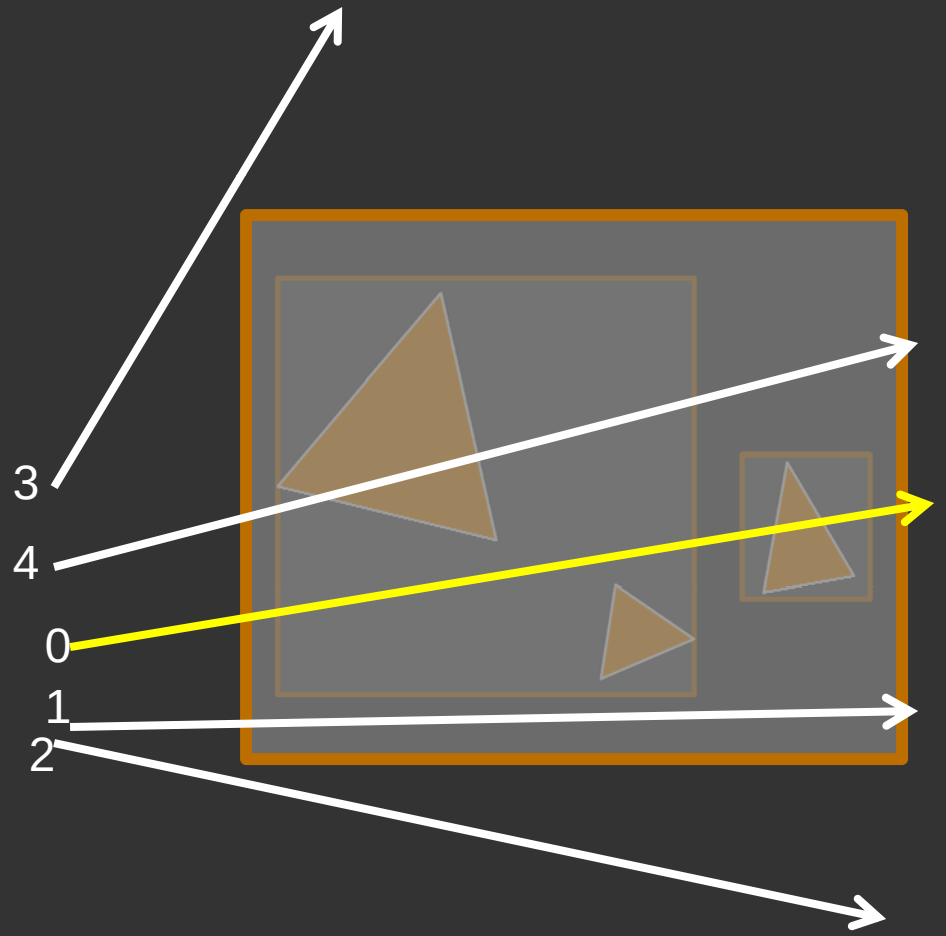

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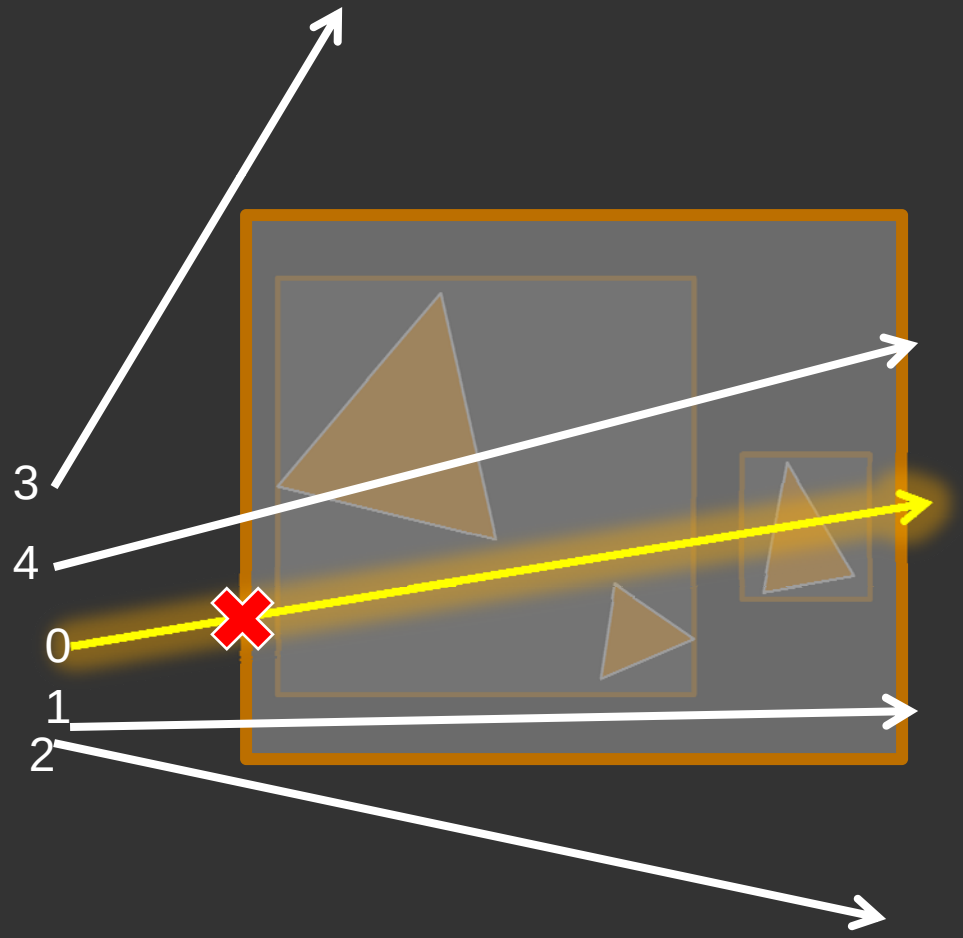

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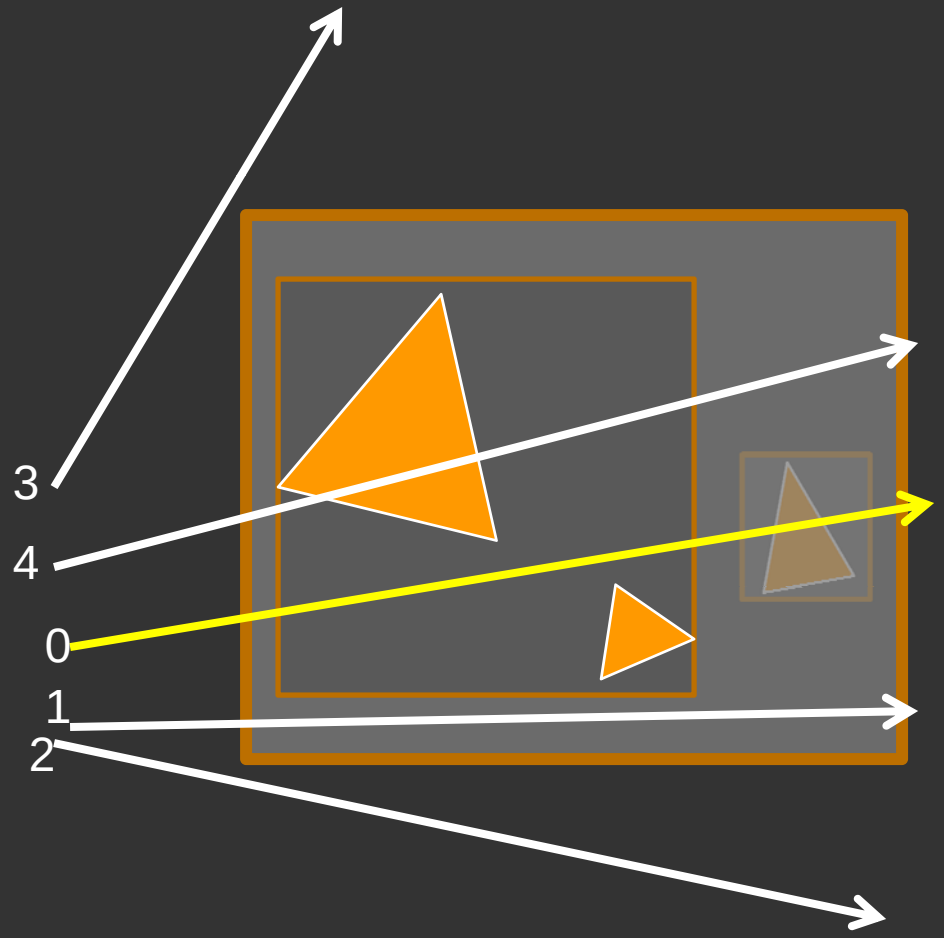

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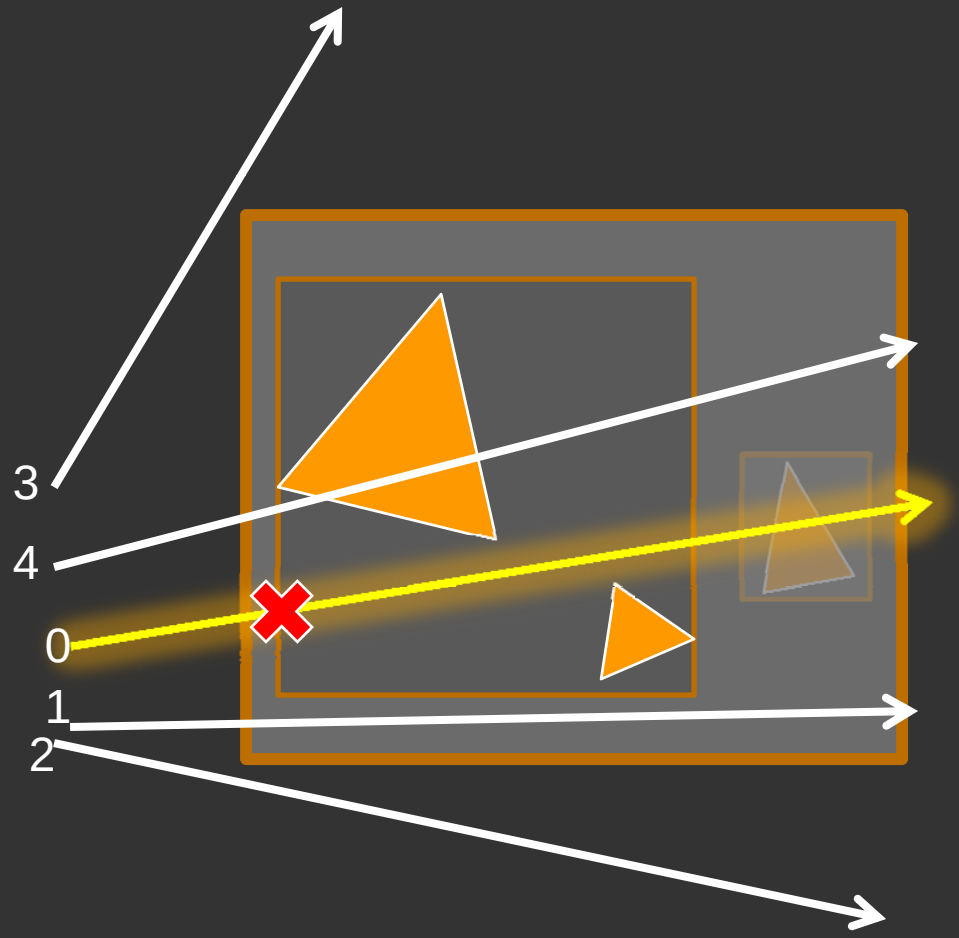

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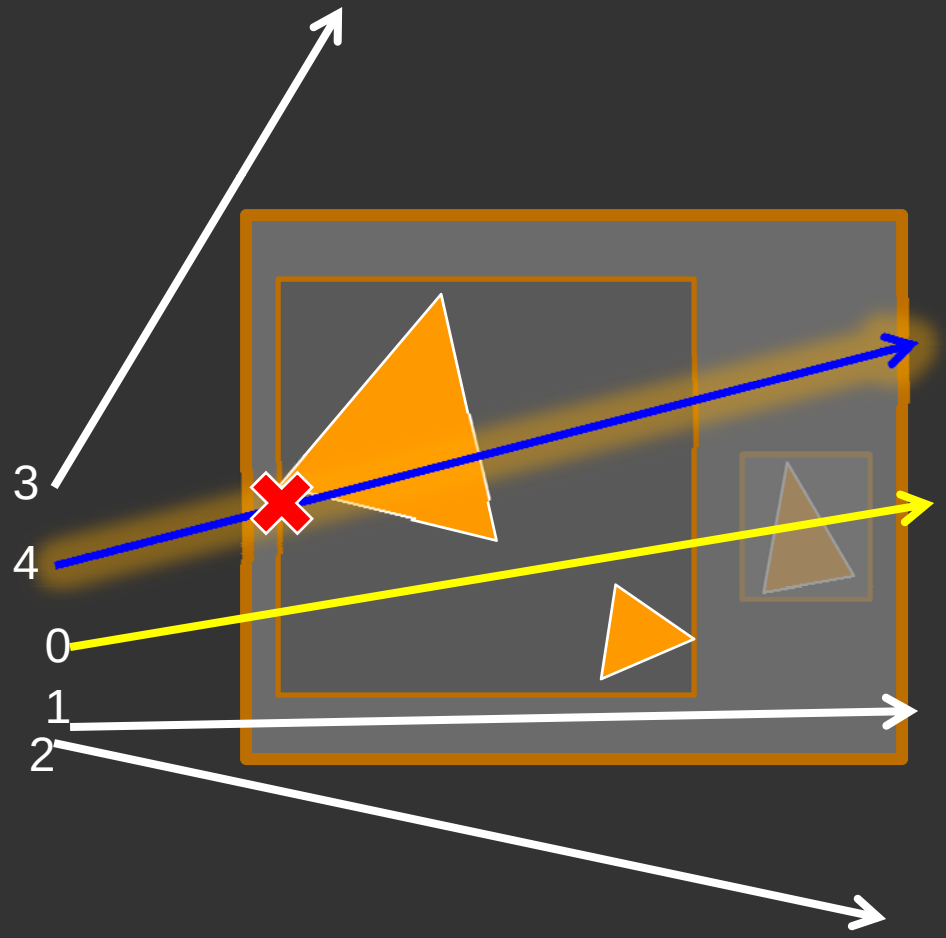

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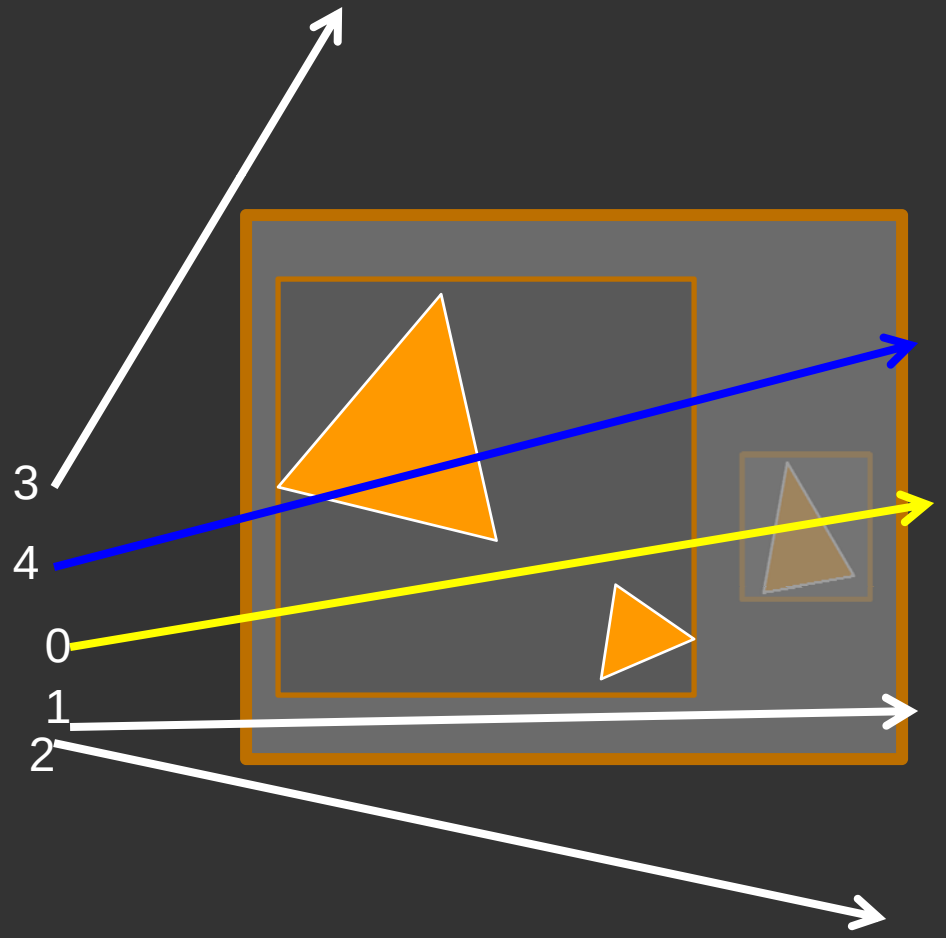

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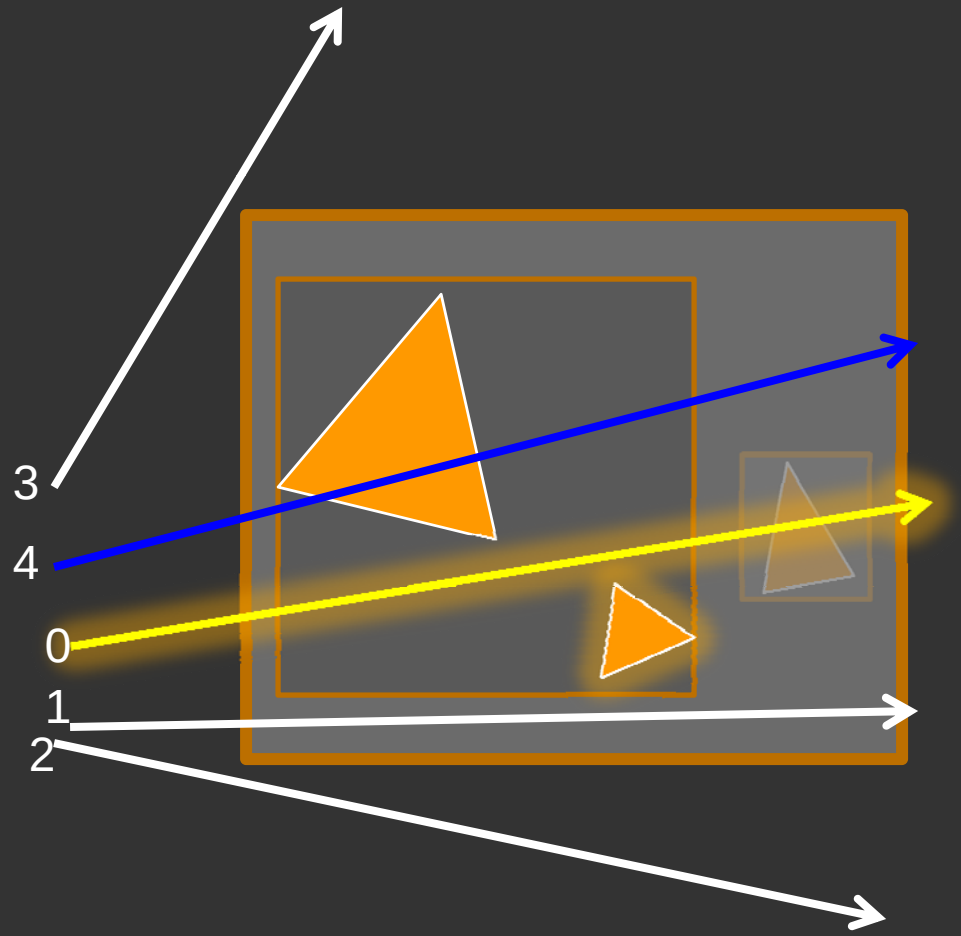

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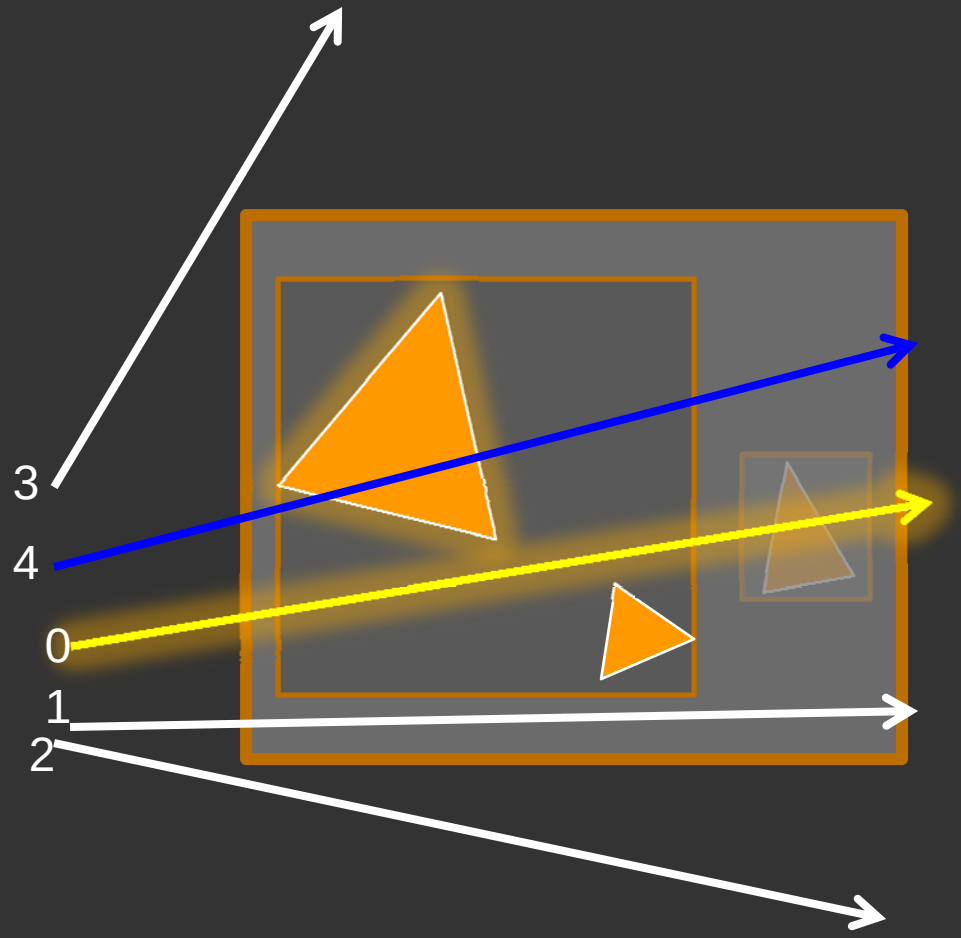

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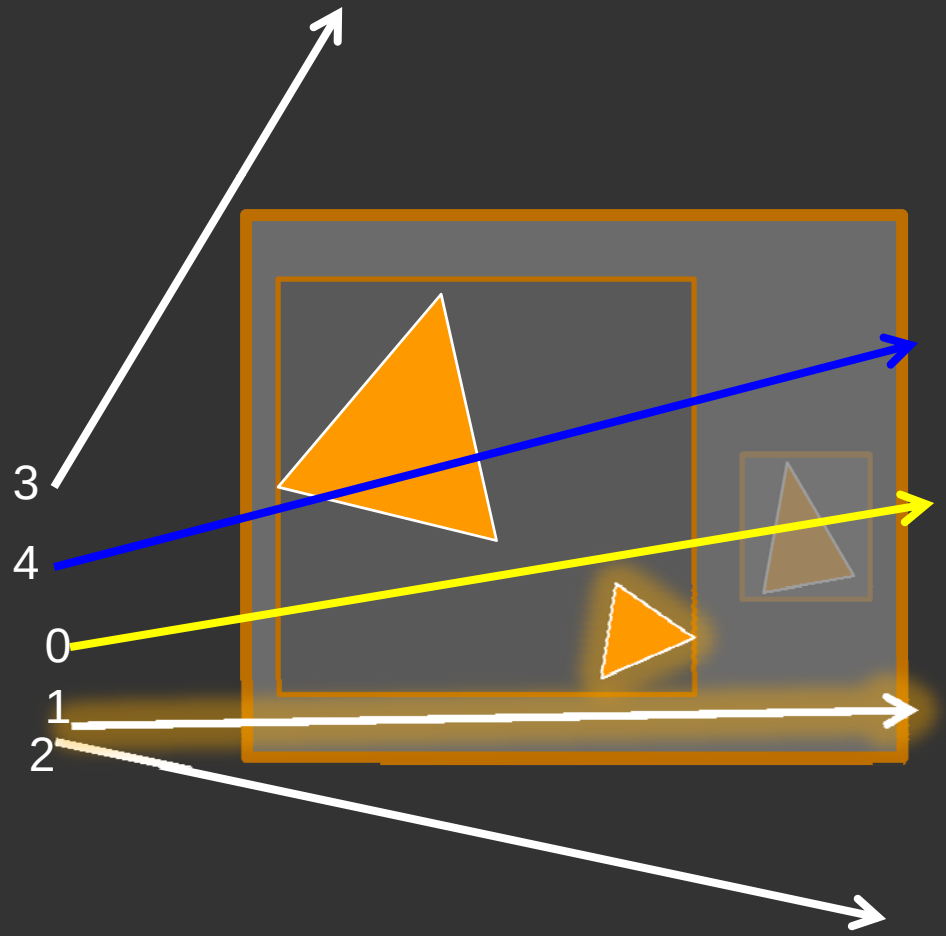

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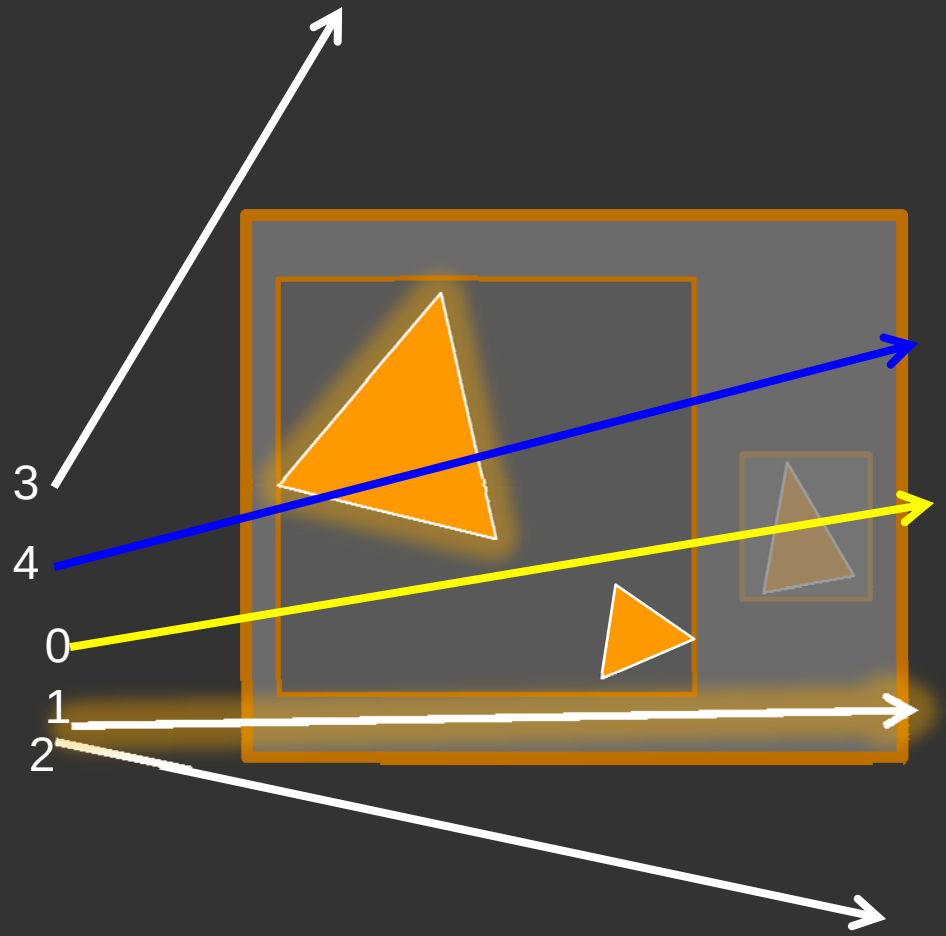

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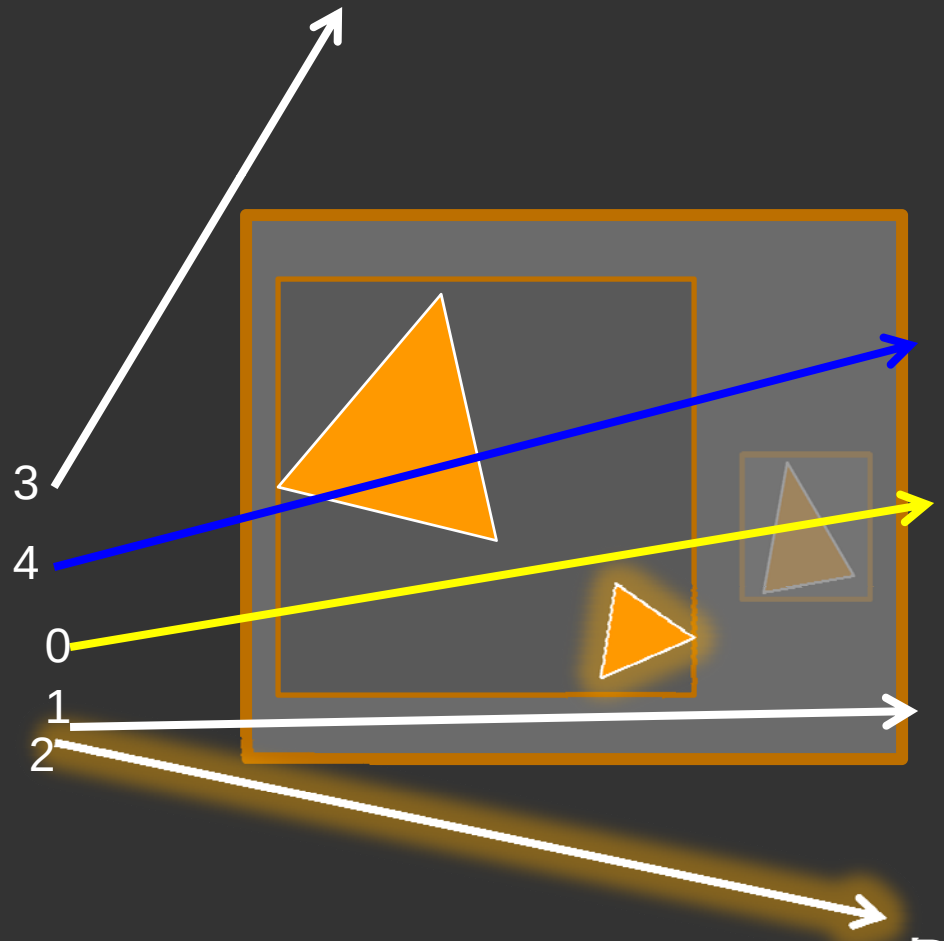

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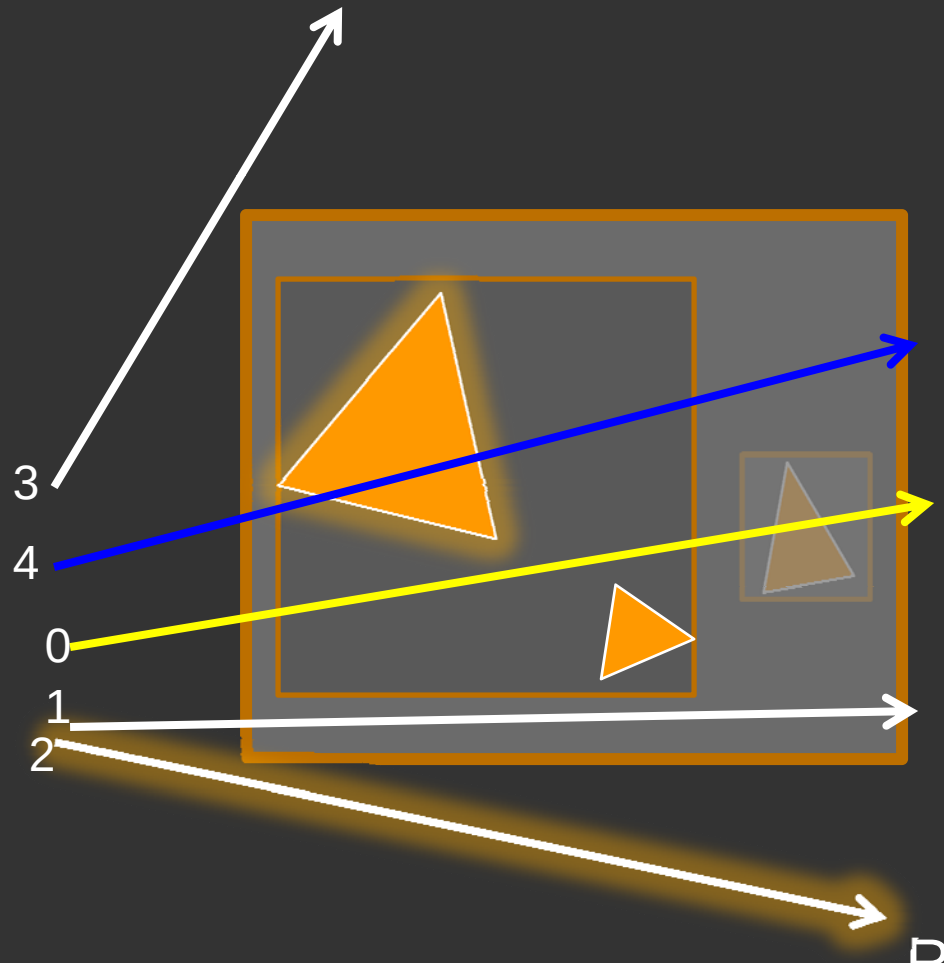

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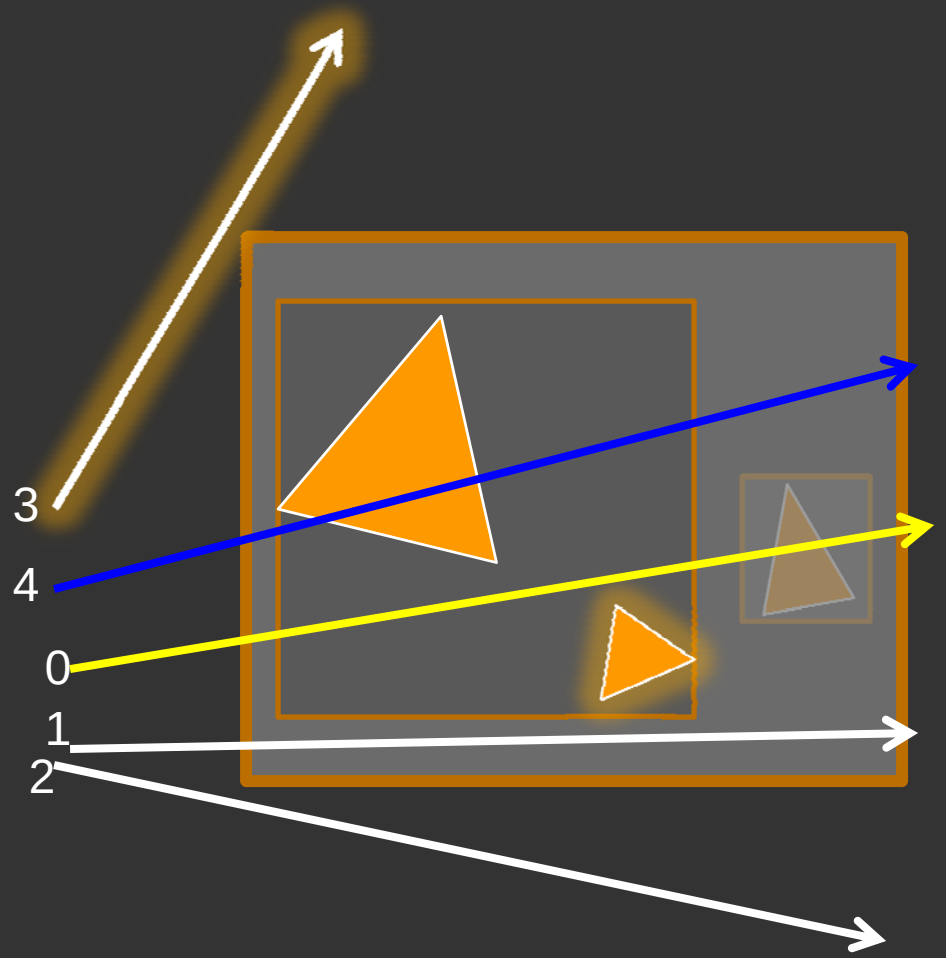

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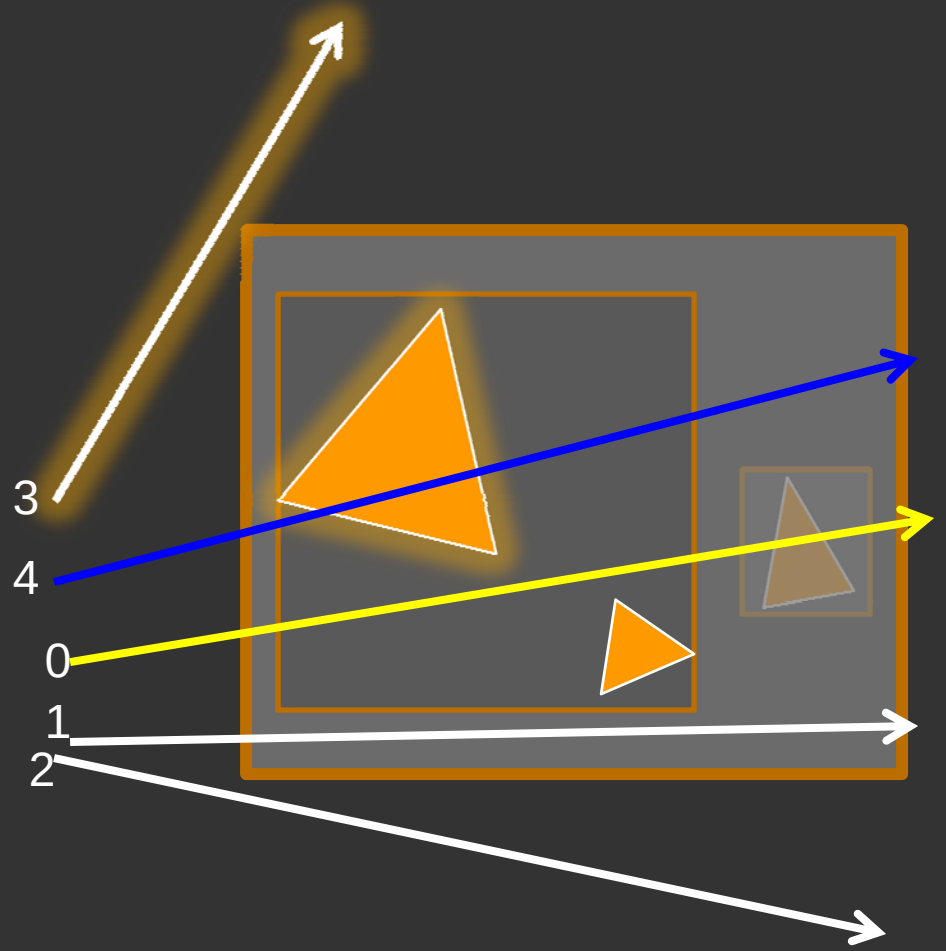

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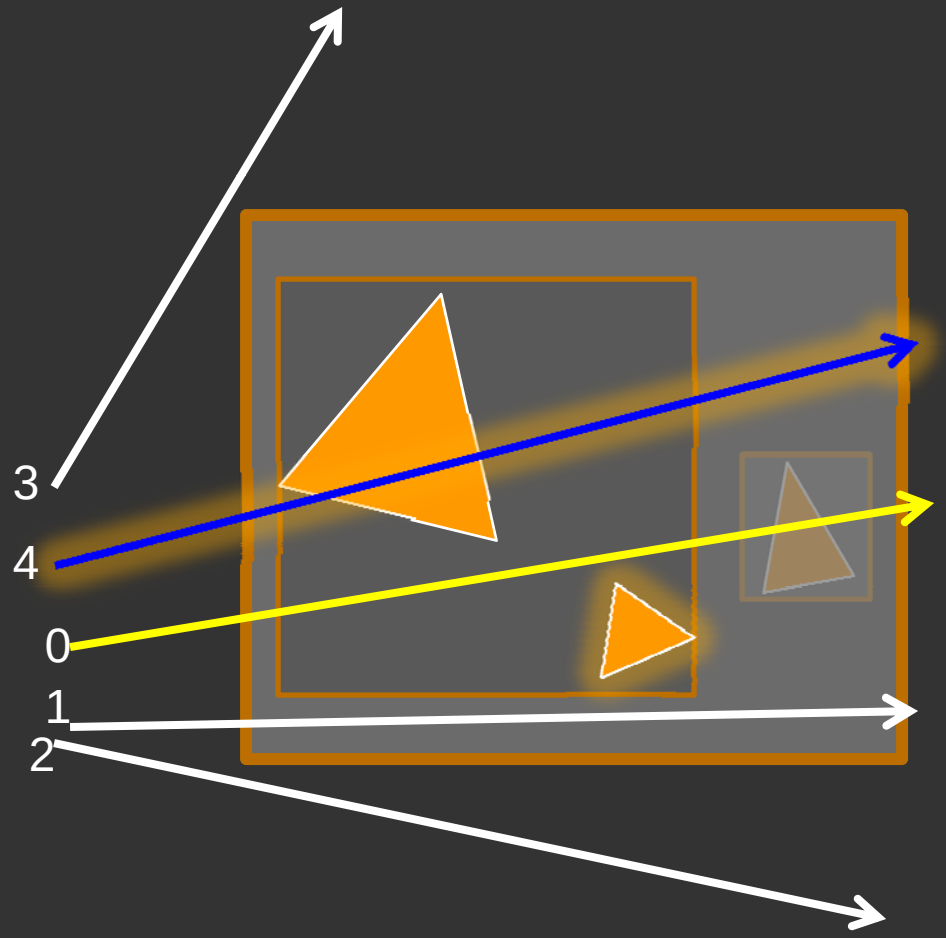
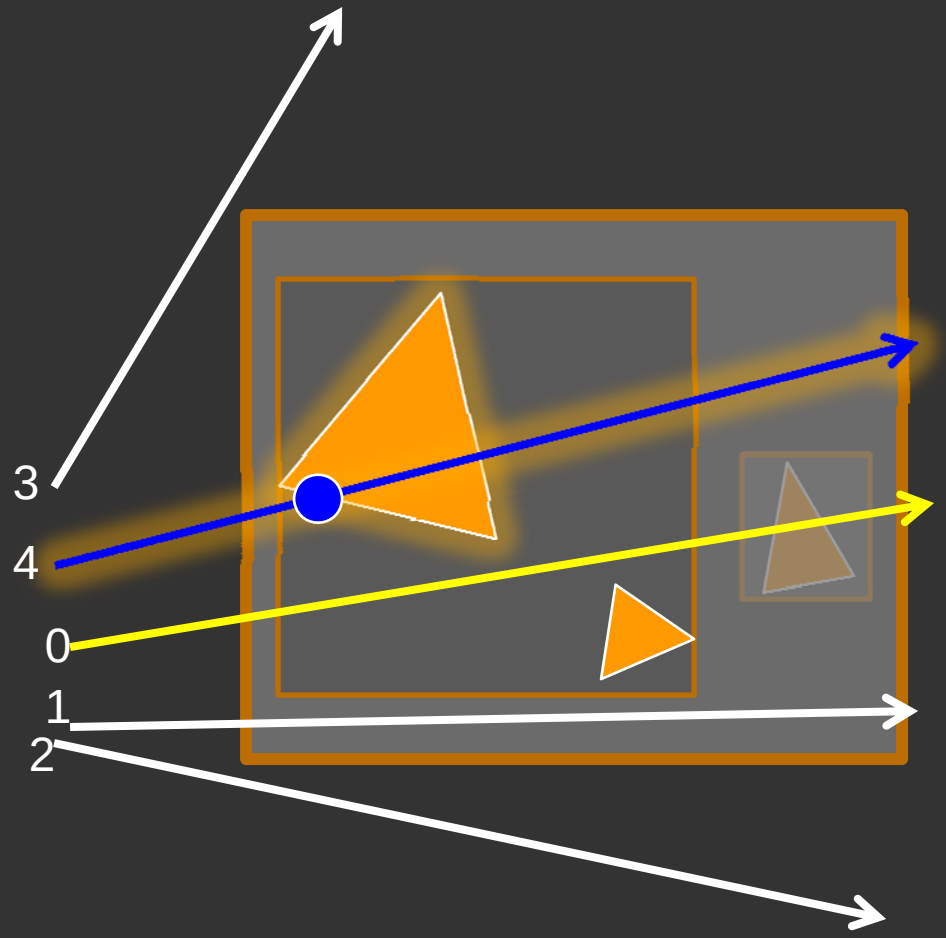
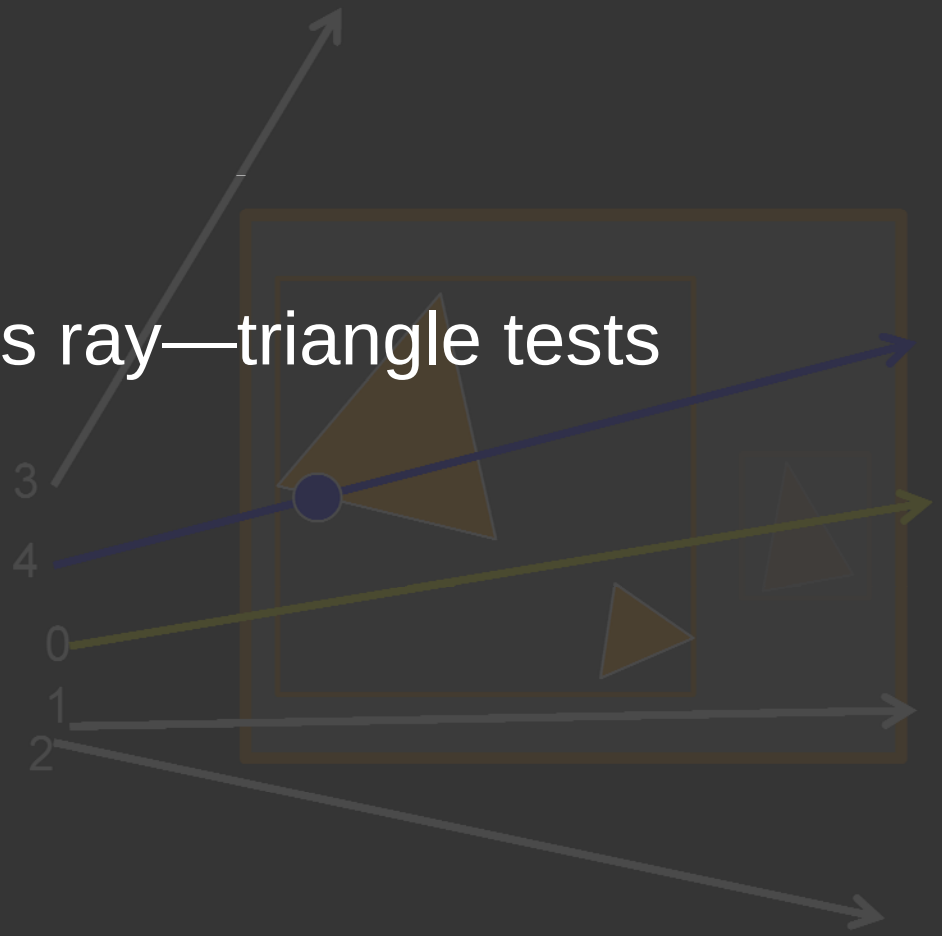


Ranged Traversal

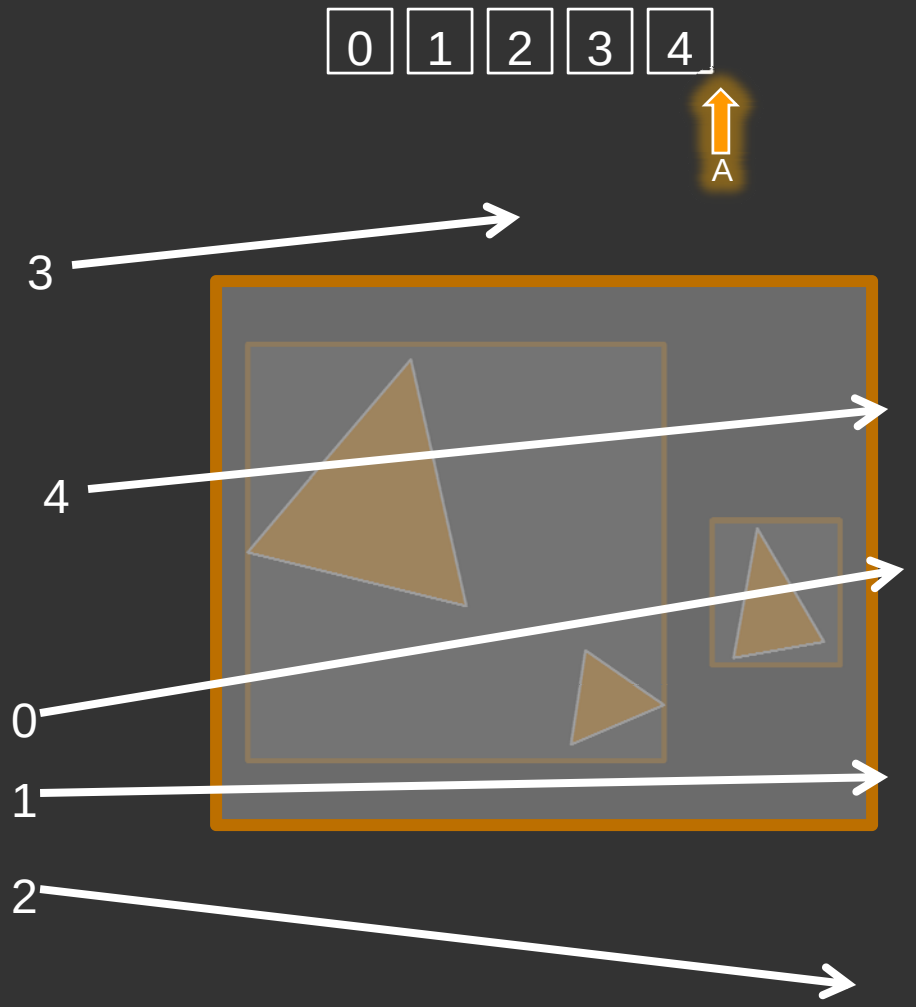


Ranged Traversal

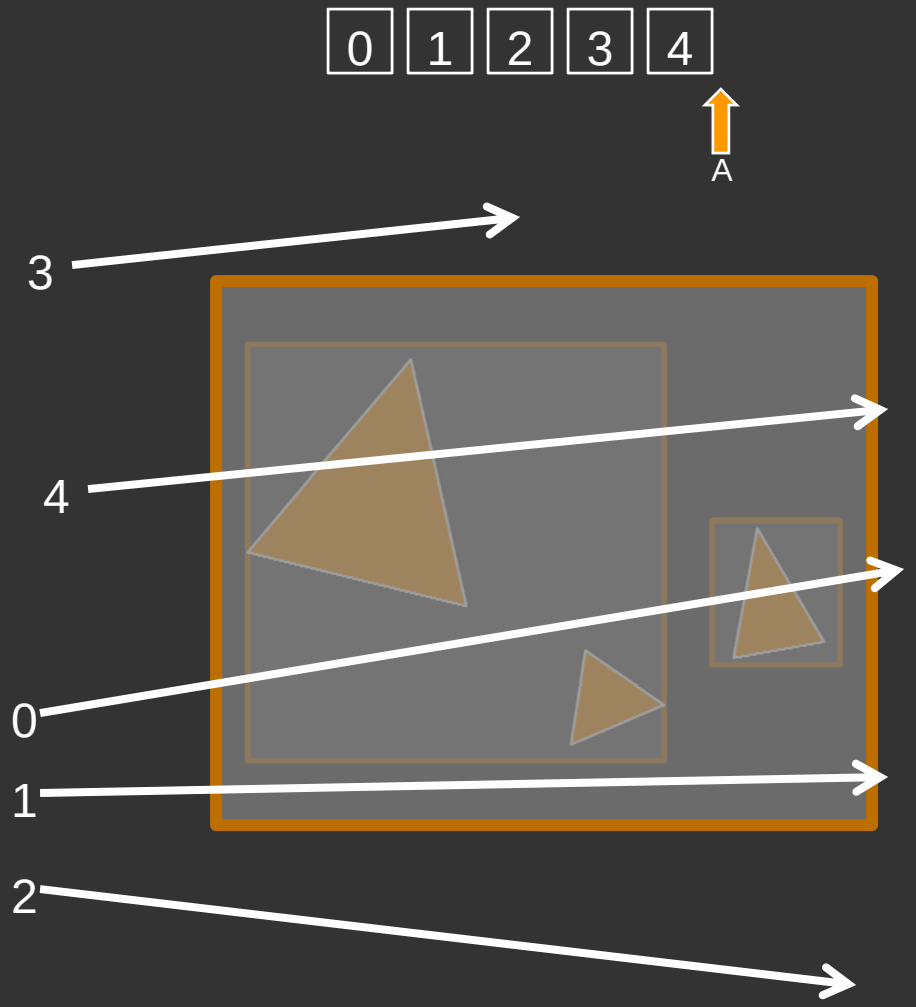
- Reduces ray—cell tests
- Increases ray—triangle tests



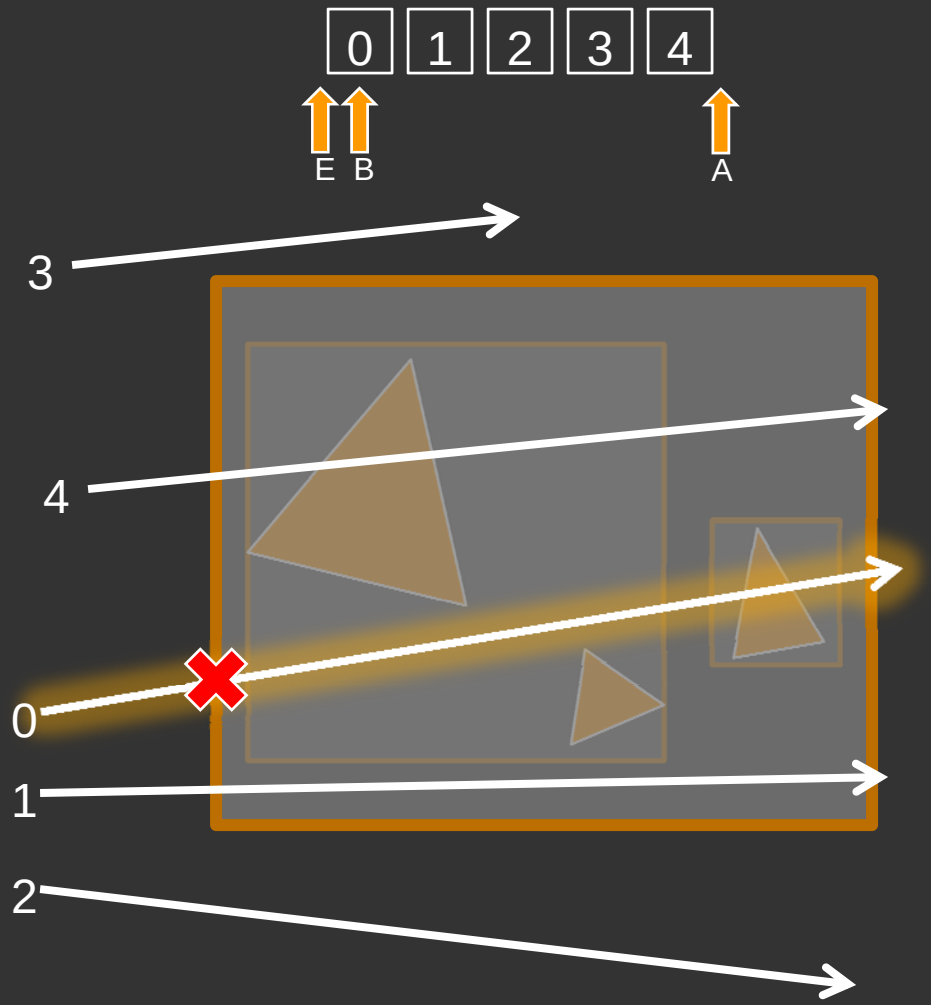
Partition Traversal (New)



Partition Traversal (New)



Partition Traversal (New)



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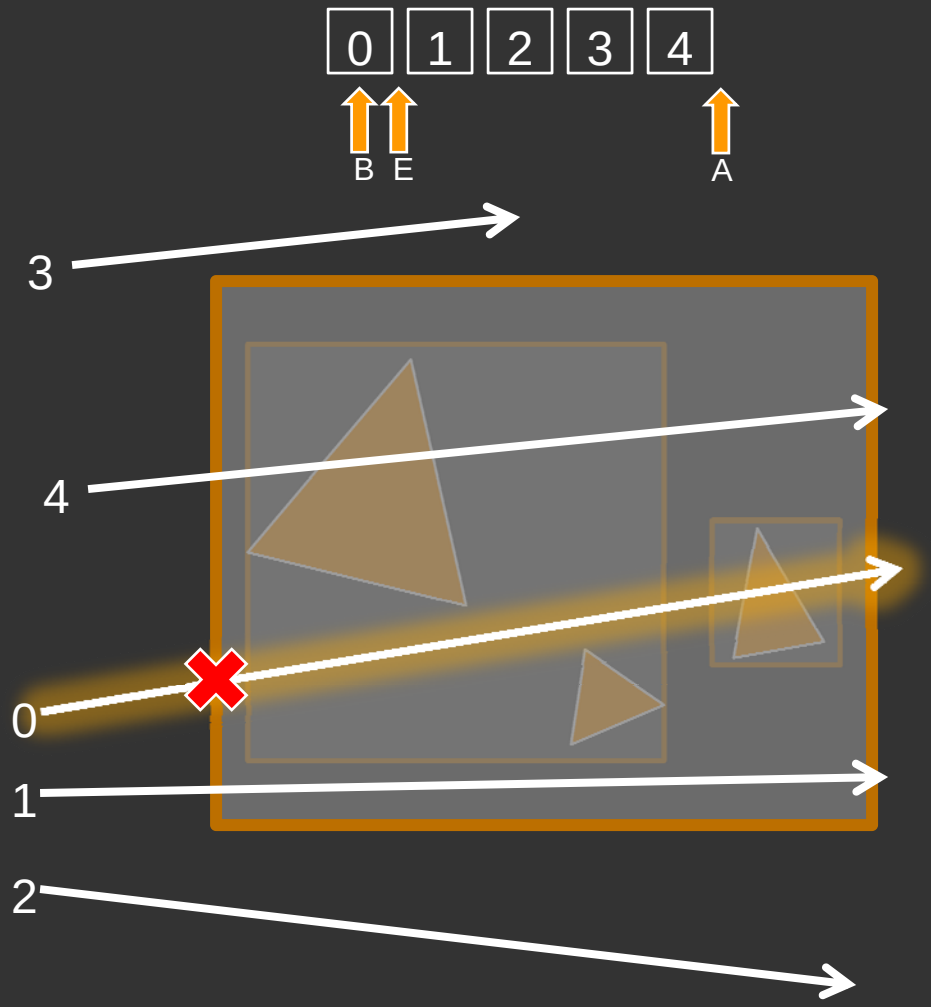
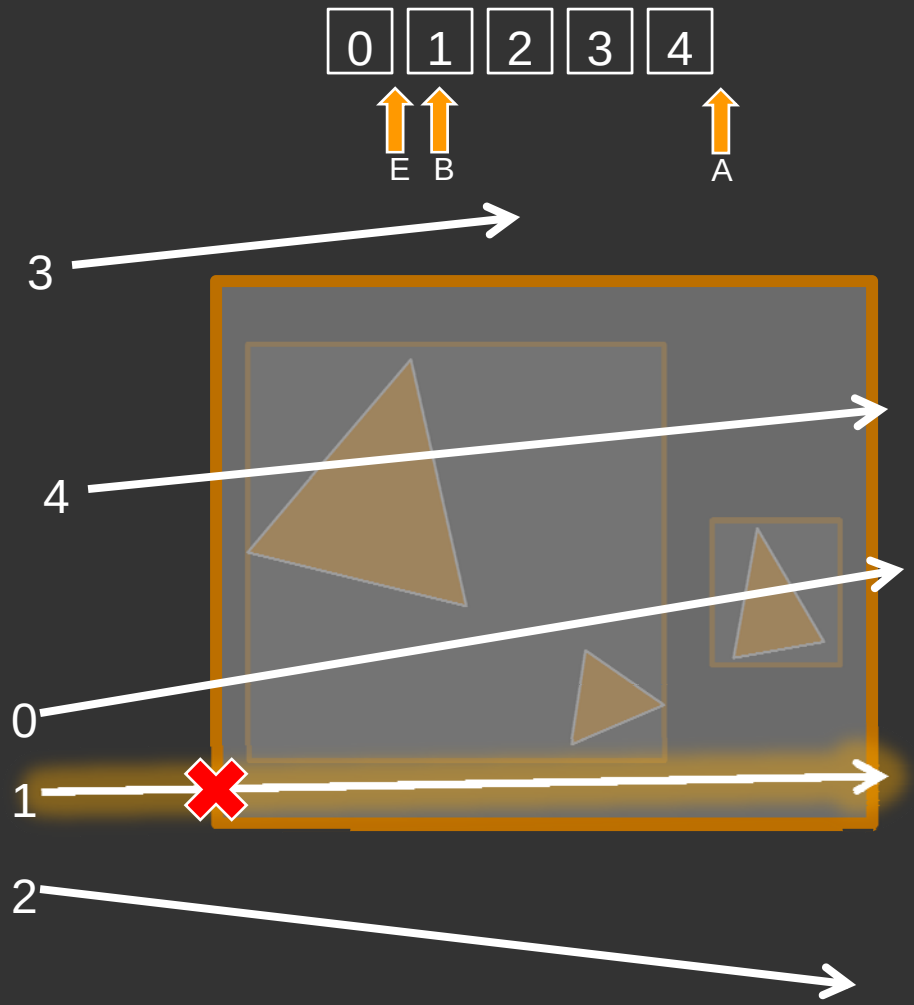
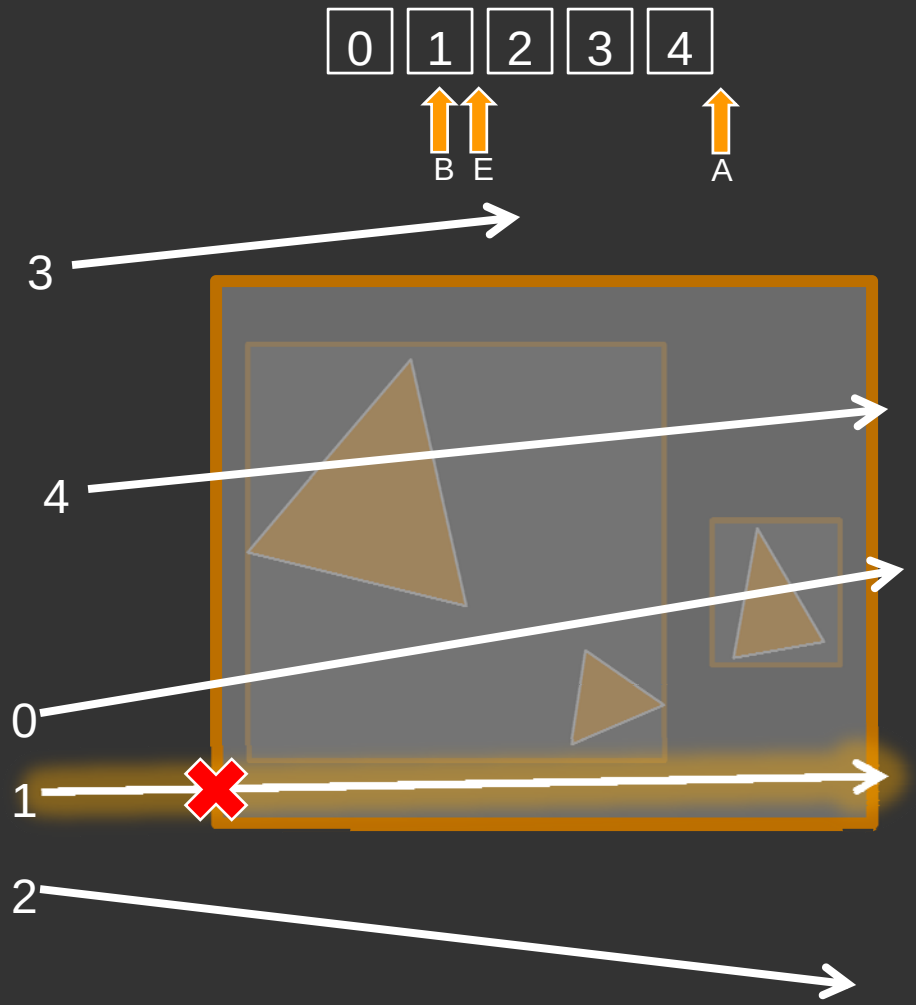


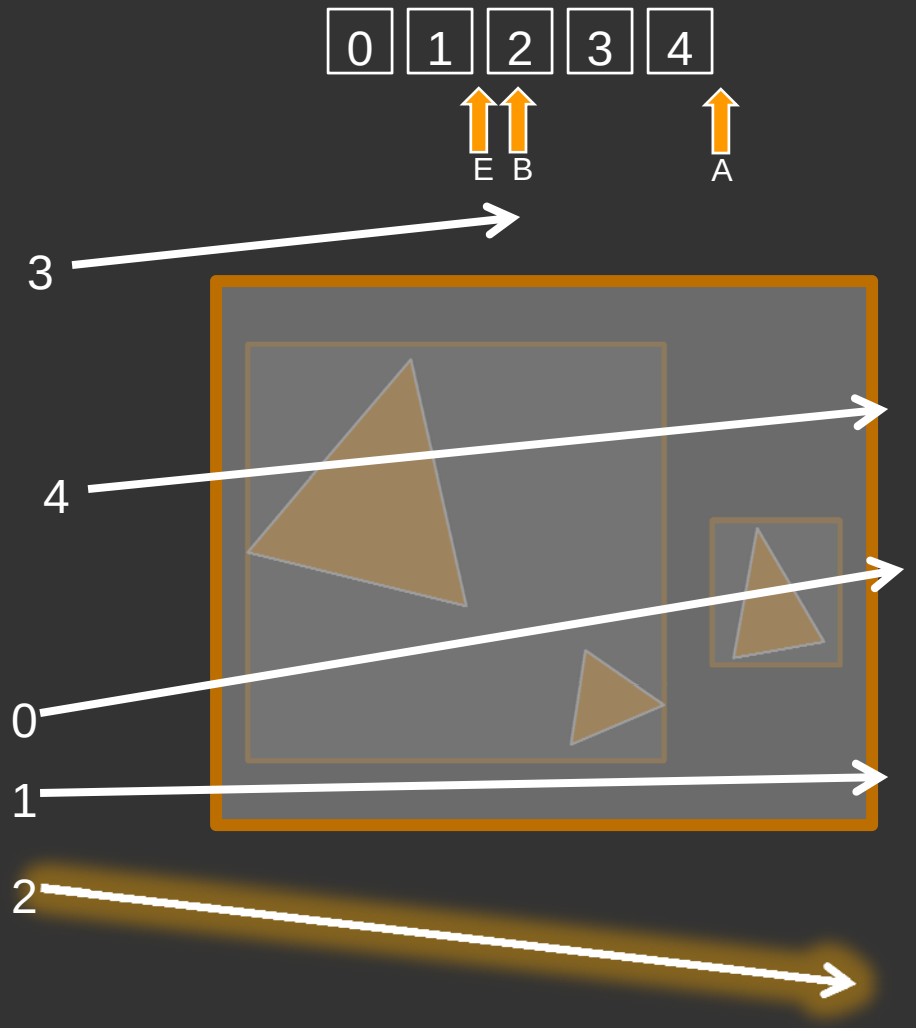
Partition Traversal (New)



Partition Traversal (New)



Partition Traversal (New)



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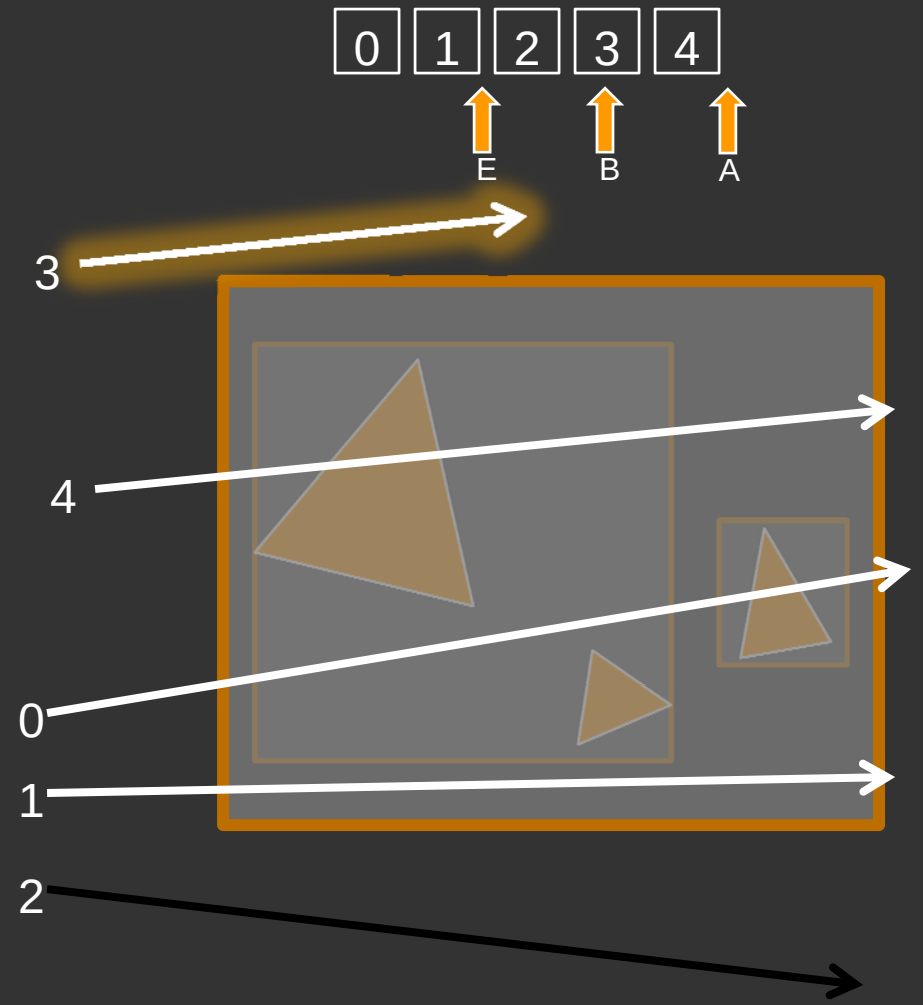

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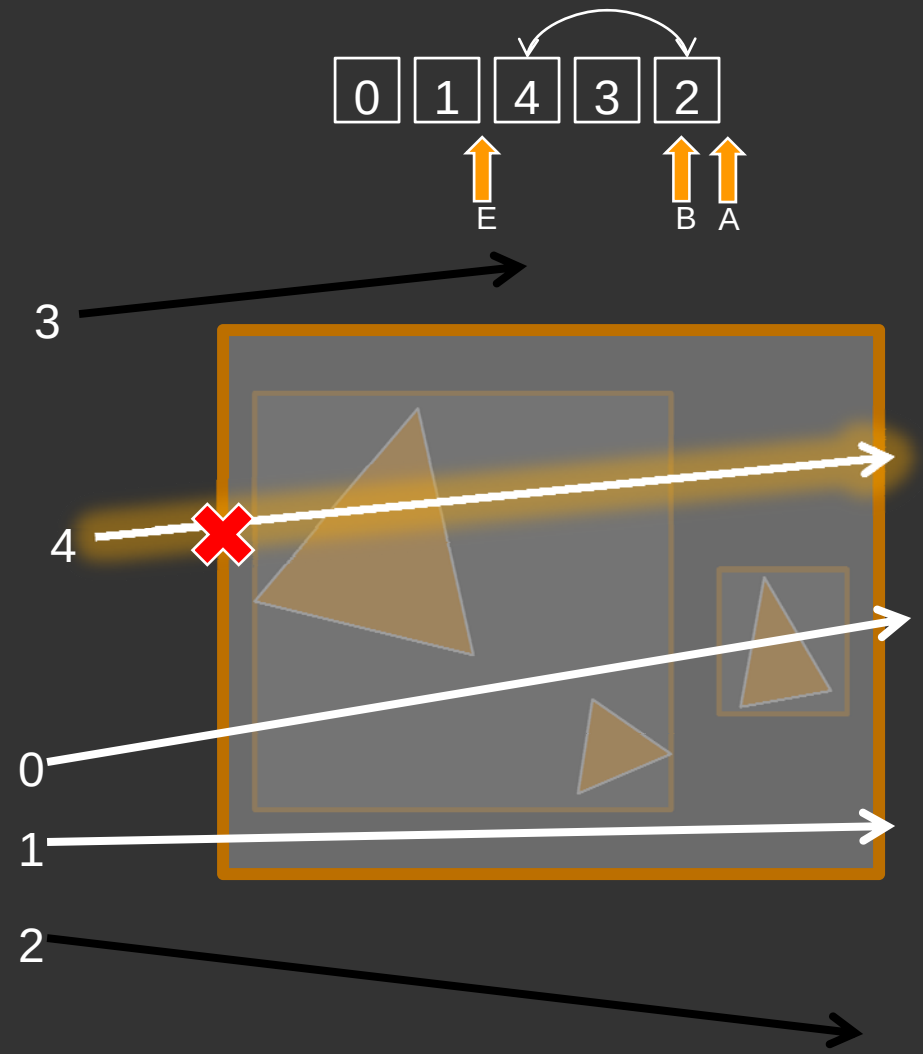
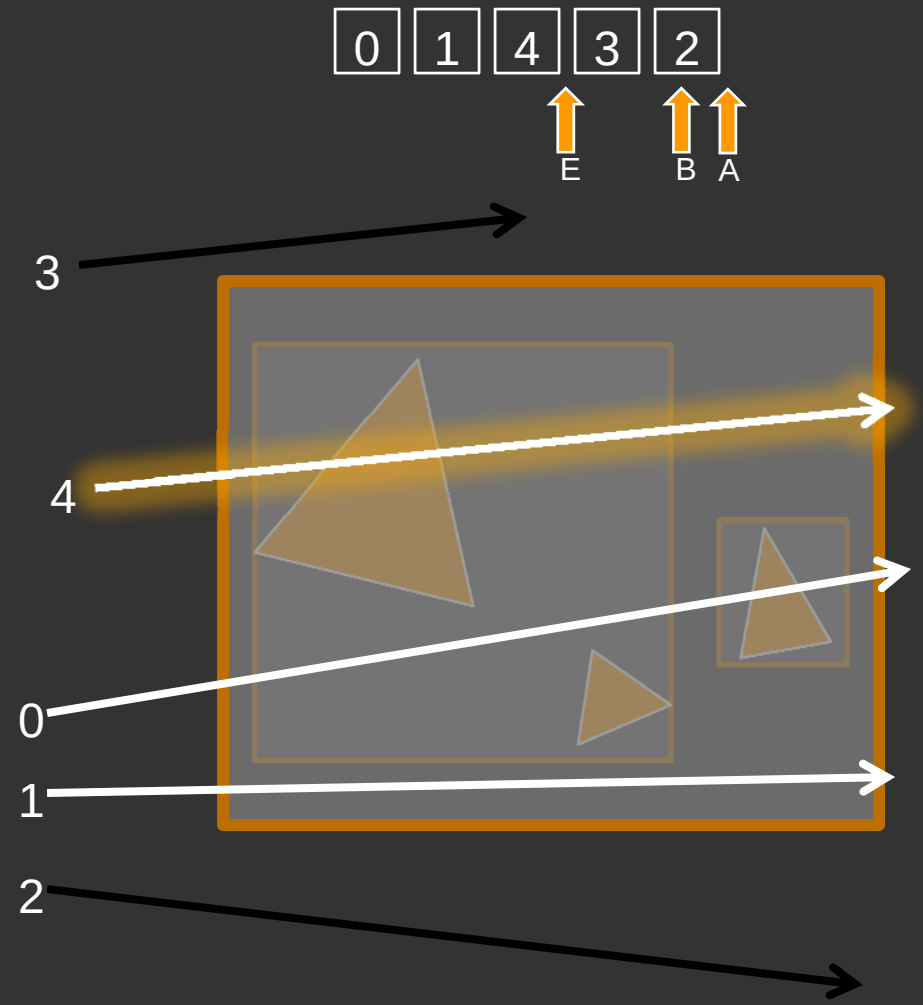
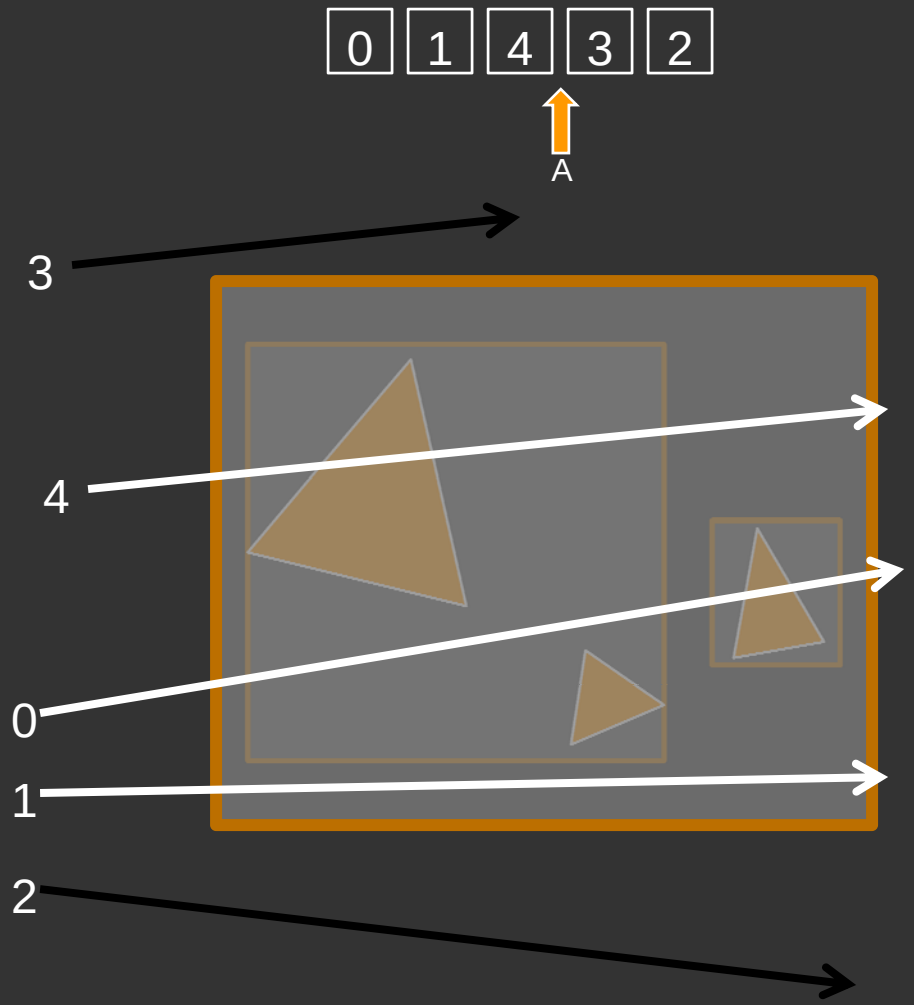


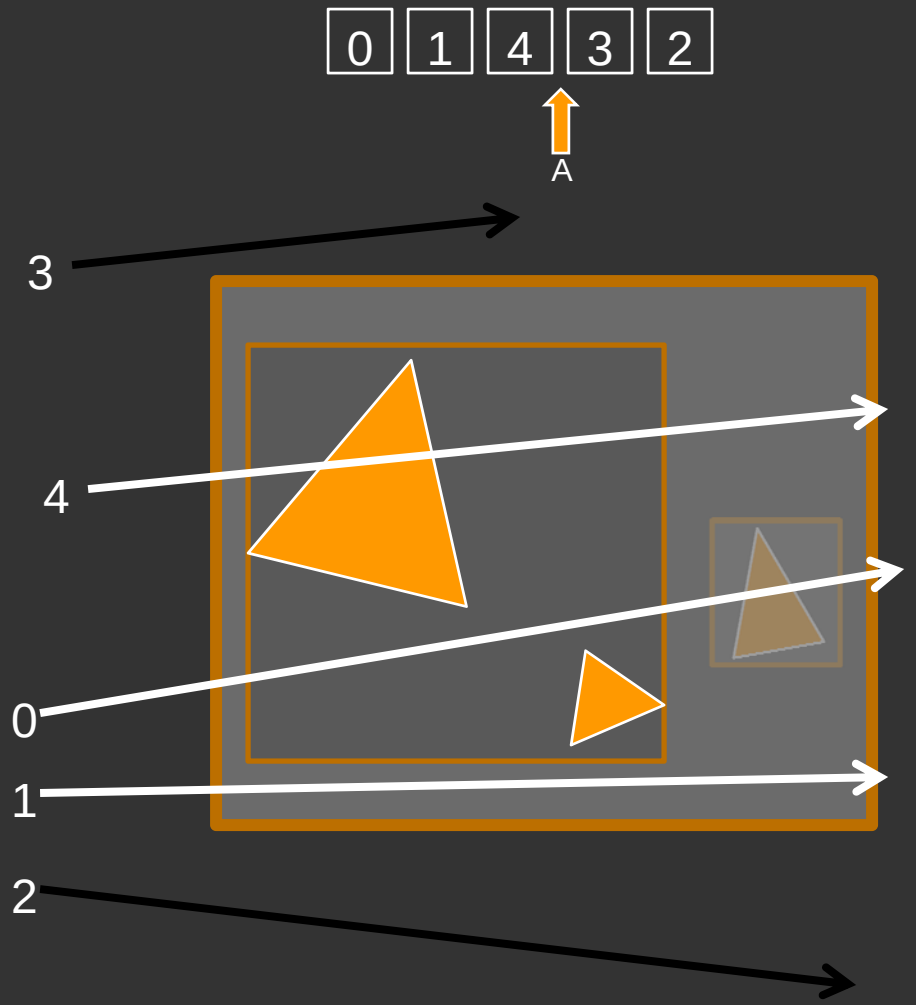
Partition Traversal (New)



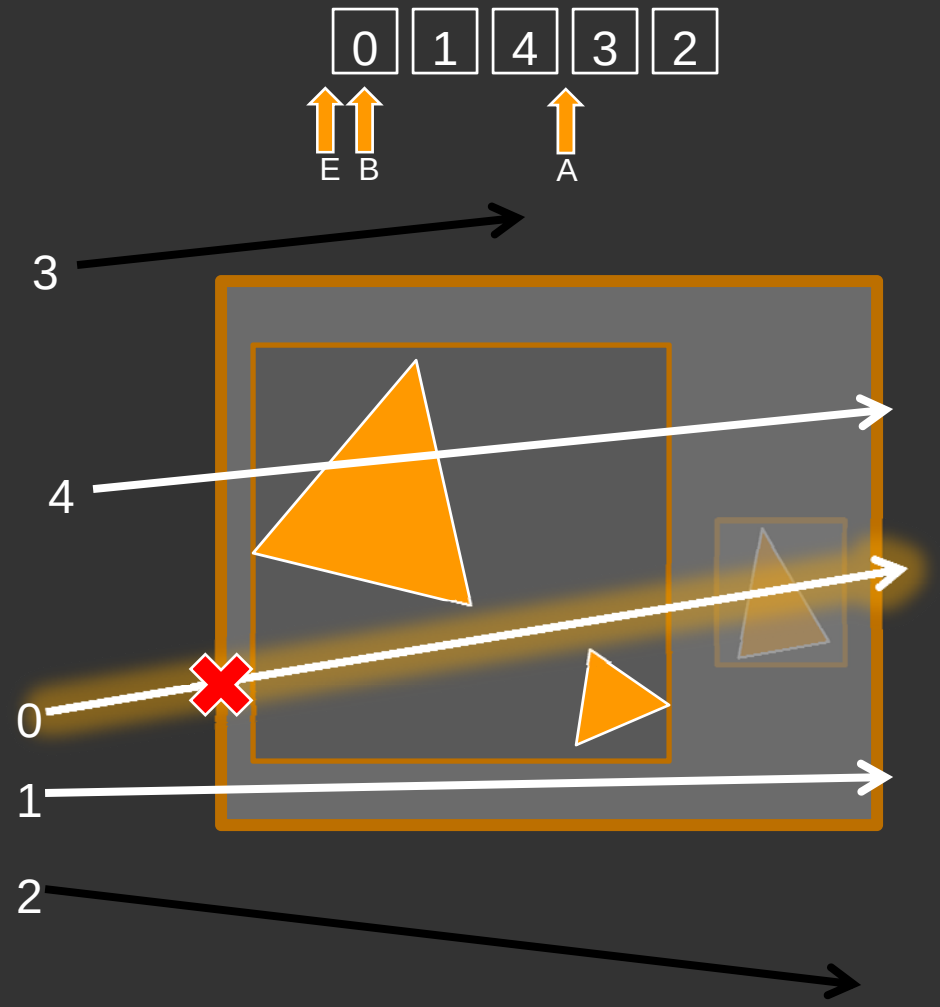
Partition Traversal (New)



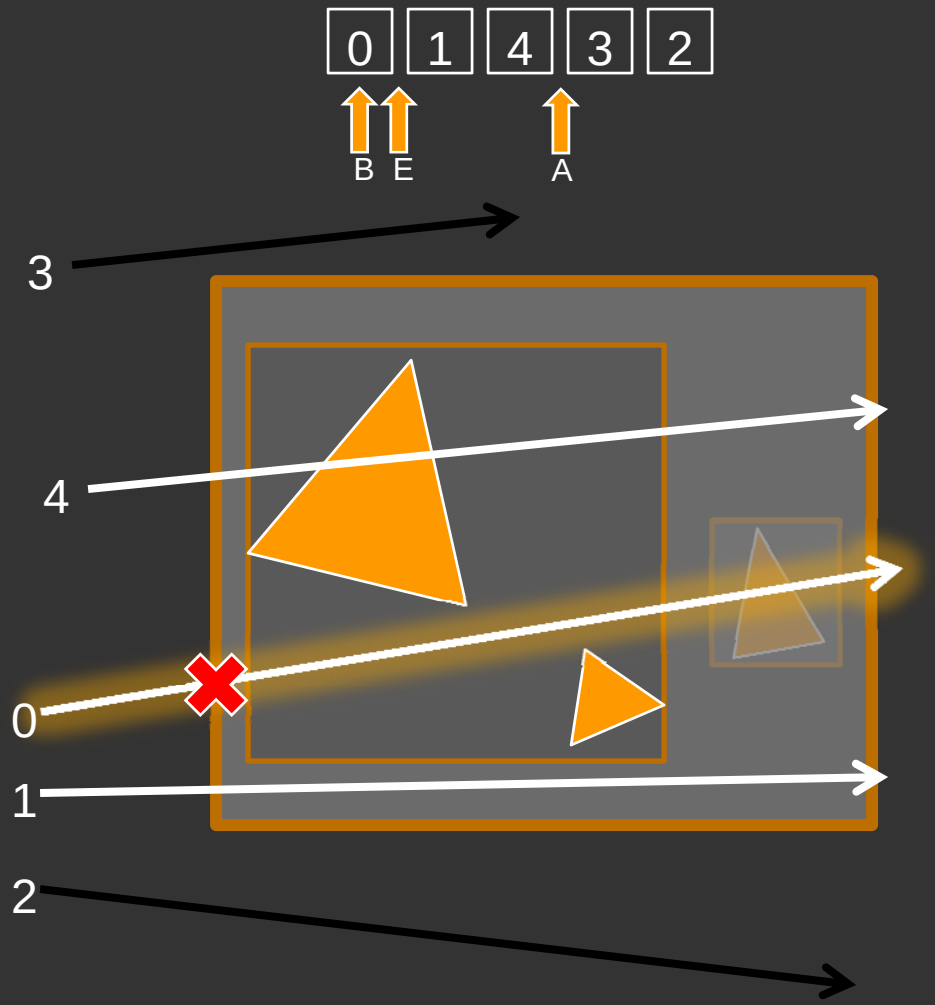
Partition Traversal (New)



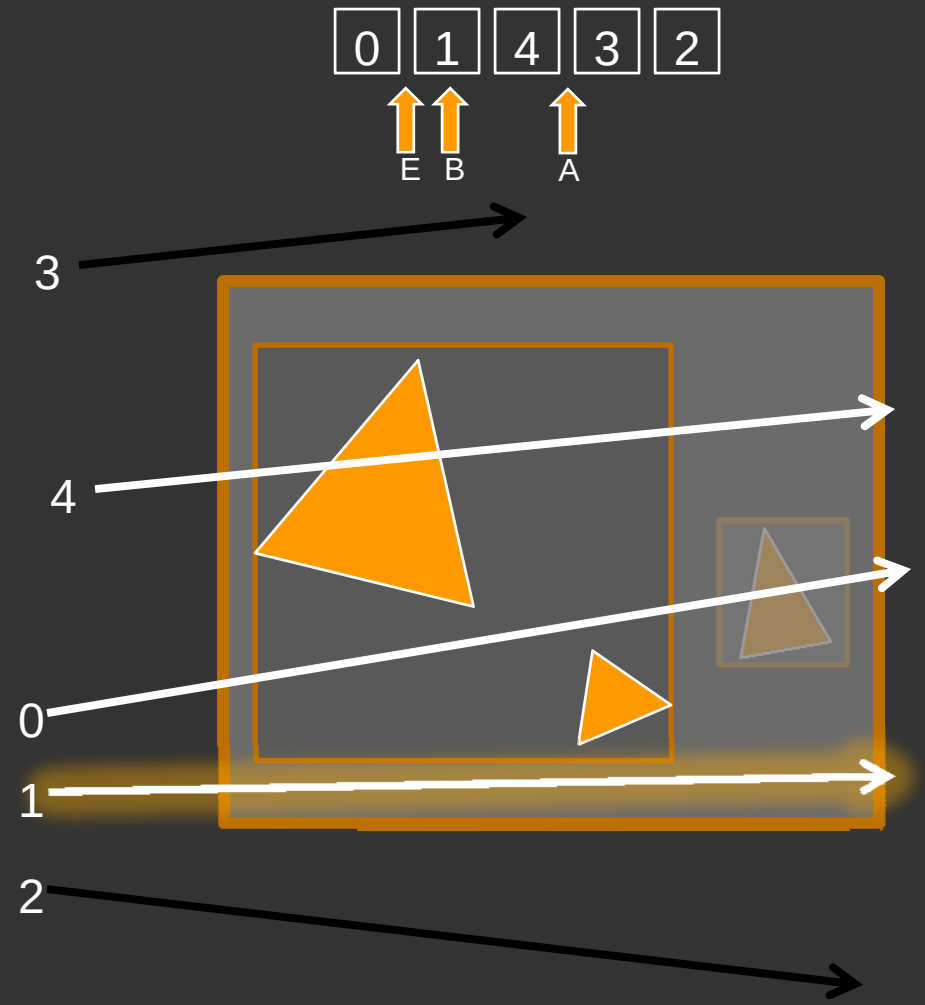
Partition Traversal (New)



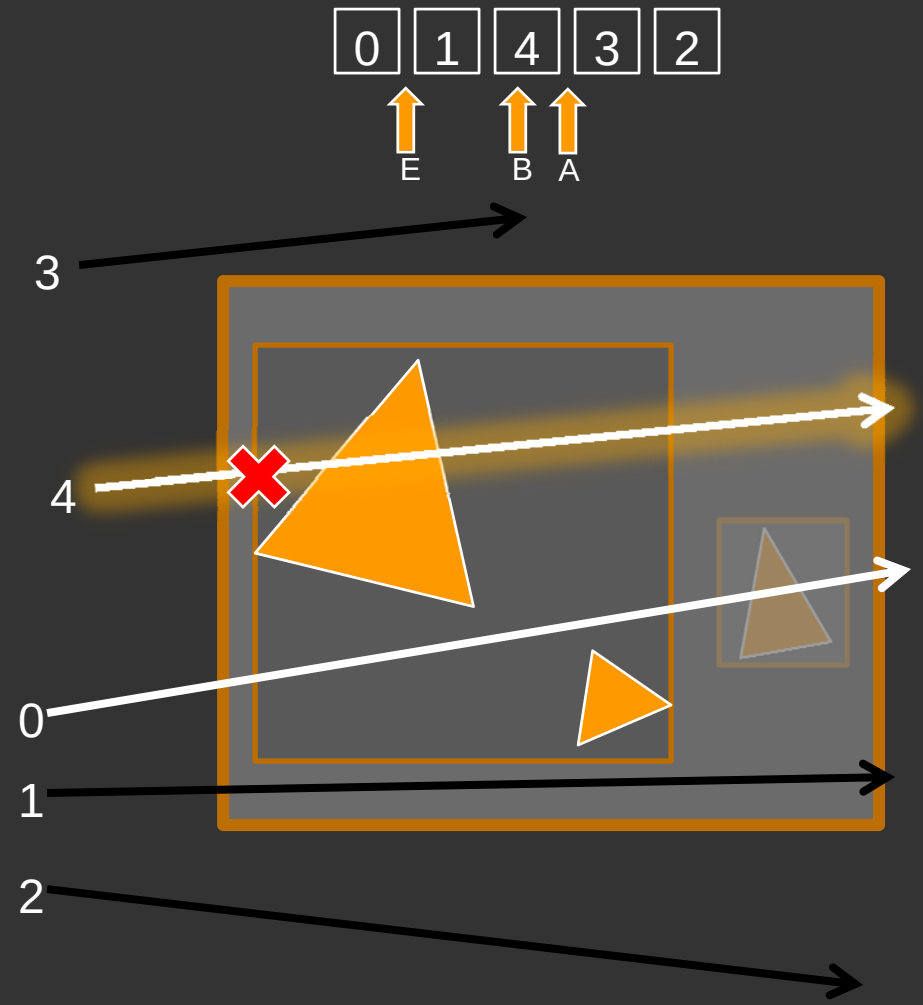
Partition Traversal (New)



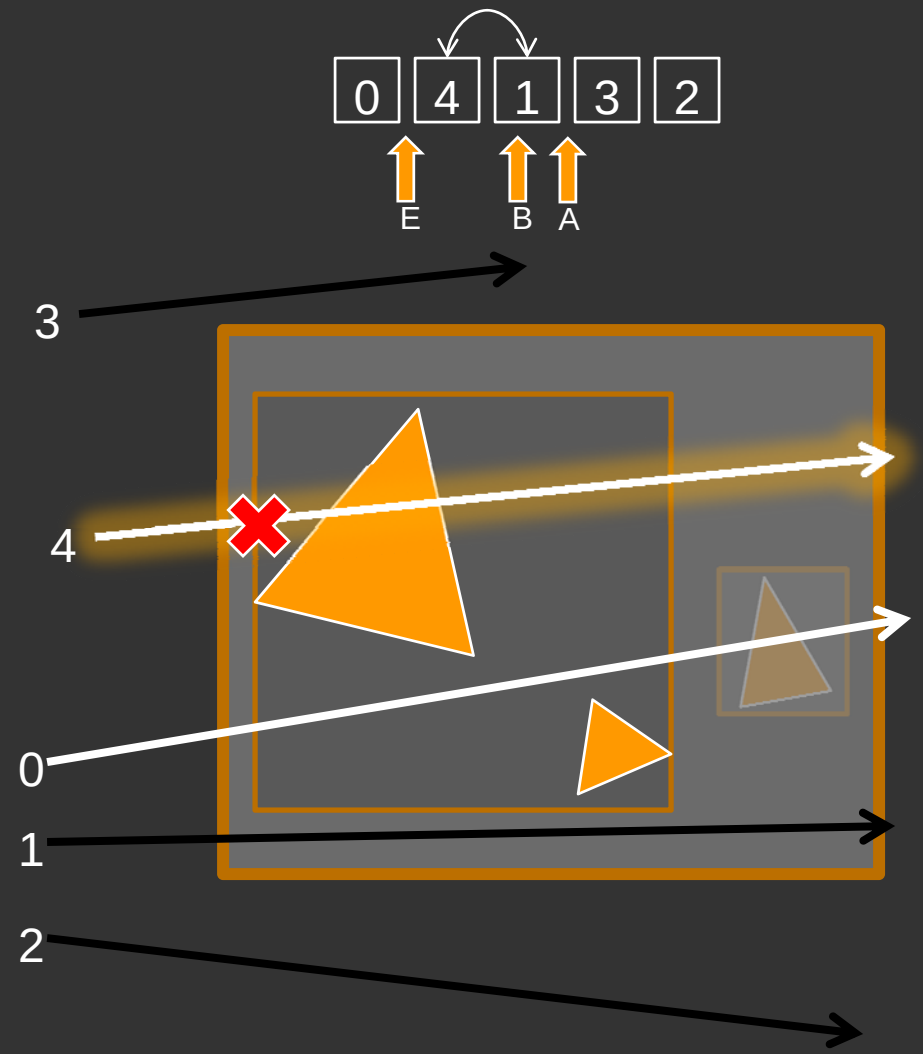
Partition Traversal (New)



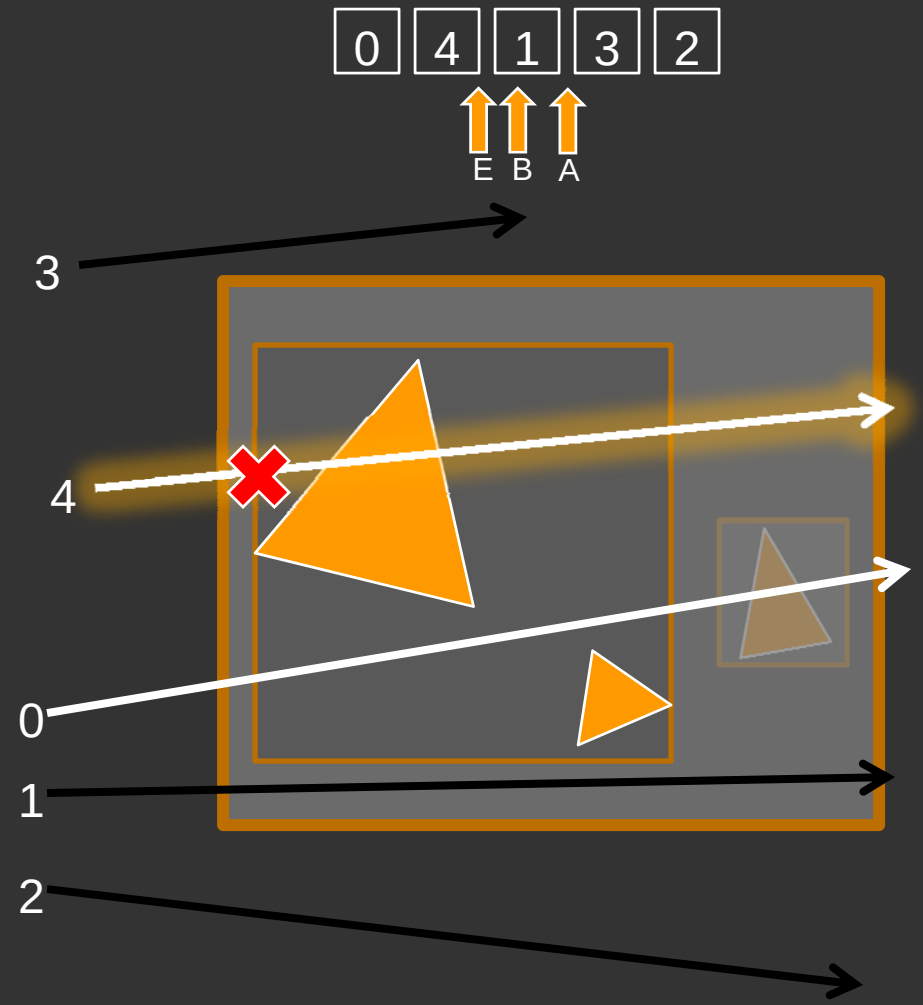
Partition Traversal (New)



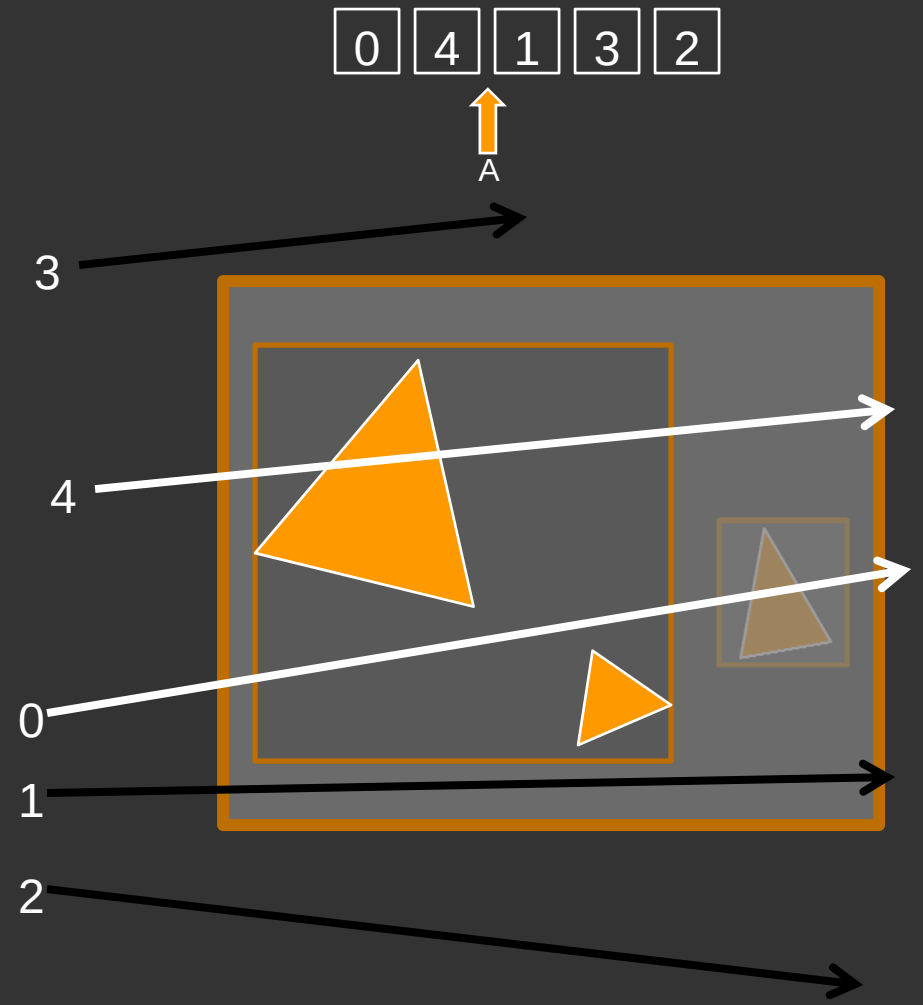
Partition Traversal (New)



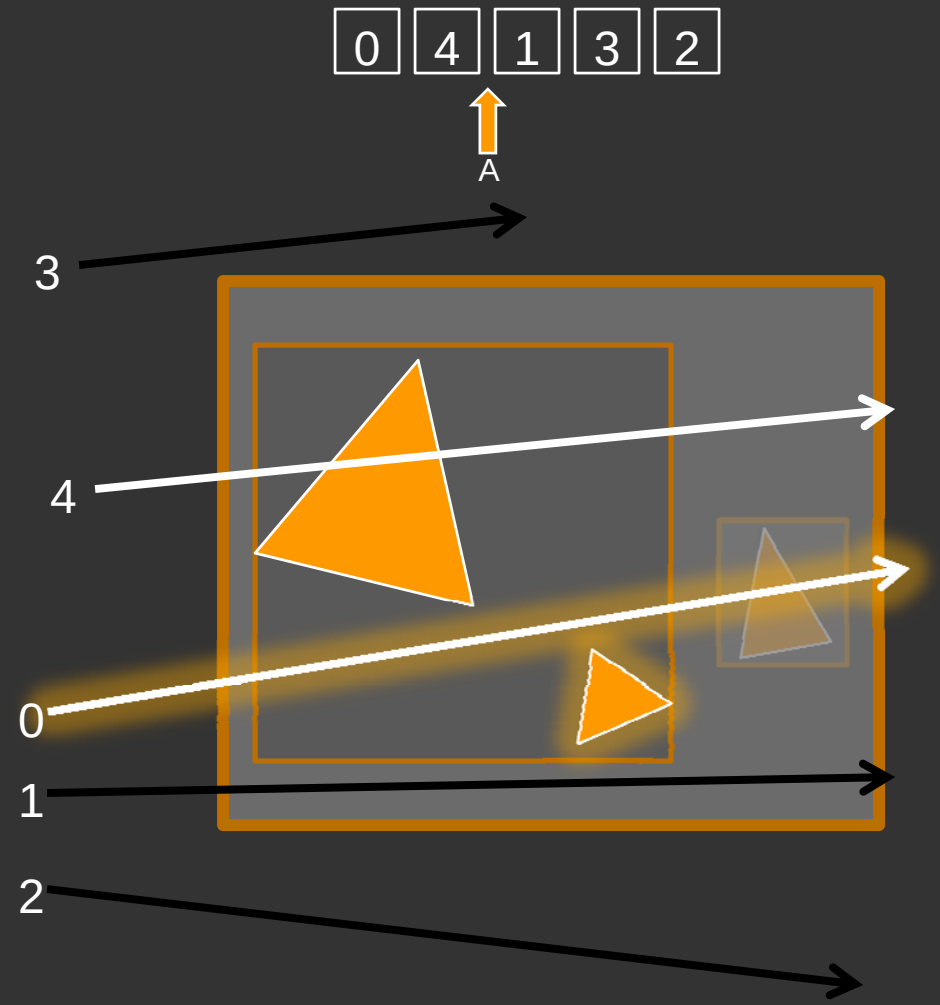
Partition Traversal (New)



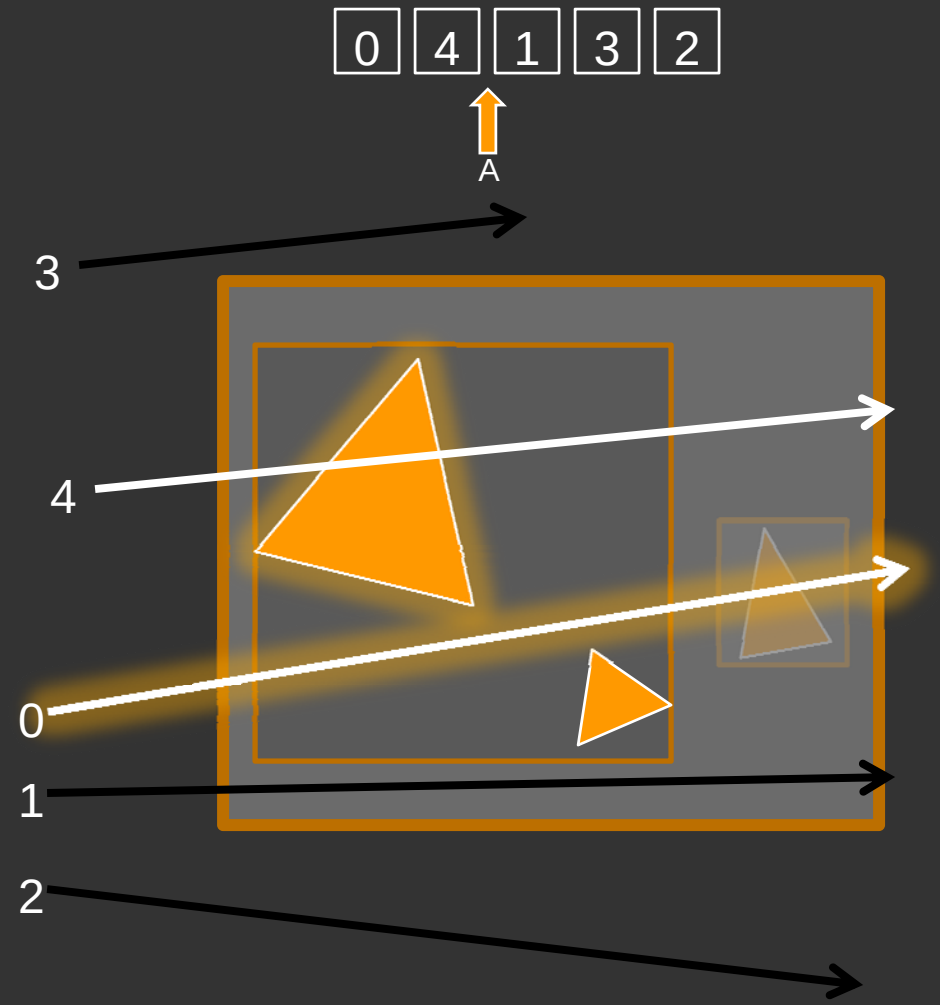
Partition Traversal (New)



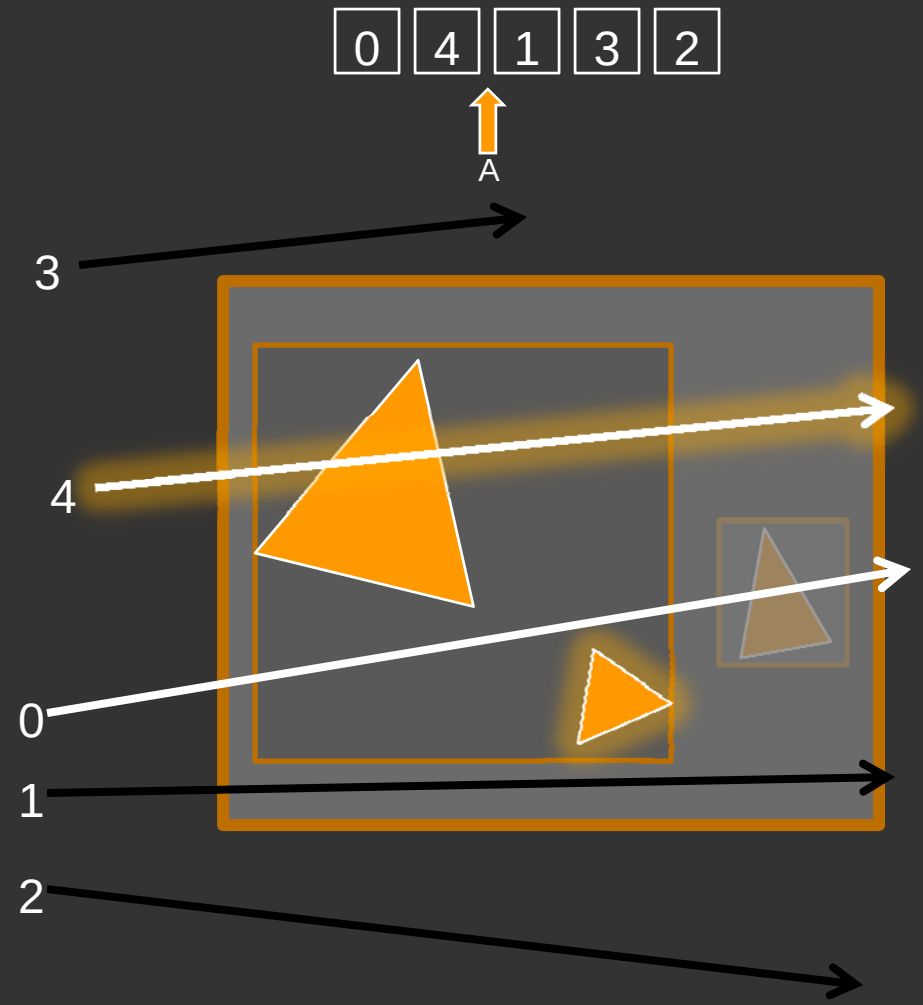
Partition Traversal (New)



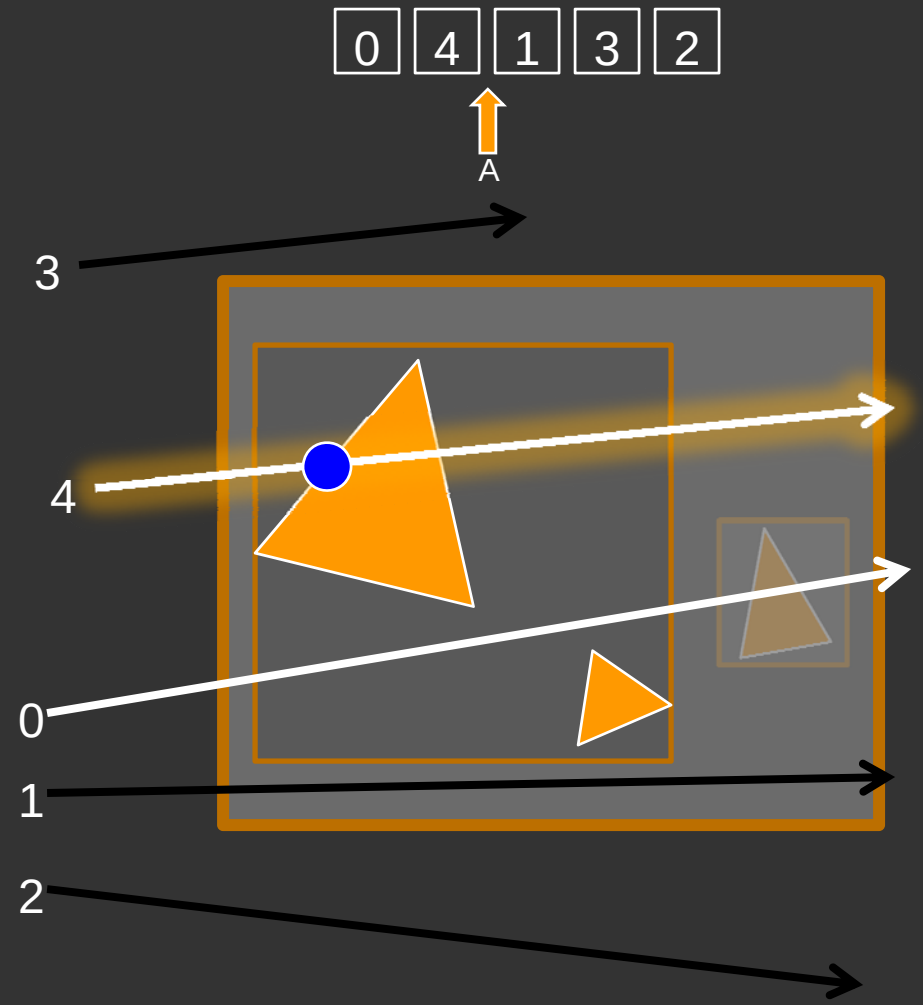
Partition Traversal (New)



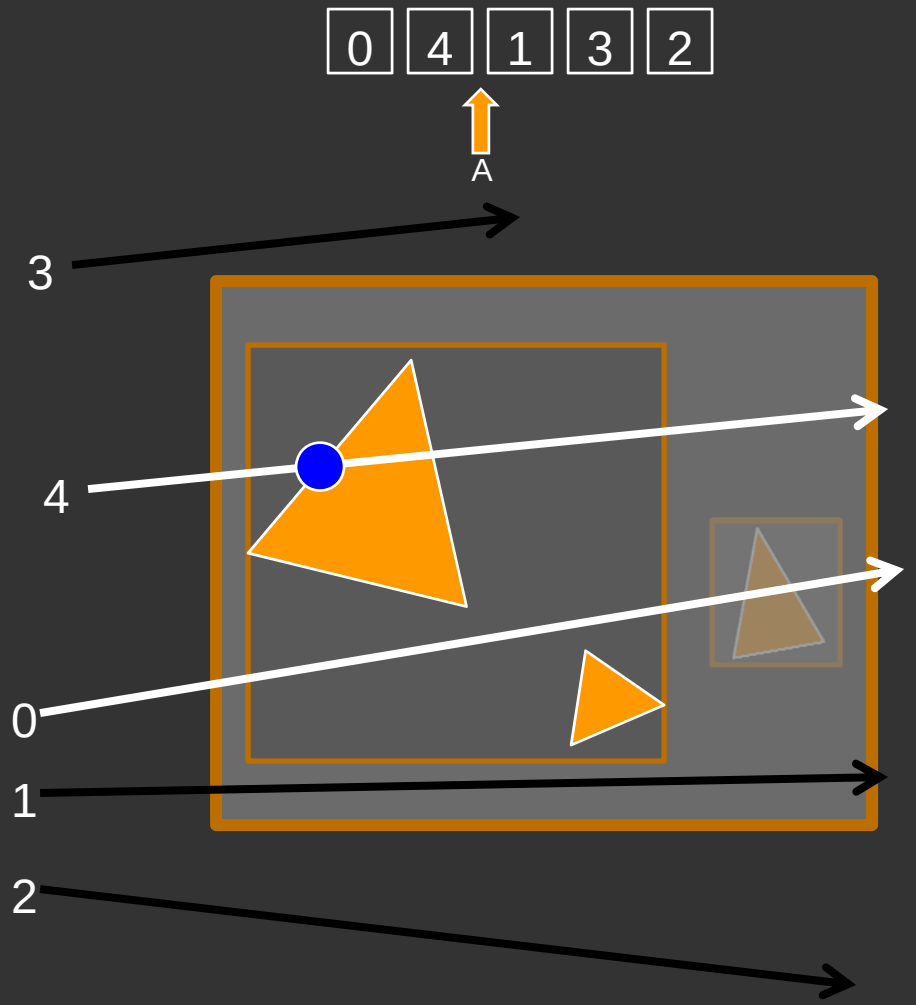
Partition Traversal (New)



Partition Traversal (New)



Partition Traversal (New)



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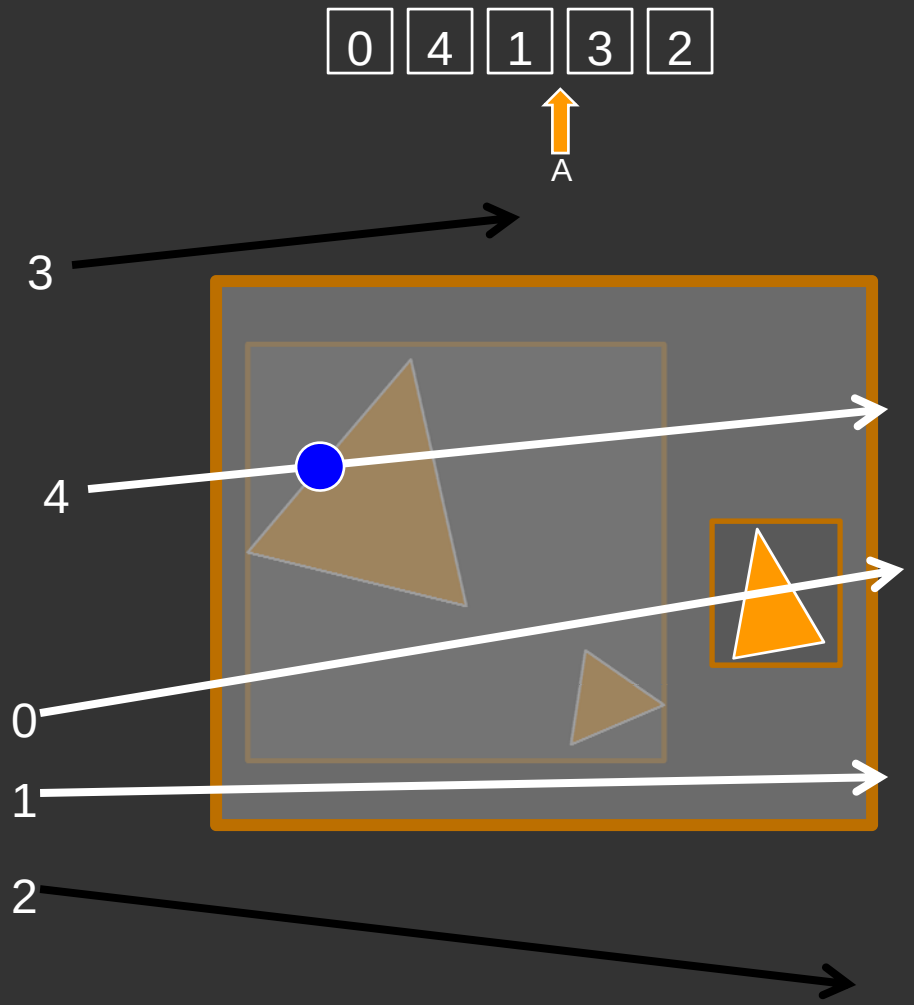
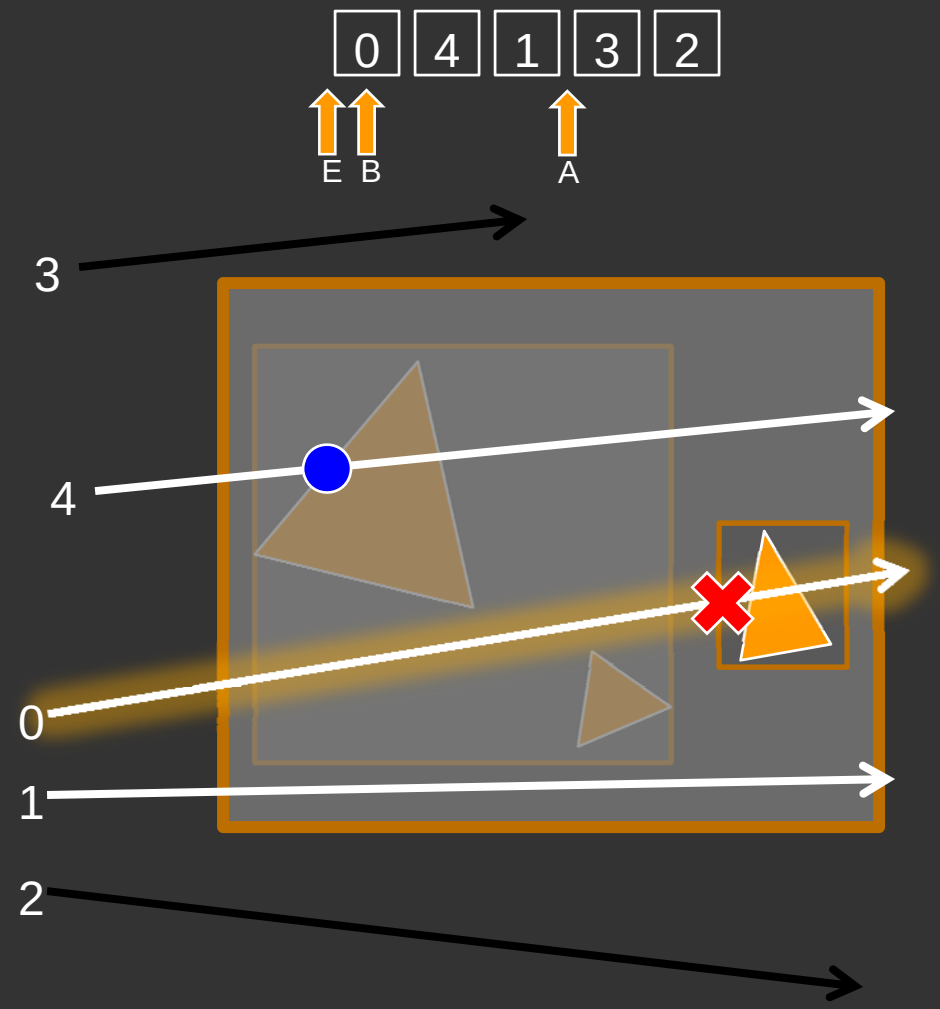
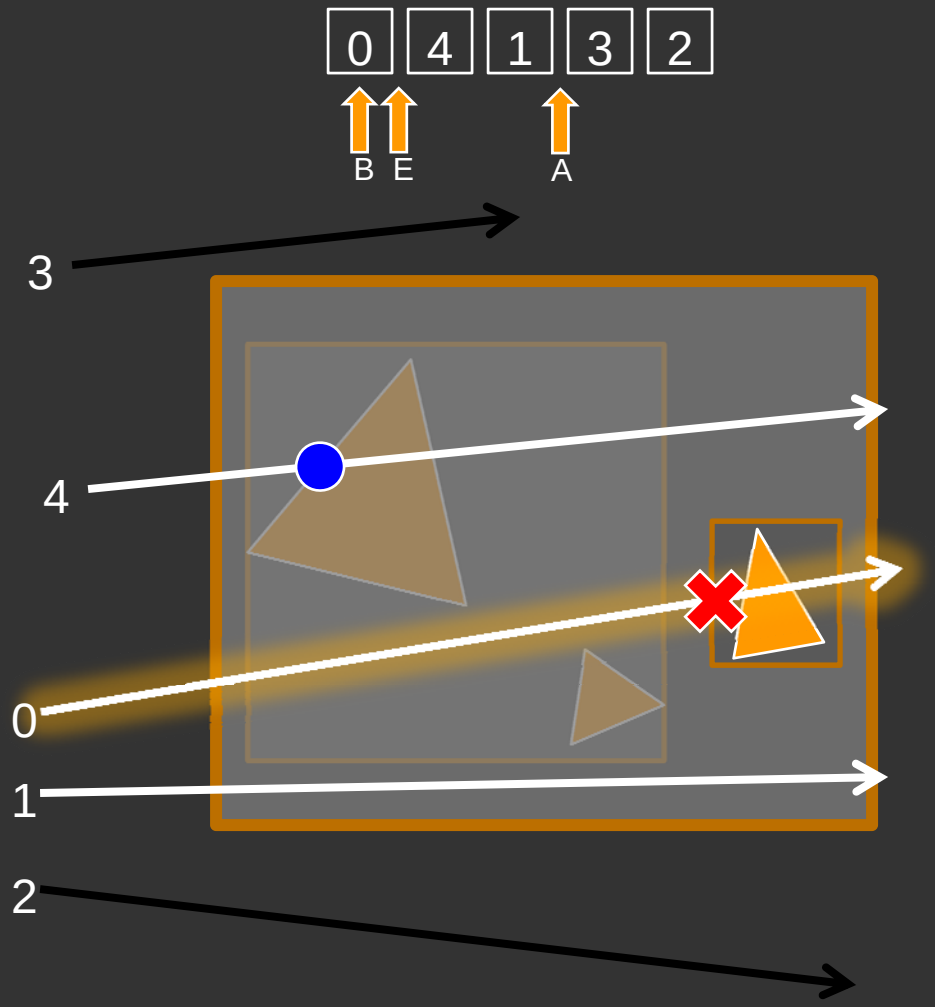


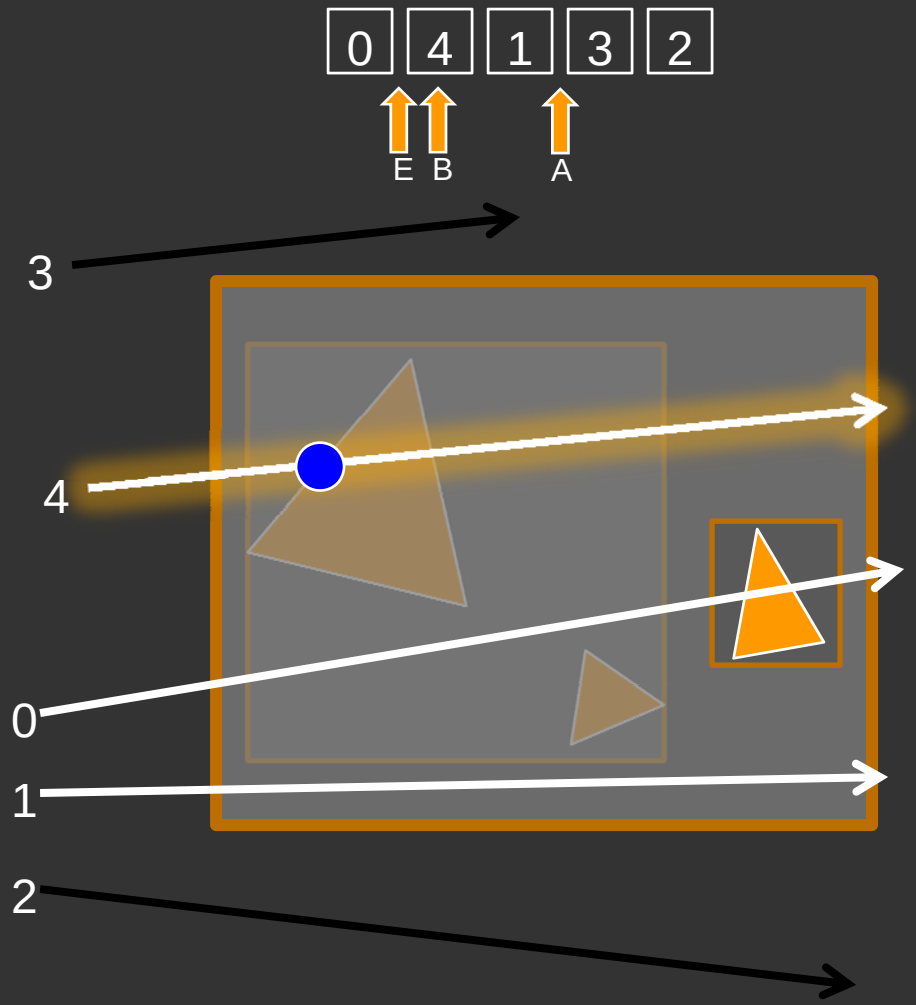
Partition Traversal (New)



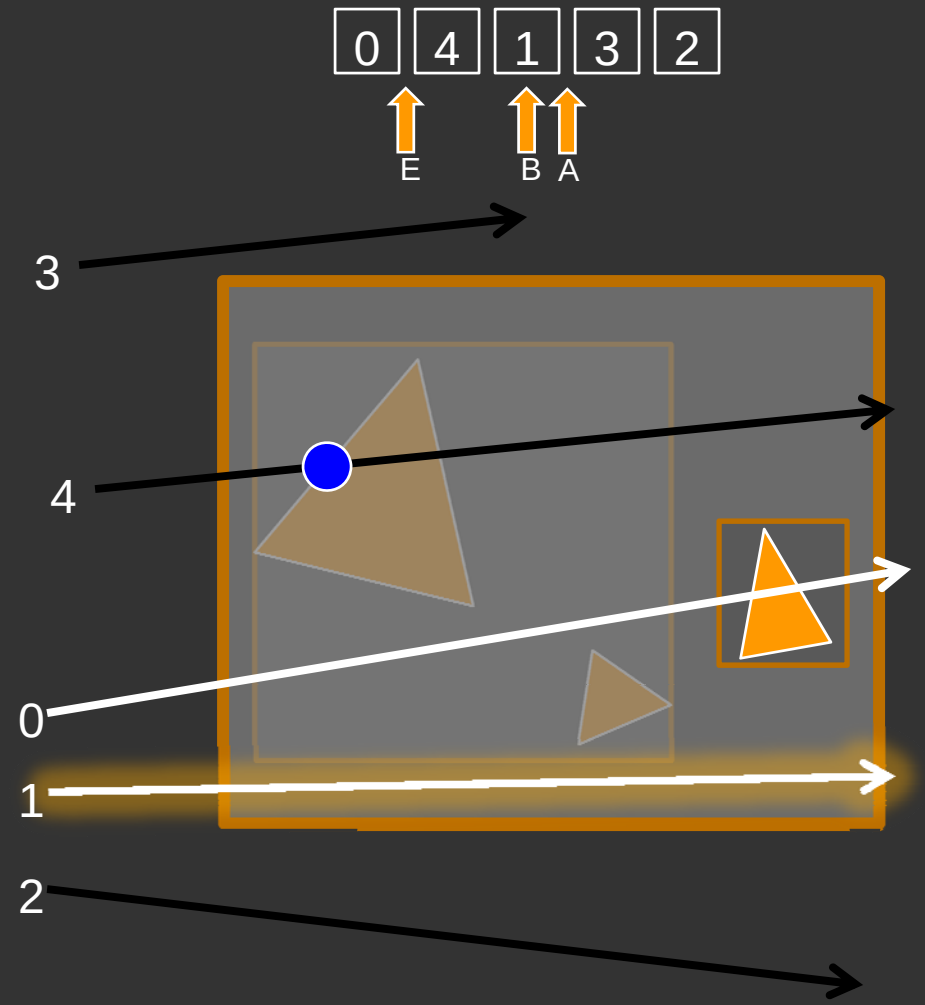
Partition Traversal (New)



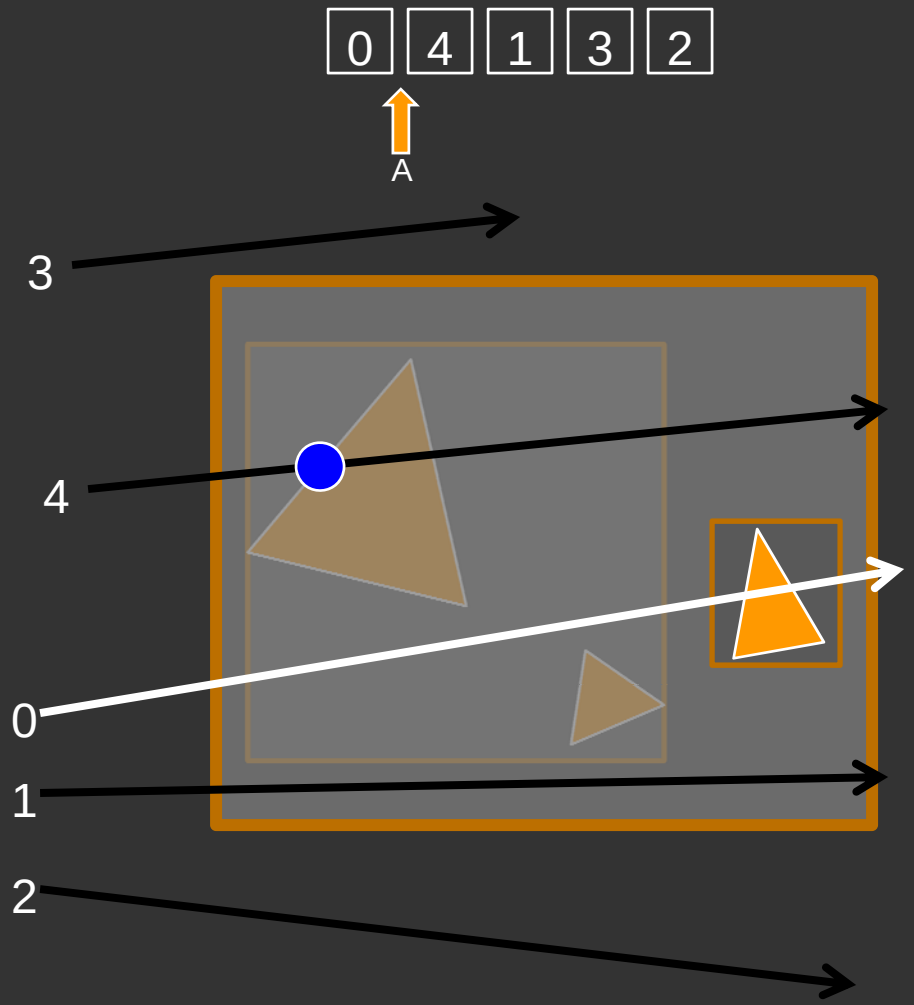
Partition Traversal (New)



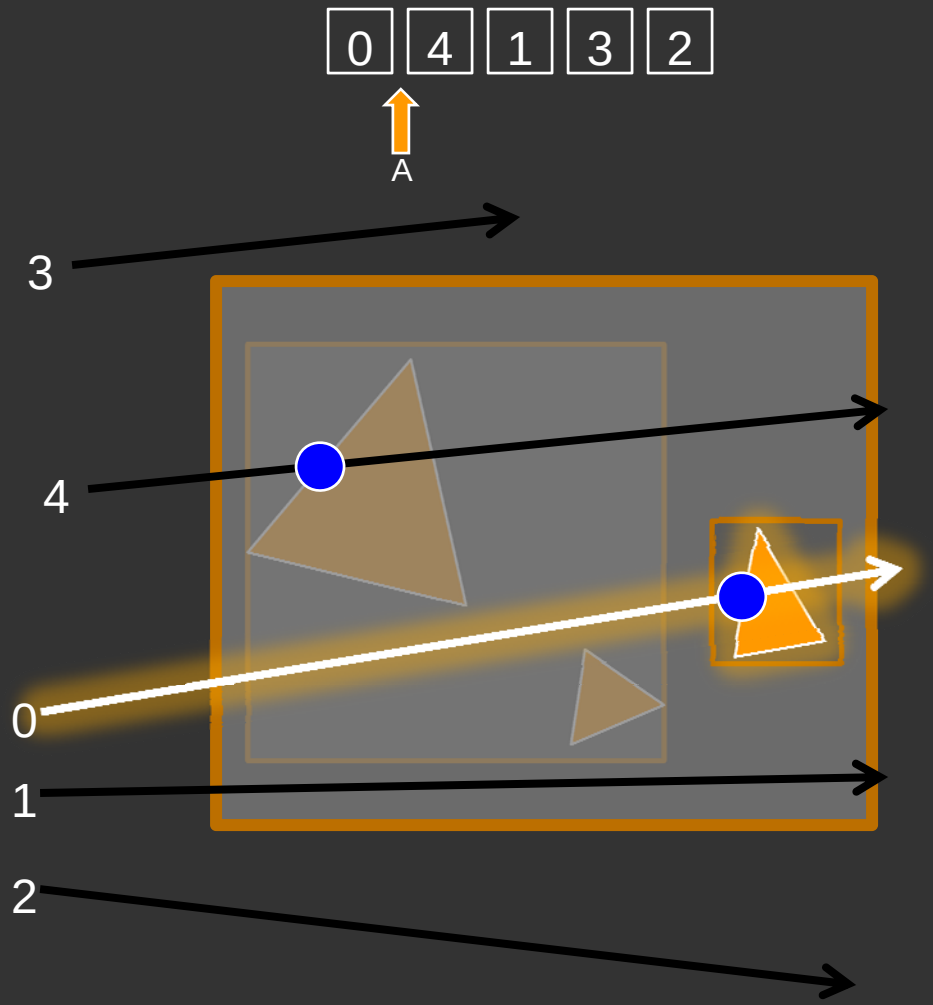
Partition Traversal (New)



Partition Traversal (New)

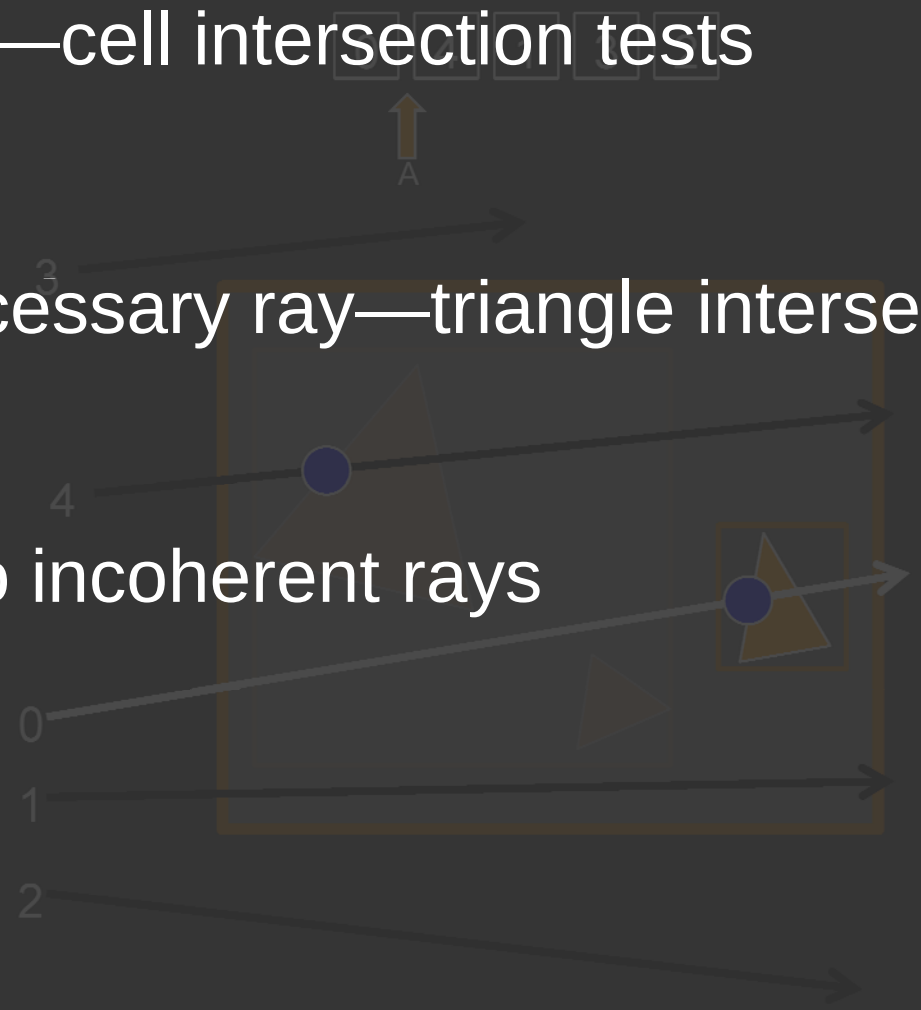


Partition Traversal (New)



Partition Traversal (New)

- More ray—cell intersection tests
- No unnecessary ray—triangle intersection tests
- Robust to incoherent rays



Outline

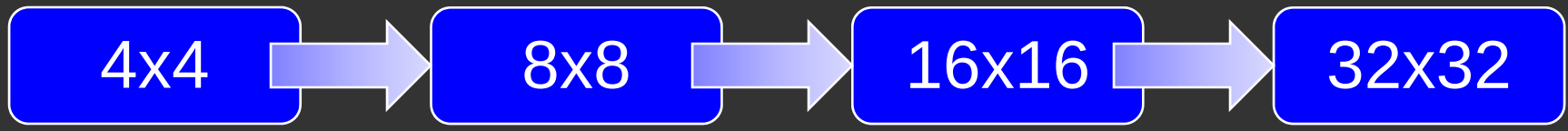
- Motivation
- Frustum Culling for Secondary Rays
- Scene Traversal with Large Ray Packets
- Results

3 Performance Variables

- Ray Packet Size
- Scene Complexity
- Ray Recursion Complexity

3 Performance Variables

- Ray Packet Size

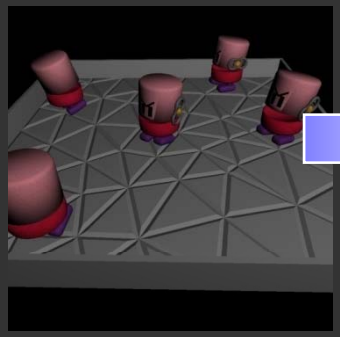


- Scene Complexity
- Ray Recursion Complexity

3 Performance Variables

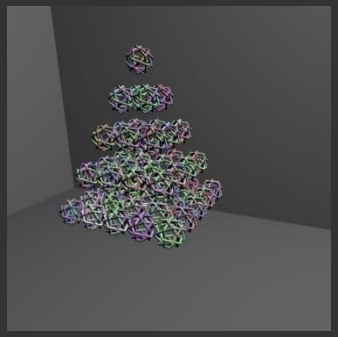
- Ray Packet Size
- Scene Complexity

ERW6
(804 Triangles)



Toasters
(11,141 Triangles)

Fairy
(172,669 Triangles)

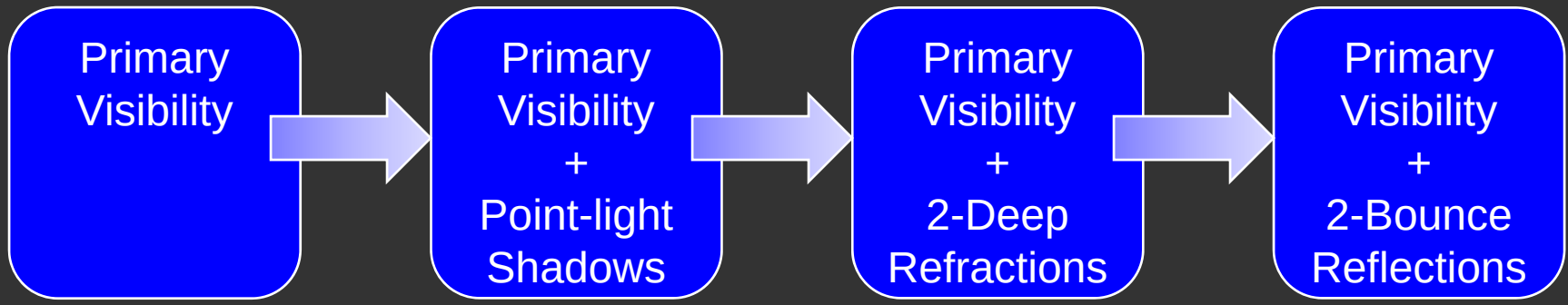


Rings
(217,812 Triangles)

- Ray Recursion Complexity

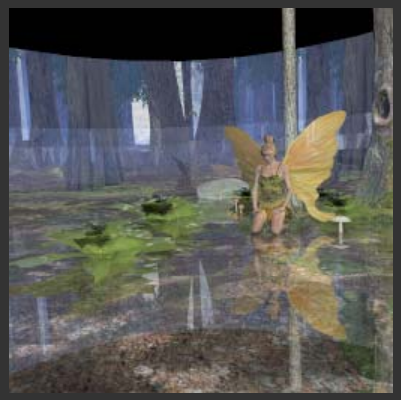
3 Performance Variables

- Ray Packet Size
- Scene Complexity
- Ray Recursion Complexity

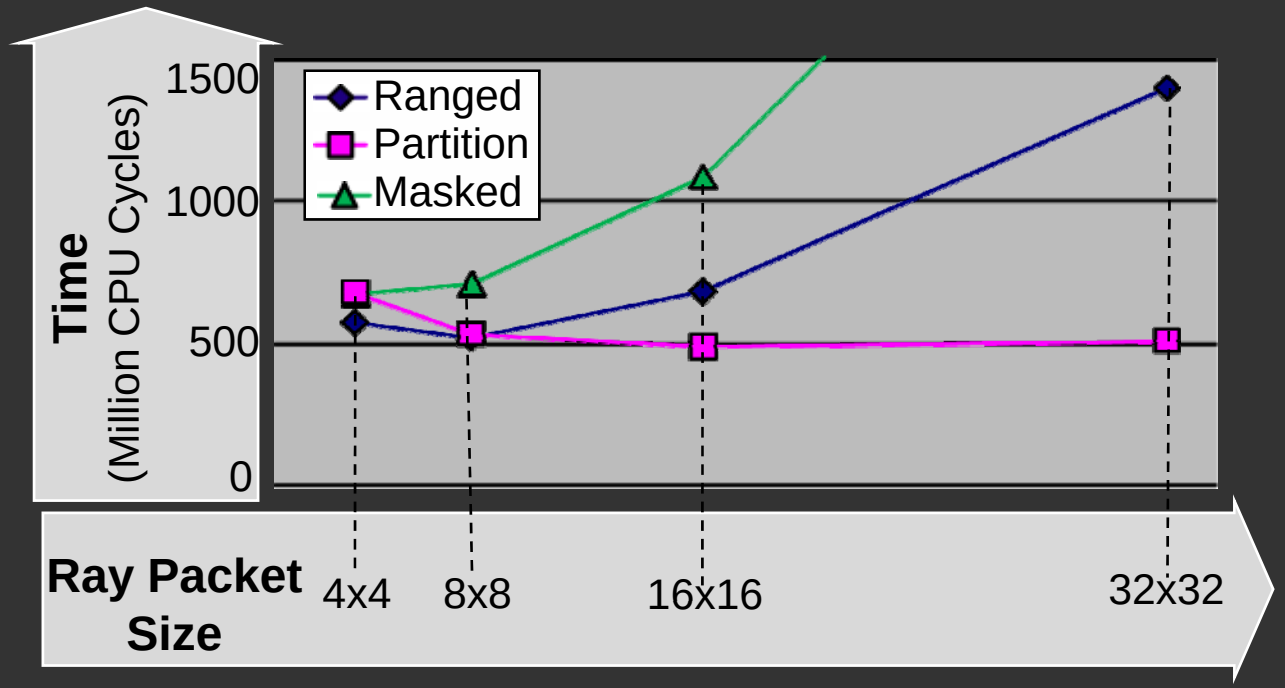


Traversal vs. Ray Packet Size

- Masked Traversal: performance degrades for > 4x4 packets
- Ranged Traversal: performance degrades for > 8x8 packets
- Paritition Traversal: performance increases with packet size



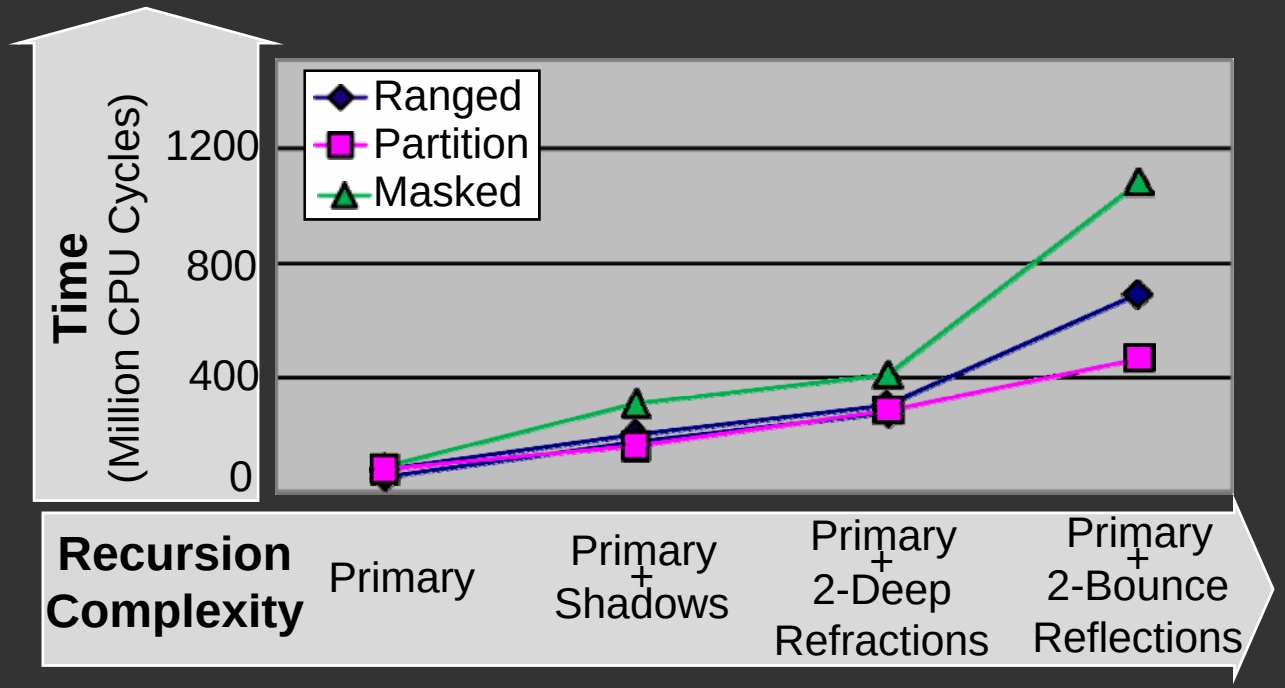
Fairy Scene
2-Bounce Reflections



Traversal vs. Recursion Complexity

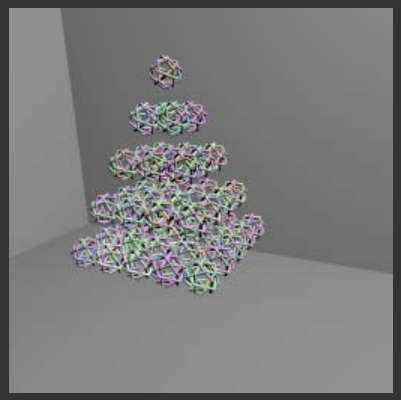
- Masked Traversal: Degrades with recursion complexity
- Ranged Traversal: Degrades with recursion complexity
- Partition Traversal: More robust to increasing recursion complexity

Fairy Scene
16x16 Packets

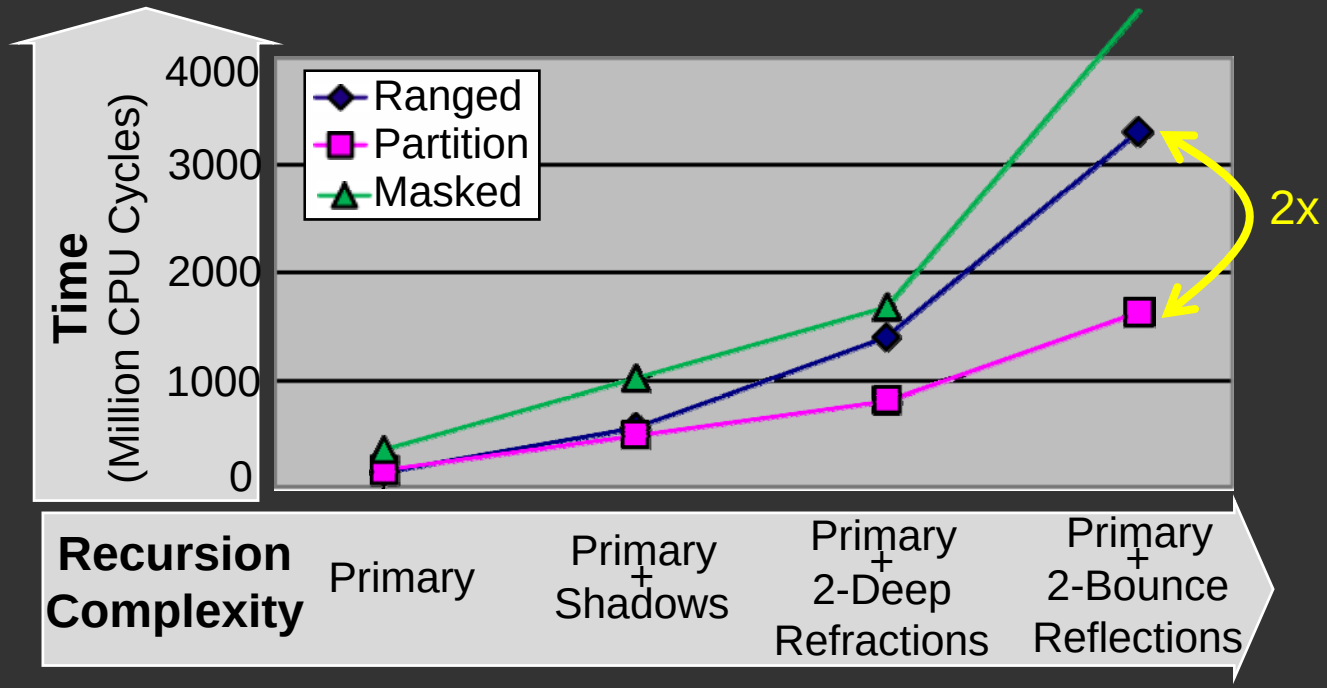


Traversal vs. Recursion Complexity

- Difference between Partition and Ranged more pronounced on more complex scenes

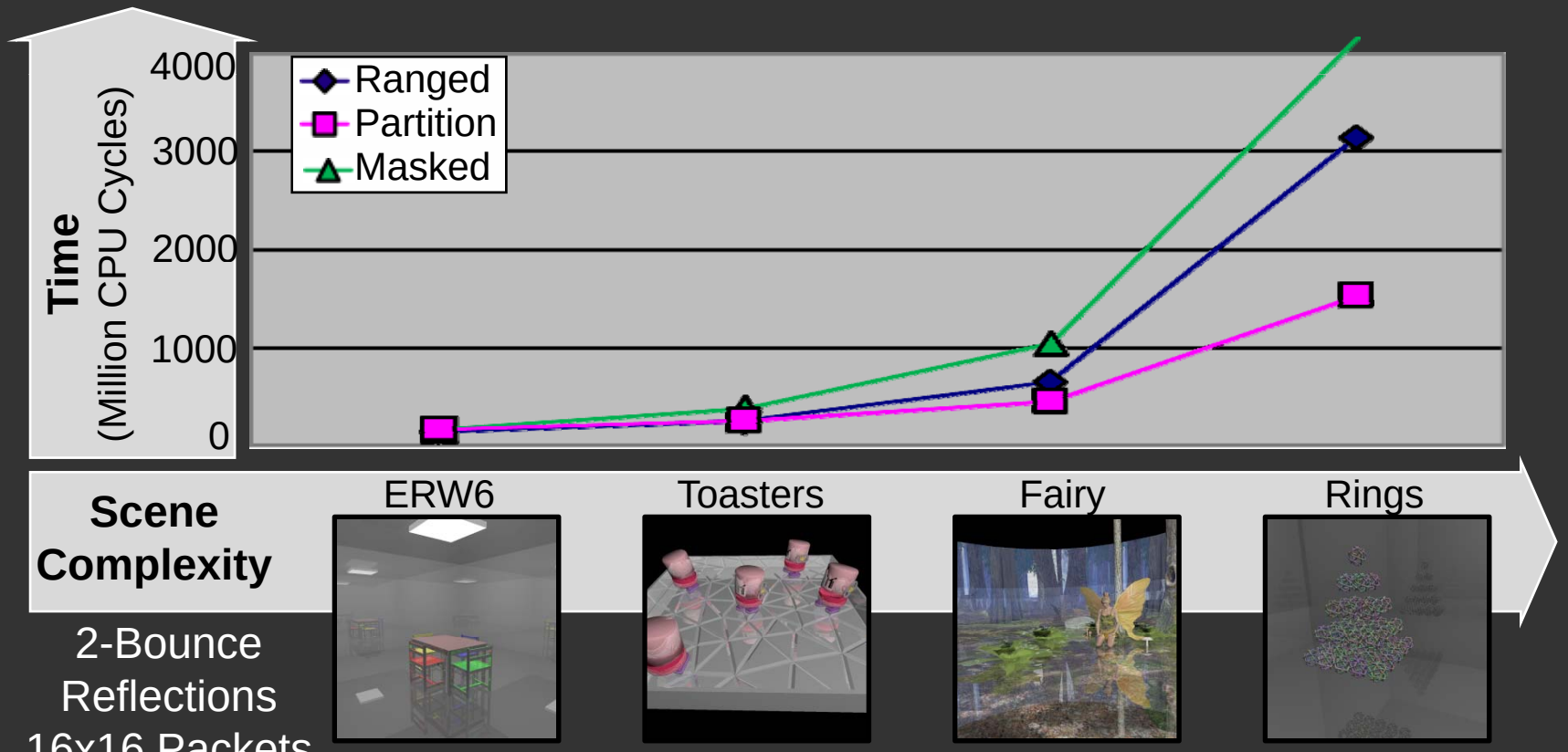


Rings Scene
16x16 Packets



Traversal vs. Scene Complexity

- Ranged Traversal: Degrades with scene complexity
- Partition Traversal: More robust to increasing scene complexity



Ranged vs. Partition Traversal

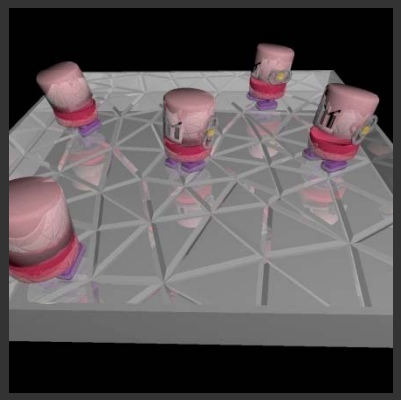
- Ranged Traversal
  - Most ray—cell tests deep in BVH
  - More extra ray—triangle tests for incoherent rays
- Partition Traversal
  - Most ray—cell tests high in BVH
  - No extra ray—triangle tests

Traversal: Summary

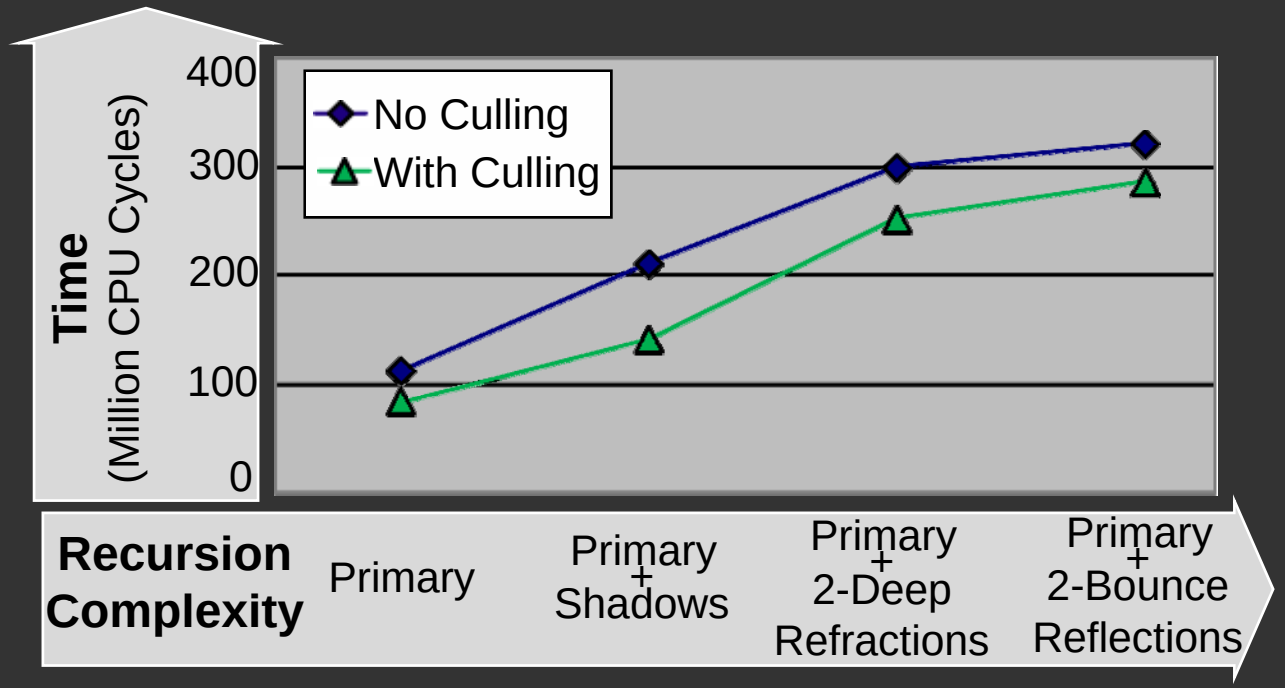
- Use Ranged Traversal
  - Primary rays and coherent point-light shadow rays
  - Small to medium packets: <= 8x8 rays
- Use Partition Traversal
  - Incoherent rays: deep reflections + refractions
  - Large ray packets: > =16x16 rays

Frustum Culling vs. Recursion Complexity

- Frustum culling provides modest benefits



Toasters Scene
16x16 Packets

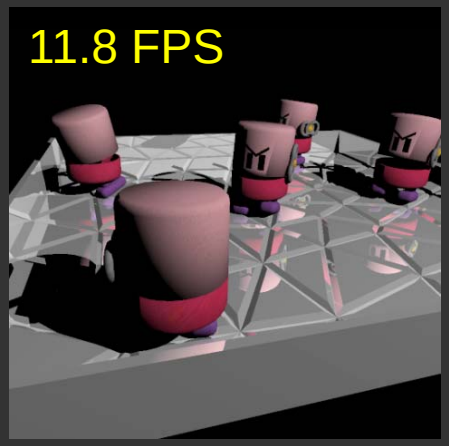


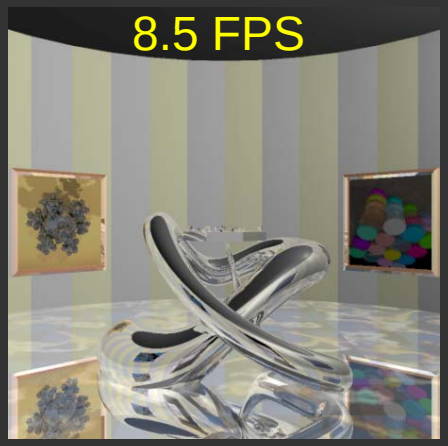
Frustum Culling: Summary

- Primary + Point-light Shadows
  - Up to 2x performance benefit possible
  - But more often ~1.5x or less
- Reflections + Refractions
  - Expect 1.2x – 1.3x performance benefit

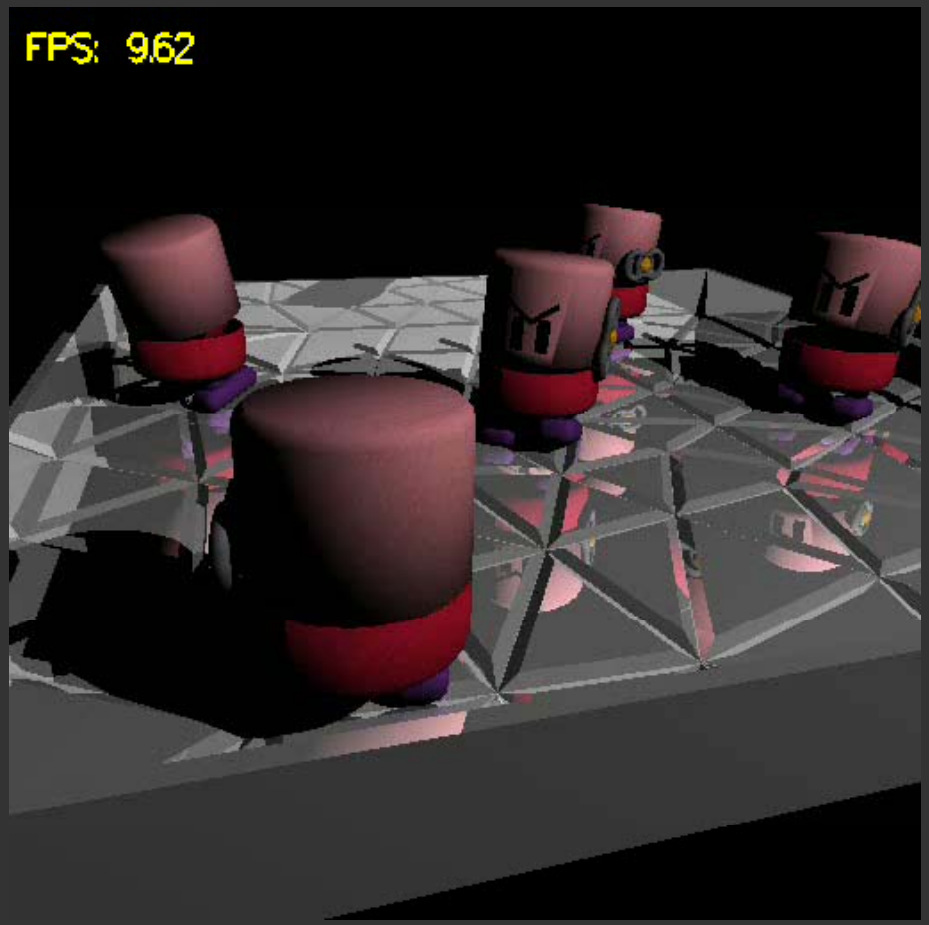
Conclusion

- Use ranged and partition traversal in correct situation
- 16x16 packets: 3x – 6x benefit over 2x2
- Whitted Ray Tracing is now interactive to real-time



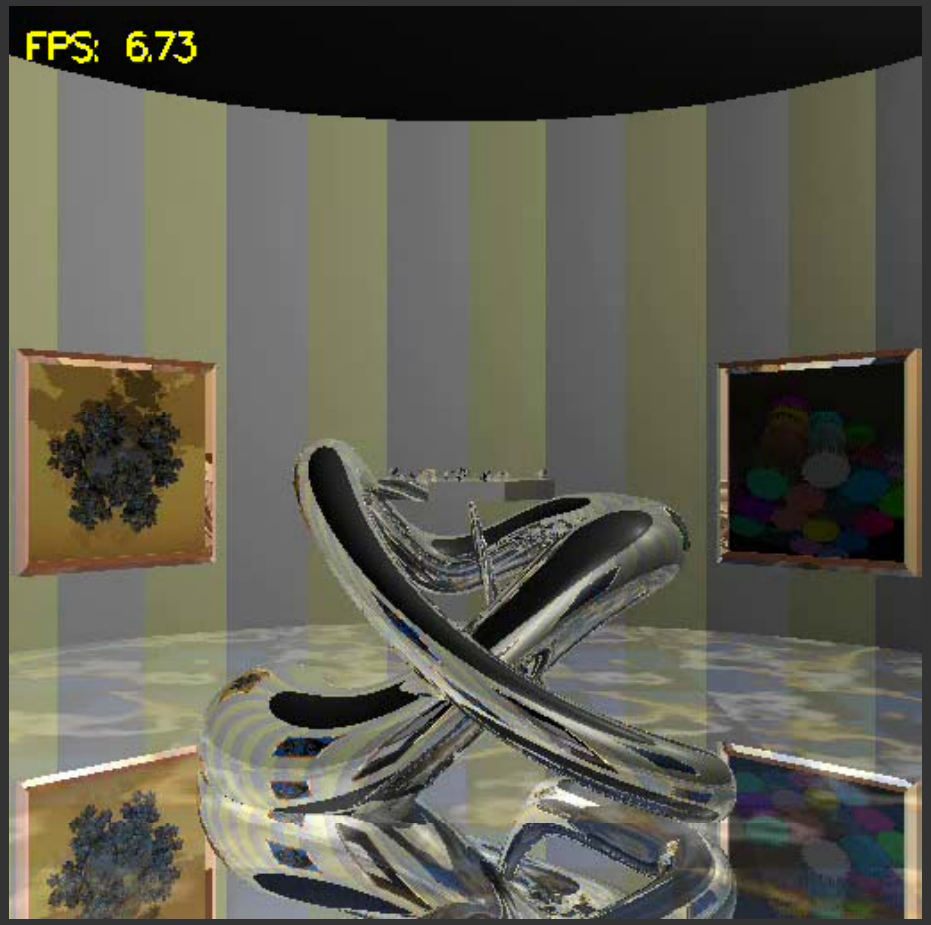


Real-Time Whitted Ray Tracing



- Primary Visibility
  - Ranged Traversal
- Point-Light
  - Ranged Traversal
- 1-Bounce Reflections
  - Ranged Traversal

Conclusion



- Primary Visibility
  - Ranged Traversal
- 3-Bounce Reflections
  - Partition Traversal

Conclusion

- Primary Visibility
  - Ranged Traversal
- Point-Light Shadows
  - Partition Traversal
- 3-Deep Refractions
  - Partition Traversal
- 1-Bounce Reflections
  - Partition Traversal

Acknowledgements

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  - Lab mates at Columbia University.
- Paid for by:
  - NSF (grants CCF 03-05322, CCF 04-46916, CCF 07-01775), a Sloan Research Fellowship, and an ONR Young Investigator Award N00014-17-1-0900.
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Questions?