Space-Time Hierarchical Occlusion Culling for Micropolygon Rendering with Motion Blur

Solomon Boulos, Edward Luong, Kayvon Fatahalian, Henry Moreton, Pat Hanrahan

HPG 2010

High interest in Motion Blur

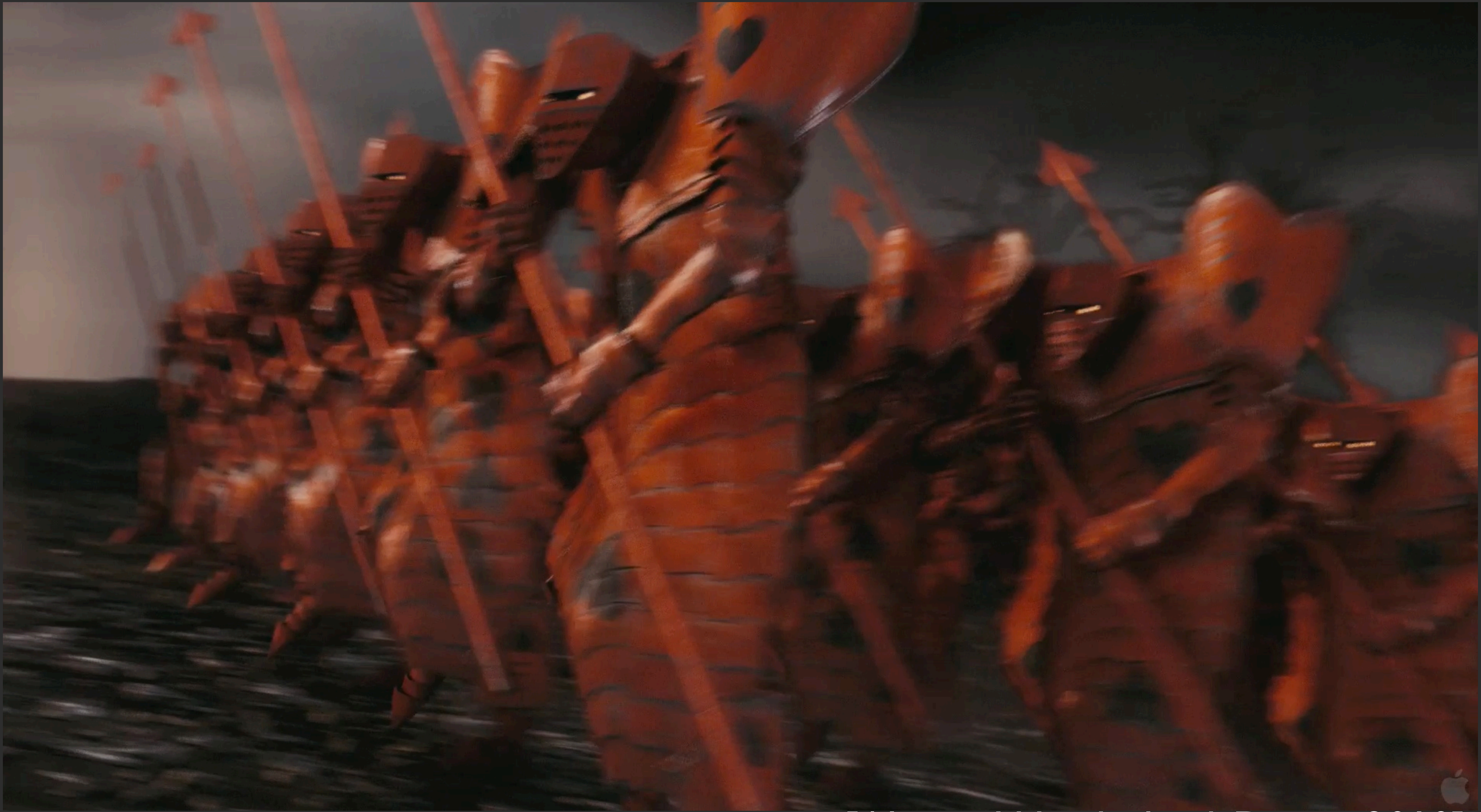
- [Akenine-Moller et al. EGSR 2007]
- [Fatahalian et al. HPG 2009]
- Three more papers here
- This paper: occlusion with motion blur

[Luxo Jr., Pixar 1986]

SALE
Clearance

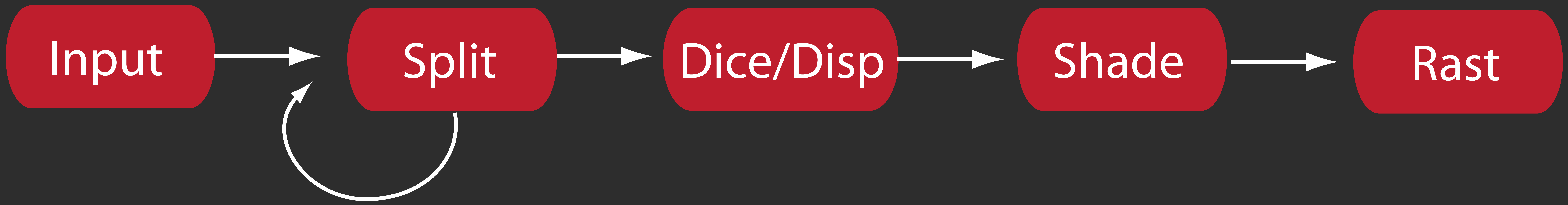
[Red’s Dream, Pixar 1987]

[Alice in Wonderland, Disney 2010]

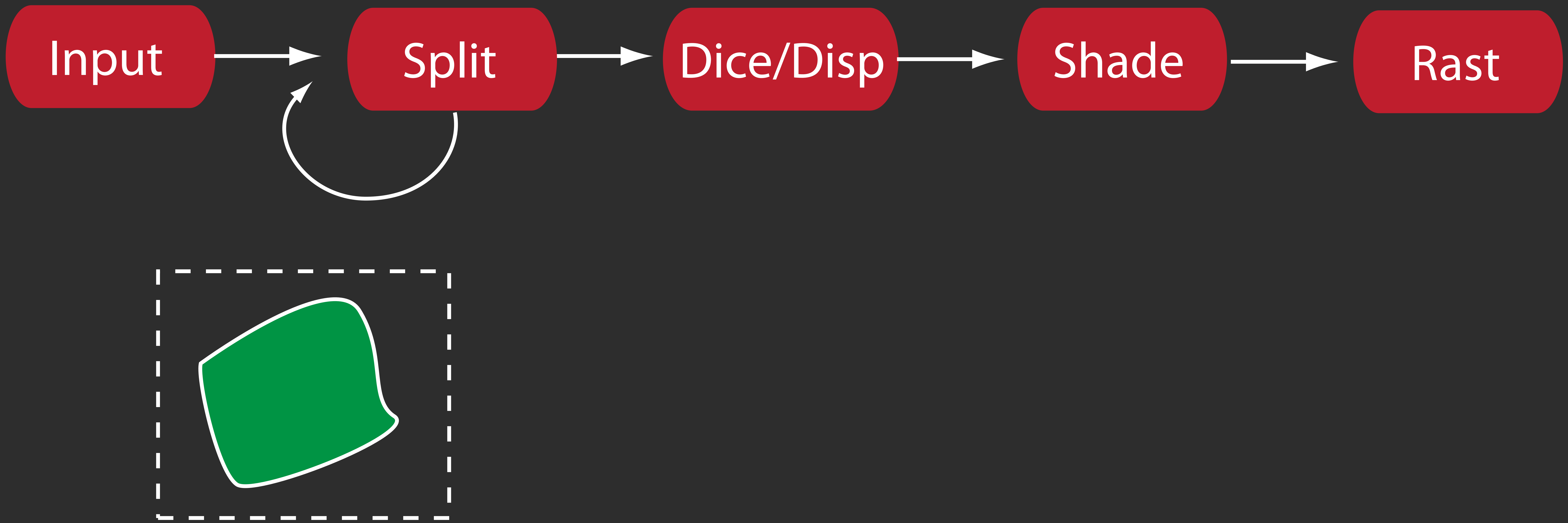


[Alice in Wonderland, Disney 2010]

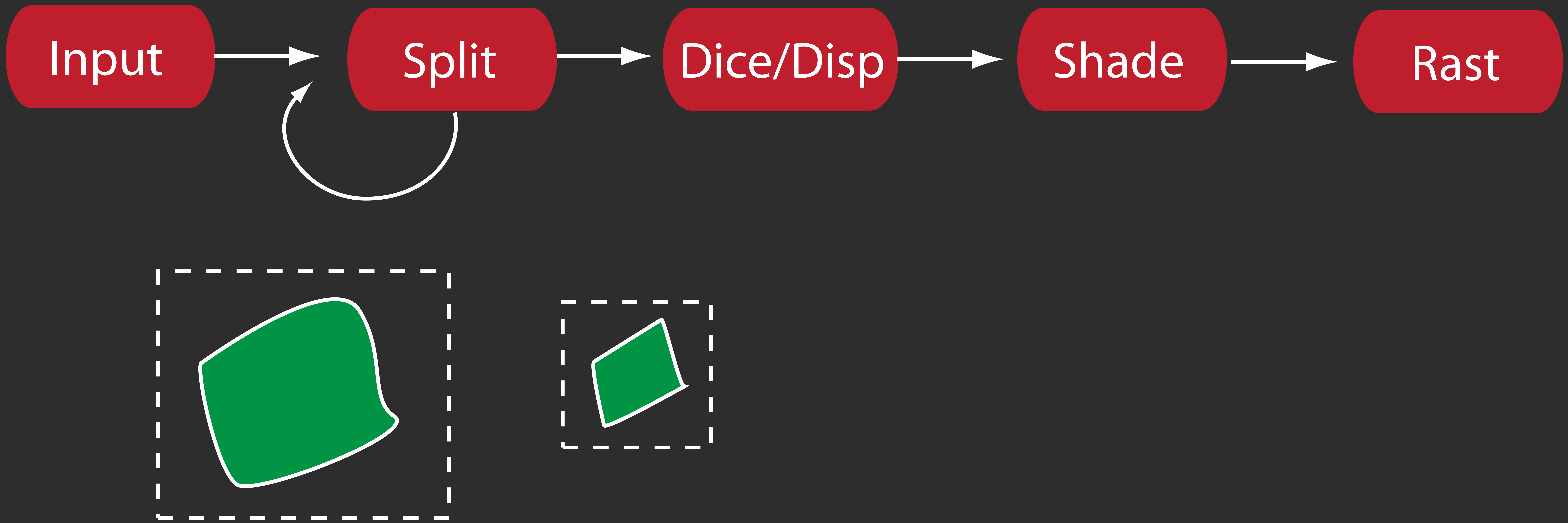
Culling: Cost/Benefit Tradeoff



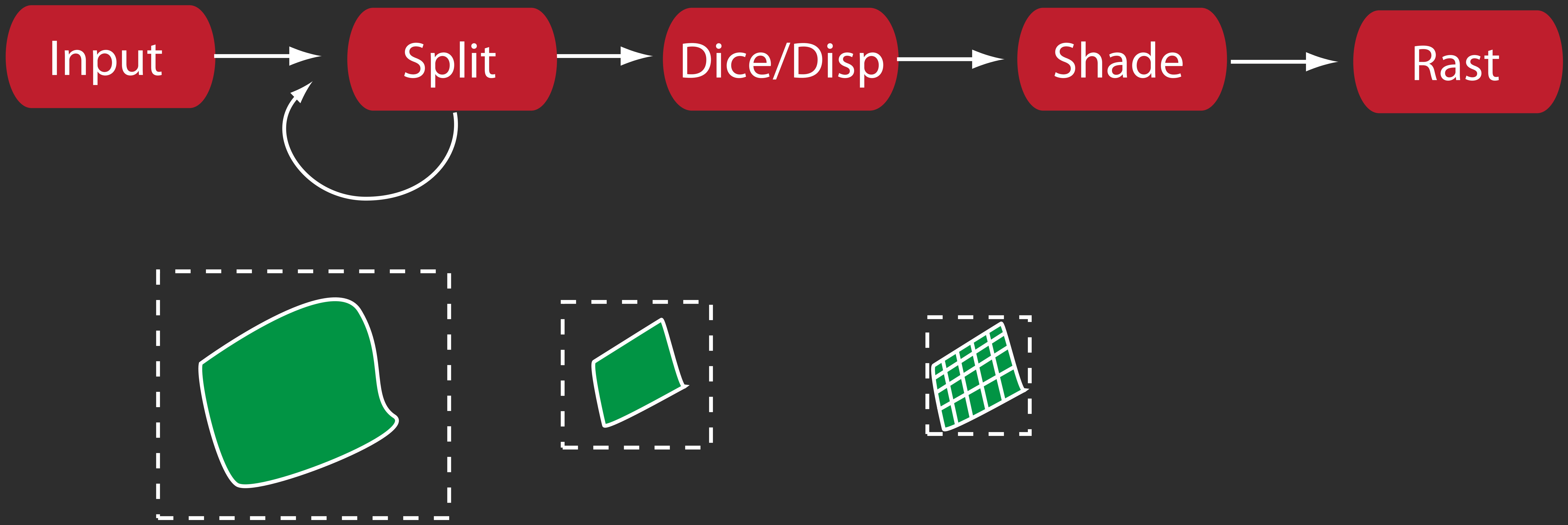
Culling: Cost/Benefit Tradeoff



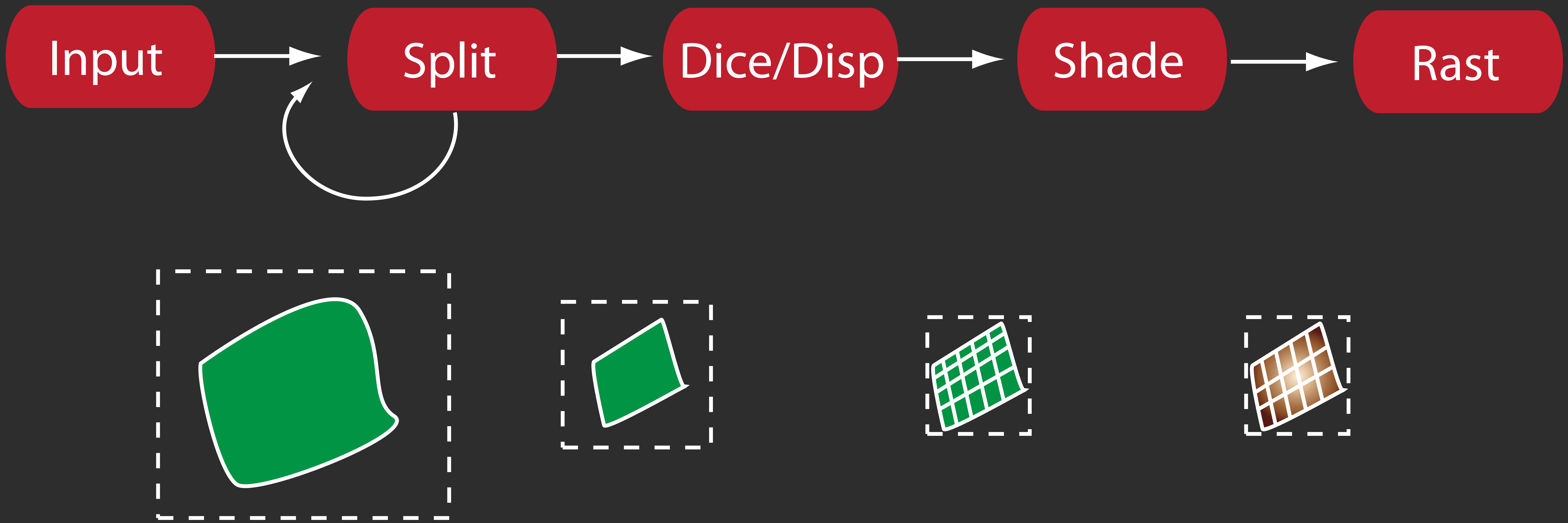
Culling: Cost/Benefit Tradeoff



Culling: Cost/Benefit Tradeoff



Culling: Cost/Benefit Tradeoff



Contributions

- TZ-Pyramid: Data structure for efficient hierarchical occlusion culling with motion blur
- Analysis: where to use the tz-pyramid in a micropolygon pipeline to optimize the cost/benefit tradeoff

Background
(Occlusion culling without motion blur)

Image Space Z-pyramid

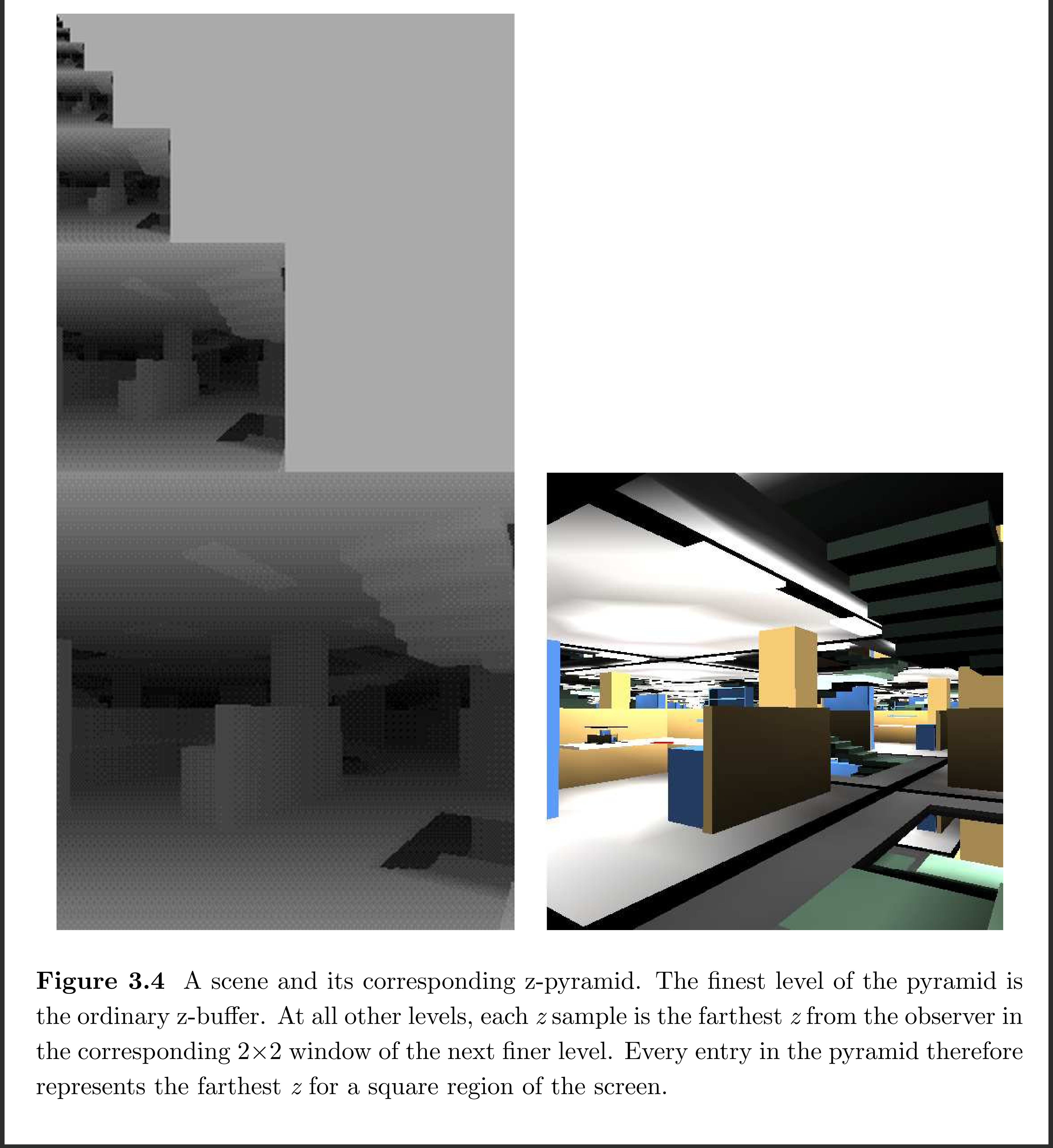
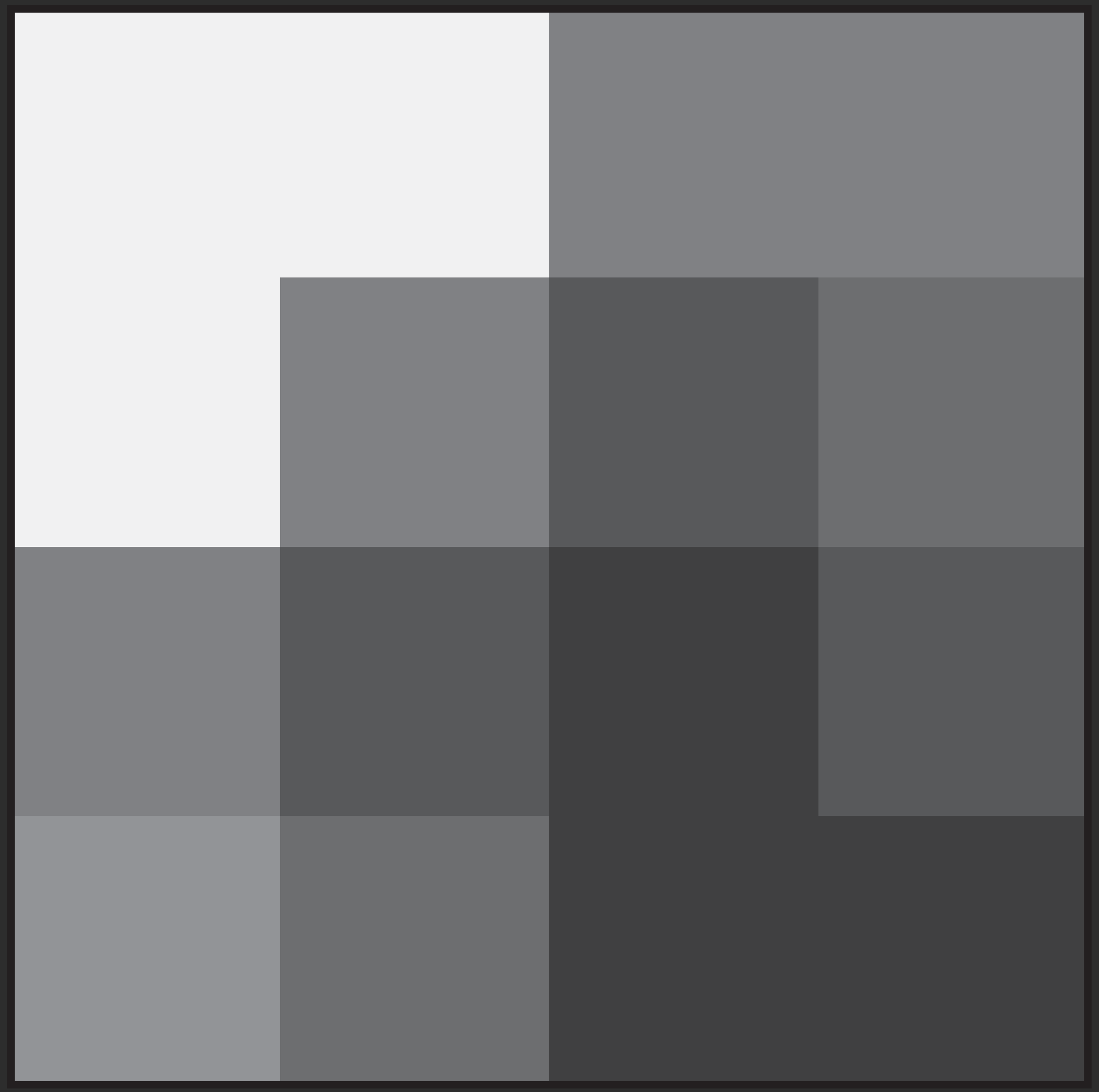


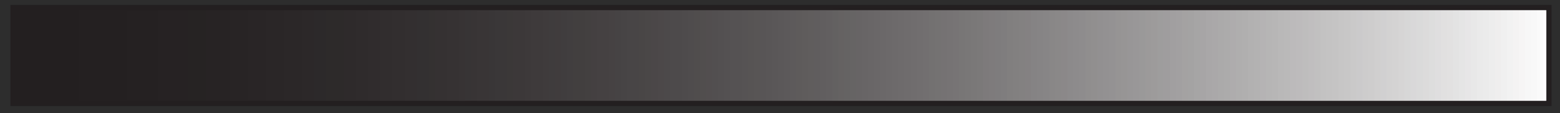
Figure 3.4 A scene and its corresponding z-pyramid. The finest level of the pyramid is the ordinary z-buffer. At all other levels, each z sample is the farthest z from the observer in the corresponding 2×2 window of the next finer level. Every entry in the pyramid therefore represents the farthest z for a square region of the screen.

[Greene et al. 1993]

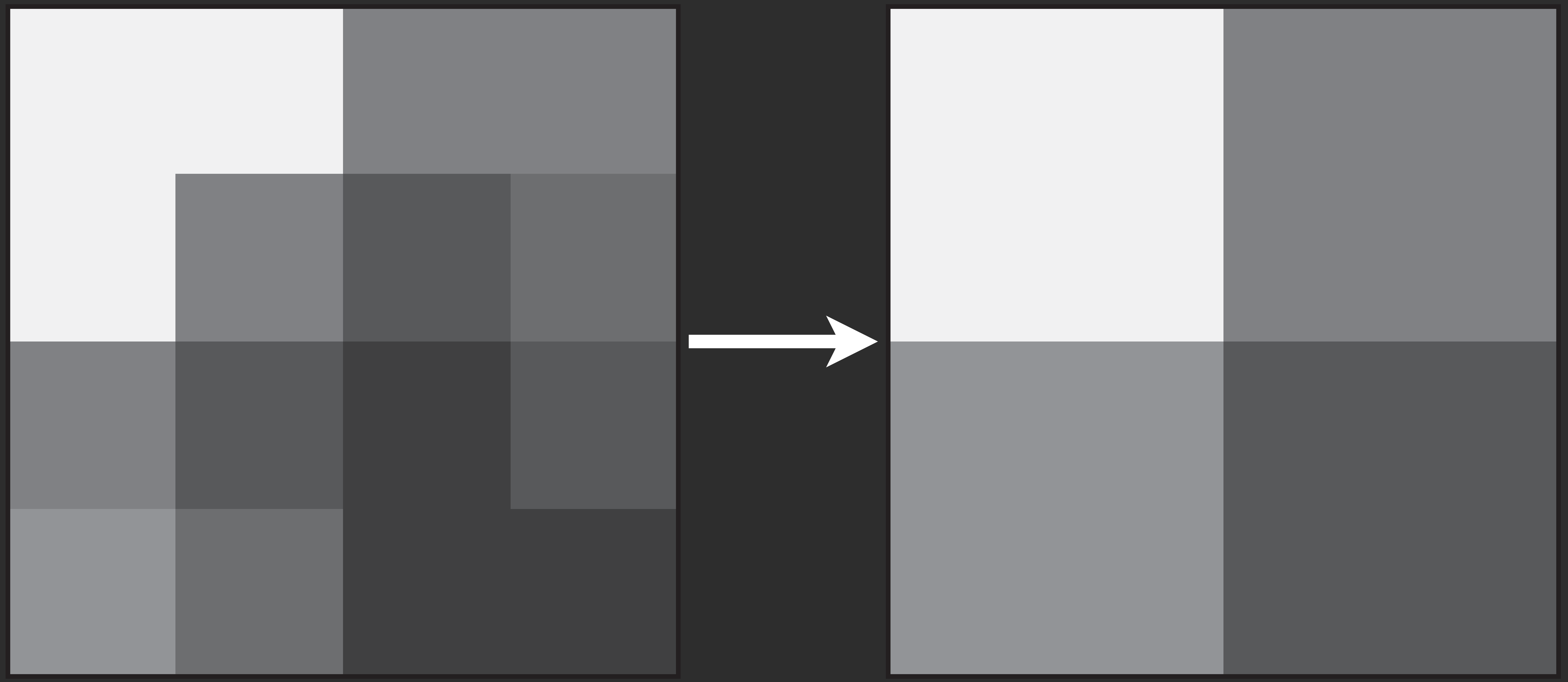
Z-pyramid Update



Multi-sample

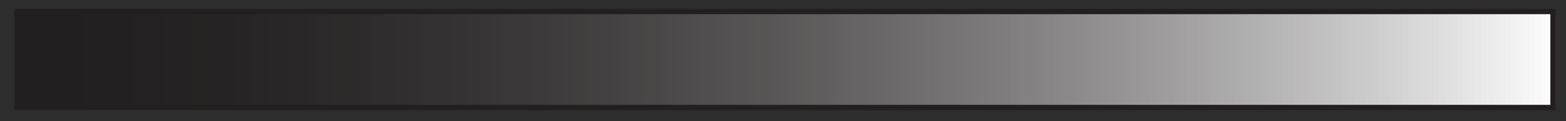


Z-pyramid Update



Multi-sample

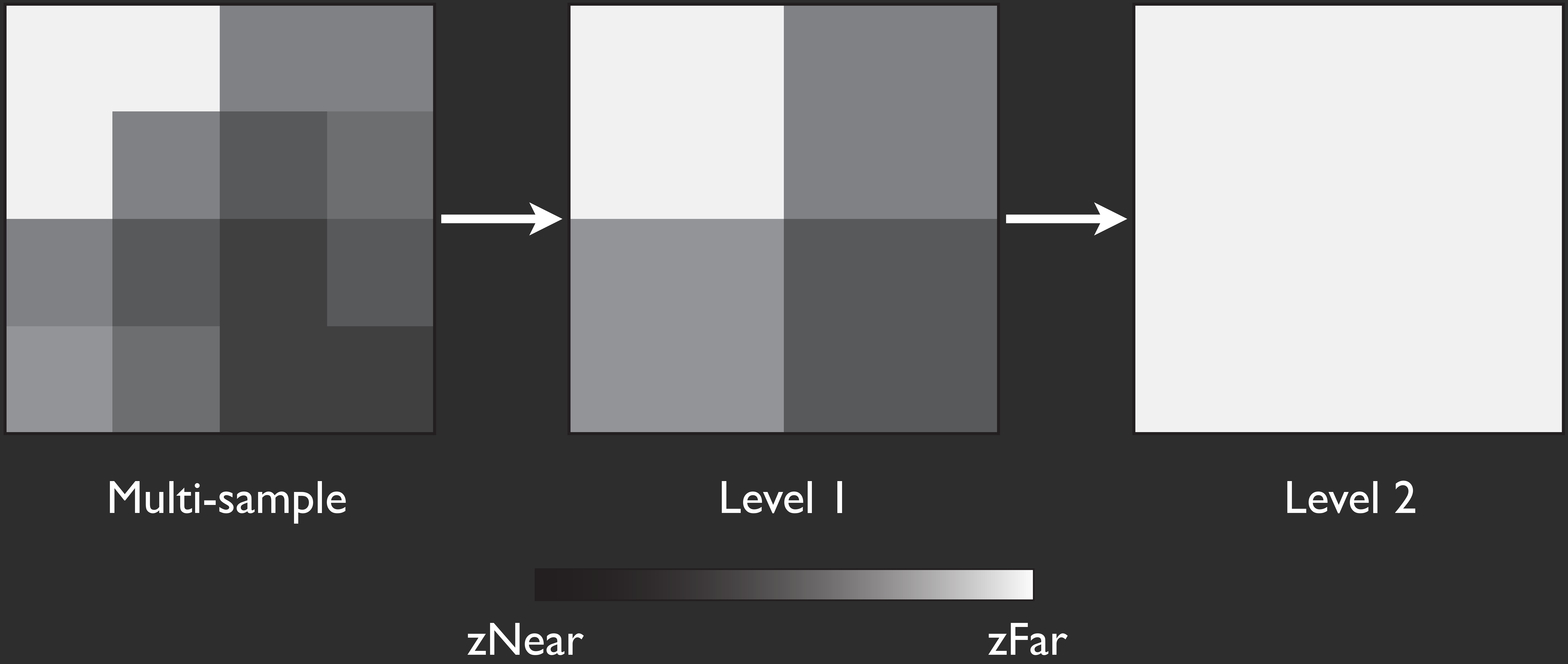
Level 1



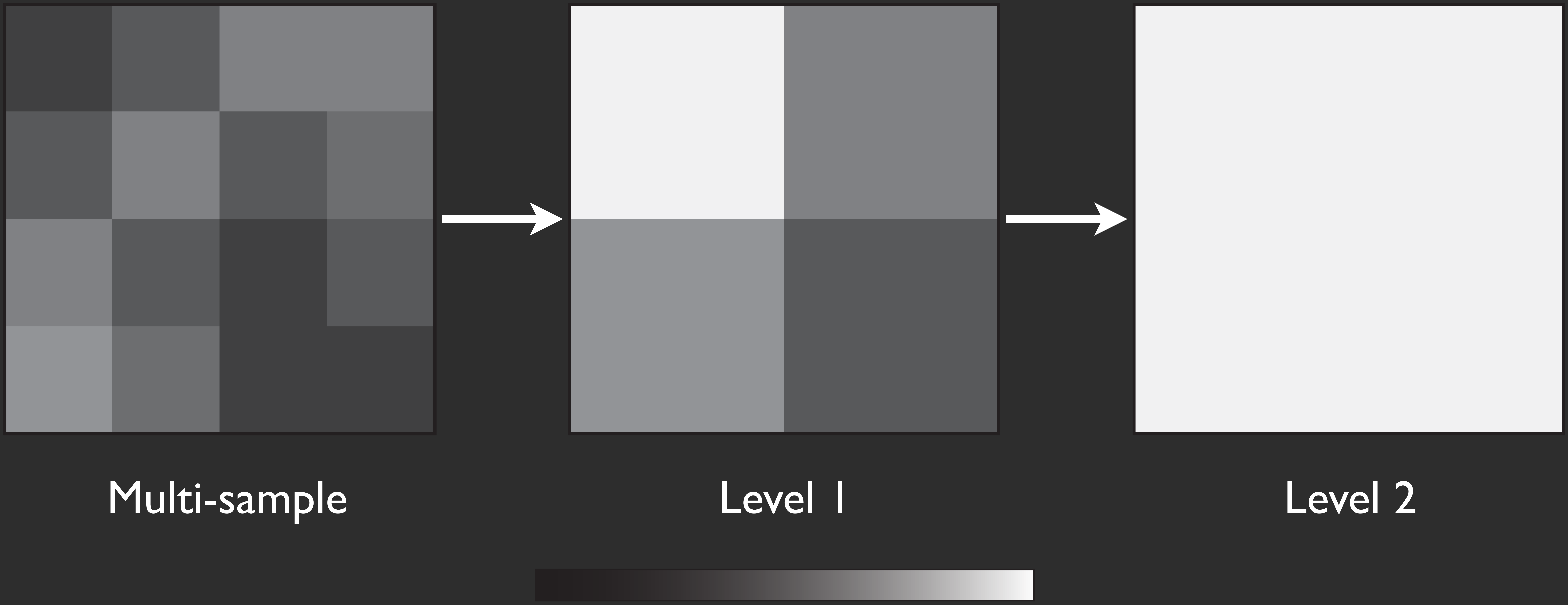
zNear

zFar

Z-pyramid Update



Z-pyramid Update



Multi-sample

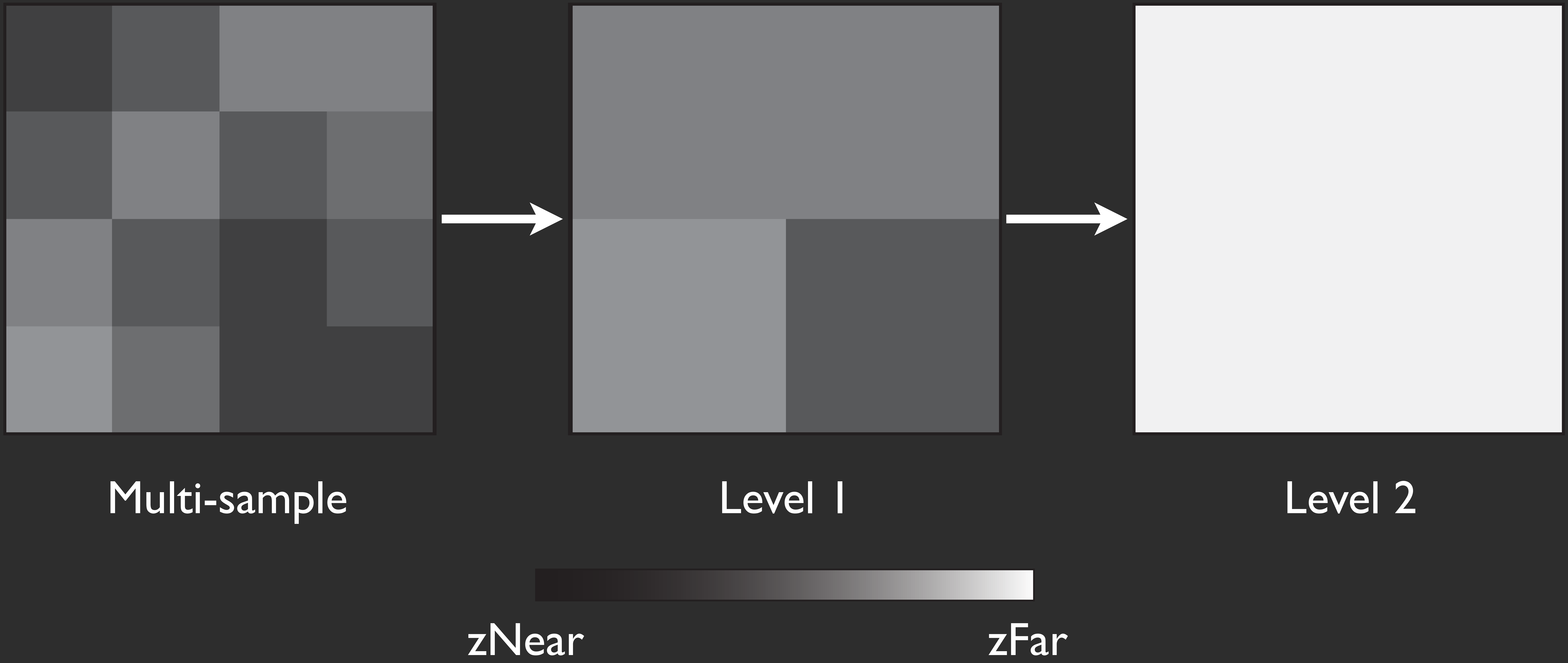
Level 1

Level 2

zNear

zFar

Z-pyramid Update



Multi-sample

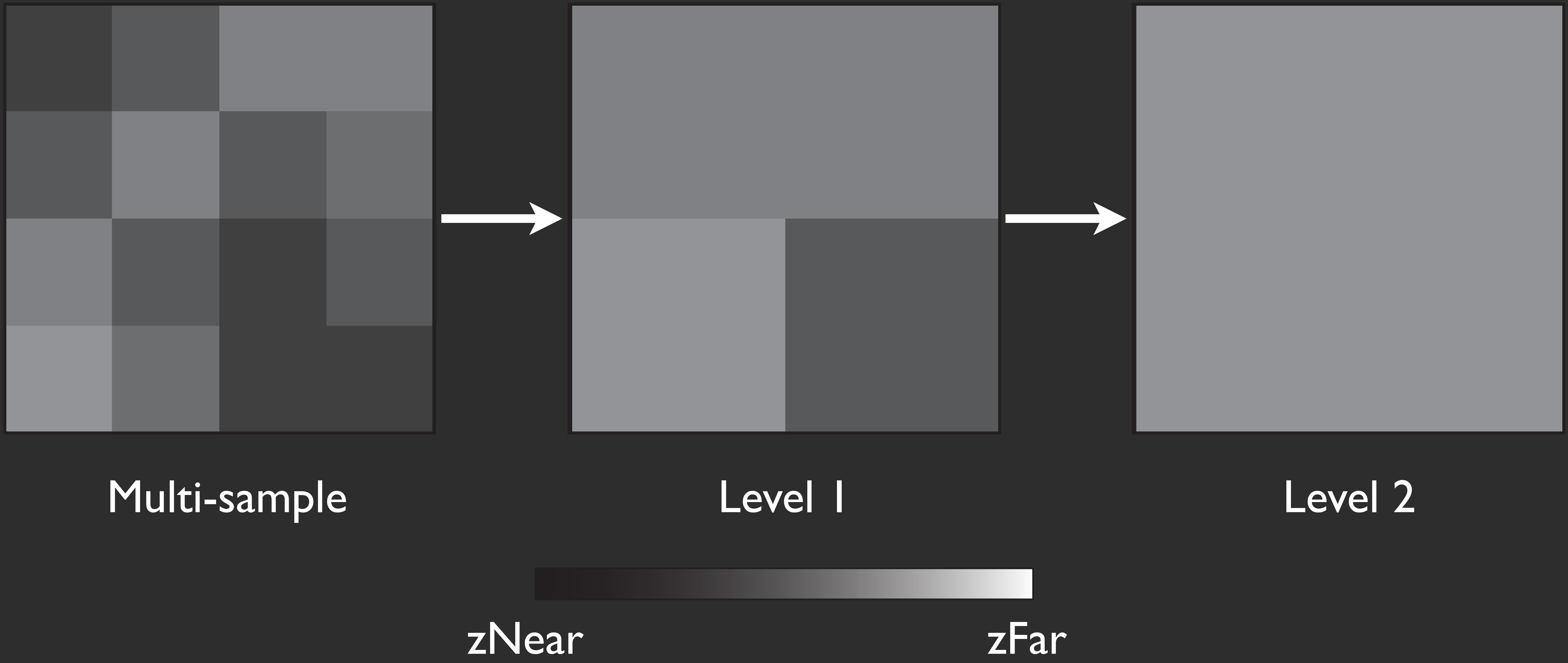
Level 1

Level 2

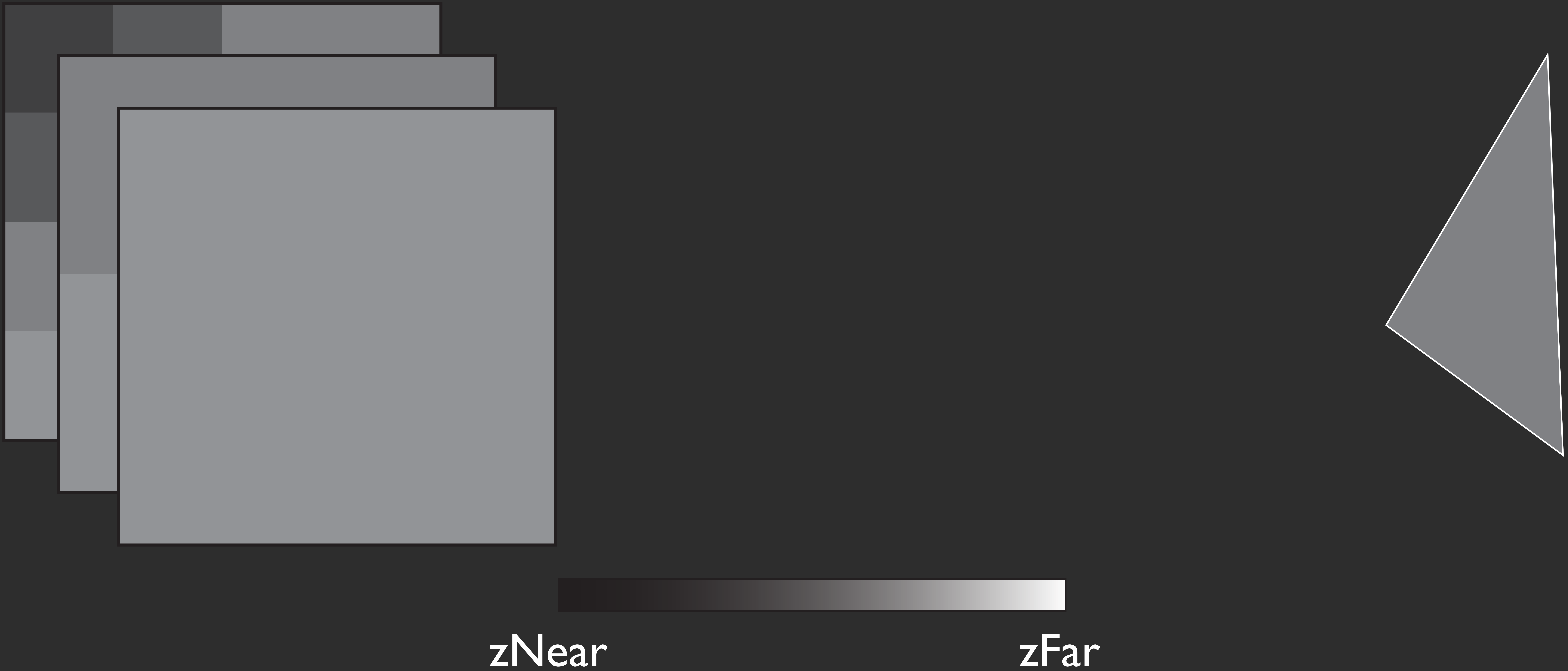
zNear

zFar

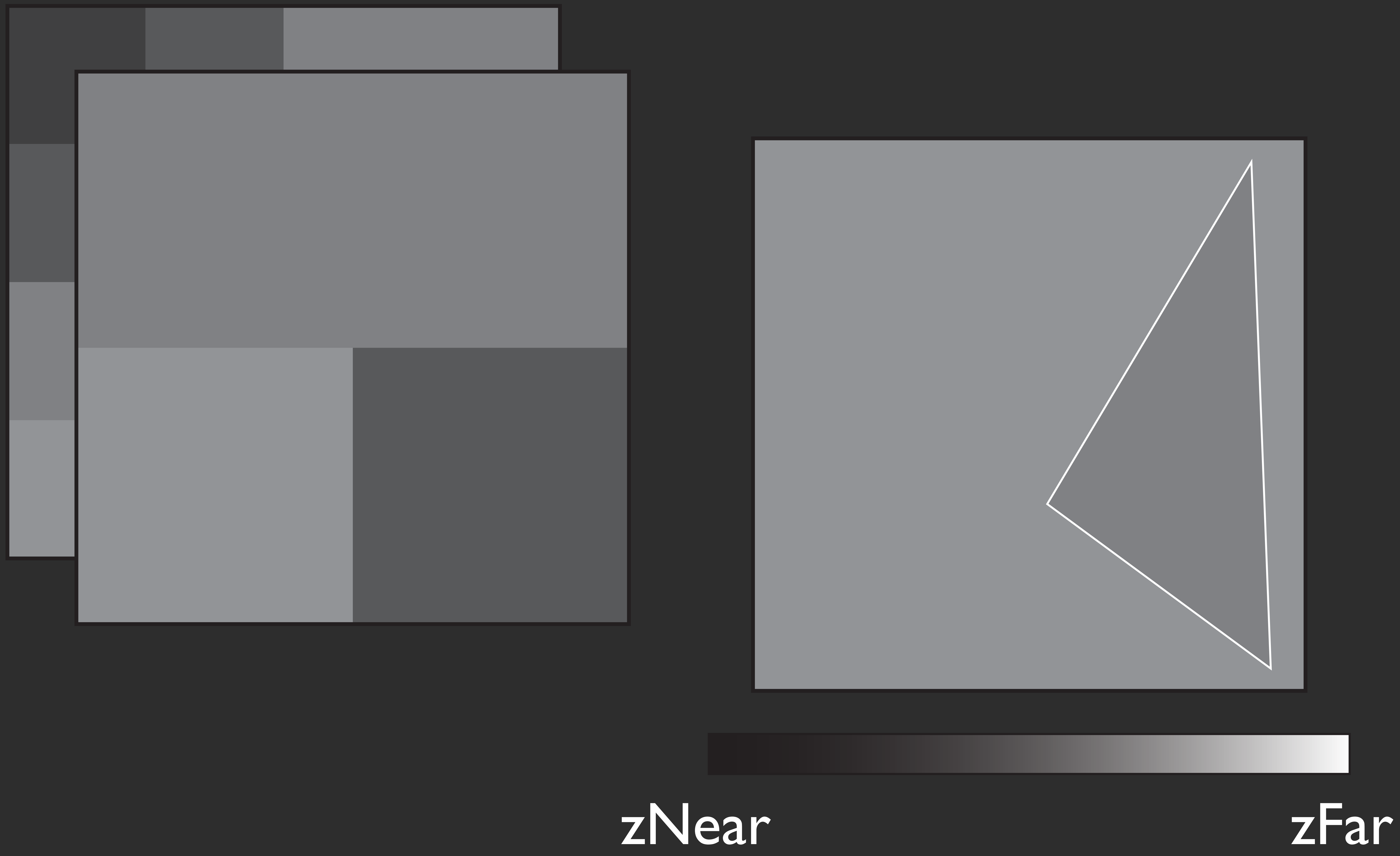
Z-pyramid Update



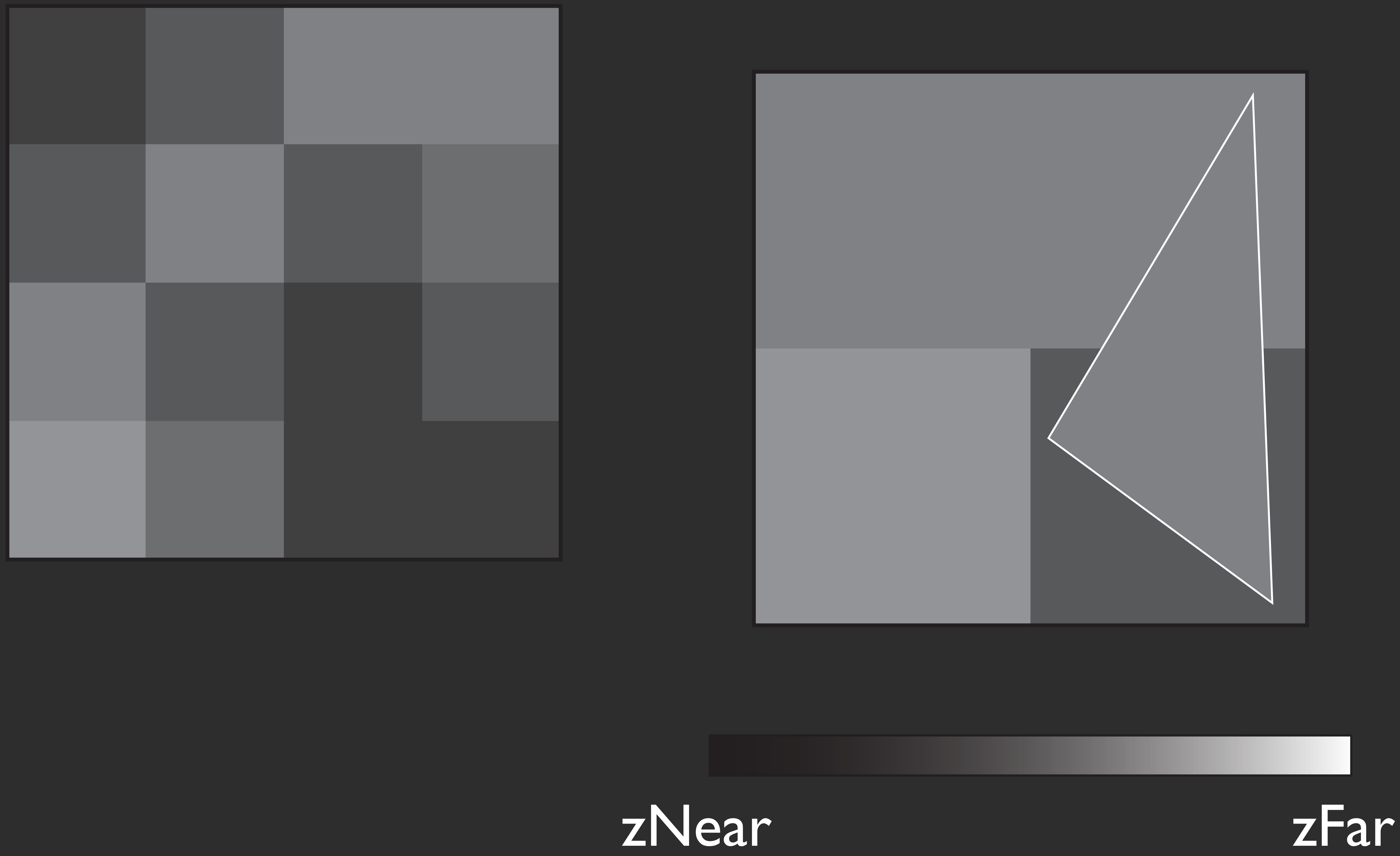
Z-pyramid Culling



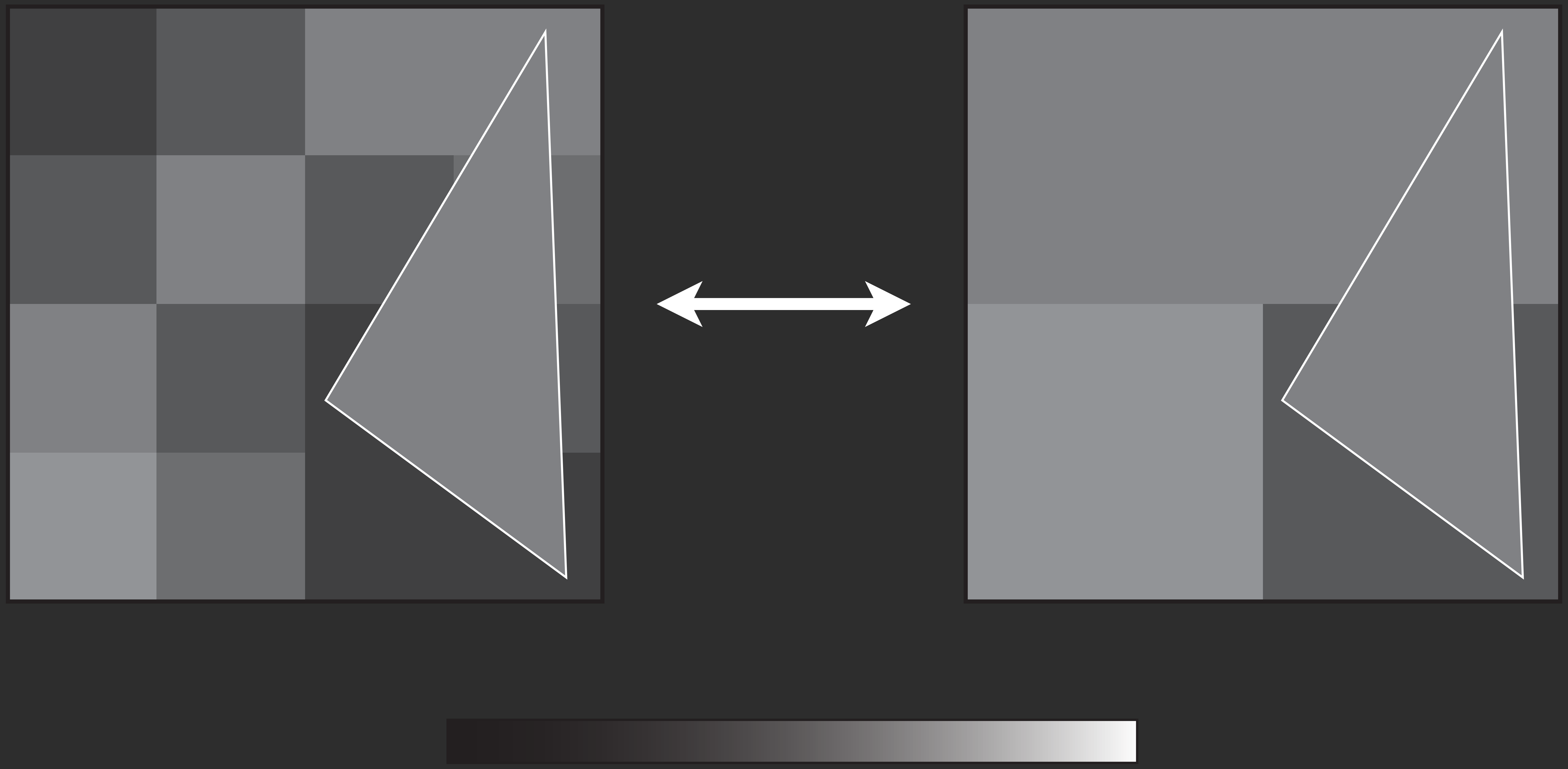
Z-pyramid Culling



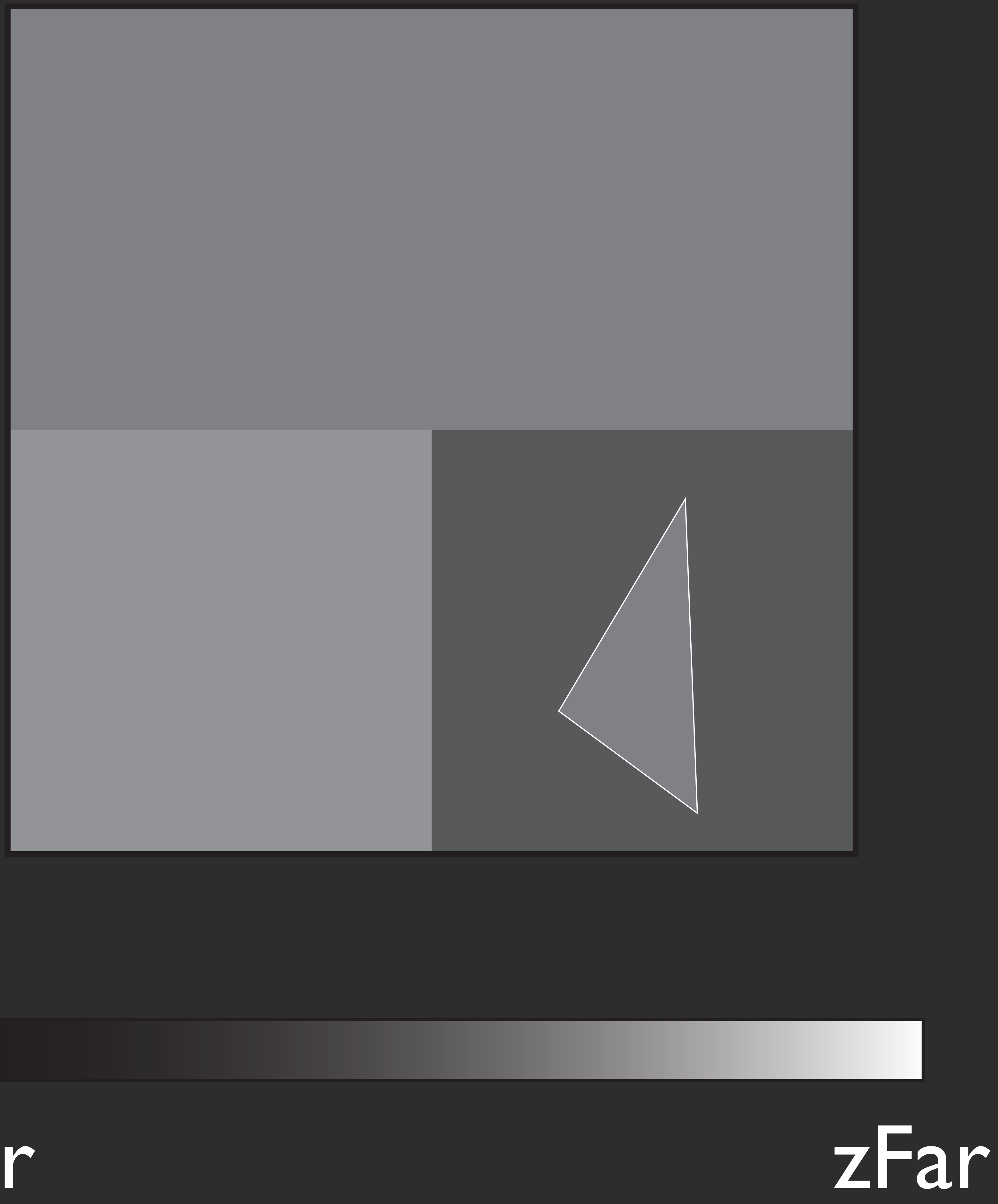
Z-pyramid Culling



Z-pyramid as Acceleration Structure

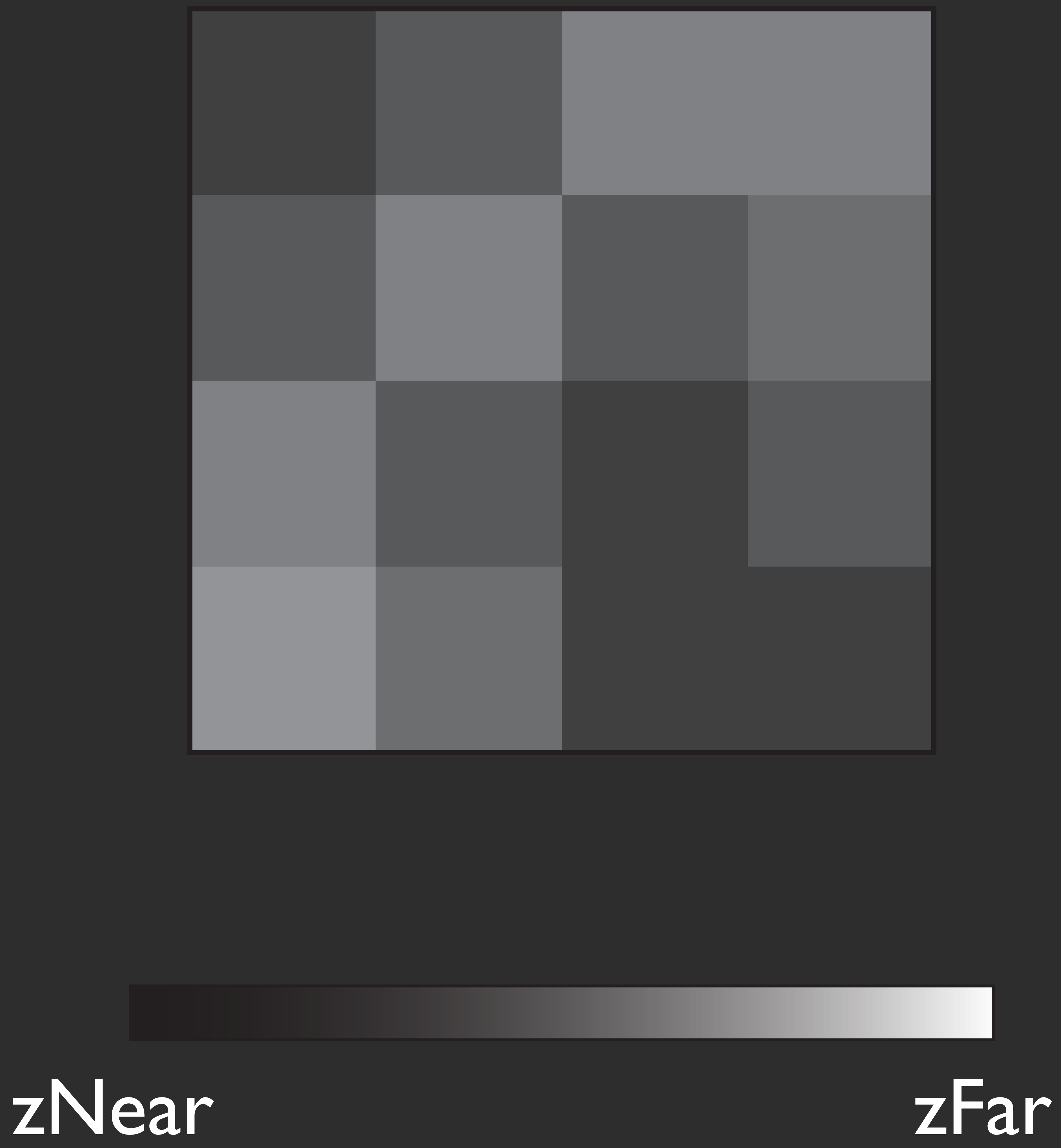


Optimization: Traversal Initialization

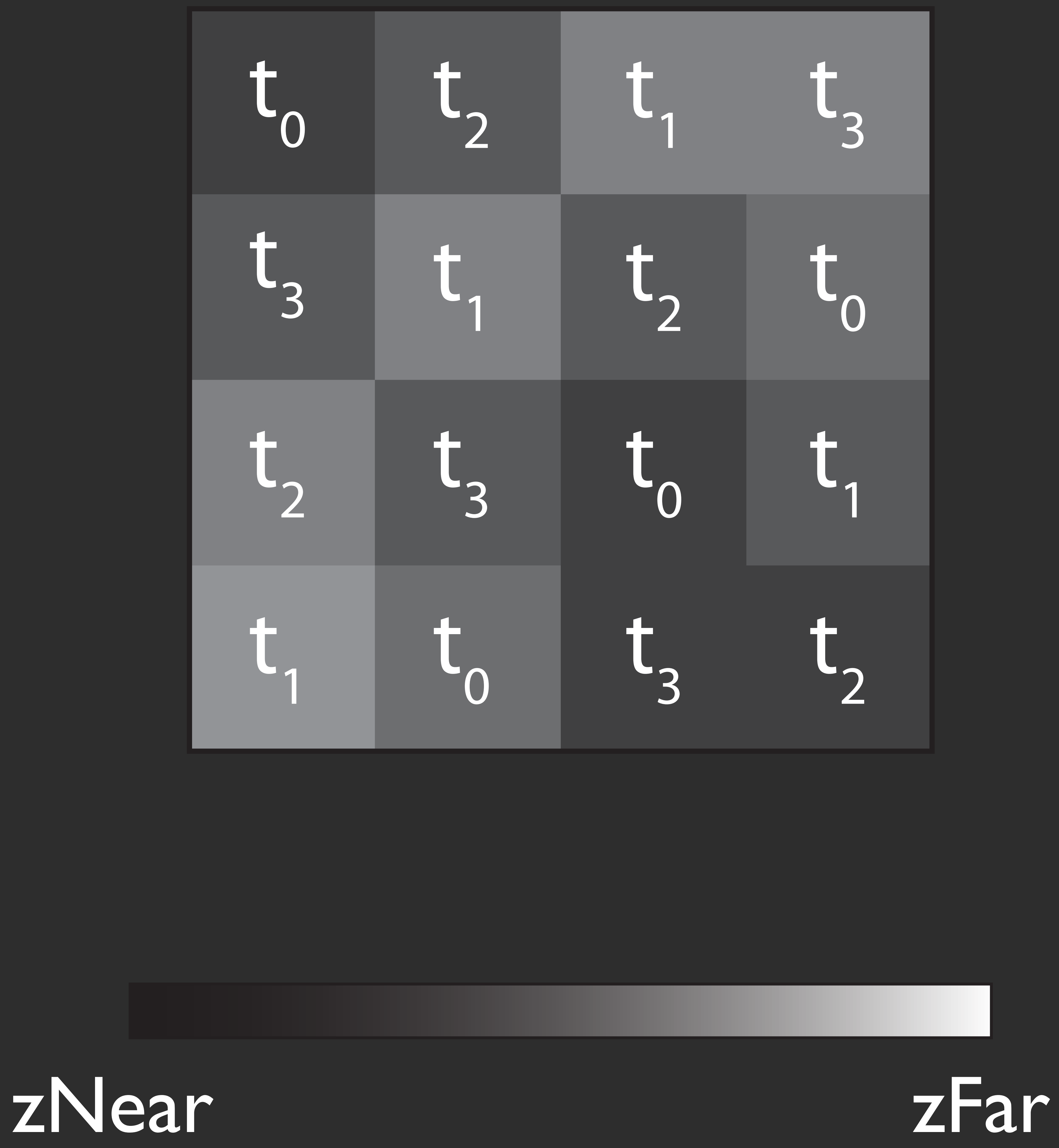


Motion Blur

Switch to Space-Time

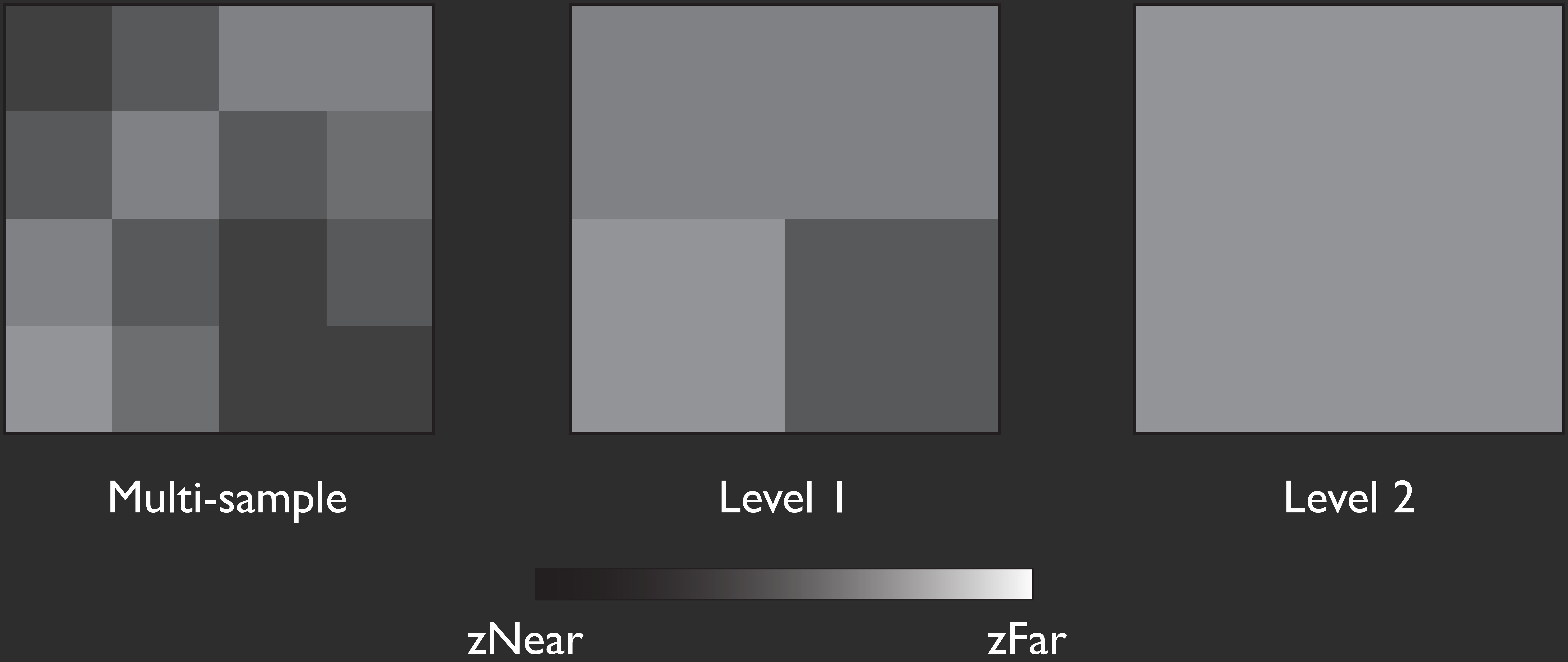


Switch to Space-Time

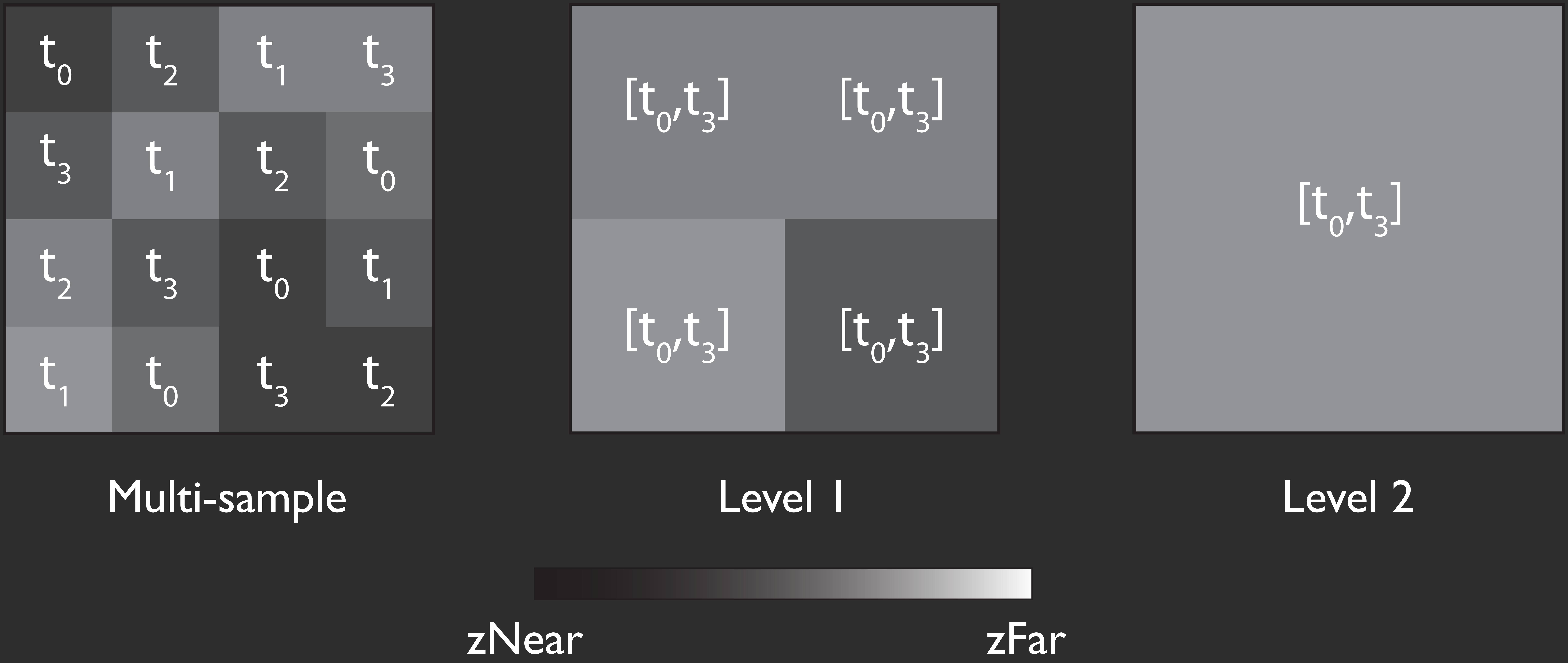


t_0	t_2	t_1	t_3
t_3	t_1	t_2	t_0
t_2	t_3	t_0	t_1
t_1	t_0	t_3	t_2

Idea 1: Reuse the current z-pyramid



Idea 1: Reuse the current z-pyramid



t_0	t_2	t_1	t_3
t_3	t_1	t_2	t_0
t_2	t_3	t_0	t_1
t_1	t_0	t_3	t_2

Multi-sample

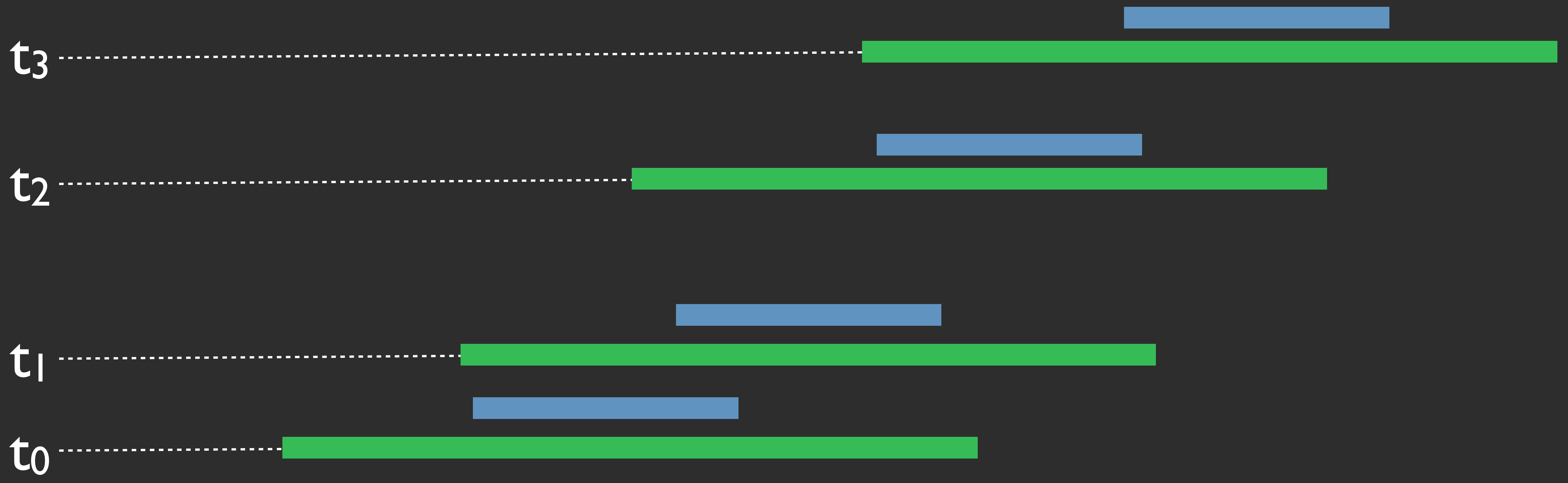
$[t_0,t_3]$	$[t_0,t_3]$
$[t_0,t_3]$	$[t_0,t_3]$

Level 1

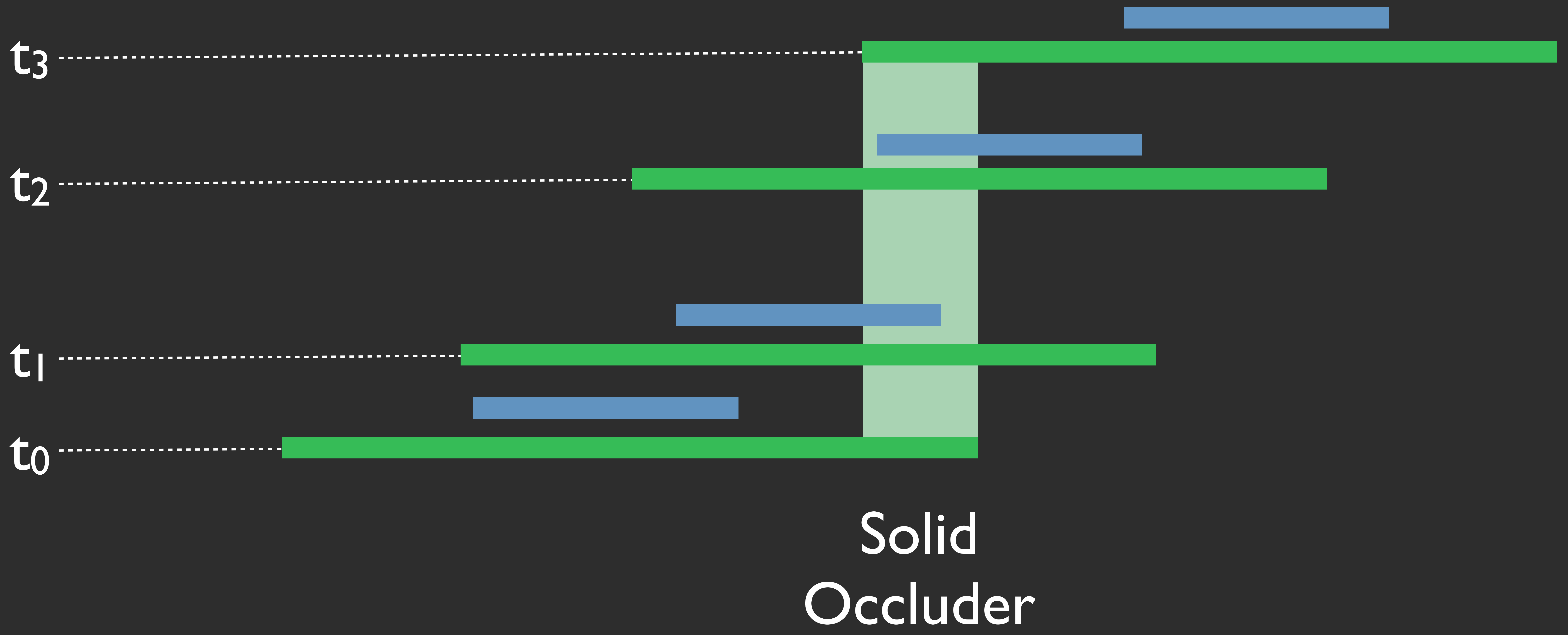
$[t_0,t_3]$

Level 2

Problem: Too Conservative



Problem: Too Conservative



Idea 2: z-pyramid per time

Multi-sample

t_0	t_2	t_1	t_3
t_3	t_1	t_2	t_0
t_2	t_3	t_0	t_1
t_1	t_0	t_3	t_2

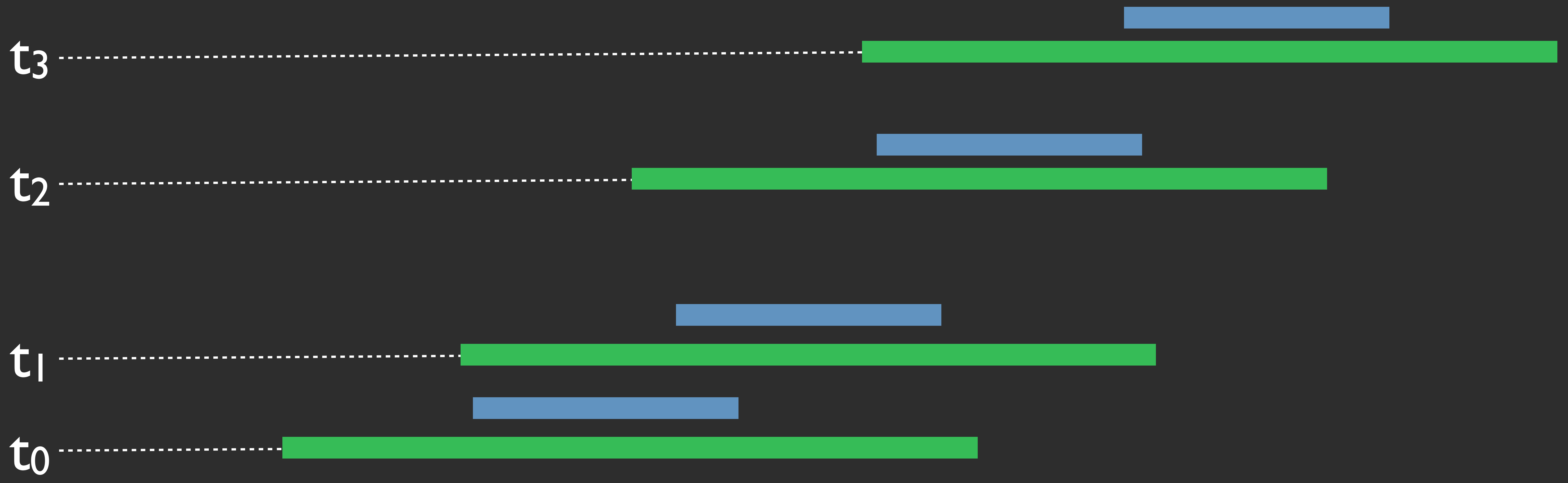
Level 1

t_0	t_0	t_1	t_1	t_2	t_2	t_3	t_3
t_0	t_0	t_1	t_1	t_2	t_2	t_3	t_3

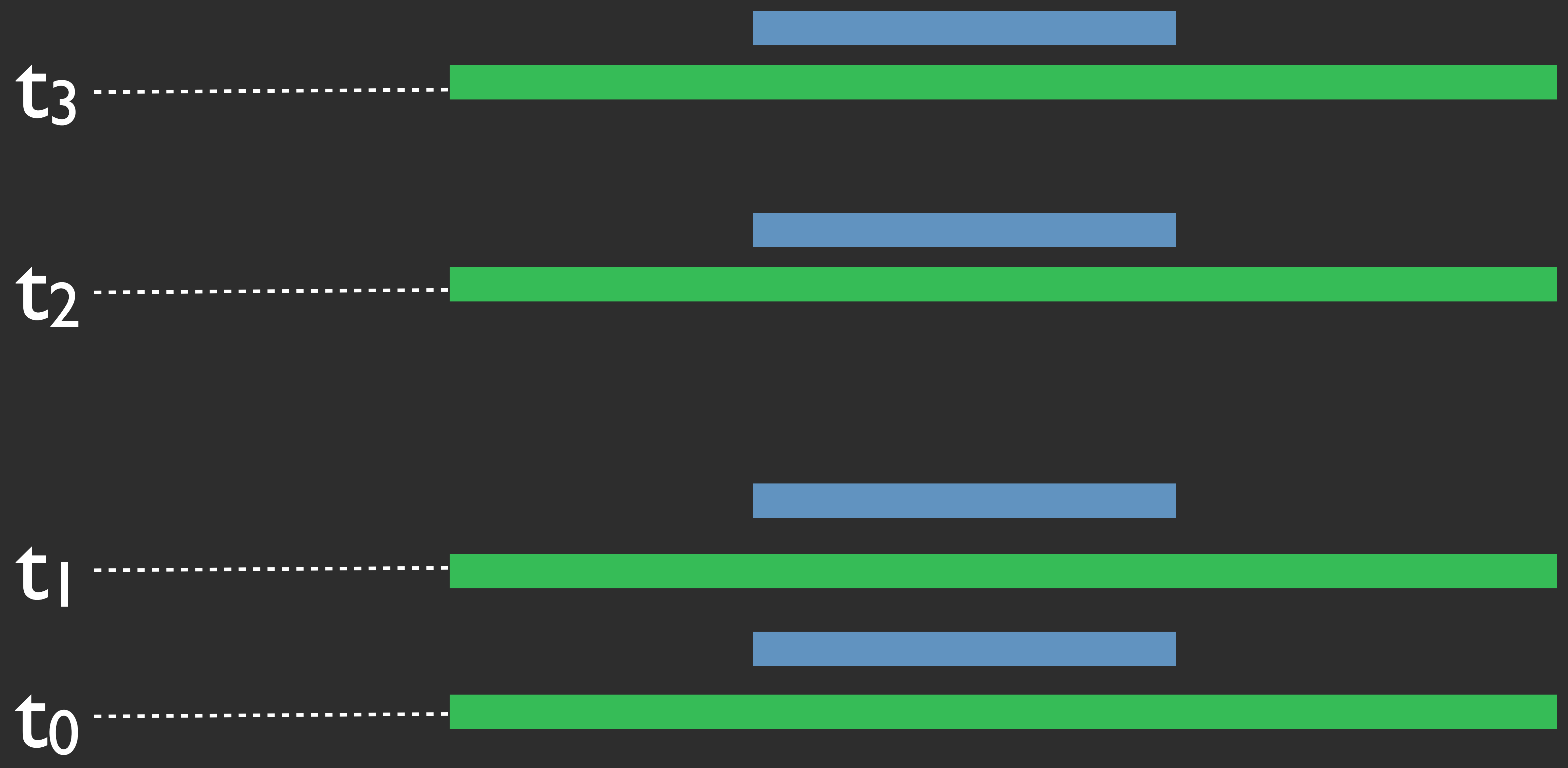
Level 2

t_0	t_1	t_2	t_3

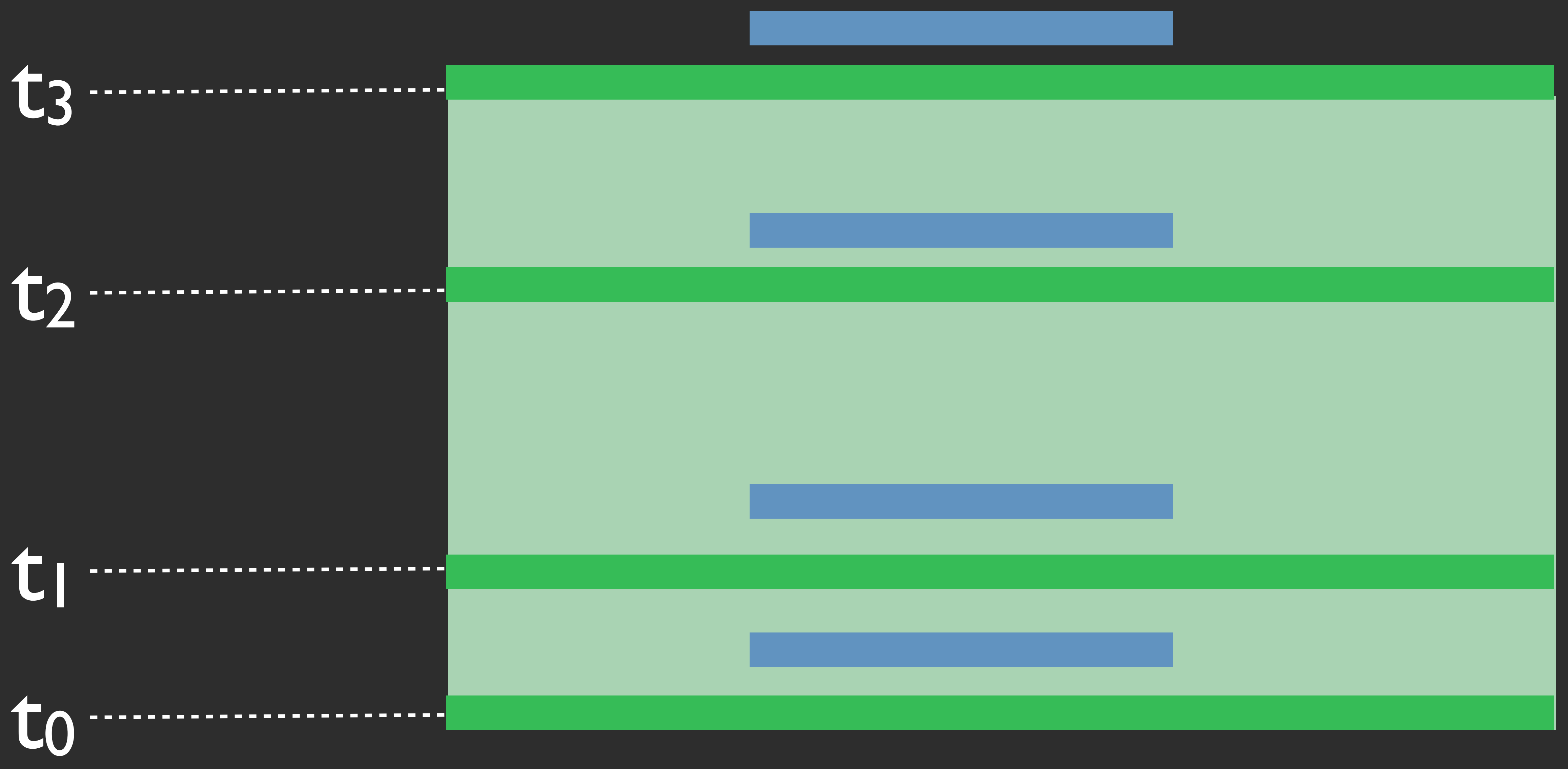
TZ-Slice: More effective



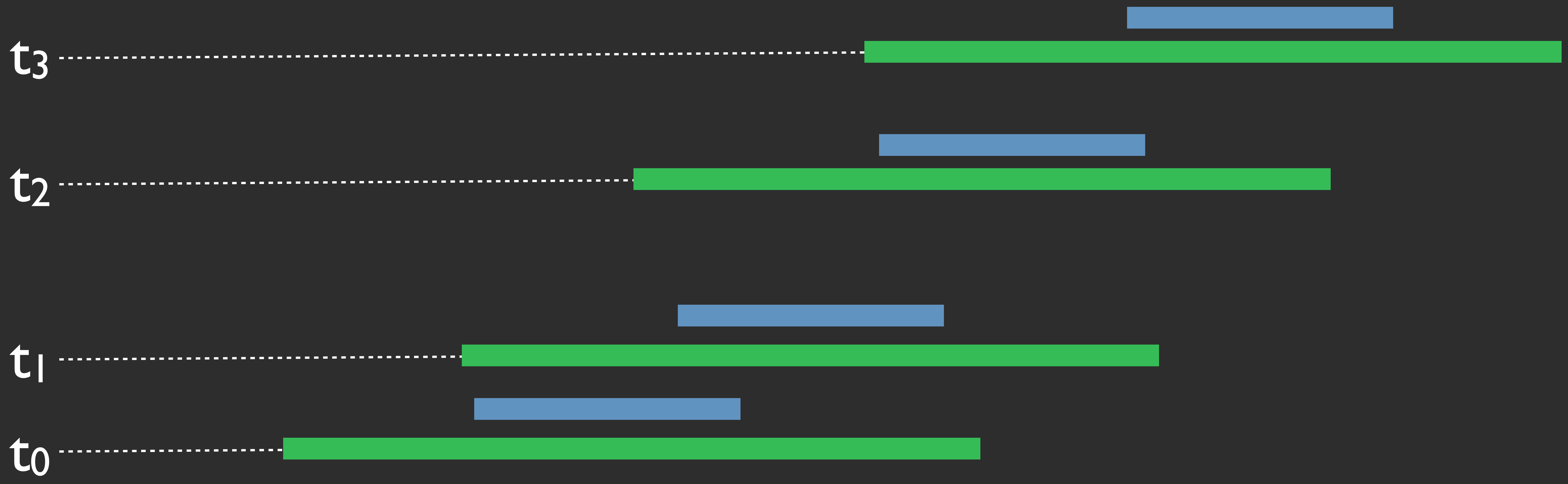
TZ-Slice: More expensive



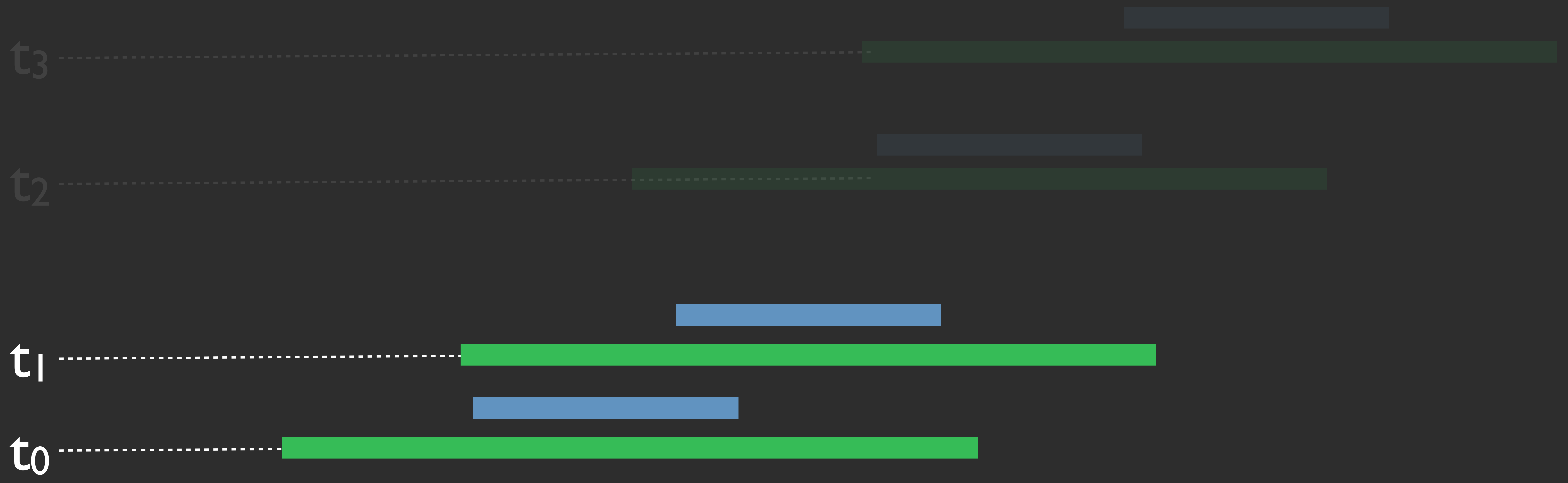
TZ-Slice: More expensive



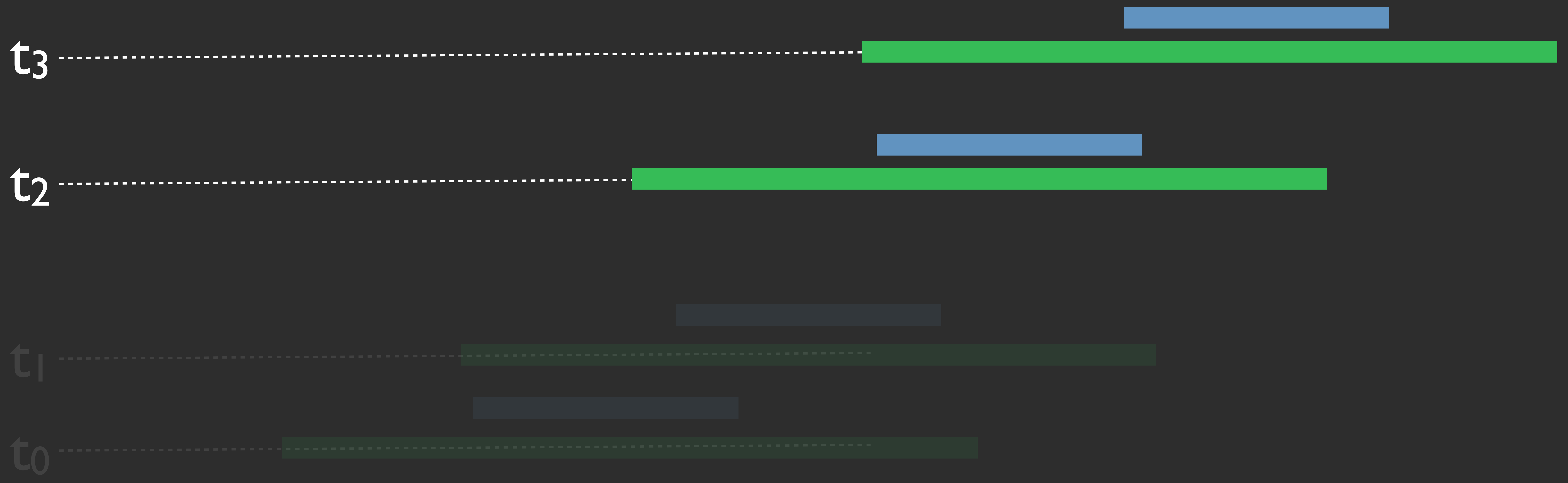
“Moving” depends on scale



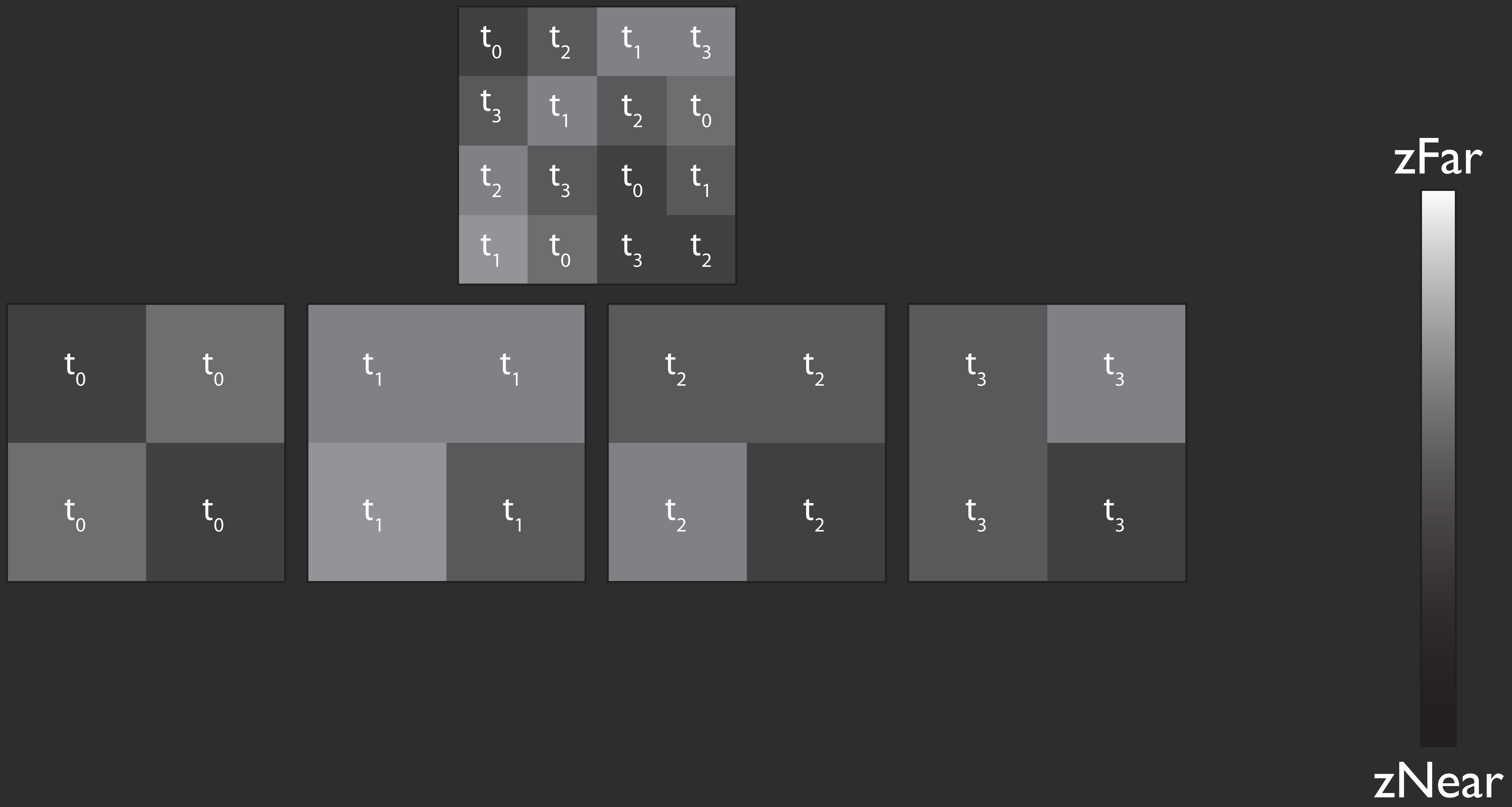
“Moving” depends on scale



“Moving” depends on scale



TZ-Pyramid



Multi-sample

t_0	t_2	t_1	t_3
t_3	t_1	t_2	t_0
t_2	t_3	t_0	t_1
t_1	t_0	t_3	t_2

Level 1

t_0	t_0
t_0	t_0

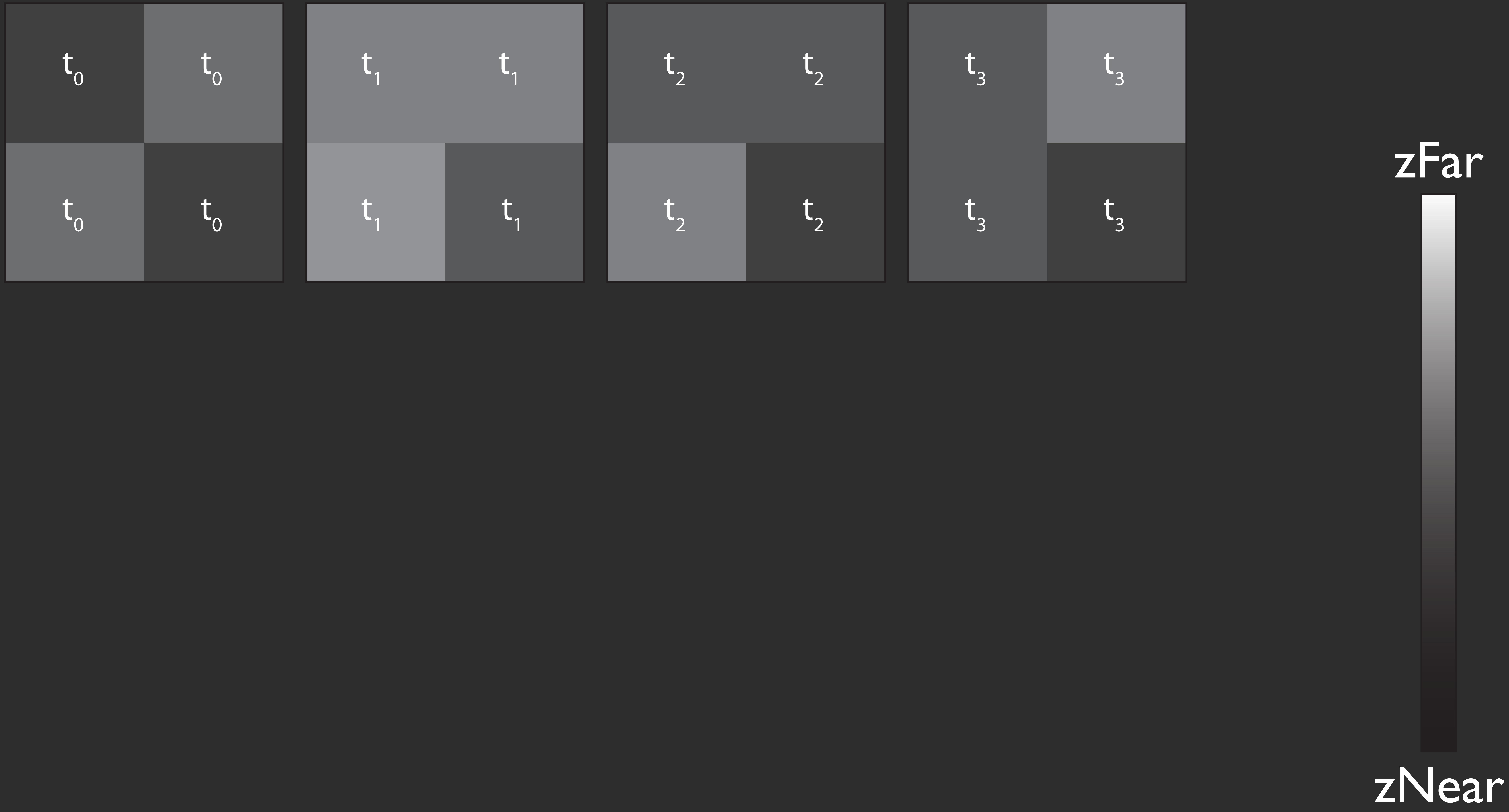
t_1	t_1
t_1	t_1

t_2	t_2
t_2	t_2

t_3	t_3
t_3	t_3

TZ-Pyramid

Time Level 1



TZ-Pyramid

Time Level 1

t_0	t_0
t_0	t_0

t_1	t_1
t_1	t_1

t_2	t_2
t_2	t_2

t_3	t_3
t_3	t_3

Time Level 2

$[t_0,t_1]$	$[t_0,t_1]$
$[t_0,t_1]$	$[t_0,t_1]$

$[t_2,t_3]$	$[t_2,t_3]$
$[t_2,t_3]$	$[t_2,t_3]$

zFar

zNear

TZ-Pyramid

Time Level 1

Time Level 2

Time Level 3

t_0 t_0
t_0 t_0
t_1 t_1
t_1 t_1
t_2 t_2
t_2 t_2
t_3 t_3
t_3 t_3
$[t_0,t_1]$ $[t_0,t_1]$
$[t_0,t_1]$ $[t_0,t_1]$
$[t_2,t_3]$ $[t_2,t_3]$
$[t_2,t_3]$ $[t_2,t_3]$
$[t_0,t_3]$ $[t_0,t_3]$
$[t_0,t_3]$ $[t_0,t_3]$
zFar
zNear

TZ-Pyramid

Time Level 1

t_0

t_1

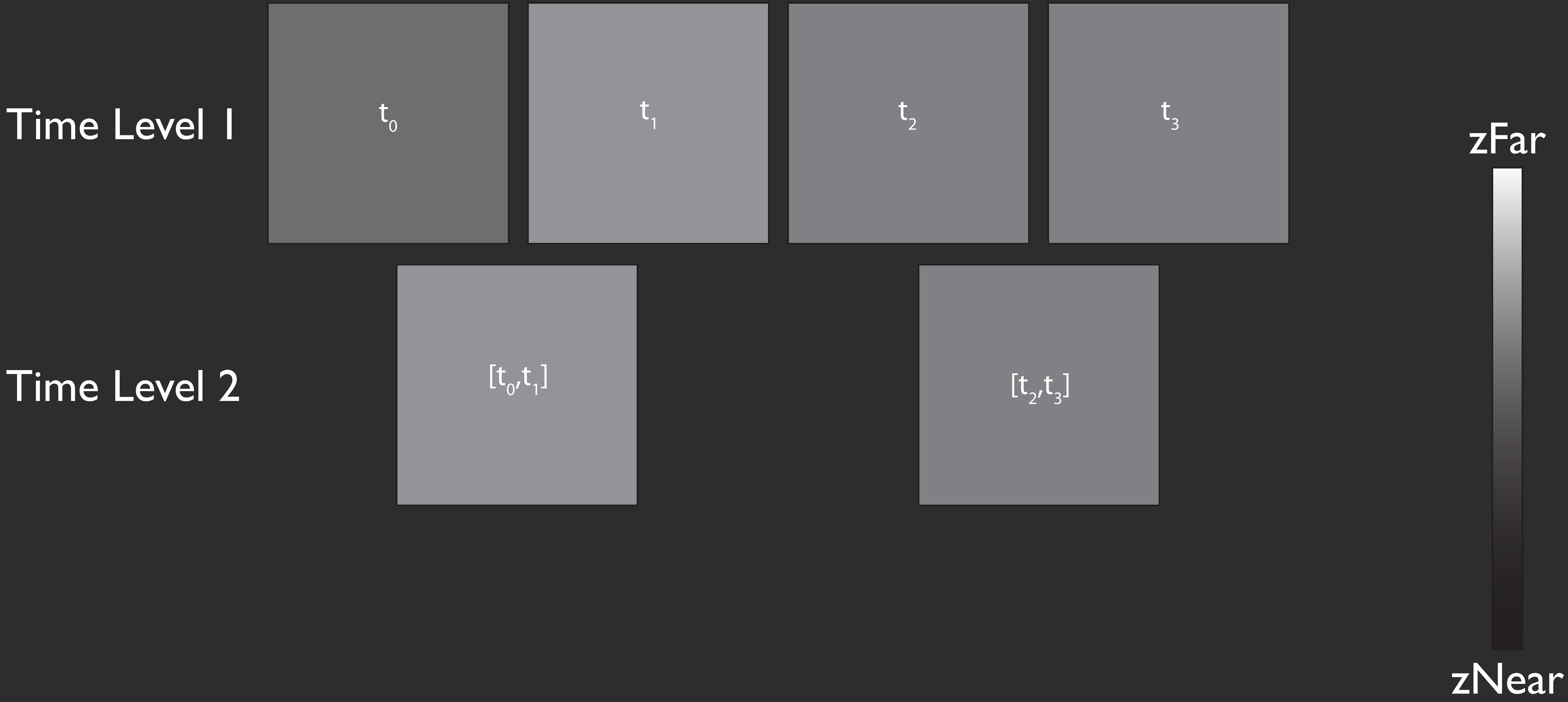
t_2

t_3

zFar

zNear

TZ-Pyramid



Time Level 1

t_0

t_1

t_2

t_3

Time Level 2

$[t_0, t_1]$

$[t_2, t_3]$

zFar

zNear

TZ-Pyramid

Time Level 1

t_0

t_1

t_2

t_3

Time Level 2

$[t_0,t_1]$

$[t_2,t_3]$

Time Level 3

$[t_0,t_3]$

zFar

zNear

Space-Time Recursive Update

Time Level 1

t_0 t_0 t_0 t_0

t_1 t_1 t_1 t_1

t_2 t_2 t_2 t_2

t_3 t_3 t_3 t_3

Time Level 2

$[t_0,t_1]$ $[t_0,t_1]$ $[t_0,t_1]$ $[t_0,t_1]$

$[t_2,t_3]$ $[t_2,t_3]$ $[t_2,t_3]$ $[t_2,t_3]$

Time Level 3

$[t_0,t_3]$ $[t_0,t_3]$ $[t_0,t_3]$ $[t_0,t_3]$

zFar

zNear

Space-Time Recursive Update

Time Level 1

t_0 t_0 t_0 t_0

t_1 t_1 t_1 t_1

t_2 t_2 t_2 t_2

t_3 t_3 t_3 t_3

Time Level 2

$[t_0,t_1]$ $[t_0,t_1]$ $[t_0,t_1]$ $[t_0,t_1]$

$[t_2,t_3]$ $[t_2,t_3]$ $[t_2,t_3]$ $[t_2,t_3]$

Time Level 3

$[t_0,t_3]$ $[t_0,t_3]$ $[t_0,t_3]$ $[t_0,t_3]$

zFar

zNear

Space-Time Recursive Update

Time Level 1

t_0	t_0
t_0	t_0

t_1	t_1
t_1	t_1

t_2	t_2
t_2	t_2

t_3	t_3
t_3	t_3

Time Level 2

$[t_0,t_1]$	$[t_0,t_1]$
$[t_0,t_1]$	$[t_0,t_1]$

$[t_2,t_3]$	$[t_2,t_3]$
$[t_2,t_3]$	$[t_2,t_3]$

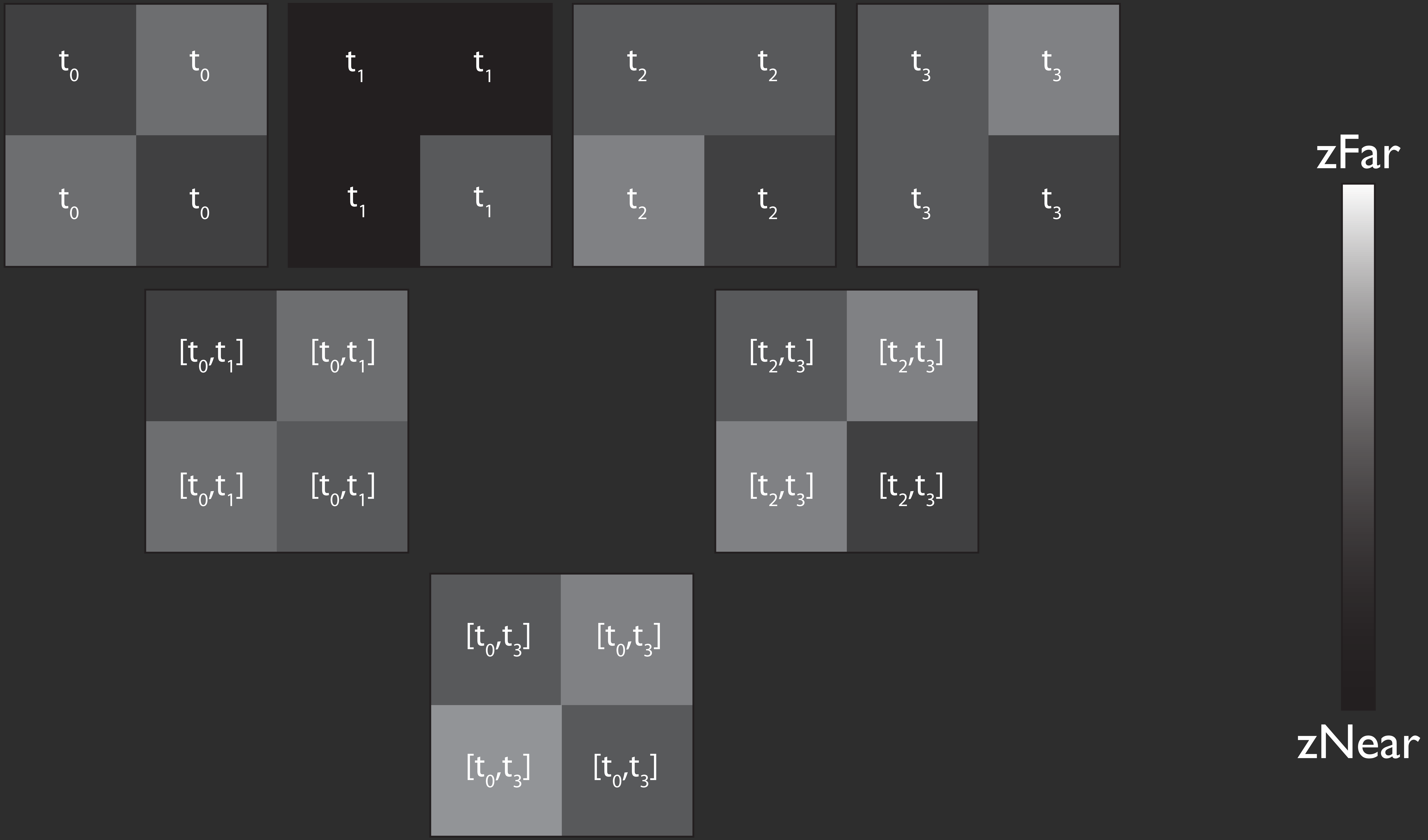
Time Level 3

$[t_0,t_3]$	$[t_0,t_3]$
$[t_0,t_3]$	$[t_0,t_3]$

zFar

zNear

Space-Time Recursive Update



Time Level 1

t_0	t_0
t_0	t_0

t_1	t_1
t_1	t_1

t_2	t_2
t_2	t_2

t_3	t_3
t_3	t_3

Time Level 2

$[t_0, t_1]$	$[t_0, t_1]$
$[t_0, t_1]$	$[t_0, t_1]$

$[t_2, t_3]$	$[t_2, t_3]$
$[t_2, t_3]$	$[t_2, t_3]$

Time Level 3

$[t_0, t_3]$	$[t_0, t_3]$
$[t_0, t_3]$	$[t_0, t_3]$

Space-Time Recursive Update

Time Level 1
t_0
t_1
t_2
t_3
zFar
Time Level 2
$[t_0,t_1]$
$[t_2,t_3]$
Time Level 3
$[t_0,t_3]$
zNear

Space-Time Recursive Update

Time Level 1

t_0

t_1

t_2

t_3

Time Level 2

$[t_0,t_1]$

$[t_2,t_3]$

Time Level 3

$[t_0,t_3]$

zFar

zNear

Space-Time Recursive Update

Time Level 1

t_0

t_1

t_2

t_3

Time Level 2

$[t_0, t_1]$

$[t_2, t_3]$

Time Level 3

$[t_0, t_3]$

zFar

zNear

Space-Time Recursive Update

Time Level 1

t_0

t_1

t_2

t_3

Time Level 2

$[t_0,t_1]$

$[t_2,t_3]$

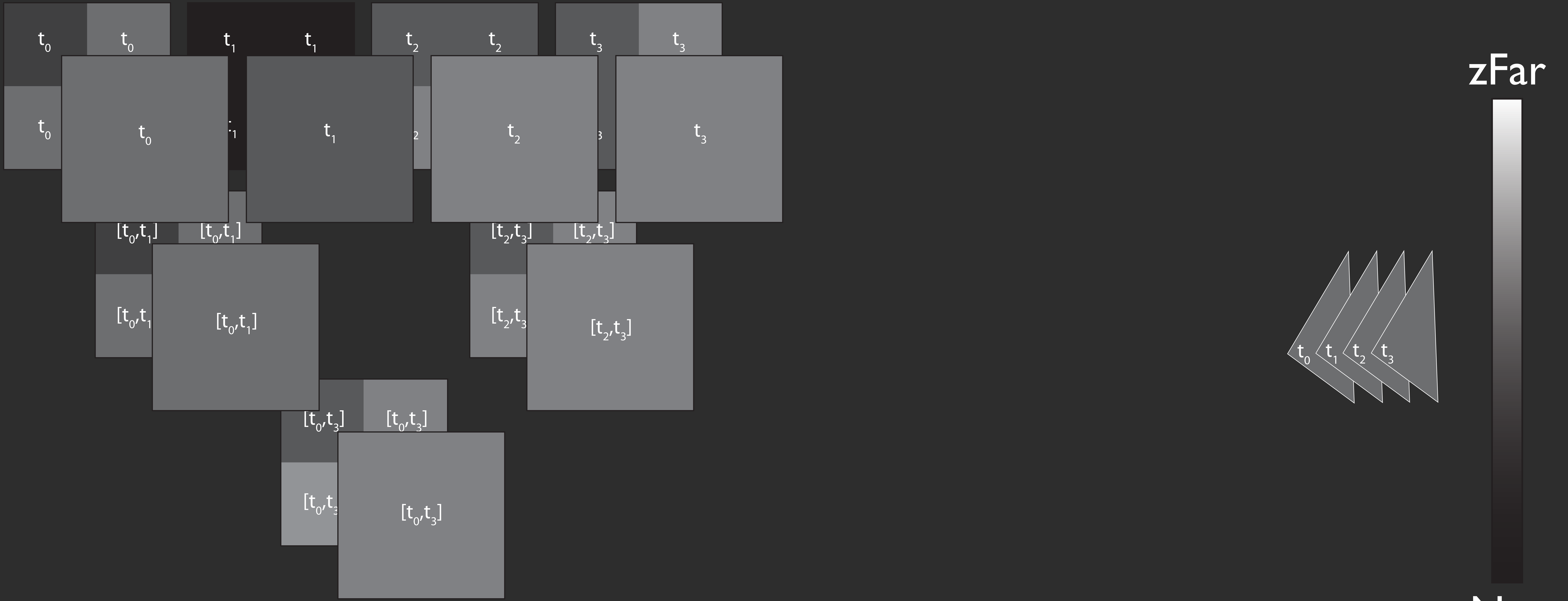
Time Level 3

$[t_0,t_3]$

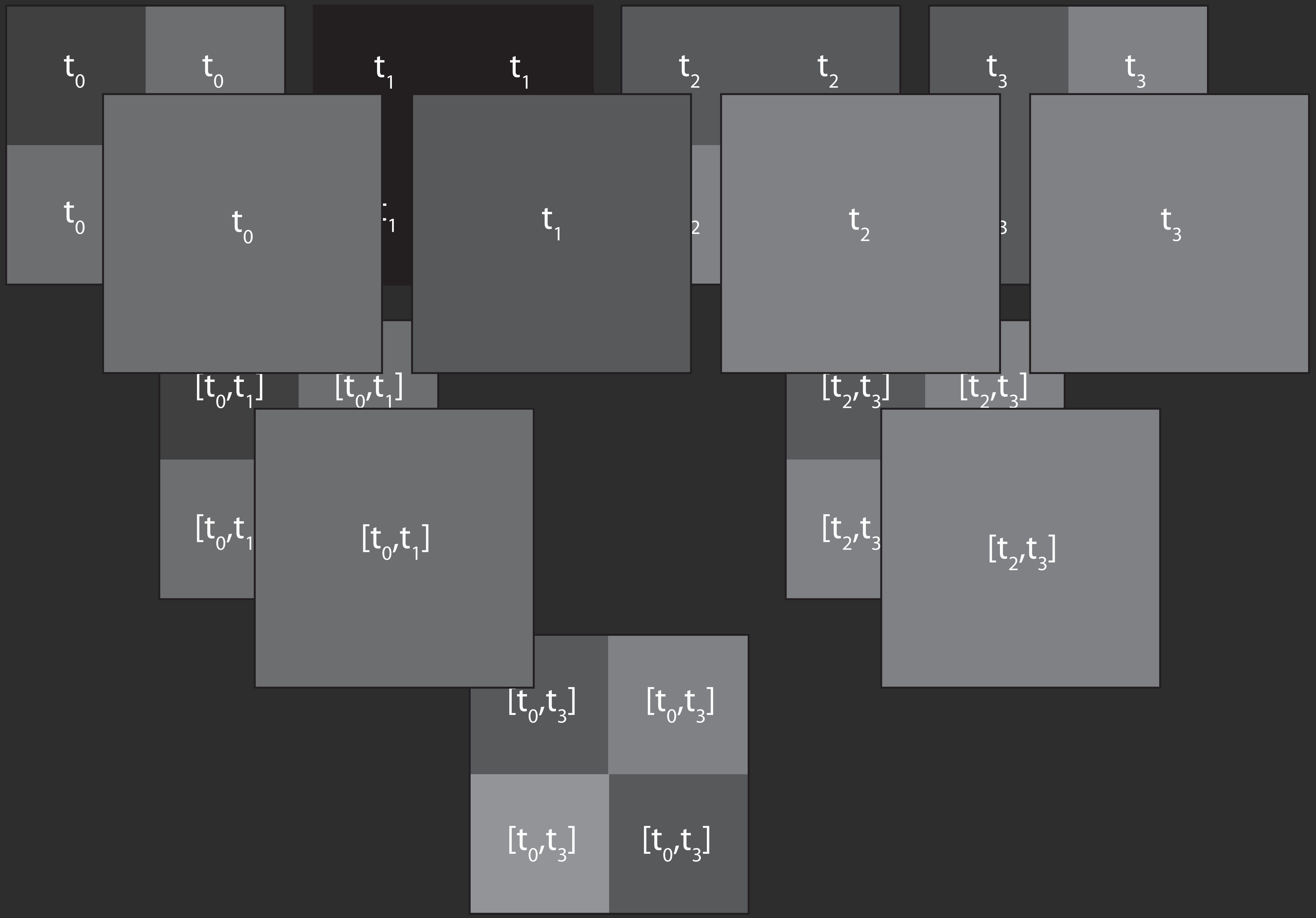
zFar

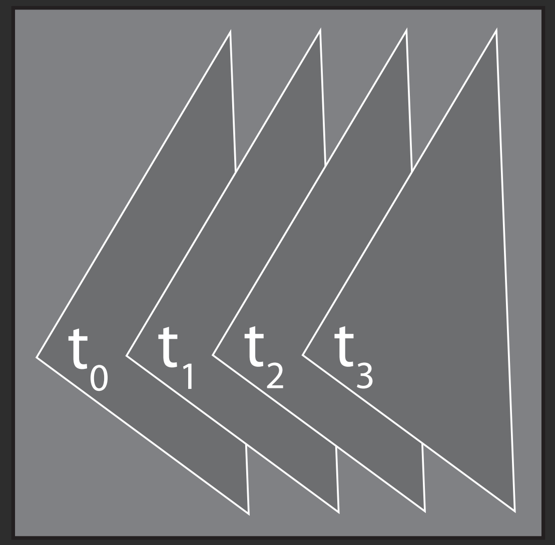
zNear

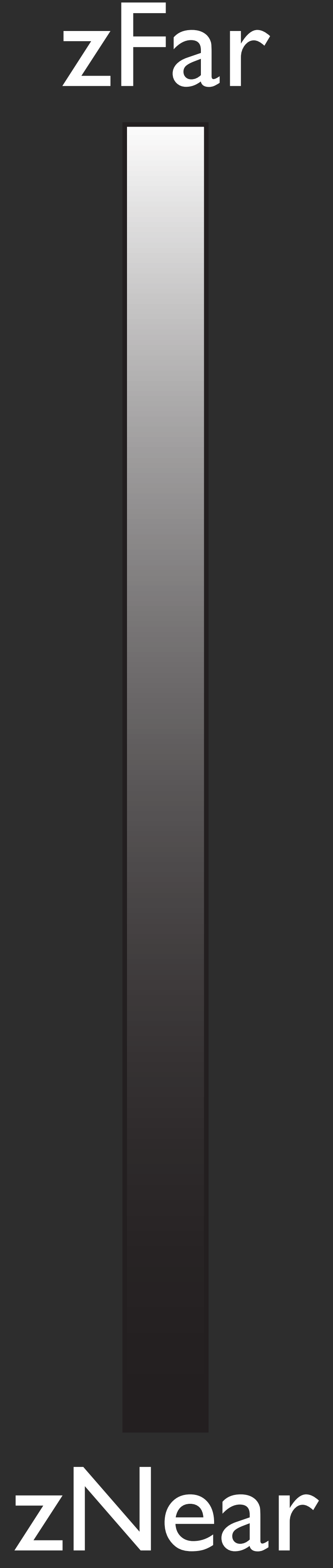
TZ-Pyramid Culling



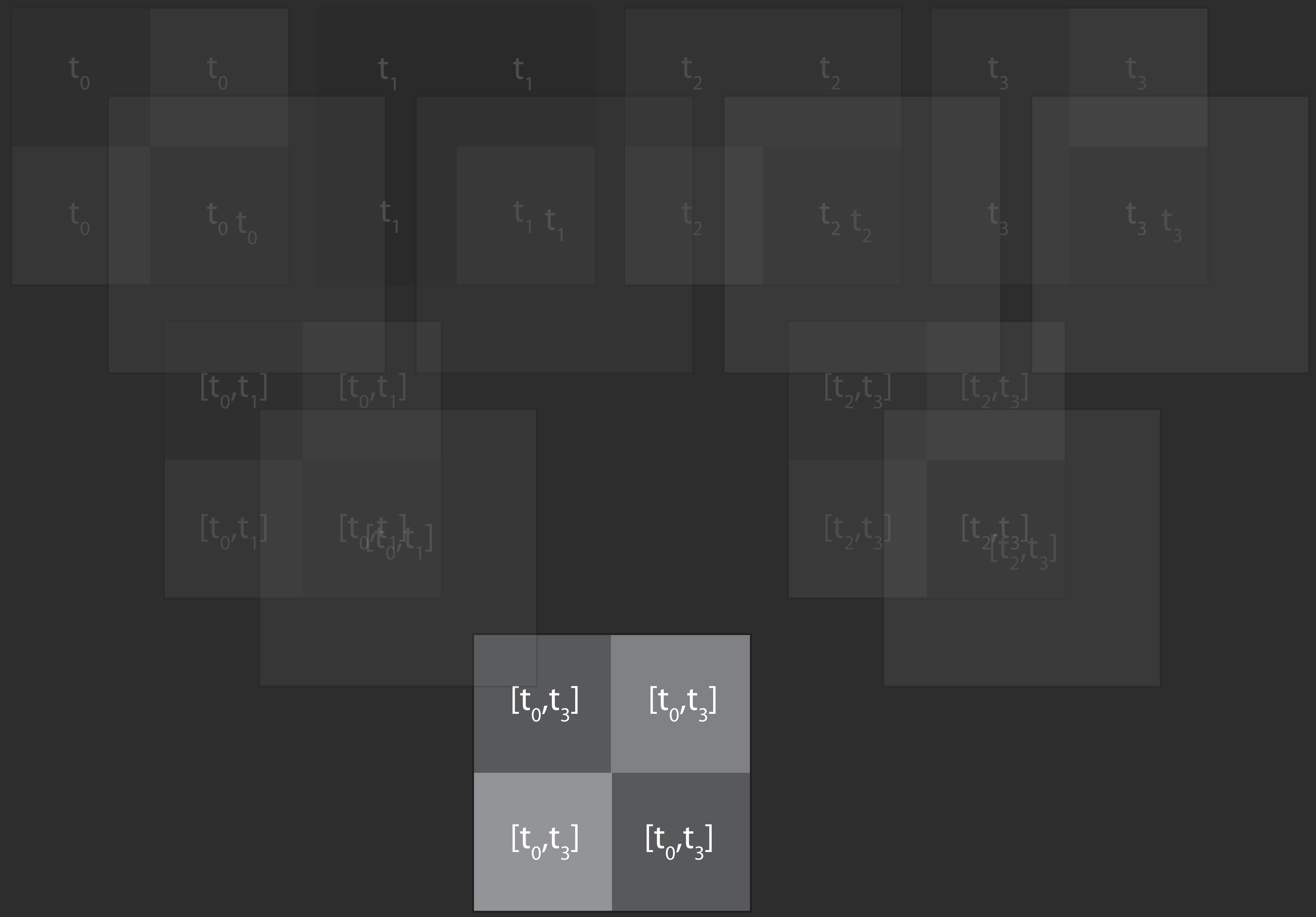
TZ-Pyramid Culling

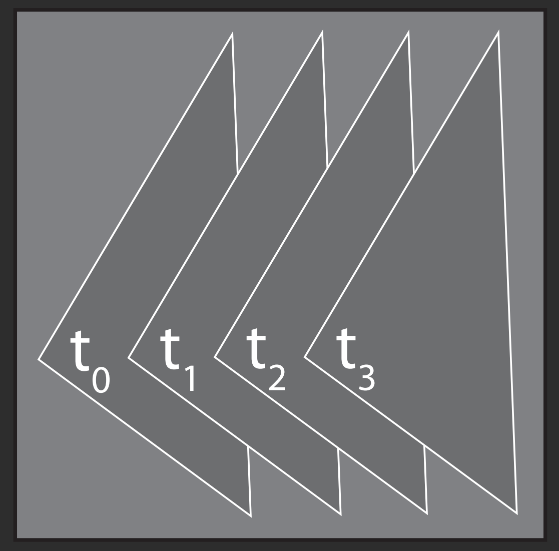


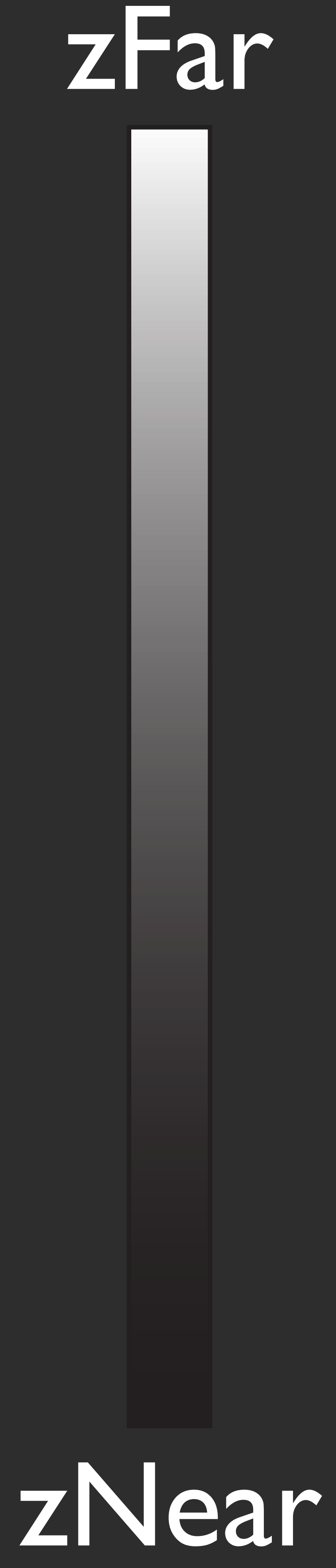




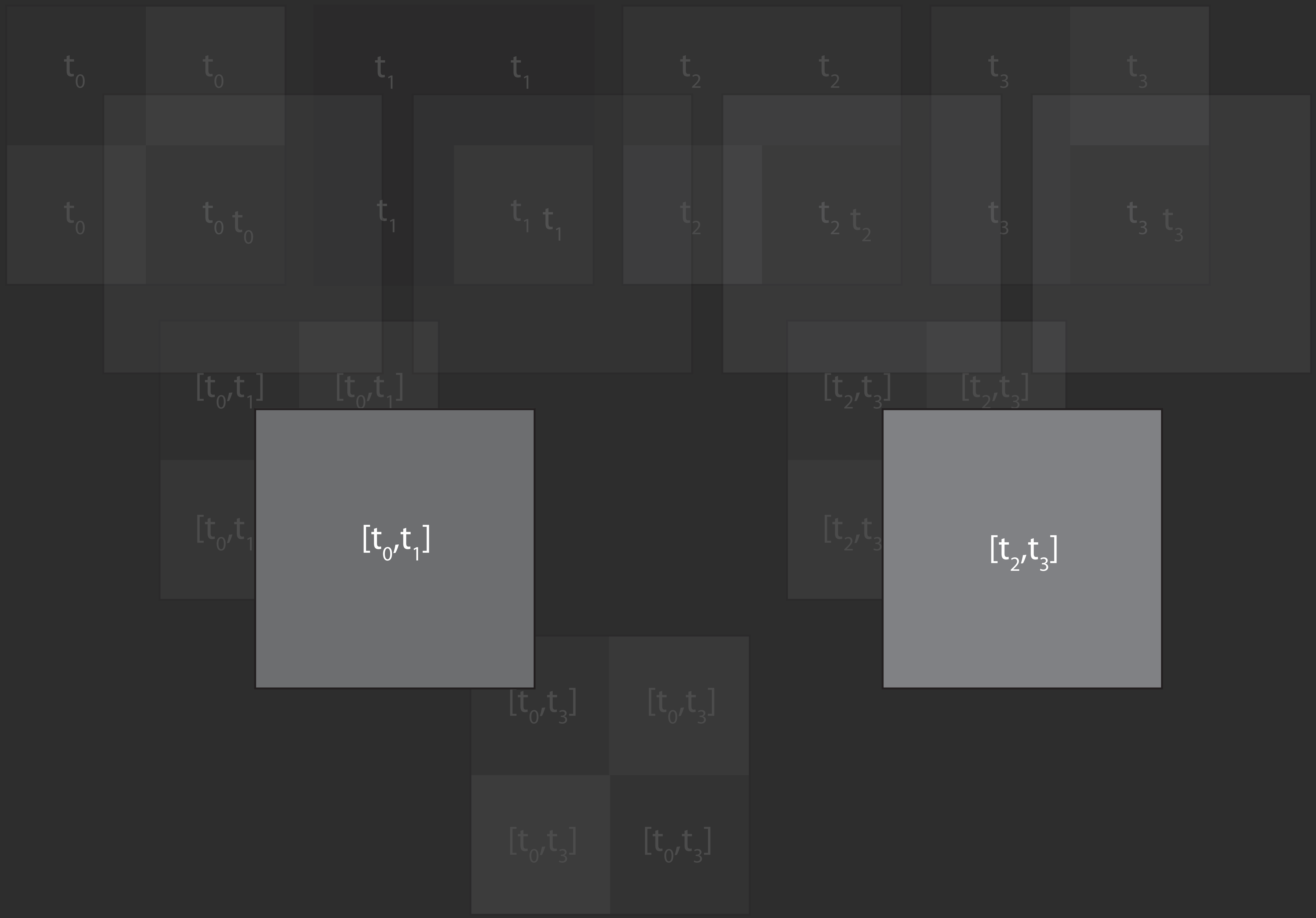
TZ-Pyramid Culling

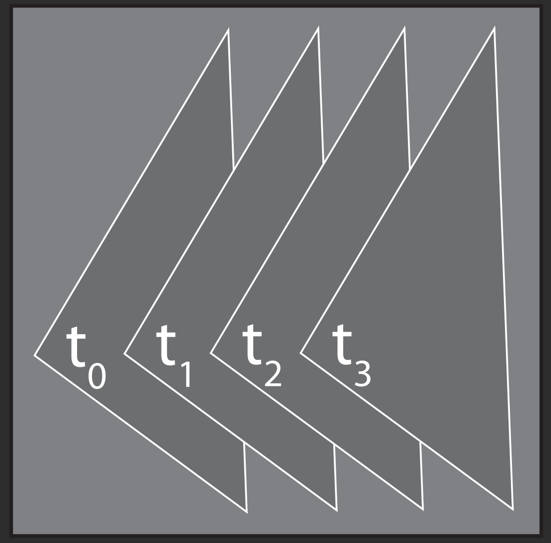




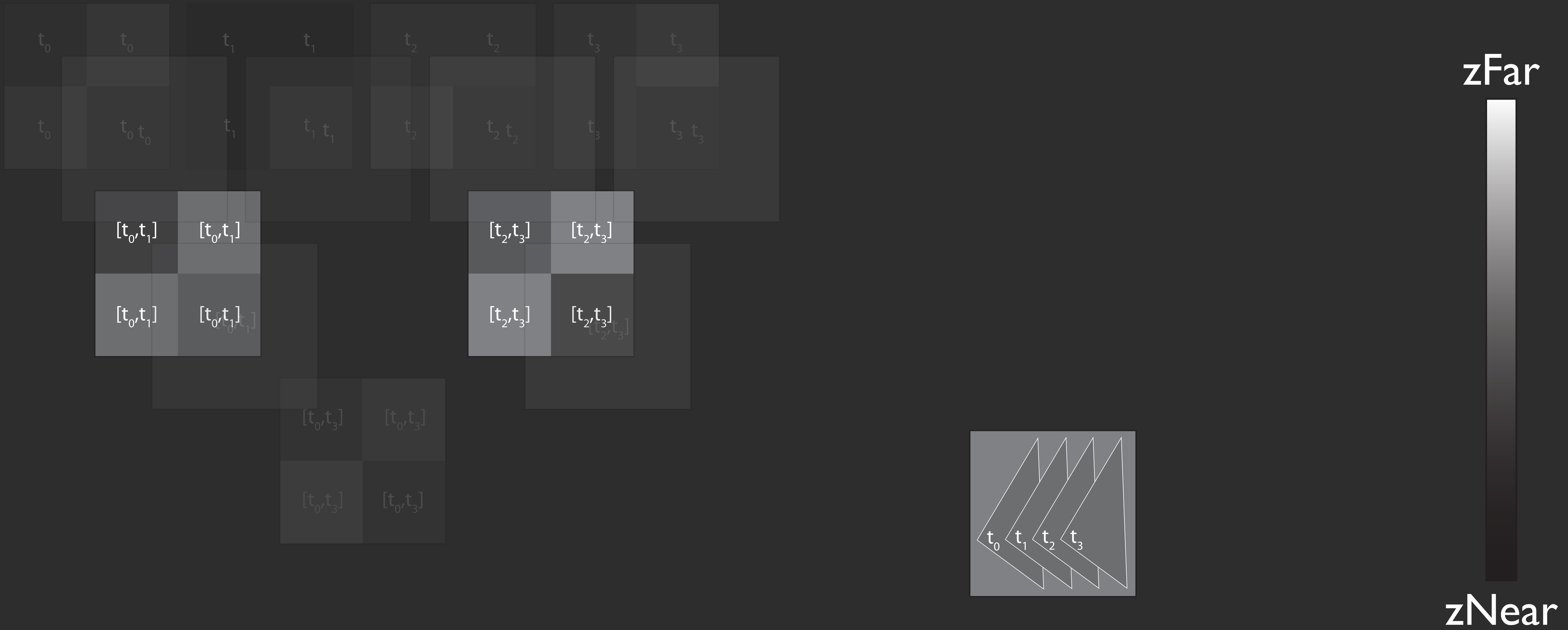


TZ-Pyramid Culling





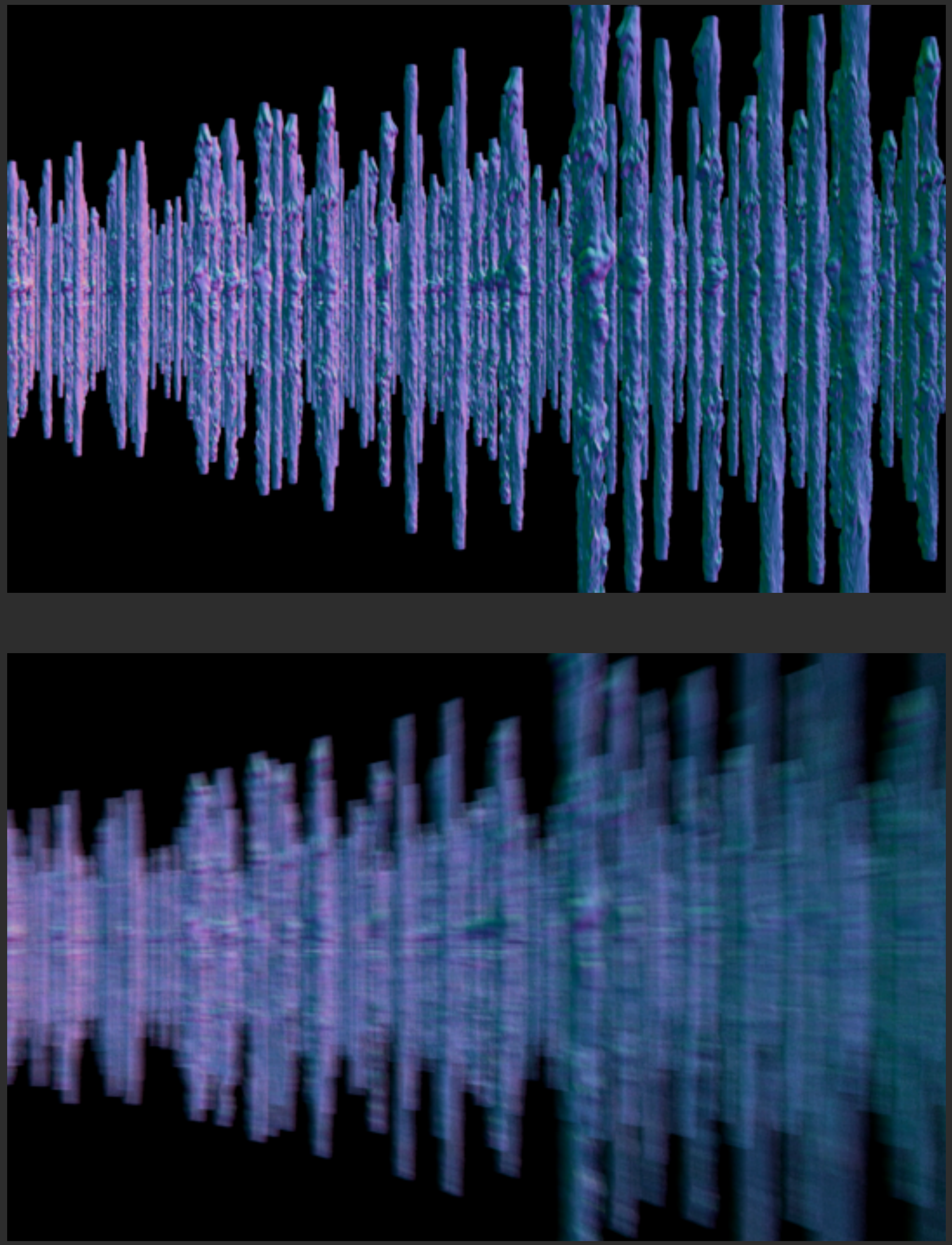
TZ-Pyramid Culling



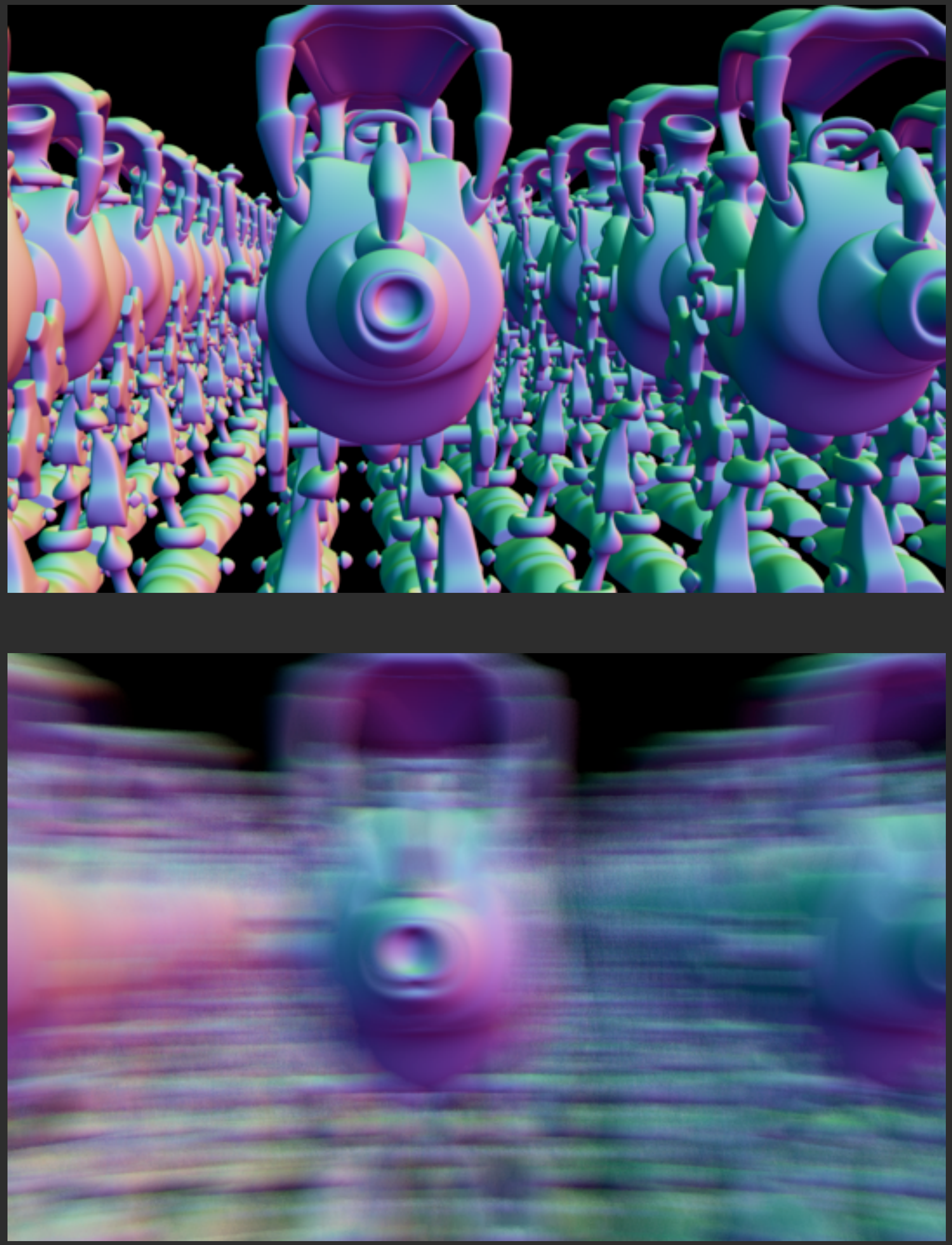
TZ-Pyramid Culling

t_0
t_1
t_2
t_3
$[t_0,t_1]$
$[t_2,t_3]$
$[t_0,t_3]$
zFar
zNear

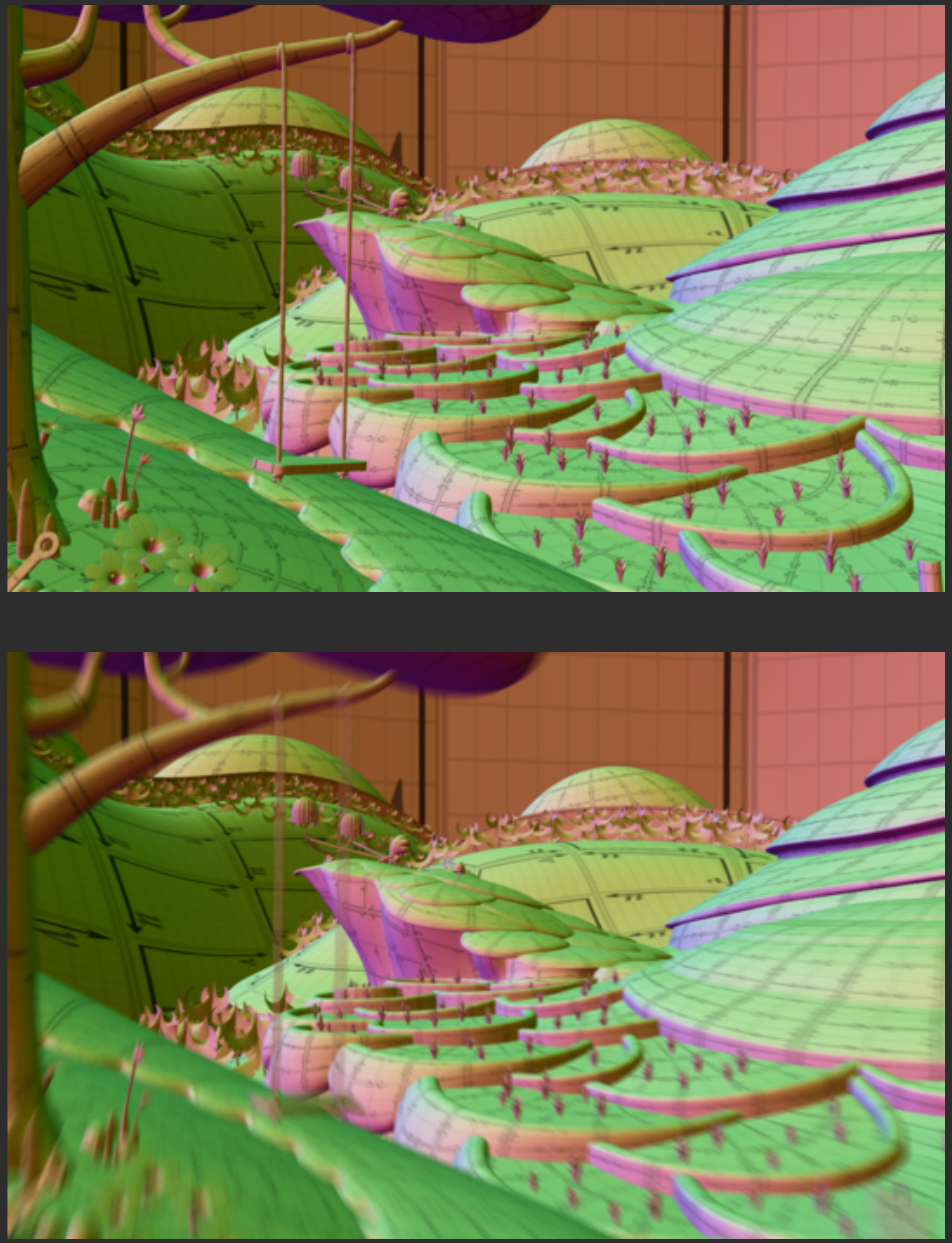
Evaluation



STICKS



ARMY



ZINKIA

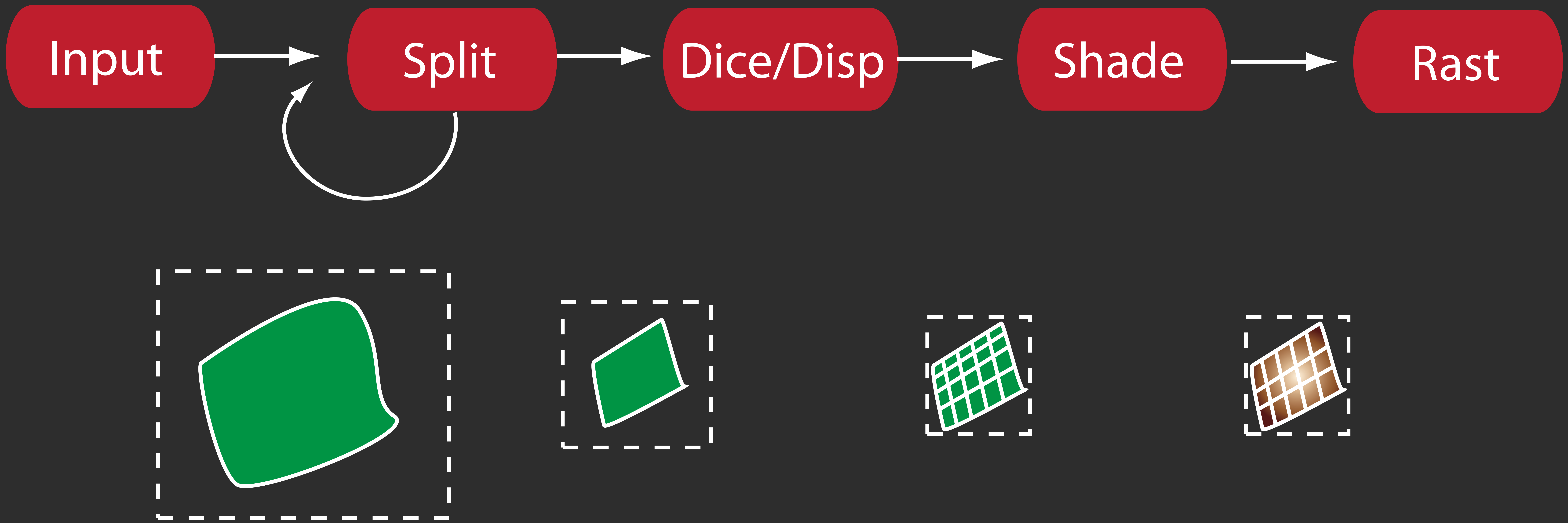
Rendered at 1080p, 16 samples per pixel, 2x2 pixel interleave

Evaluation: Metrics of Interest

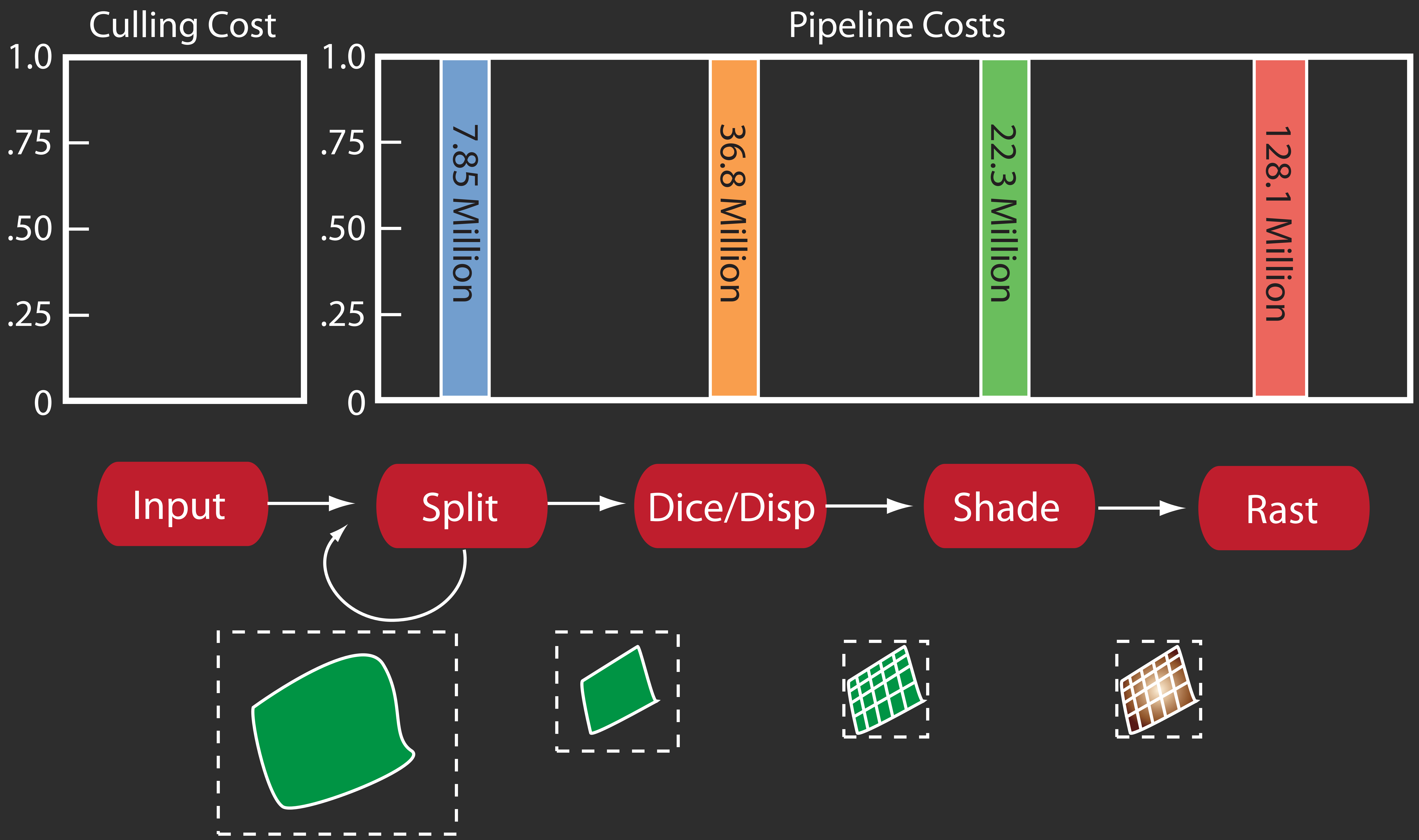
- Diced vertices
- Shaded vertices

- Depth comparisons
  - Coarse: Inner nodes
  - Fine: Multi-sample z

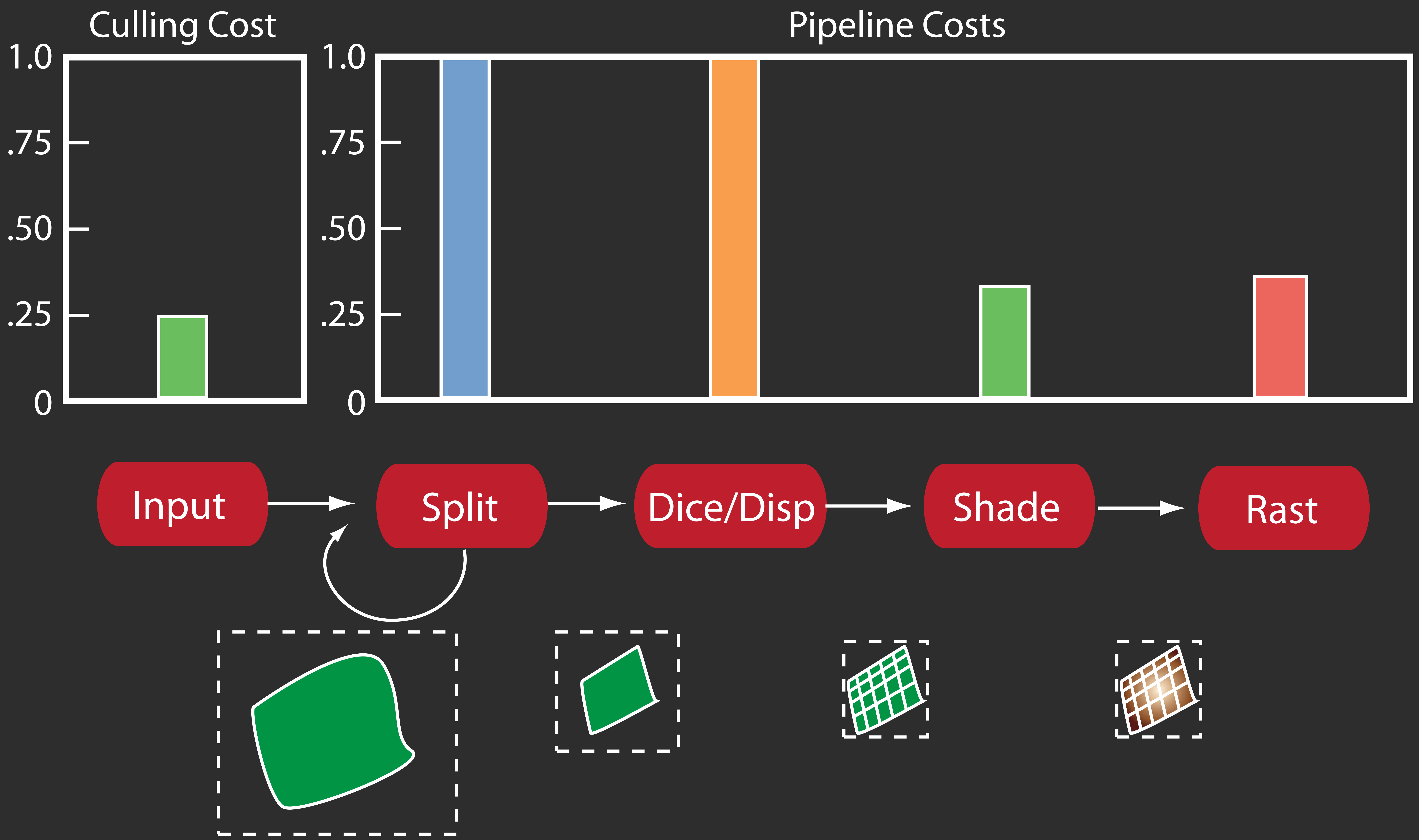
When to Cull



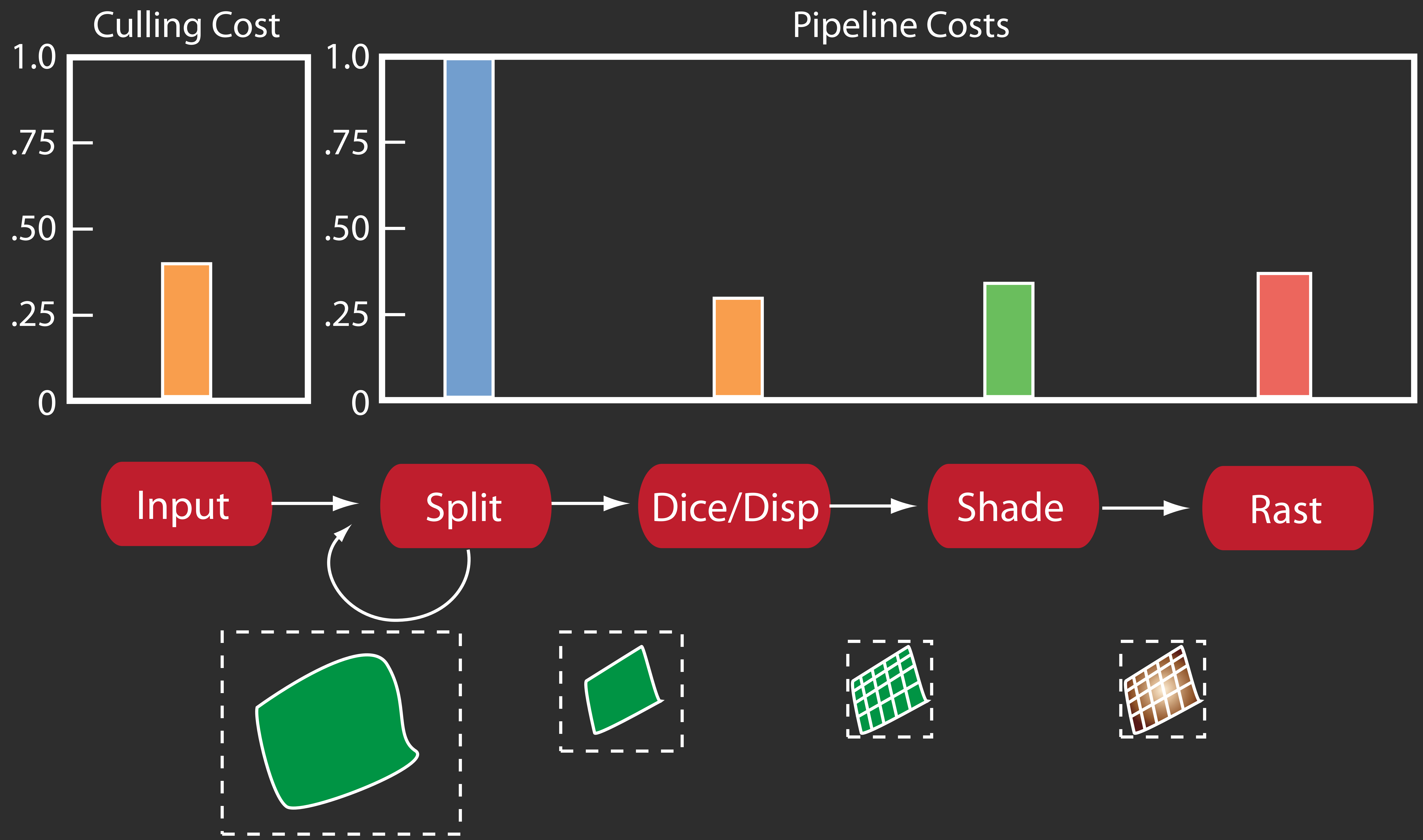
No Occlusion Culling



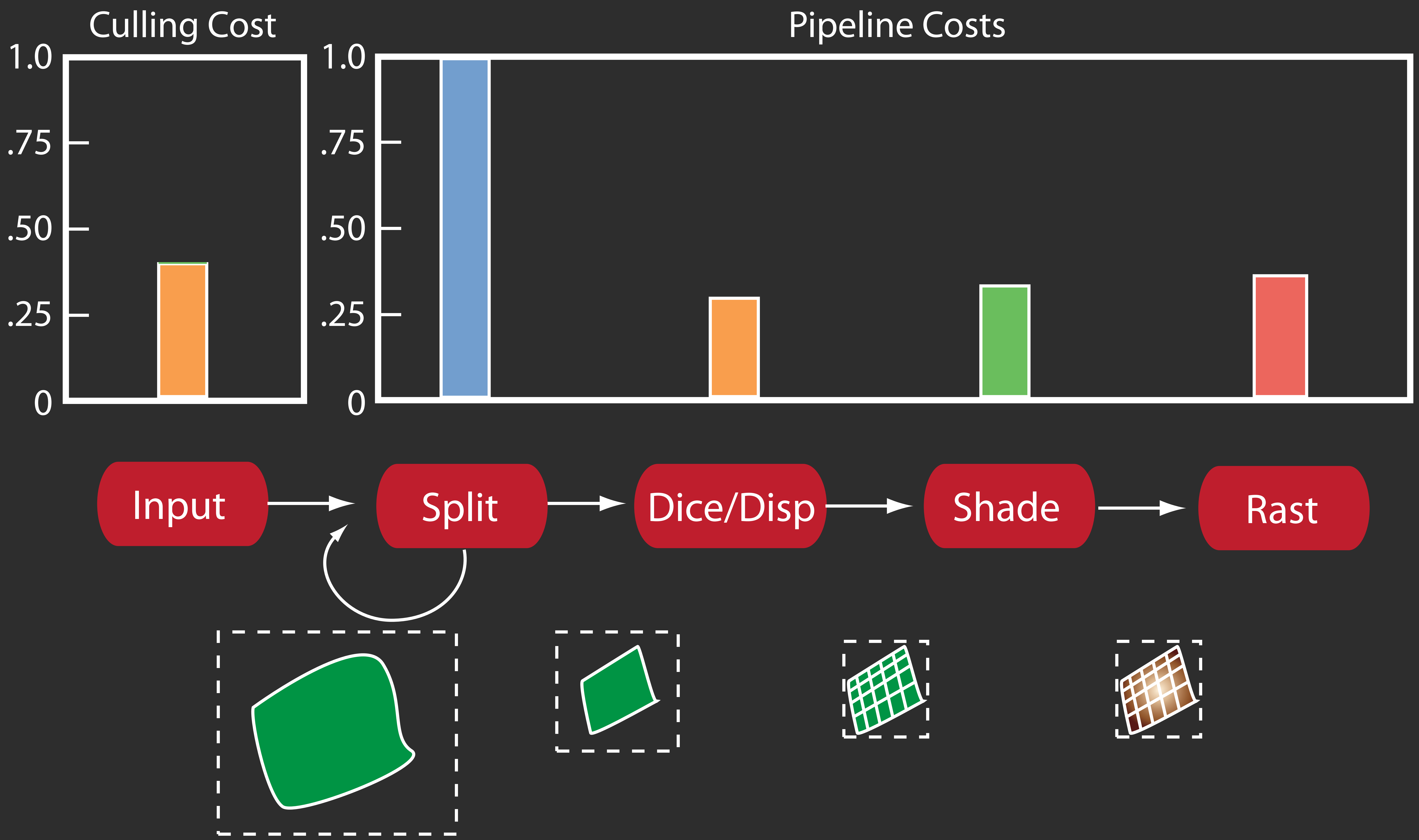
Just prior to shading



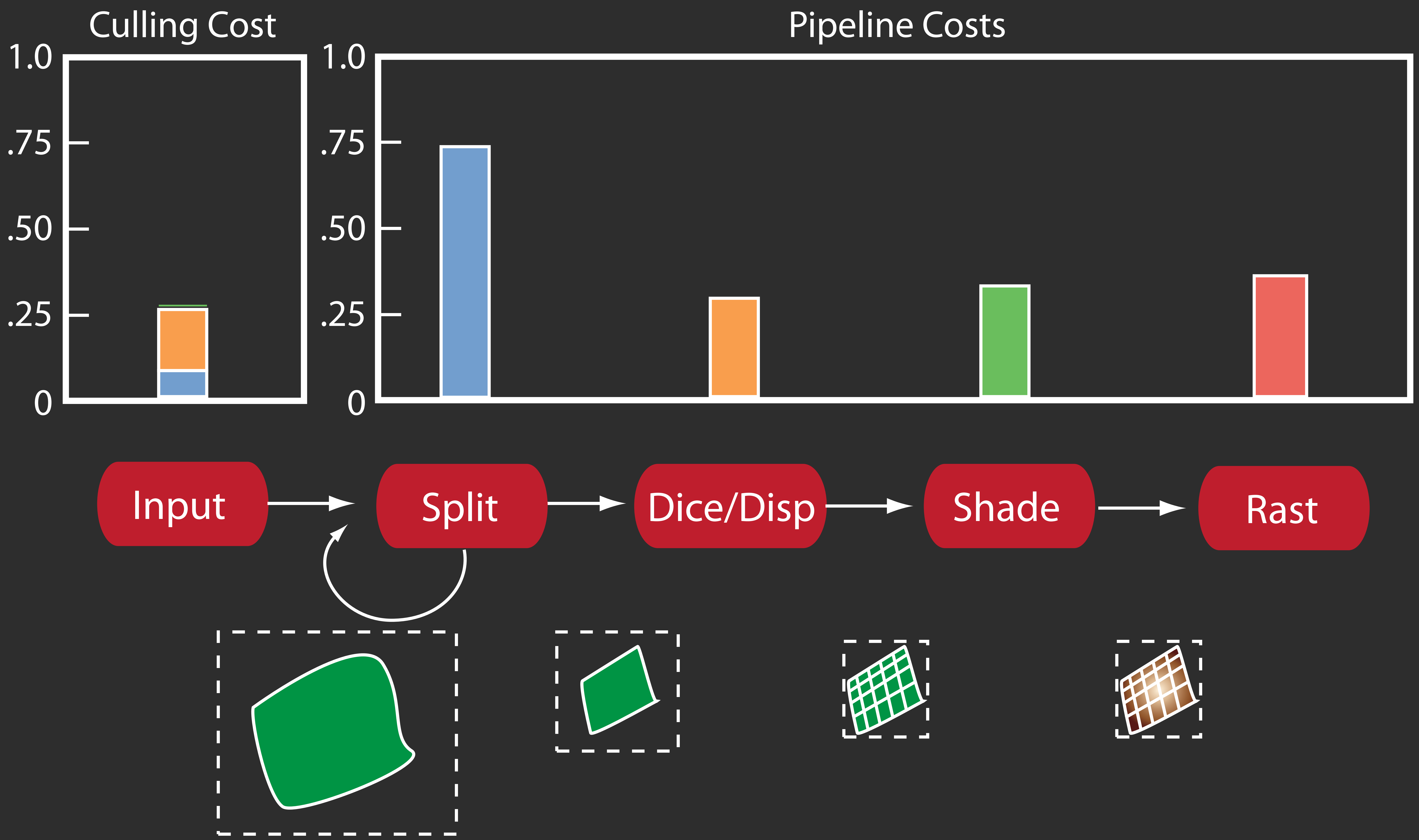
Just prior to dicing



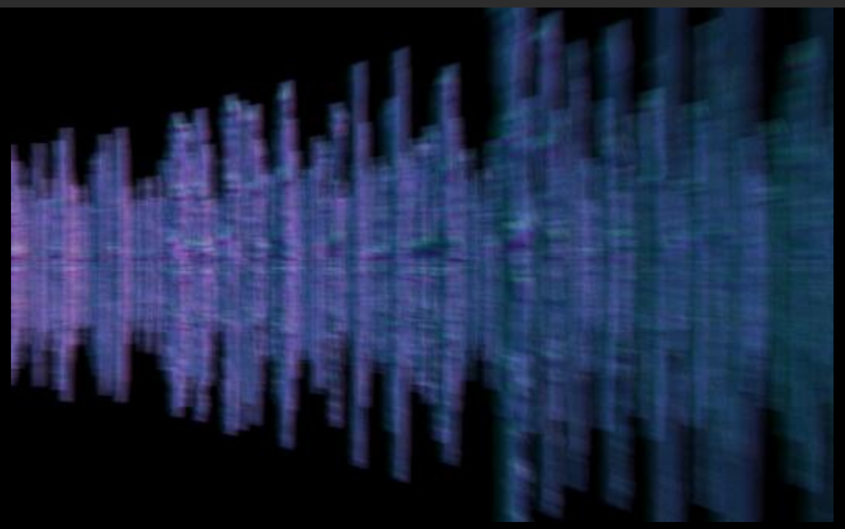
Both before dicing and shading

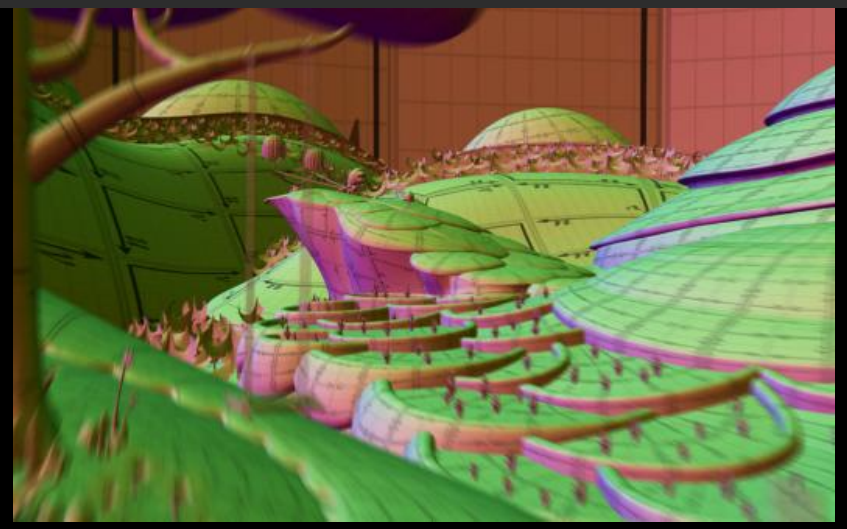


Cull at all stages

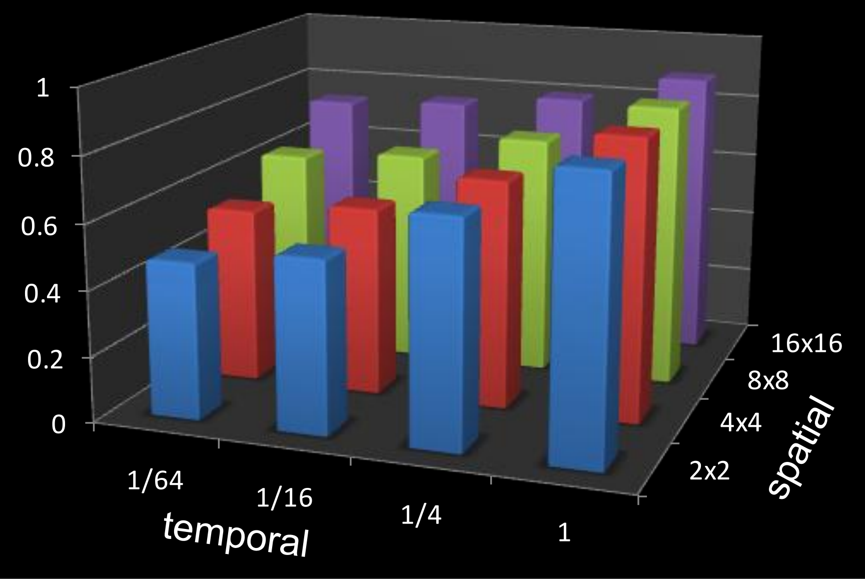


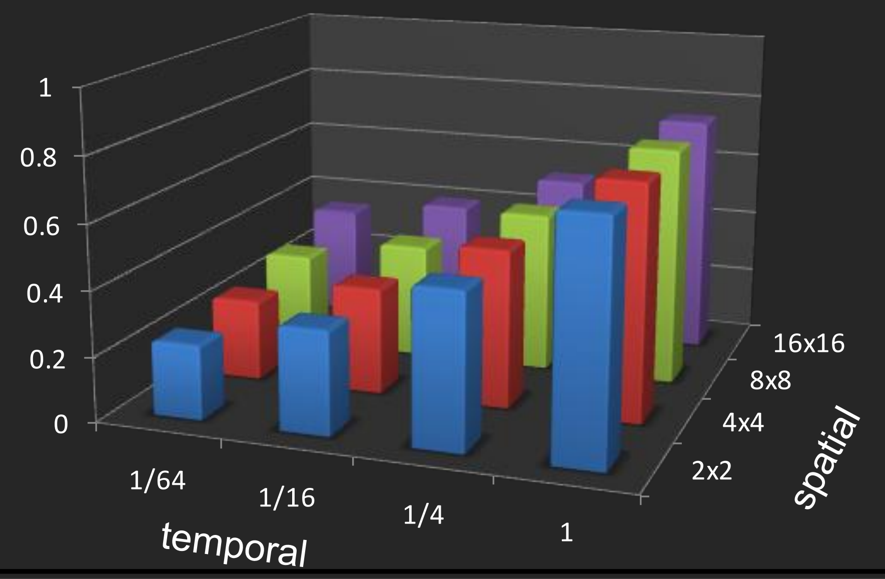
Resolution Tradeoff: Prefer Temporal

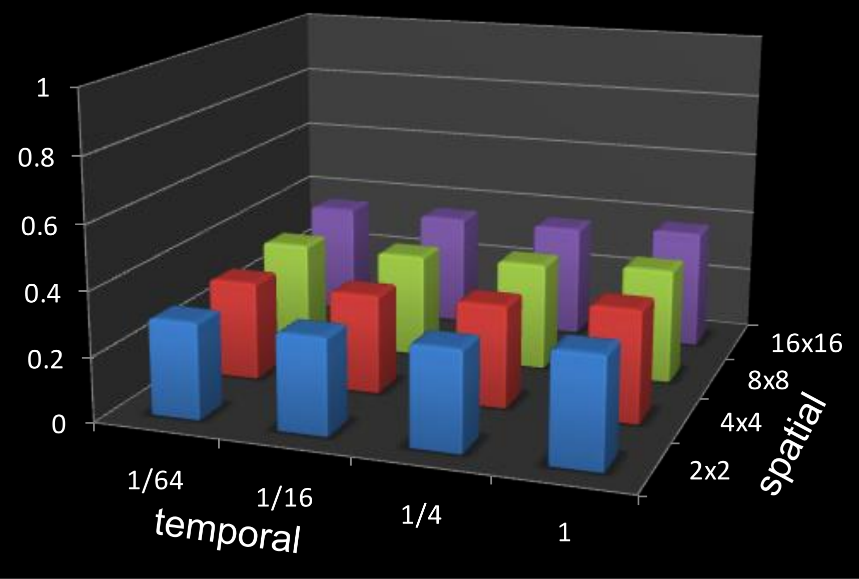




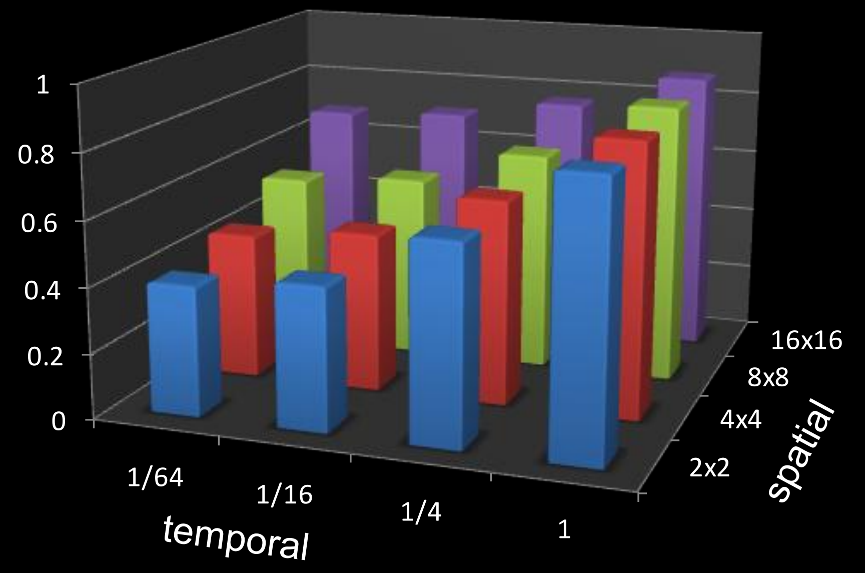
diced
points

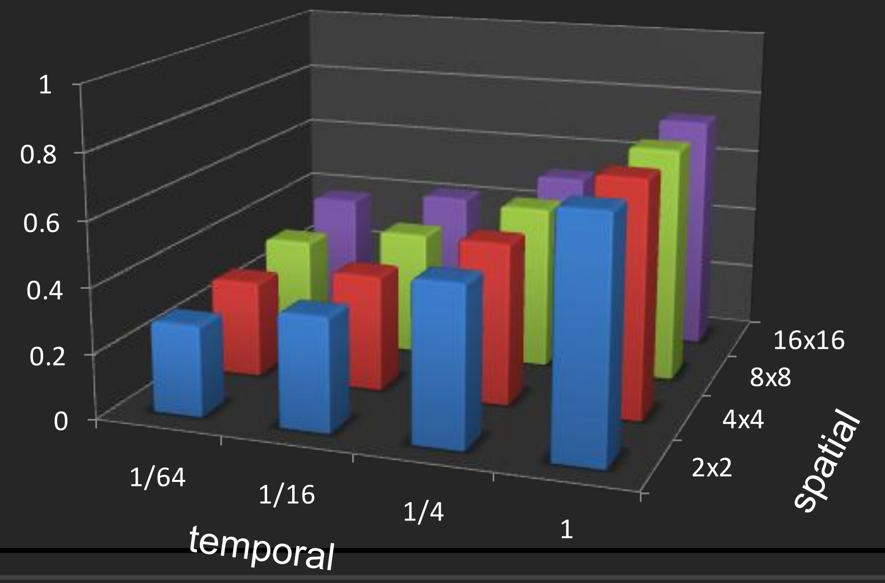


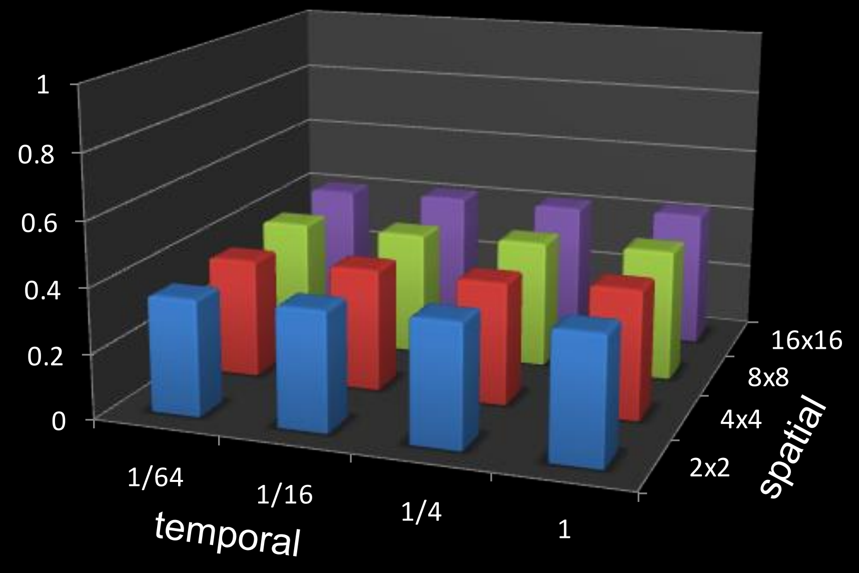




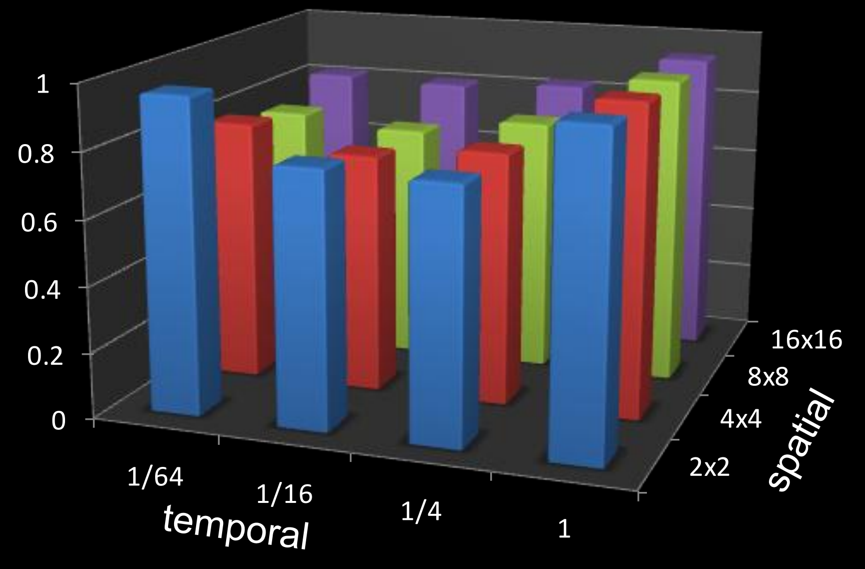
shaded
points

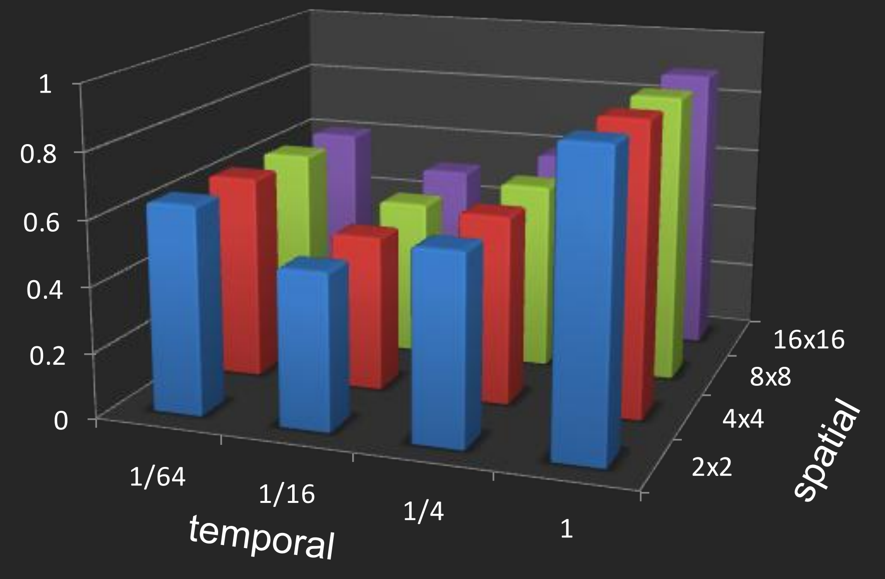


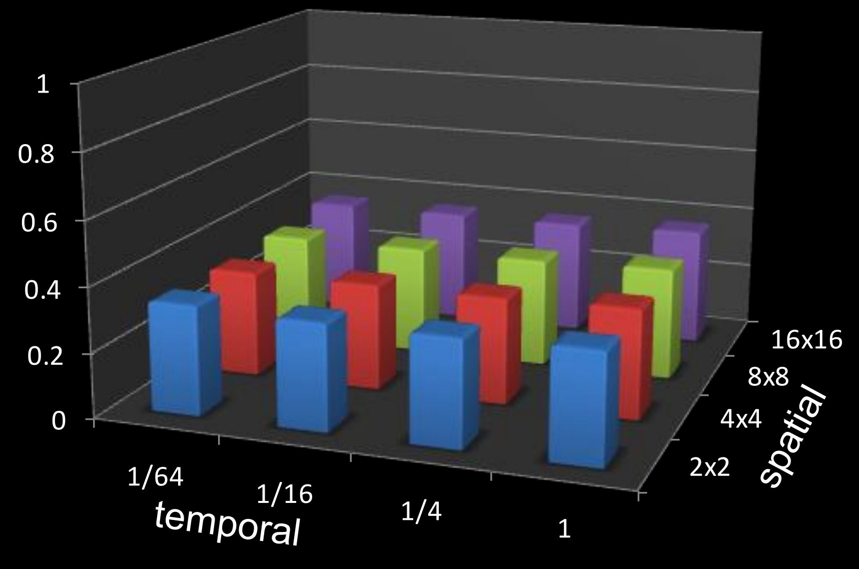




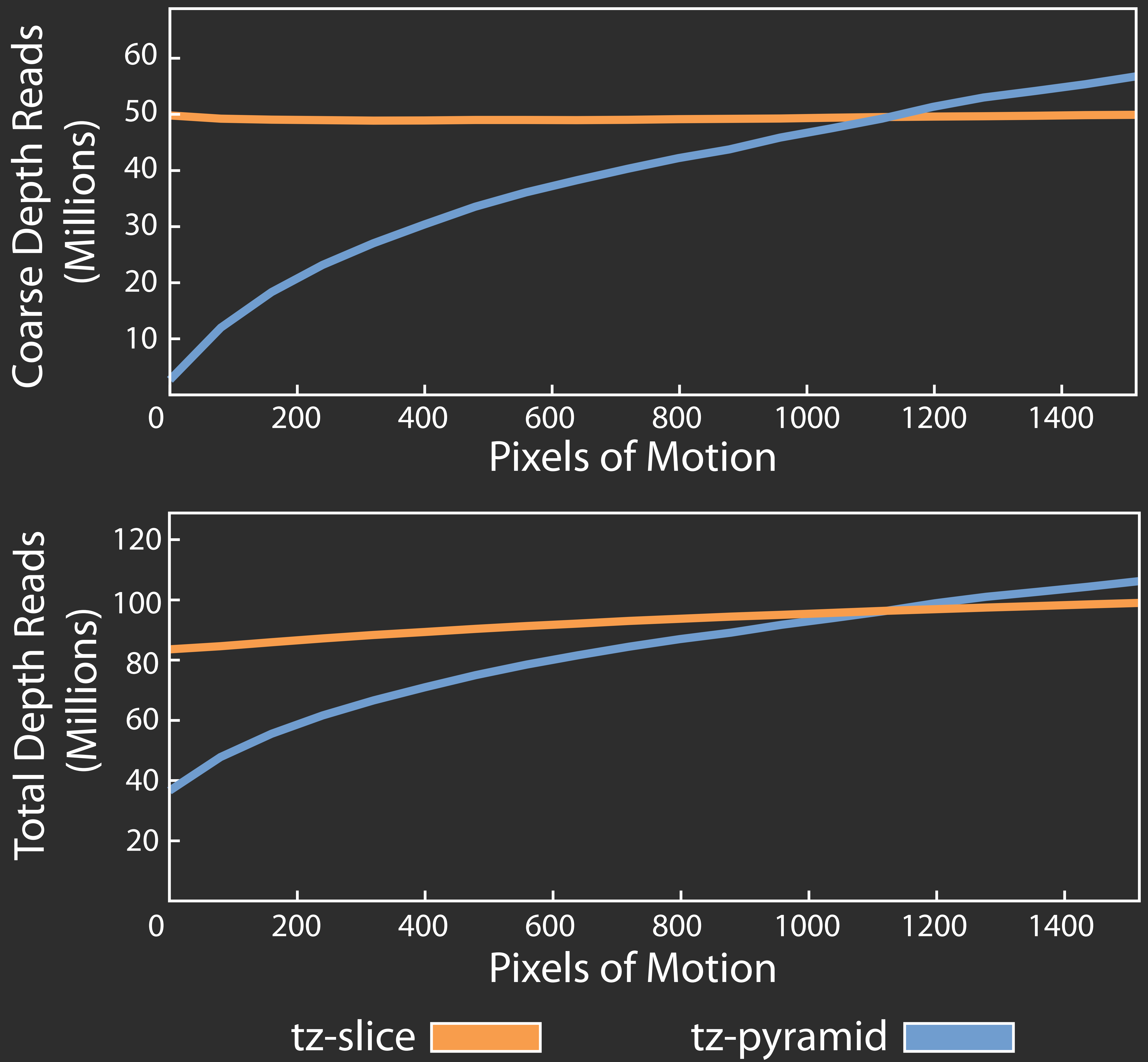
z reads







TZ-Pyramid: More efficient



Recap

- TZ-Pyramid: extension of z-pyramid for motion blur
  - More effective than reusing z-pyramid
  - More efficient than TZ-slice
  - Manageable footprint
- Culling at all stages works best
  - Pays for itself
  - Culling earlier increases benefit while reducing cost

Next Steps

- Traditional optimizations
  - Compression, Resolution Tradeoffs, Fixed-Function
- More applications
- Future pipeline integration

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- National Science Foundation Graduate Research Fellowship
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- Zinkia Entertainment, S.A.