

Real-Time Volumetric Shadows using 1D Min-Max Mipmaps

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1

Volumetric scattering with shadows

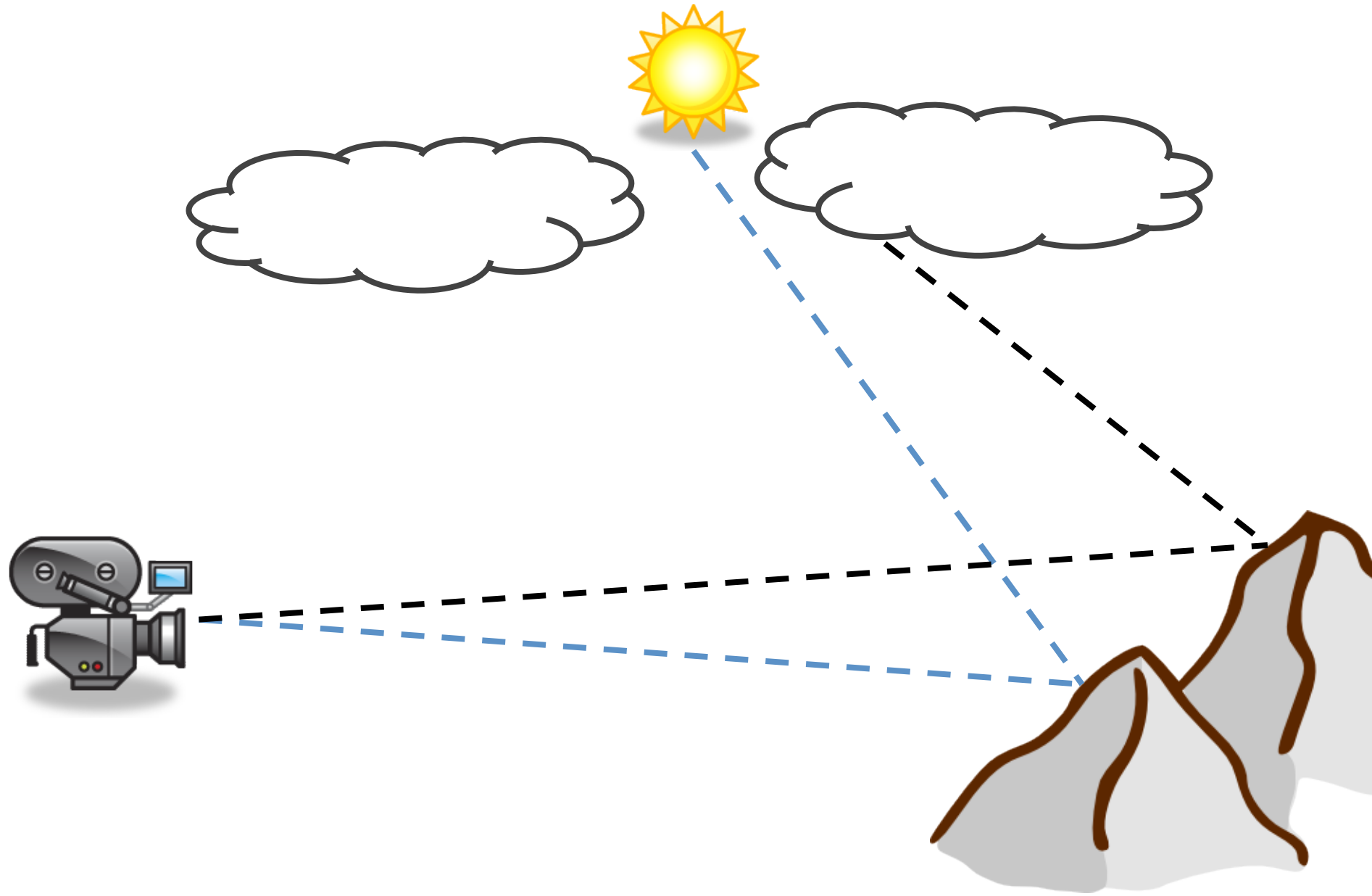


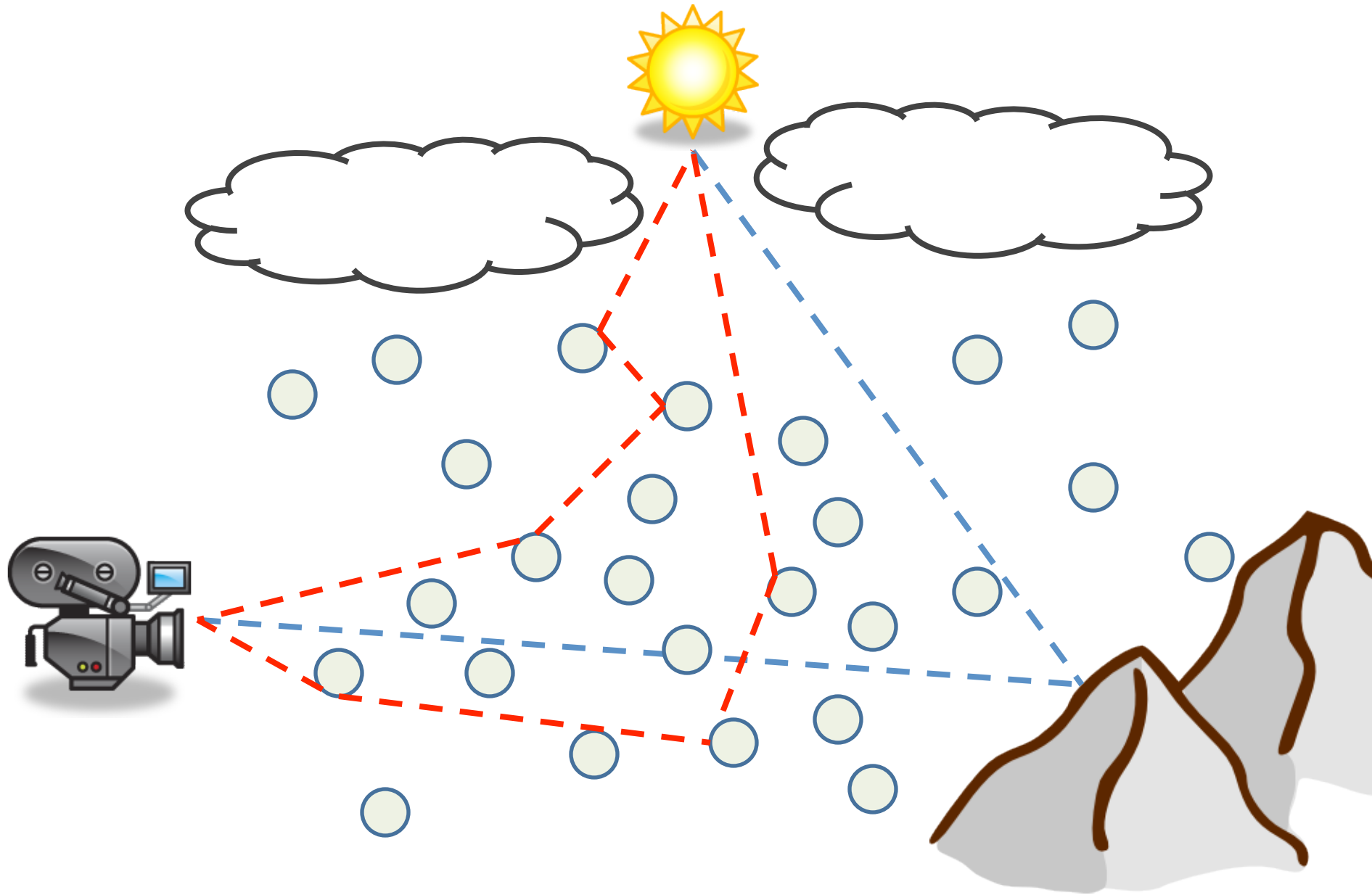
Fredo Durand

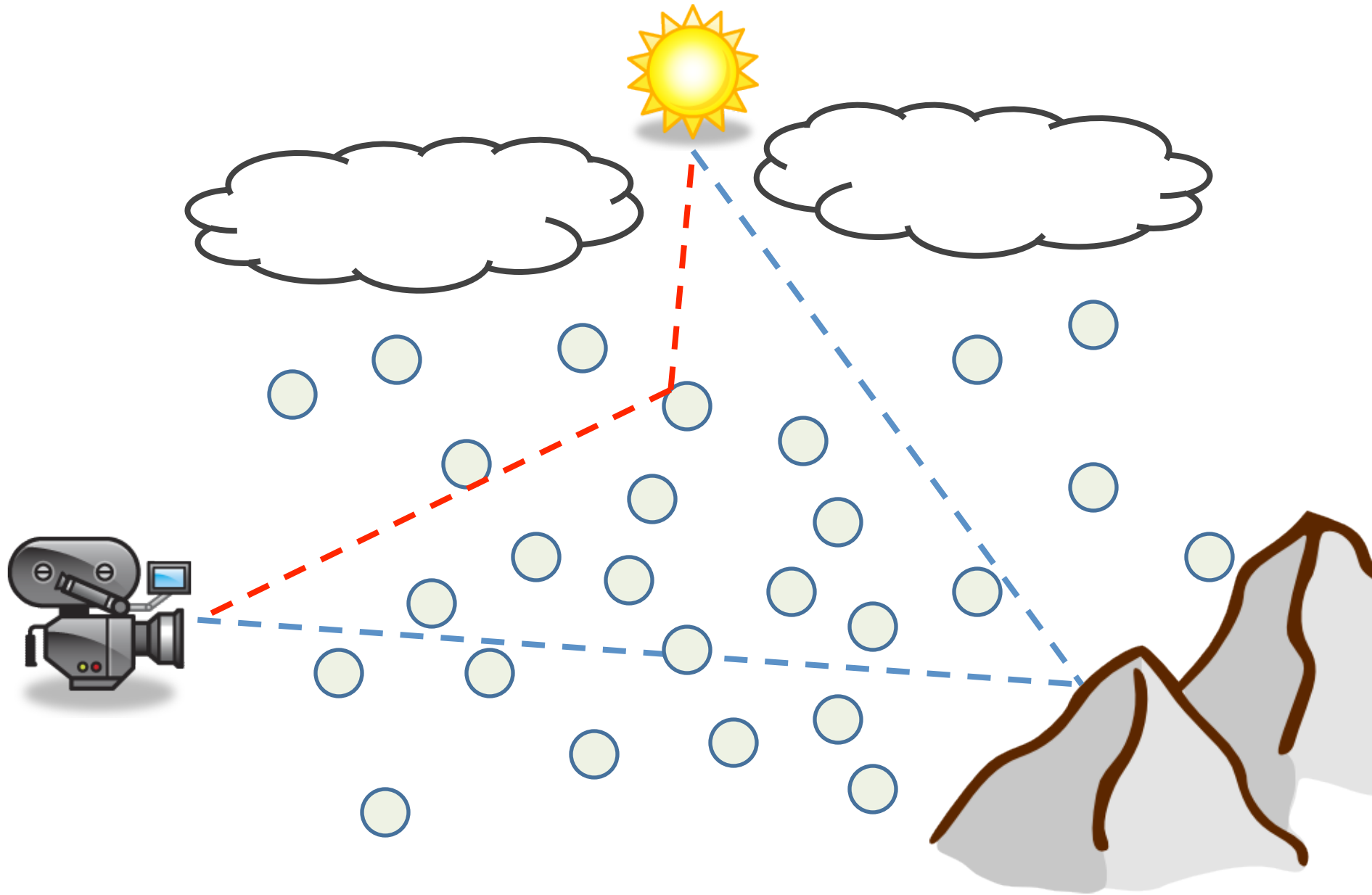
Photo by Frédo Durand

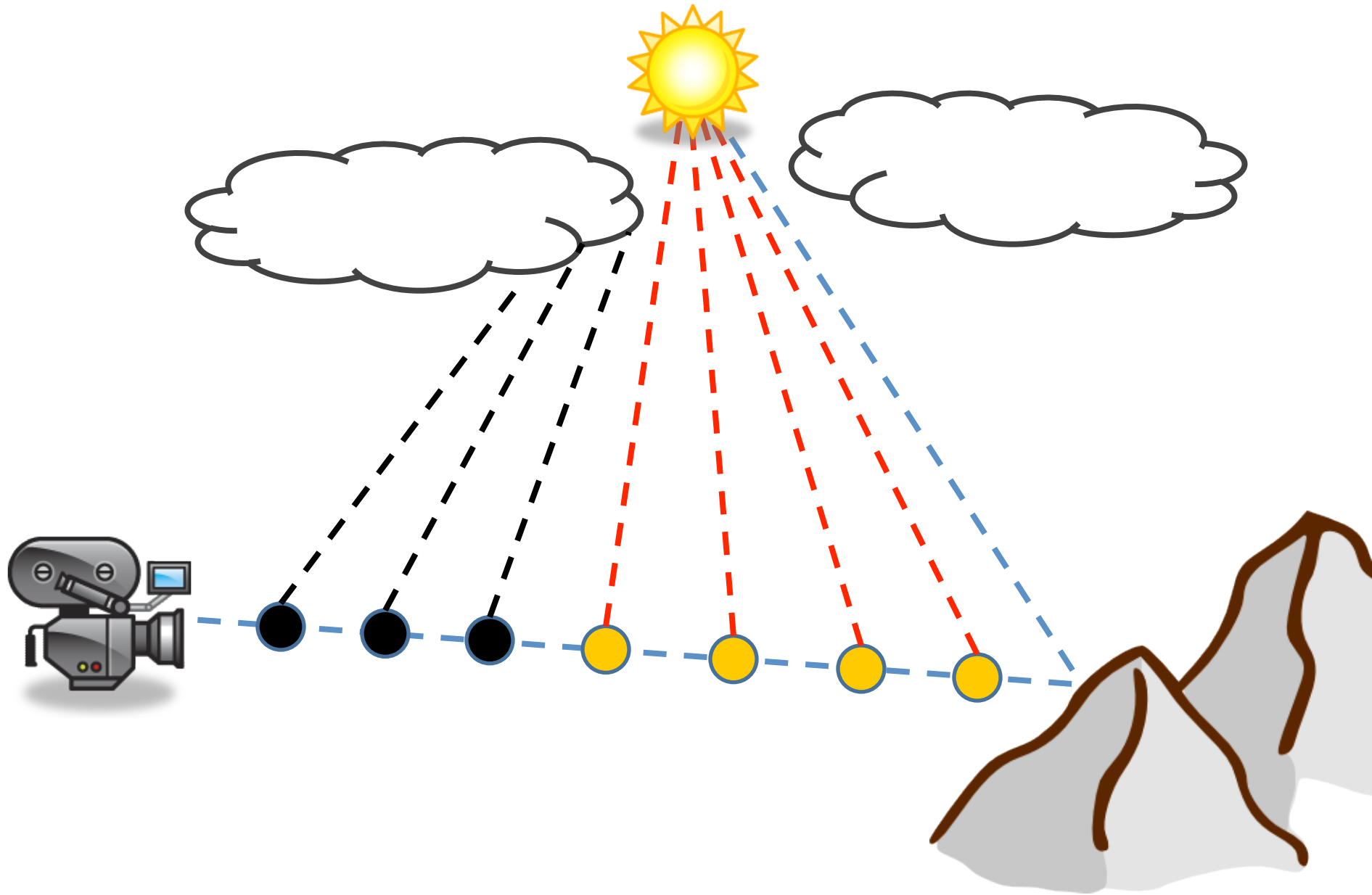


Alan Wake by Remedy Entertainment



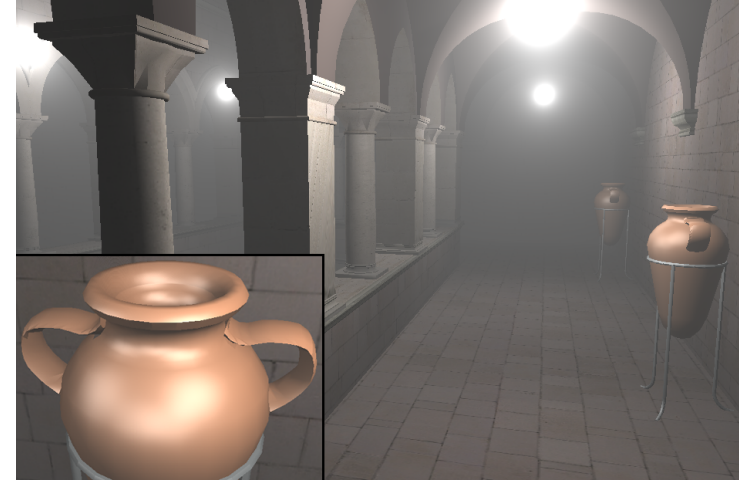




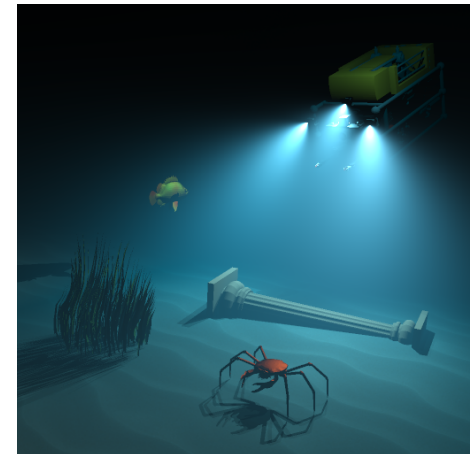


Related work

- Analytical scattering models
[Sun et al. 2005],
[Pegoraro et al. 2009, 2010]
- Sky lighting, bloom near light sources, attenuation
- Doesn't account for visibility



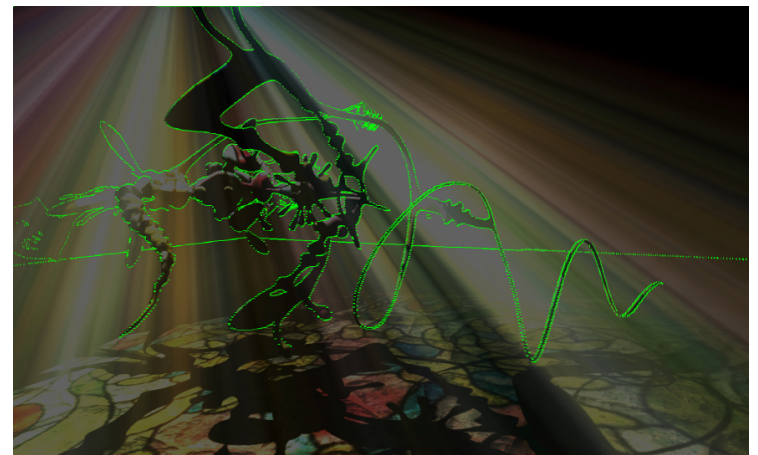
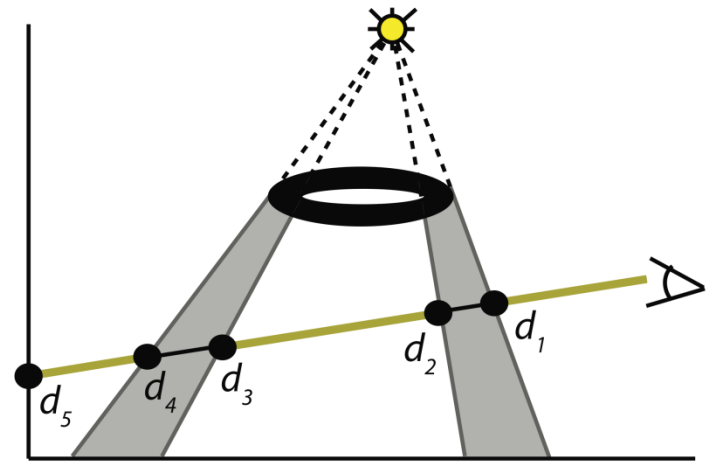
Sun et al. [2005]



Pegoraro et al. [2010]

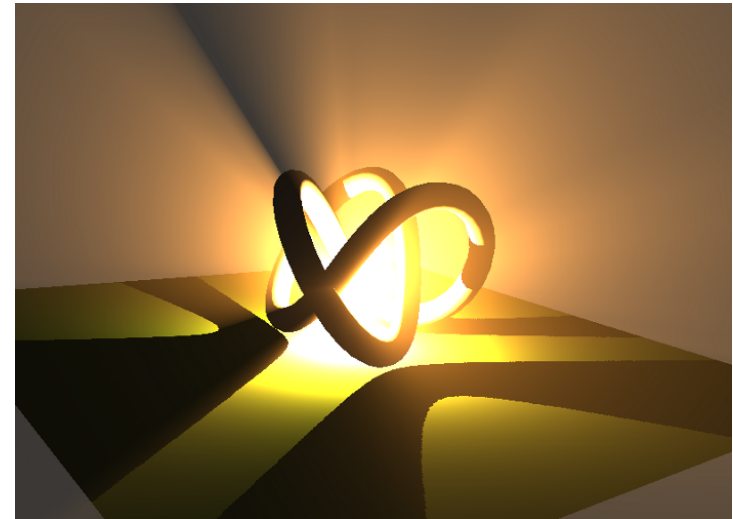
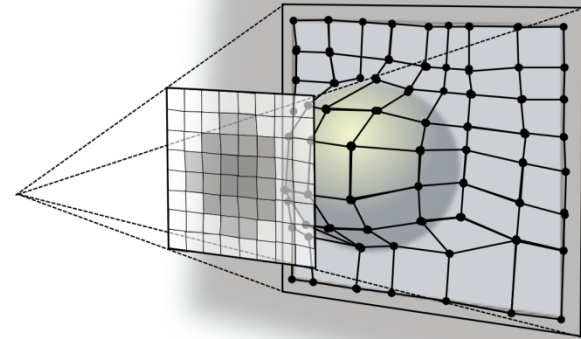
Related work

- Max [1986]
 - Analytical integration
- Wyman and Ramsey [2008]
 - Ray marching along intervals
- Engelhardt and Dachsbacher [2010]
 - Detect discontinuities, subsample and interpolate



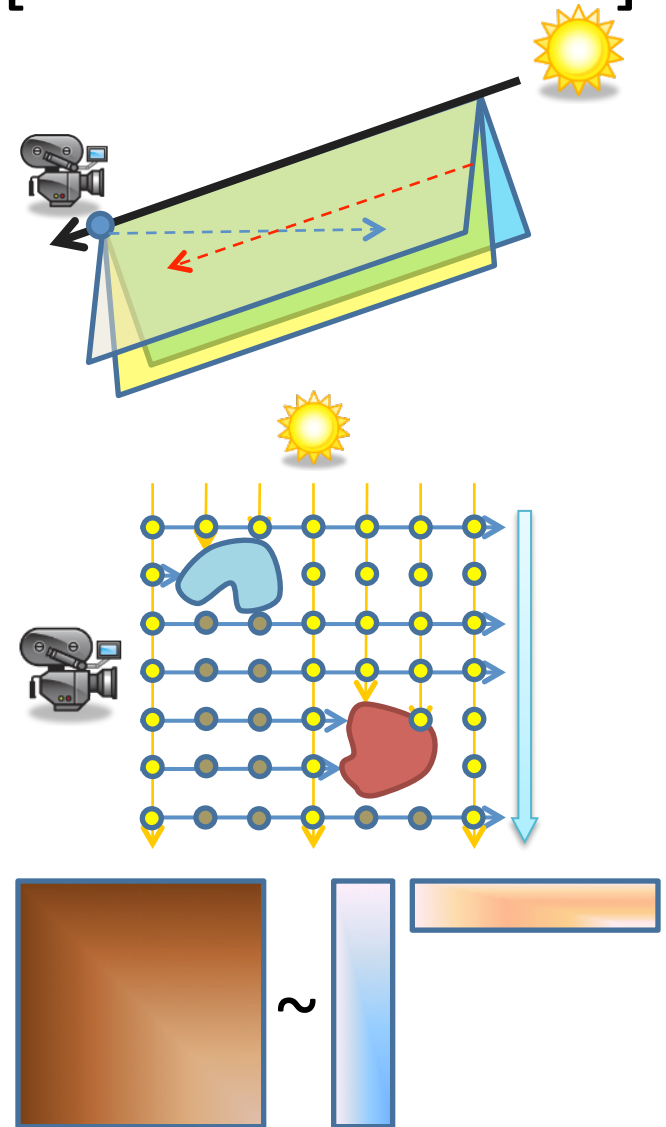
Related work

- Billeter et al. [2010]
 - Interpret shadow map as a height field
 - Rasterize height field and analytically accumulate scattering integral
 - Vertex and fragment overhead
- We ray trace instead



Incremental integration [Baran et al. 2010]

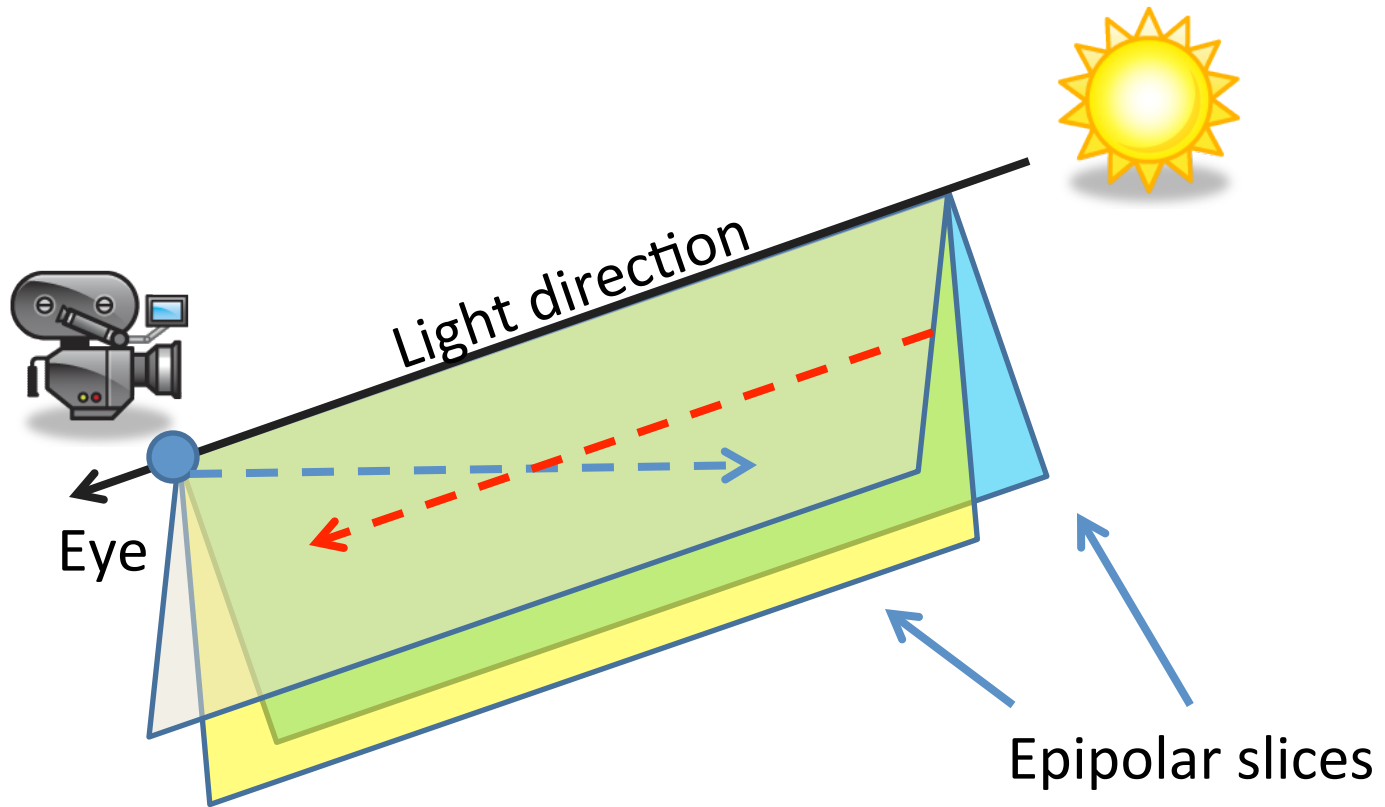
- Epipolar rectification
- SVD approximation for smooth, non-analytic integrands
- Partial sum trees



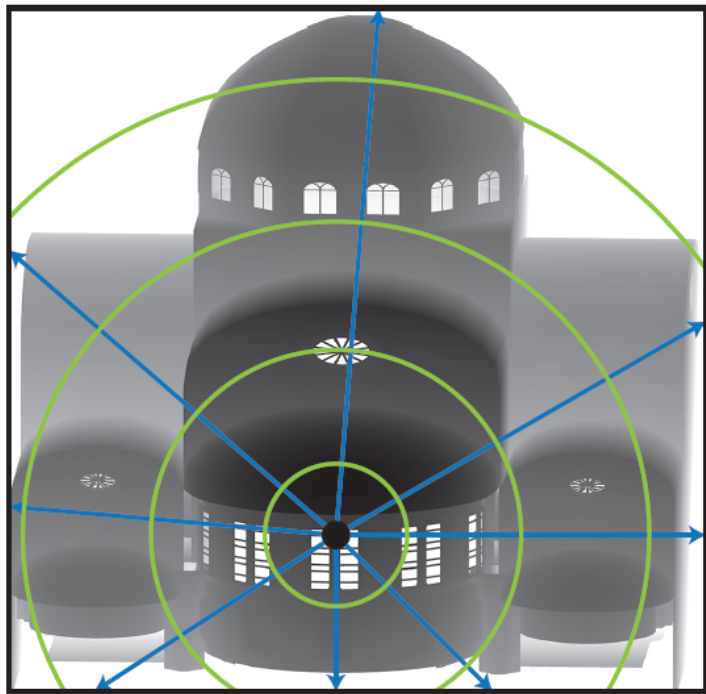
Overview

- Review of epipolar geometry and visibility integration
- Min-max mipmap data structure
- Results and discussion

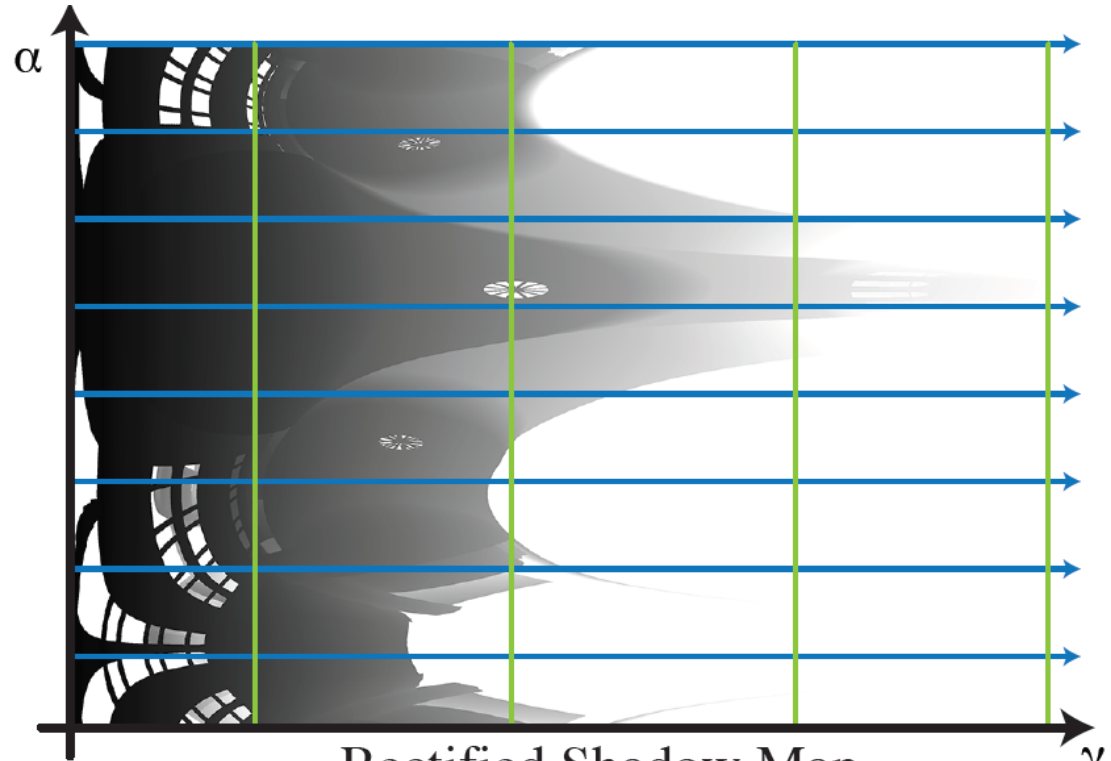
Epipolar rectification



Epipolar rectification



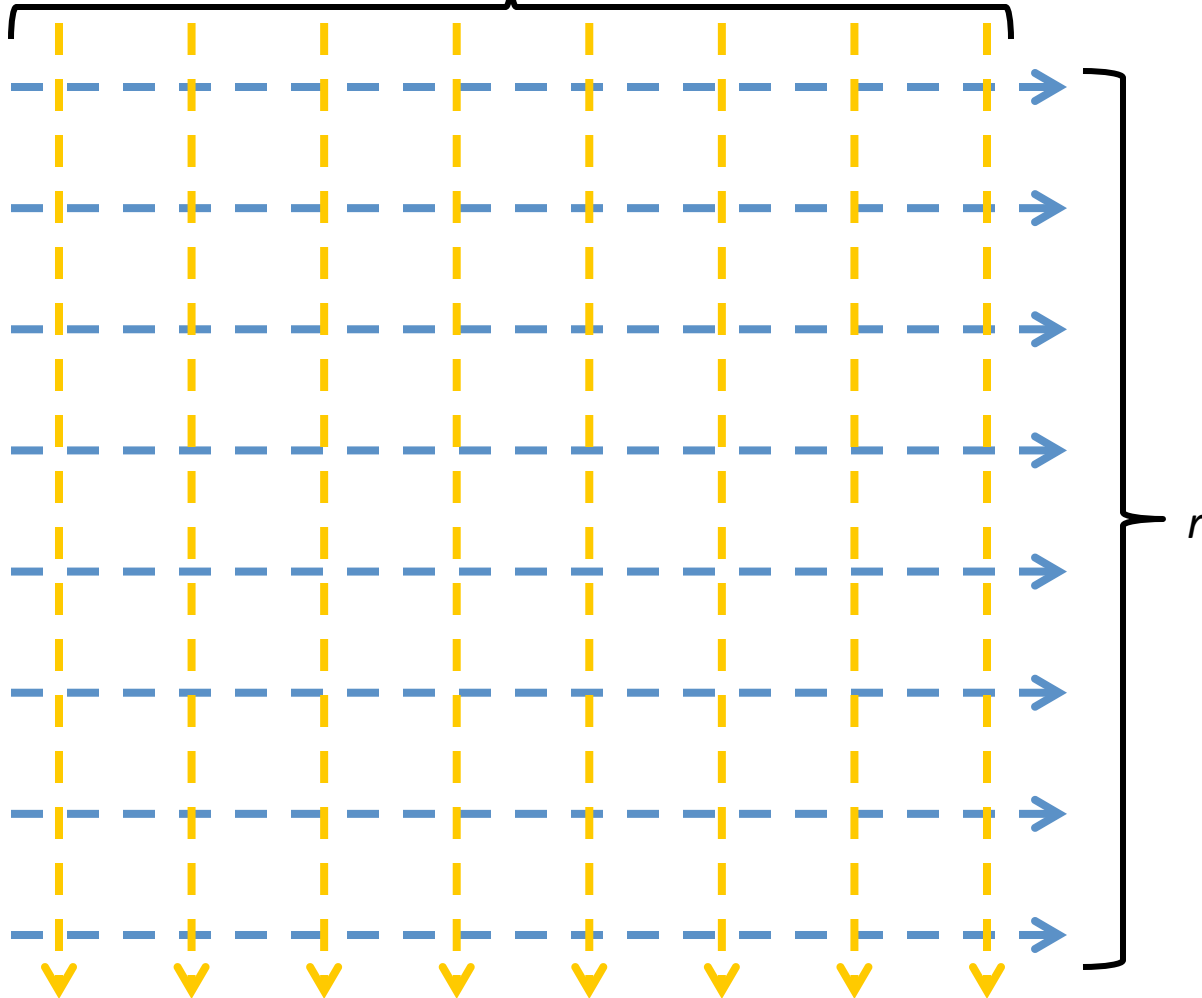
Shadow Map

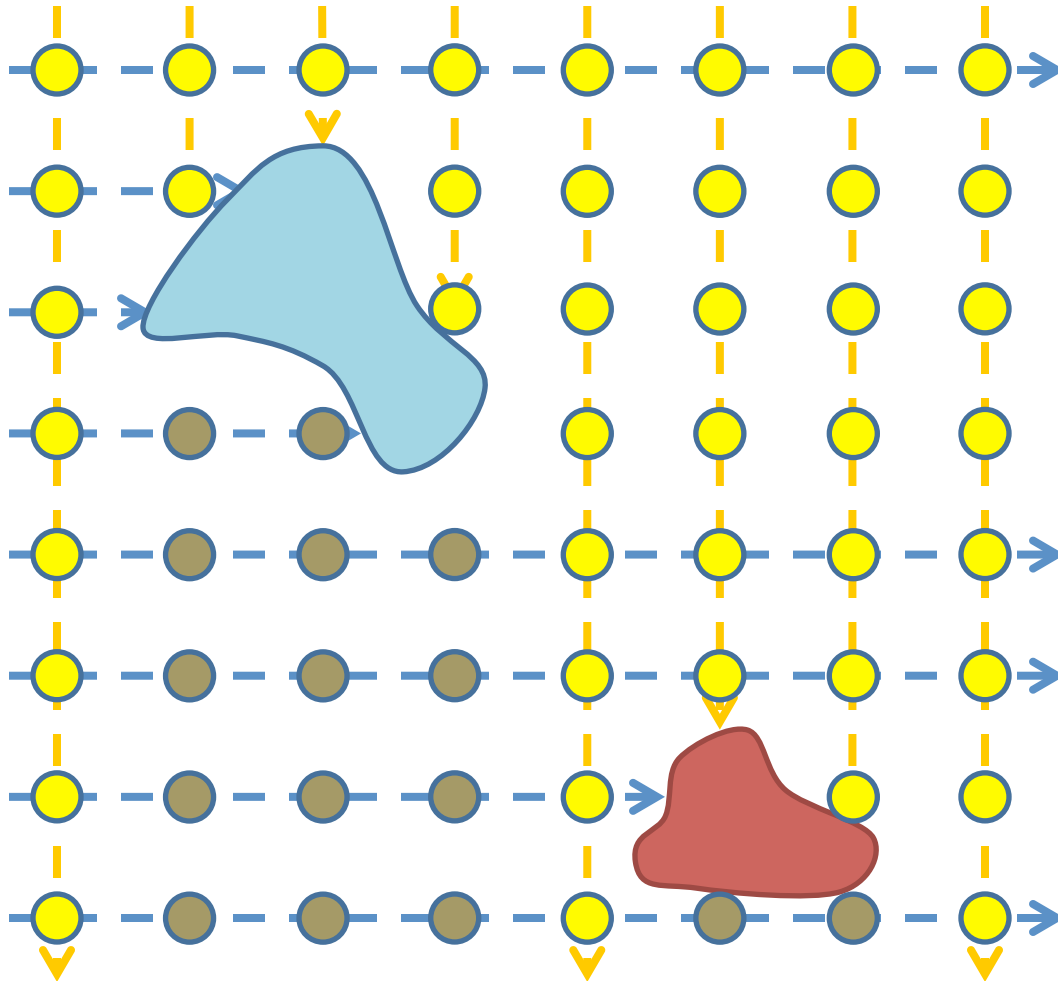


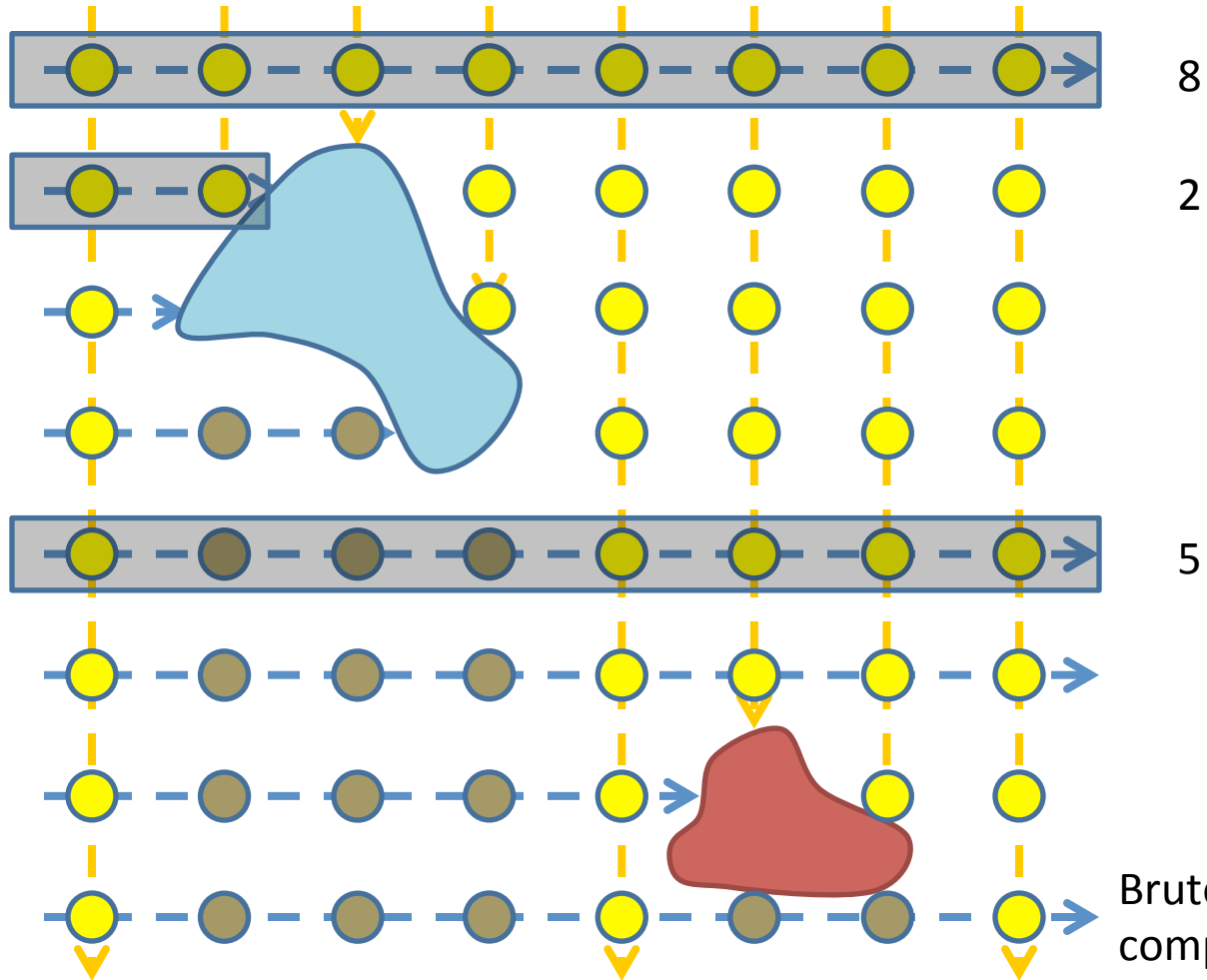
Rectified Shadow Map



d

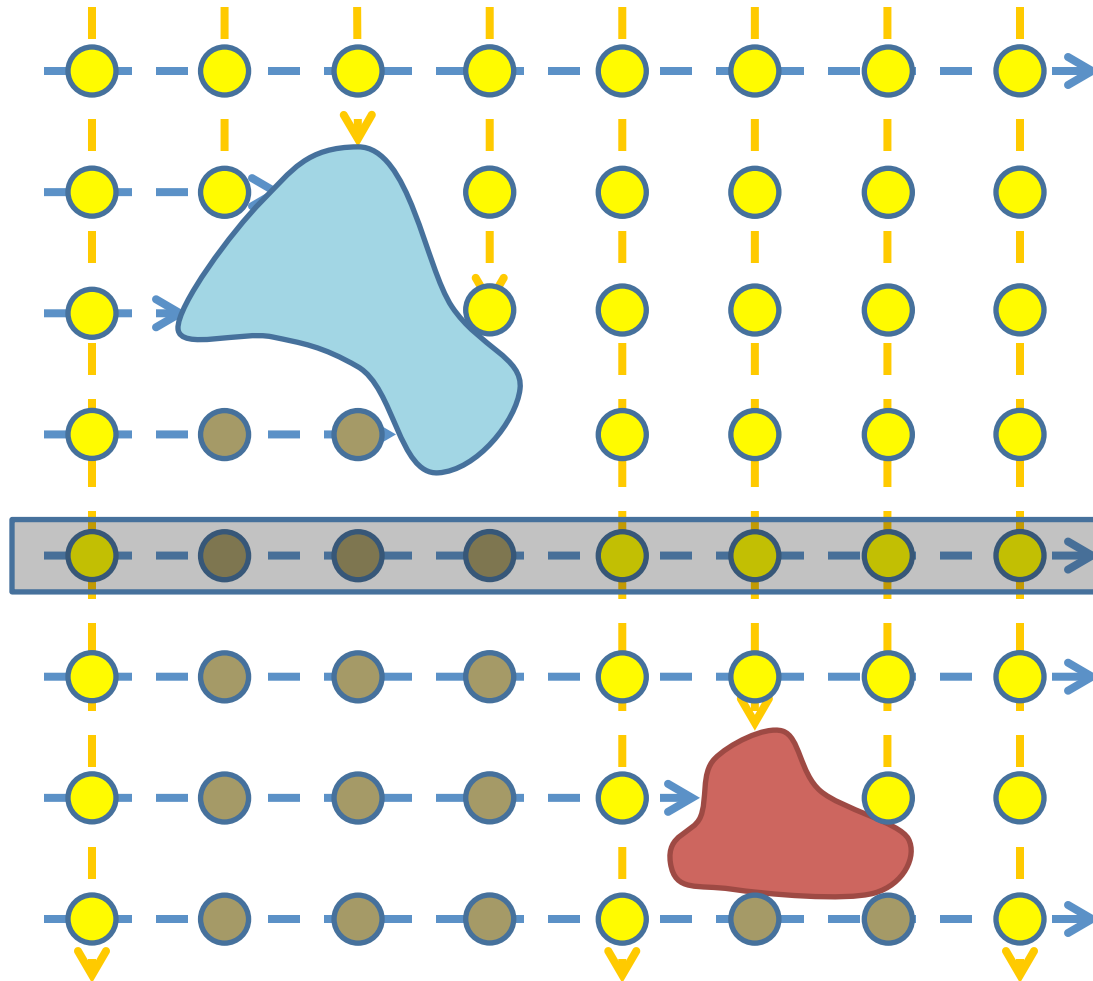






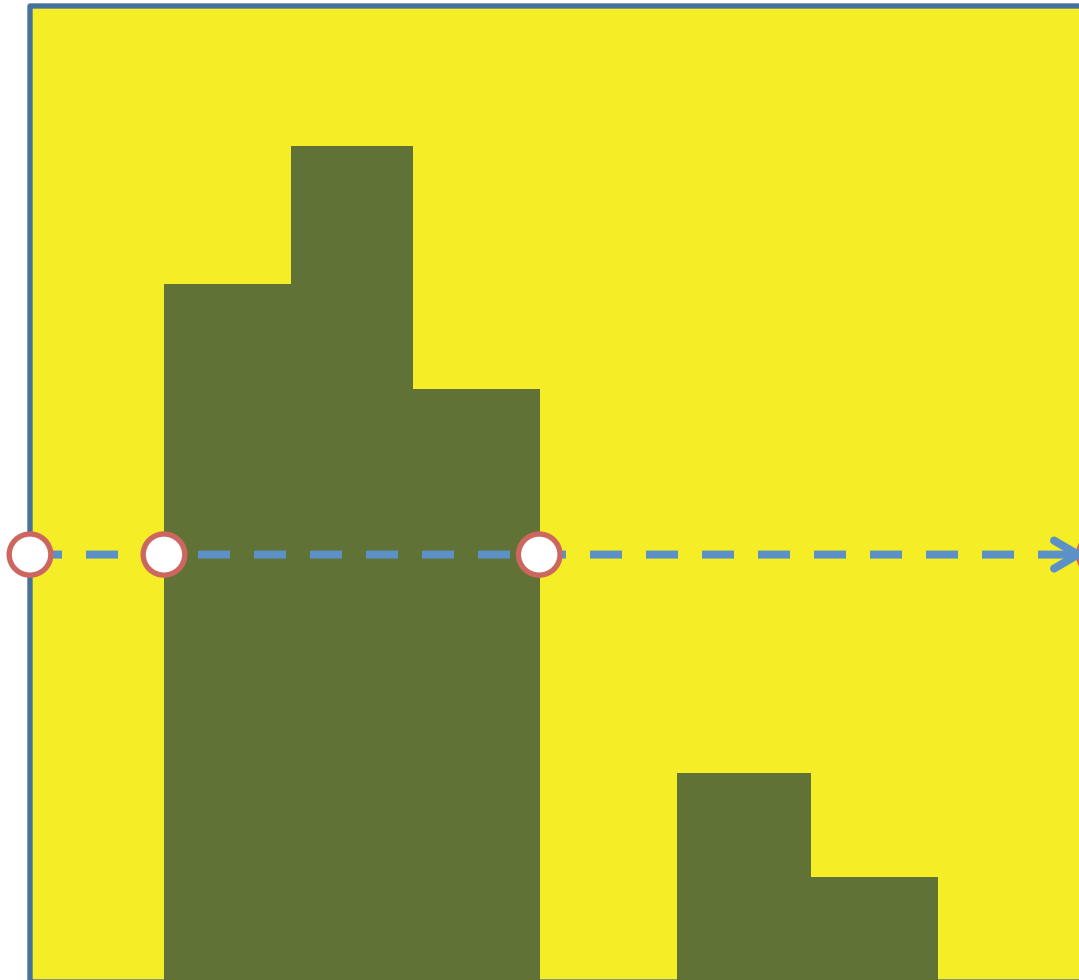
Brute force
complexity: $O(rd)$

Visibility integration revisited



View ray:
 $y = 5, x = 9$

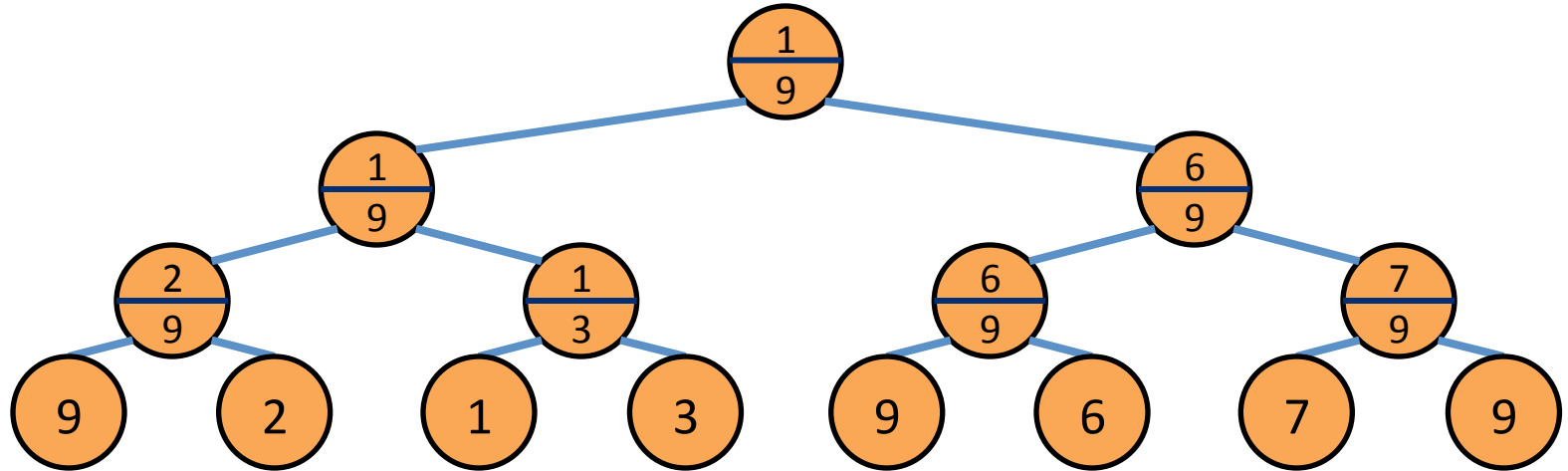
Height field intersection



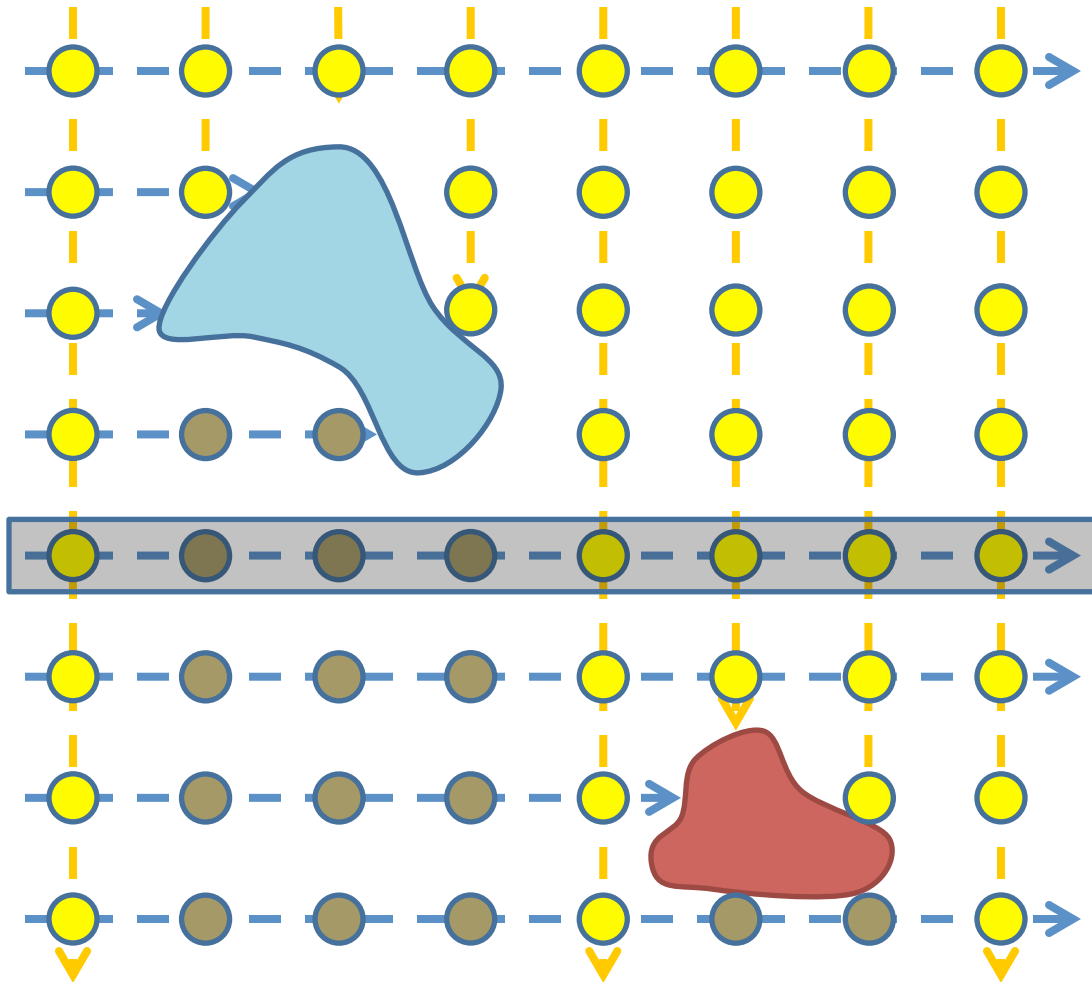
View ray:
 $y = 5, x = 9$

1D Min-Max Mipmap

- Binary tree of shadow map depths
 - Each node stores **min** and **max** of children



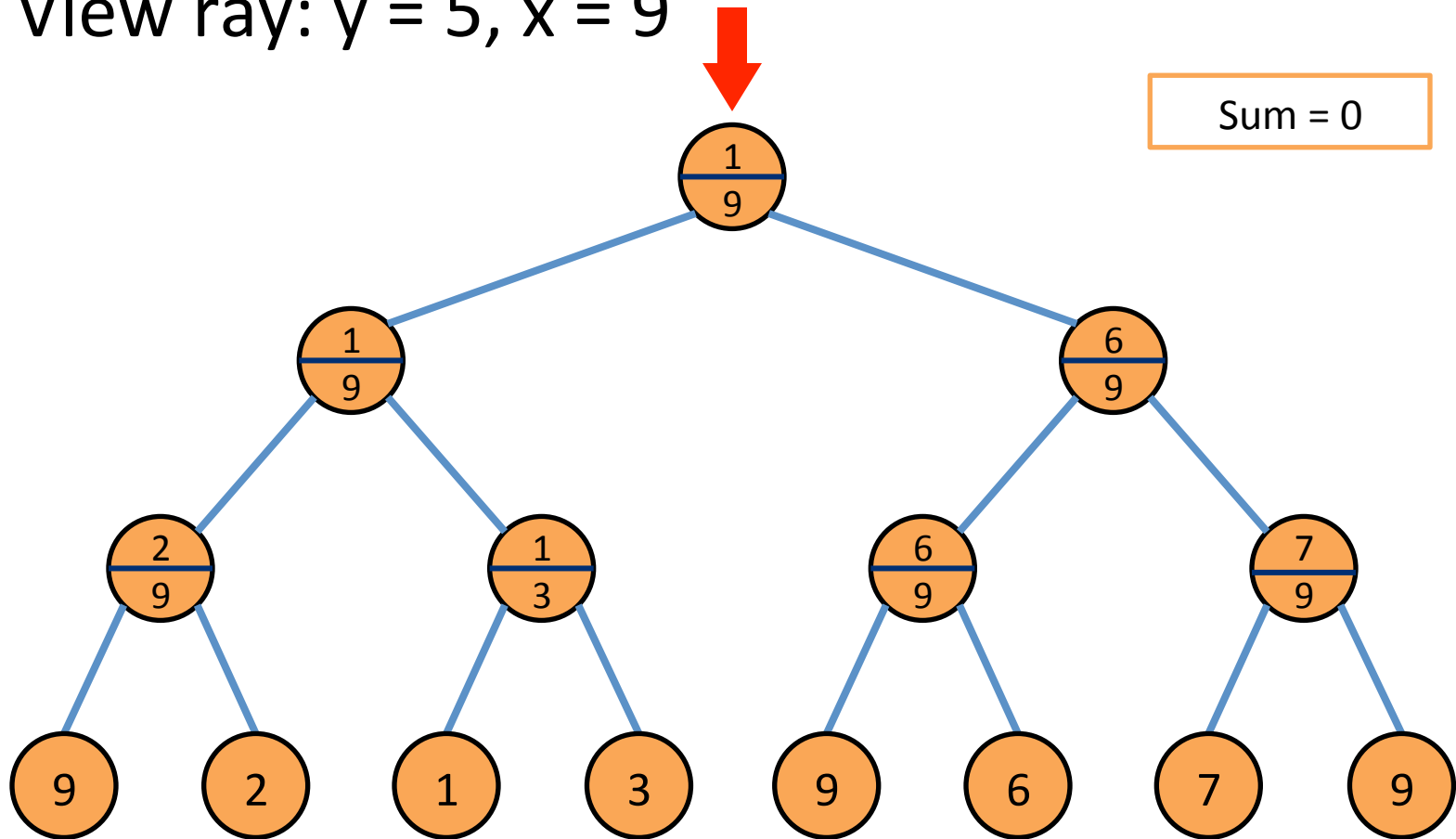
Mipmap traversal



View ray:
 $y = 5, x = 9$

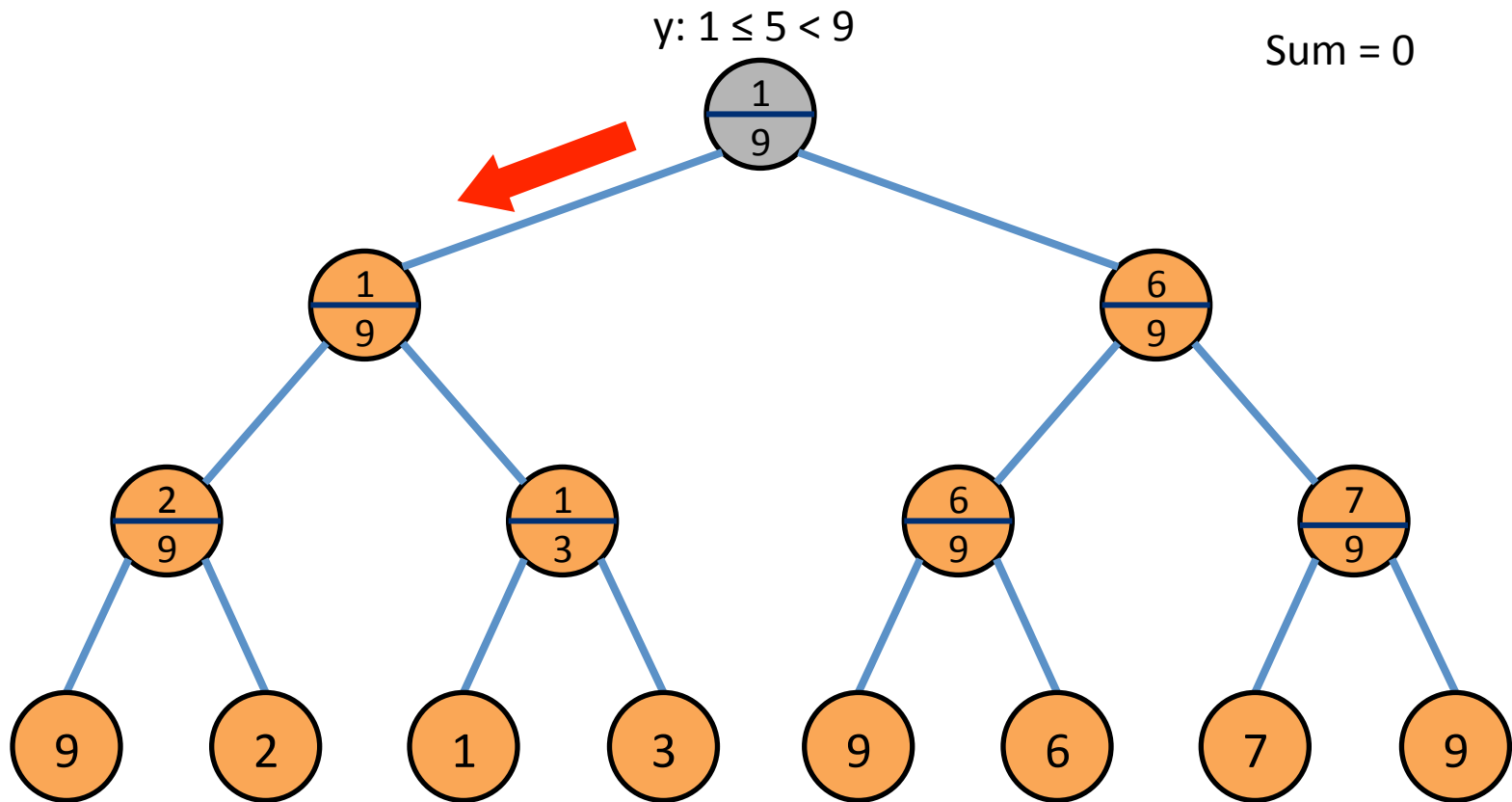
Mipmap traversal

- View ray: $y = 5, x = 9$



Mipmap traversal

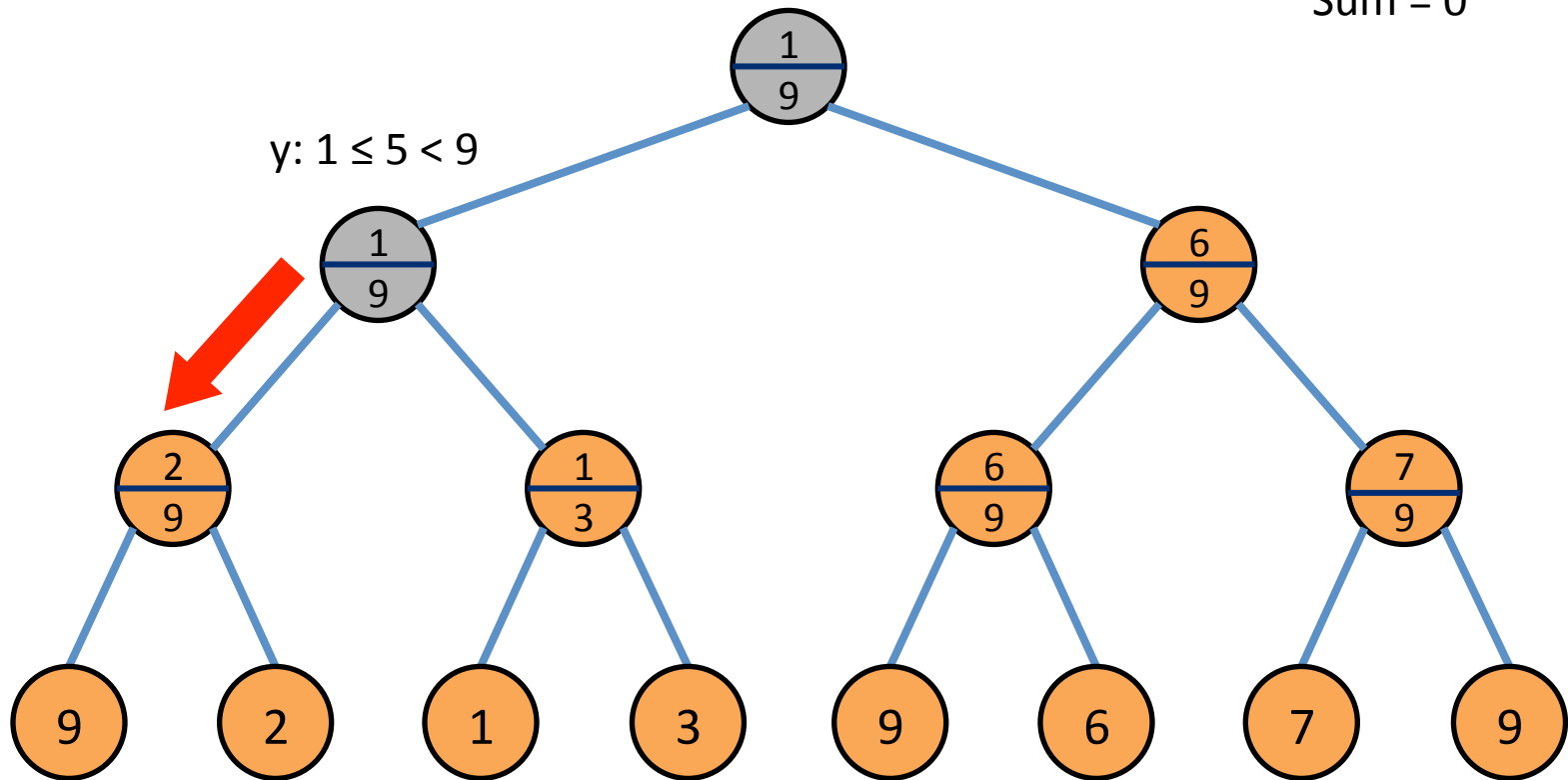
- View ray: $y = 5, x = 9$



Mipmap traversal

- View ray: $y = 5, x = 9$

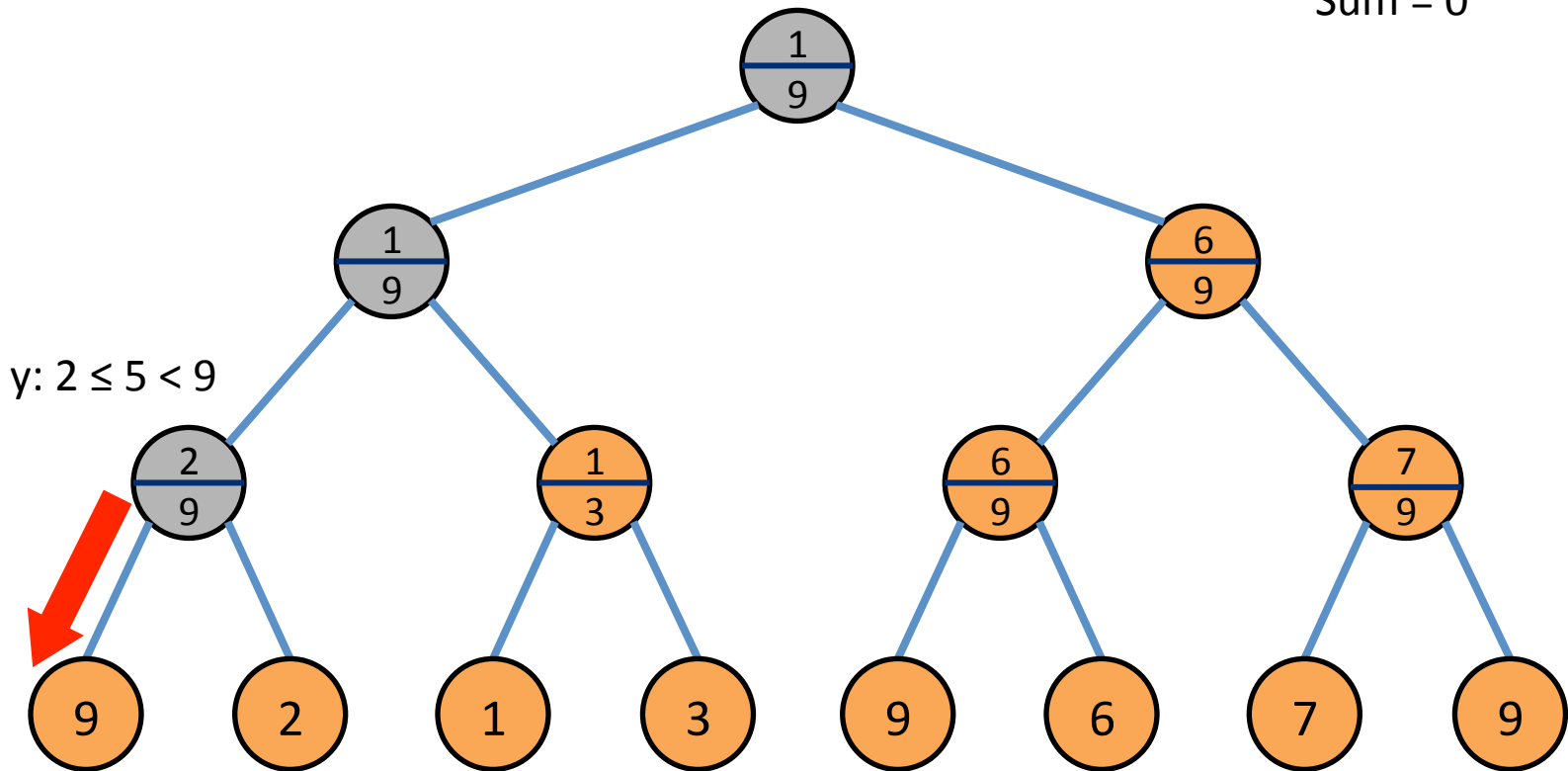
Sum = 0



Mipmap traversal

- View ray: $y = 5, x = 9$

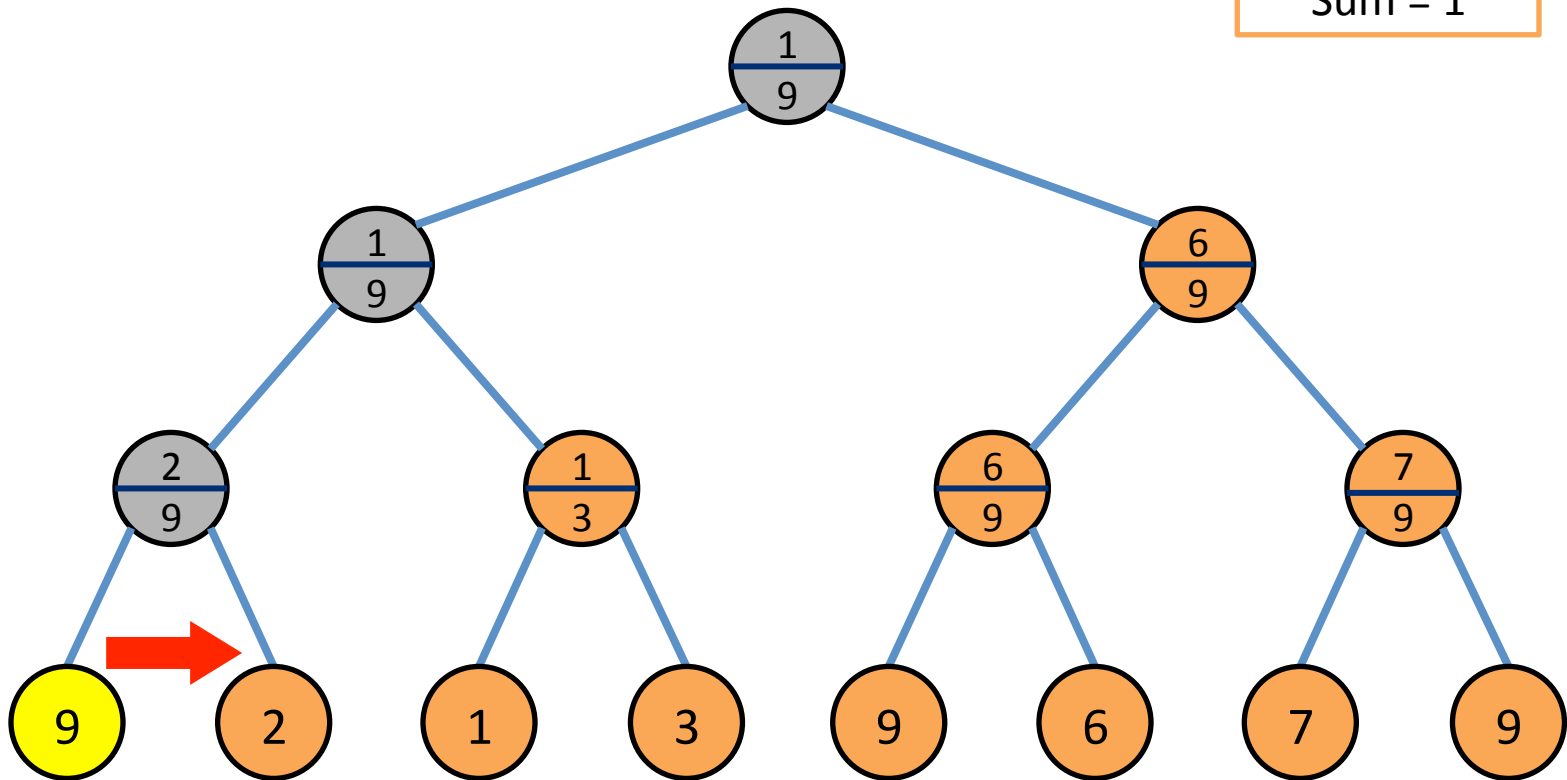
Sum = 0



Mipmap traversal

- View ray: $y = 5, x = 9$

Sum = 1

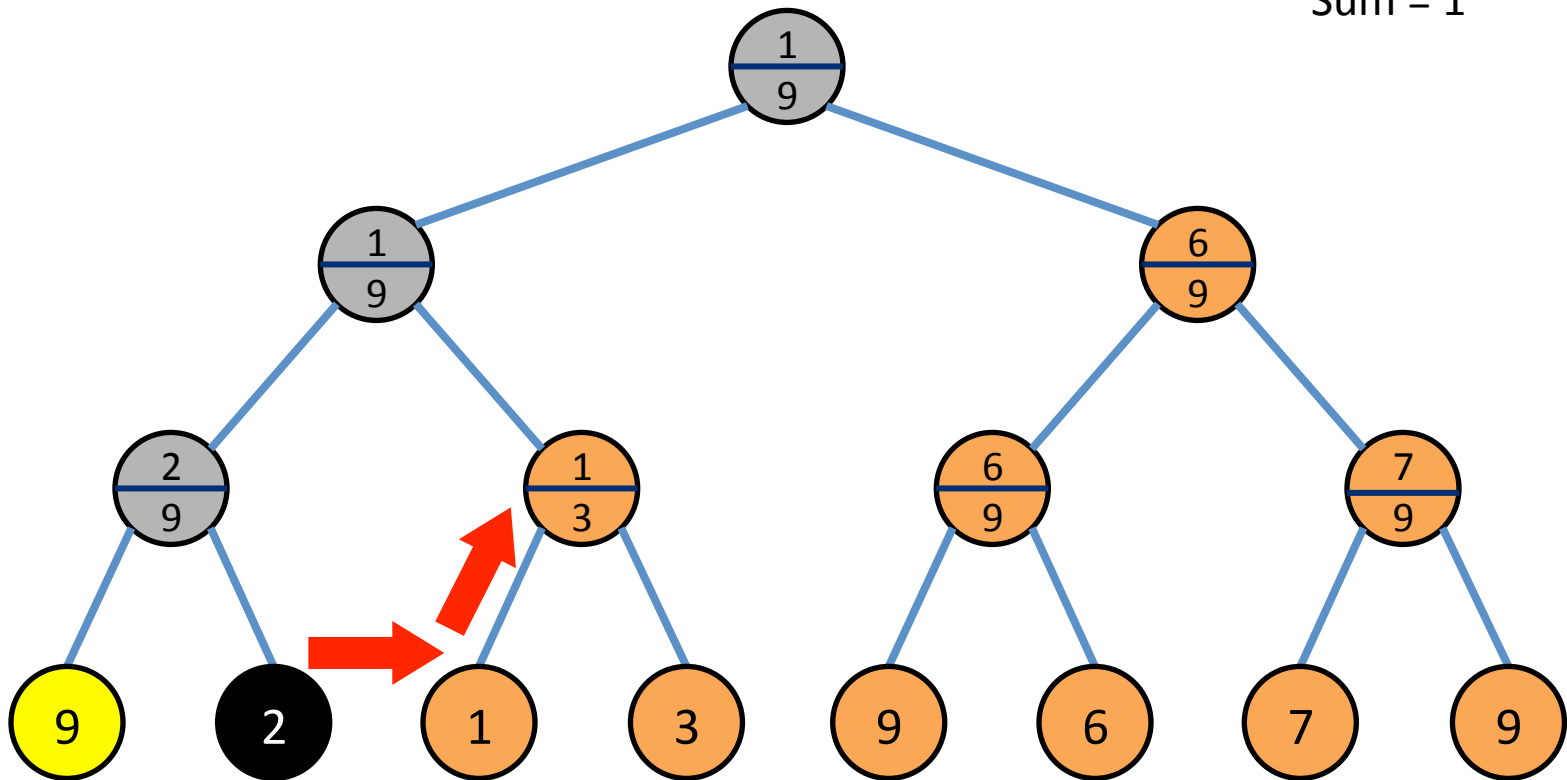


$y: 5 < 9$, lit

Mipmap traversal

- View ray: $y = 5, x = 9$

Sum = 1

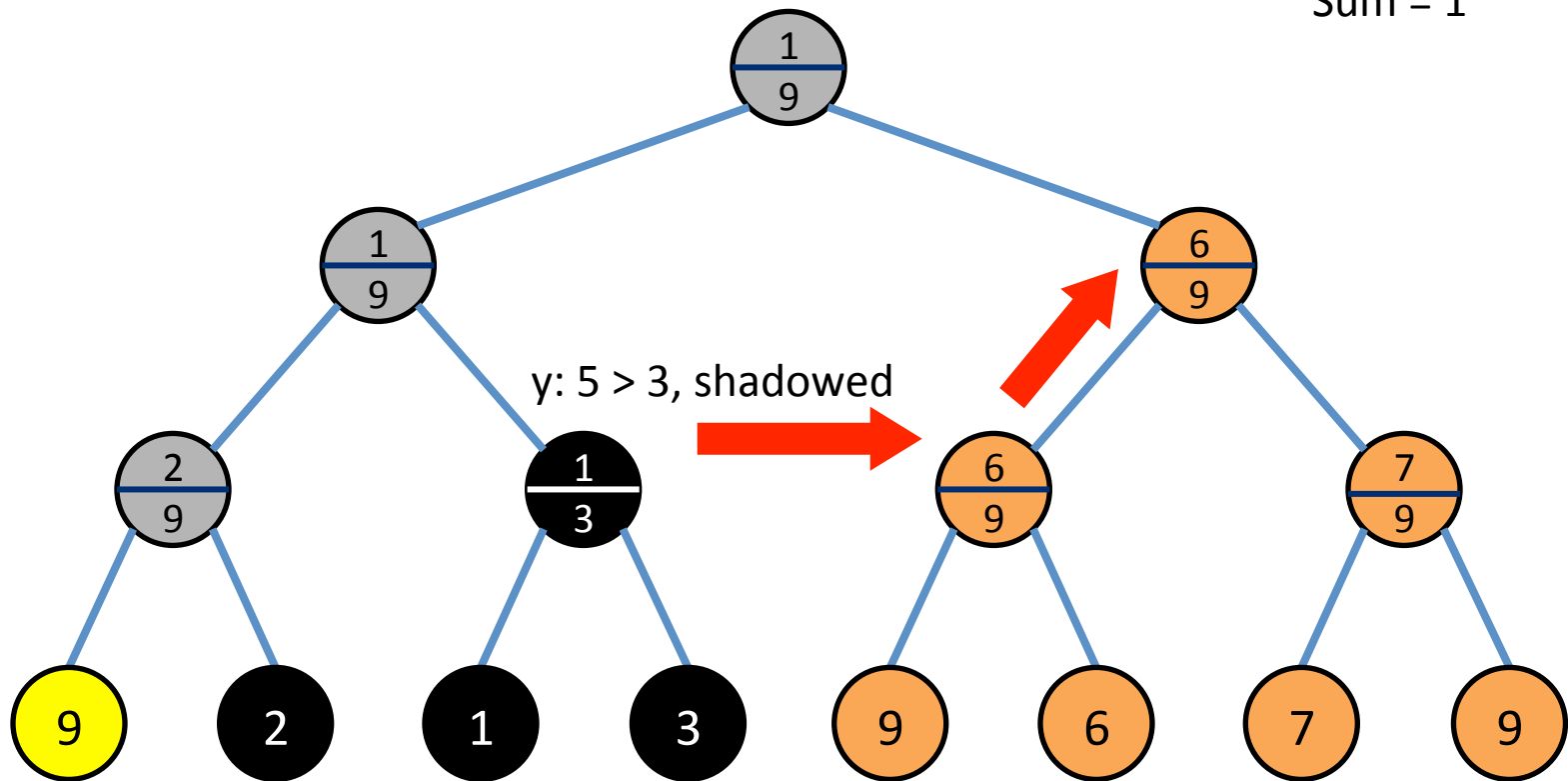


$y: 5 > 2$, shadowed

Mipmap traversal

- View ray: $y = 5, x = 9$

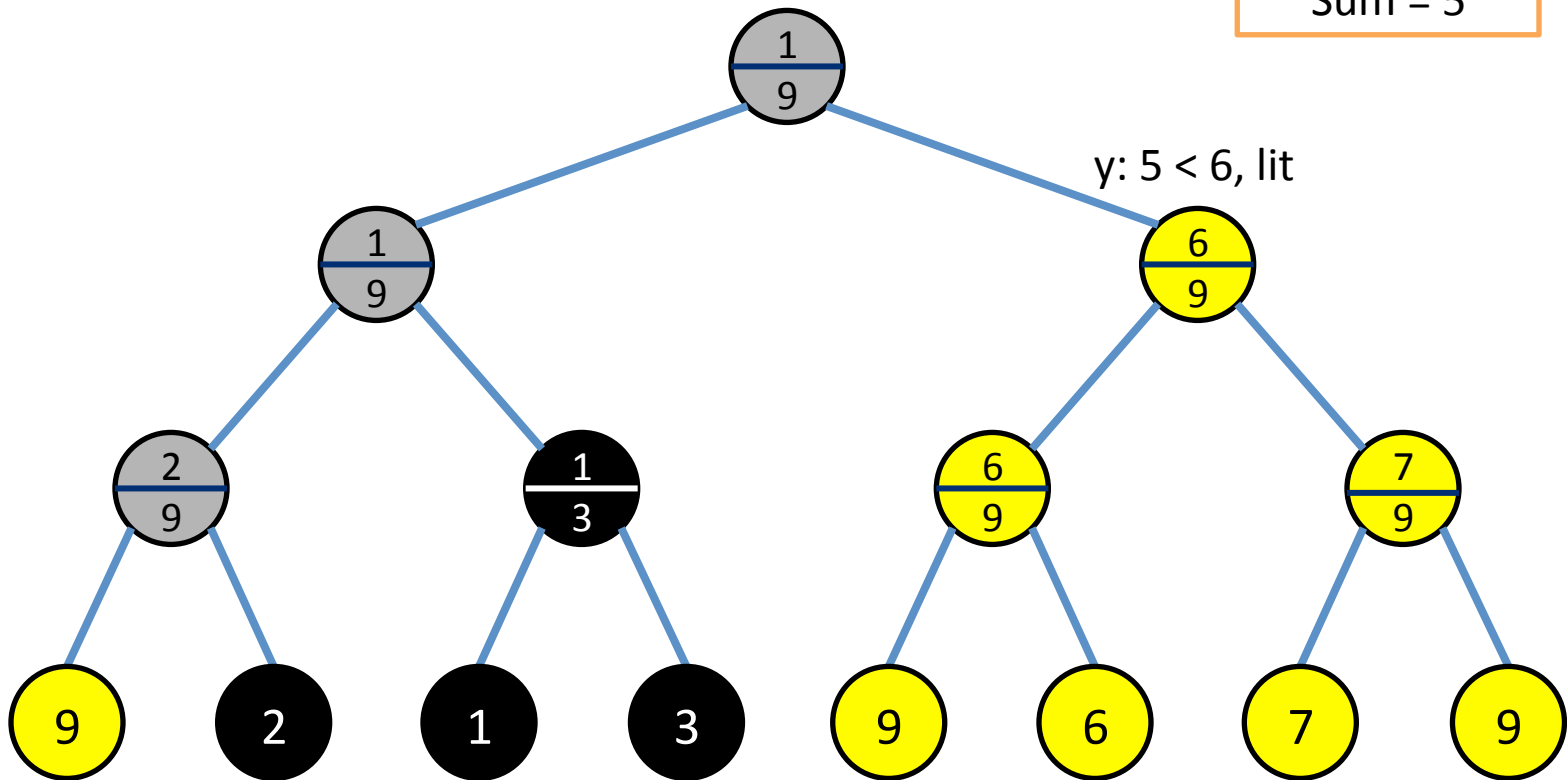
Sum = 1



Mipmap traversal

- View ray: $y = 5, x = 9$

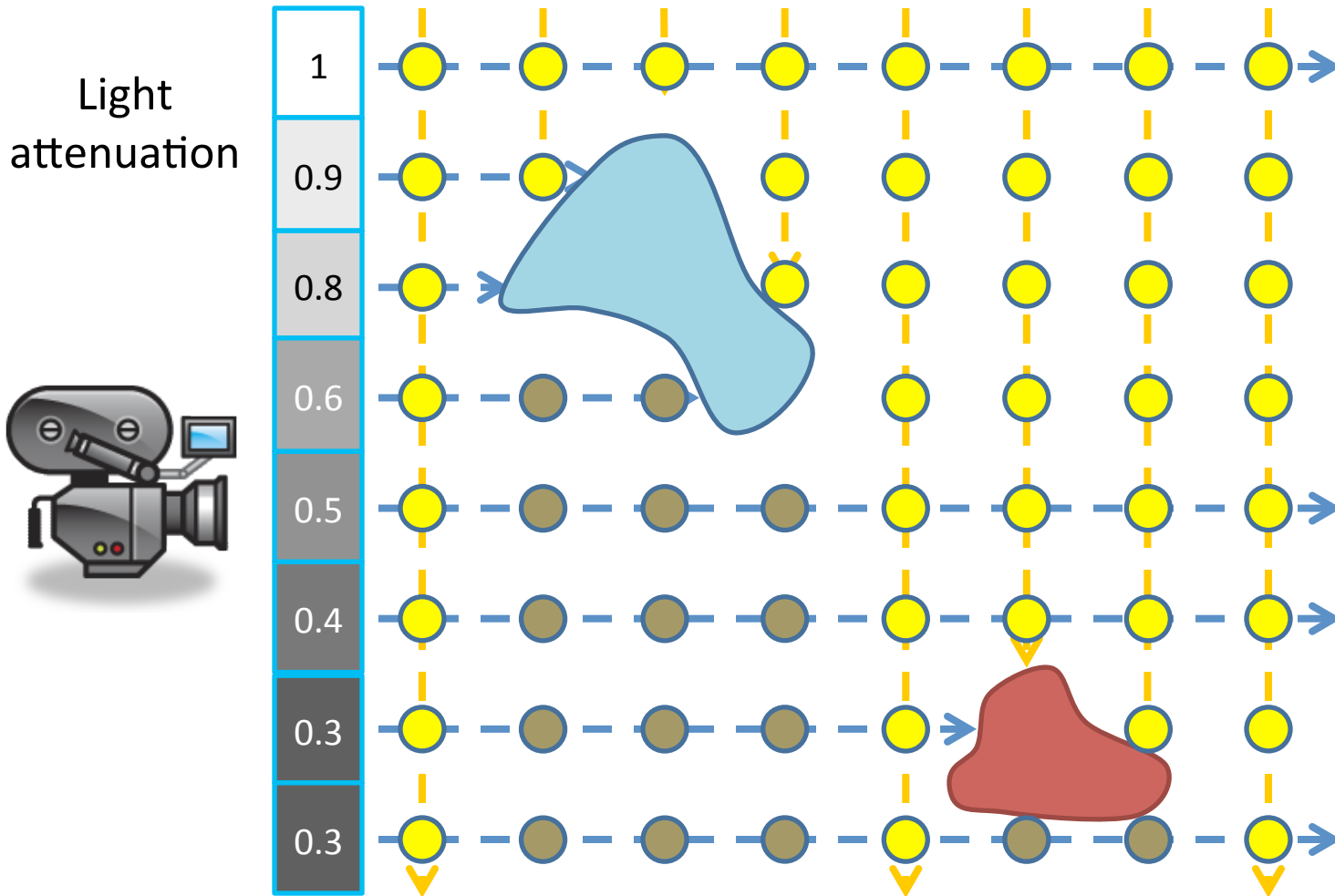
Sum = 5



Textured lights and attenuation

Light texture

0.8	0.1	0.5	0.3	0.2	1	0.8	0.4
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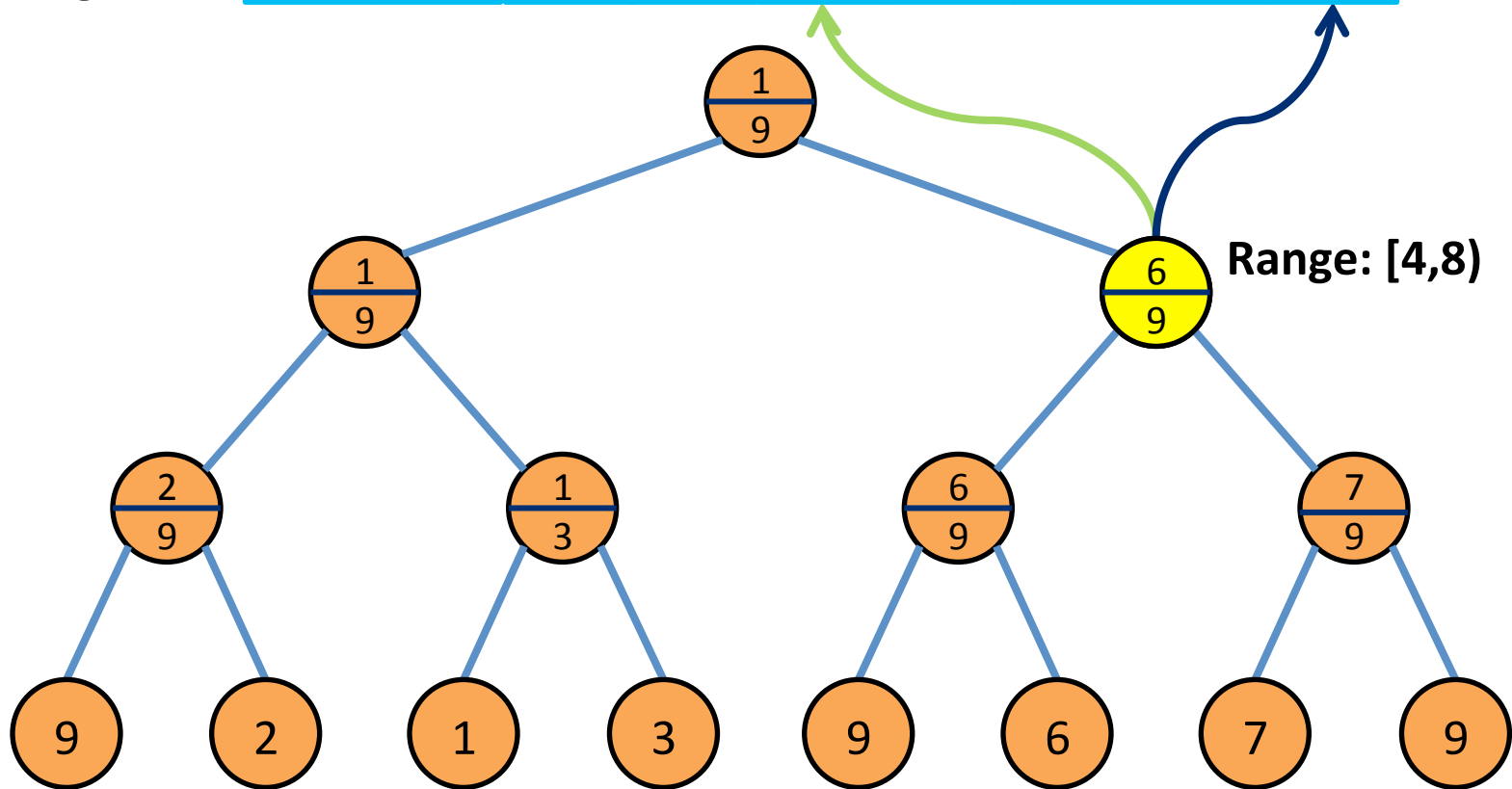
Textured lights using prefix sums

Light texture

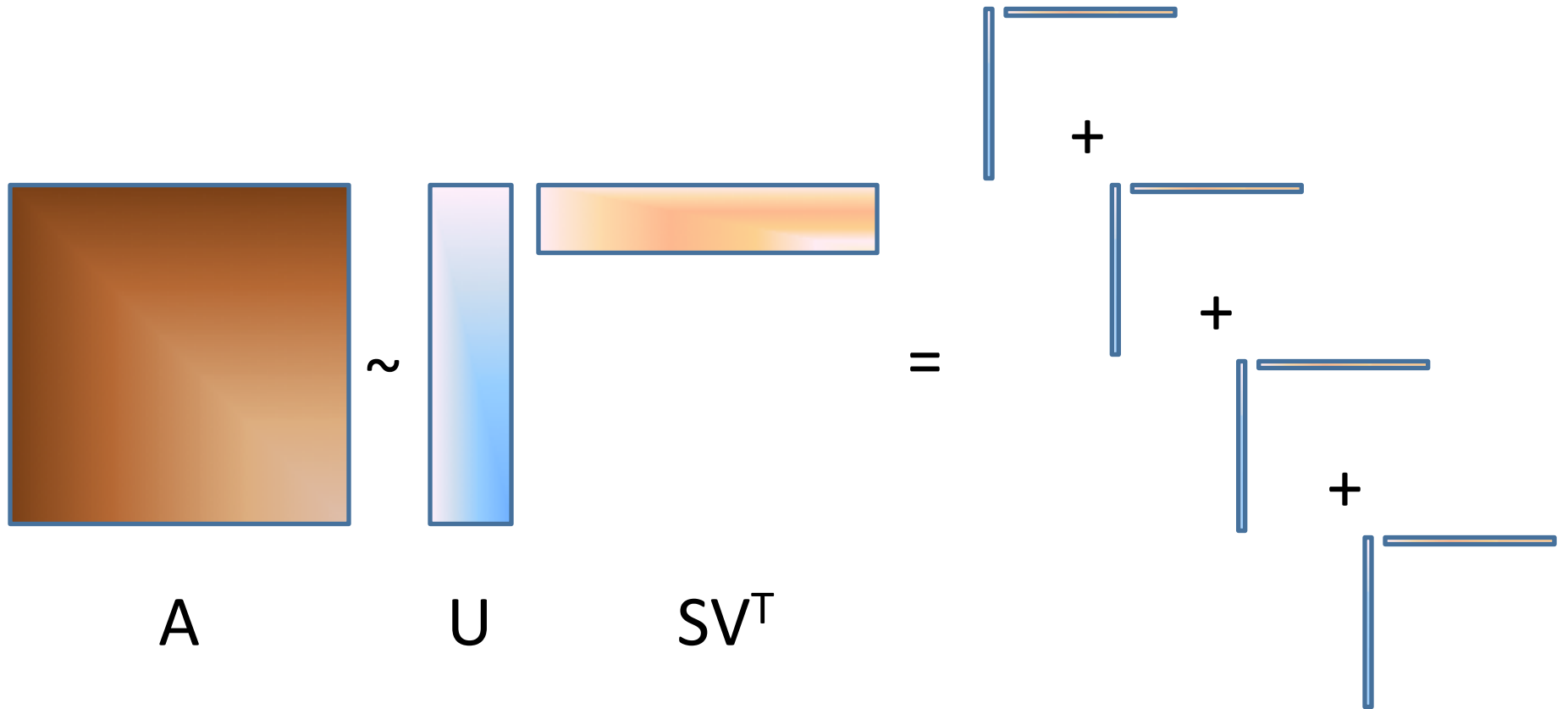
0.8	0.1	0.5	0.3	0.2	1	0.8	0.4
-----	-----	-----	-----	-----	---	-----	-----

Light CDF

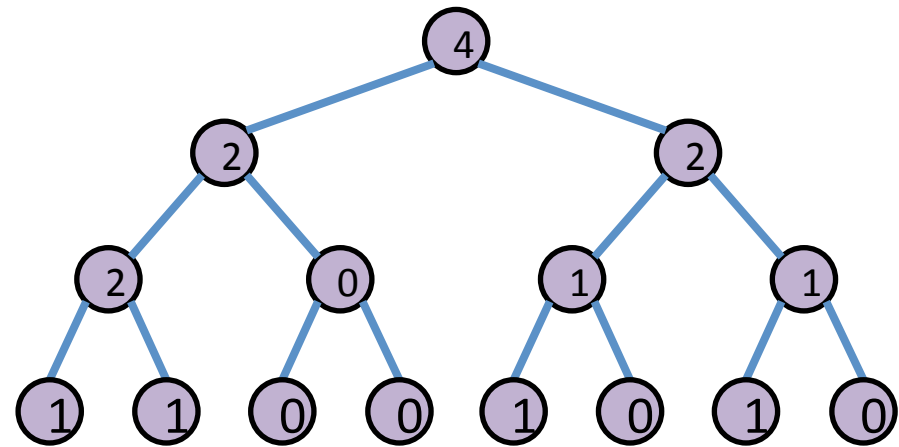
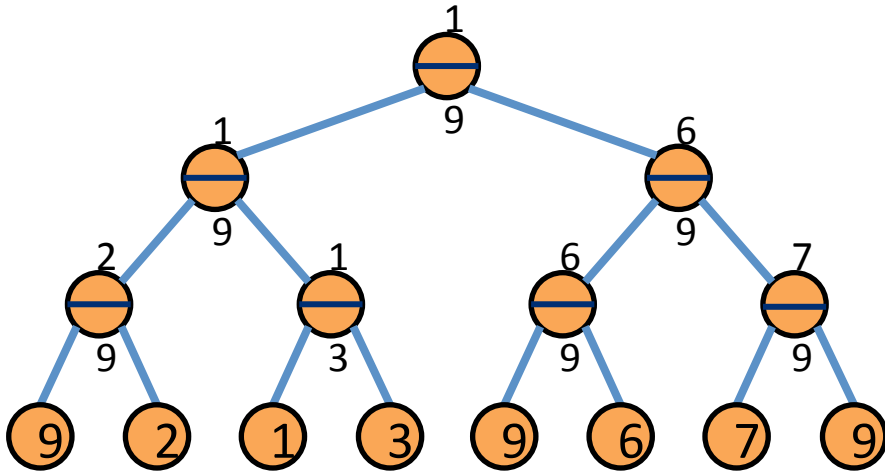
0	0.8	0.9	1.4	1.7	1.9	2.9	3.7	4.1
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SVD approximation



Min-Max Mipmap vs. Partial Sum Tree [Baran et al. 2010]



- Static
- Stores shadow map structure

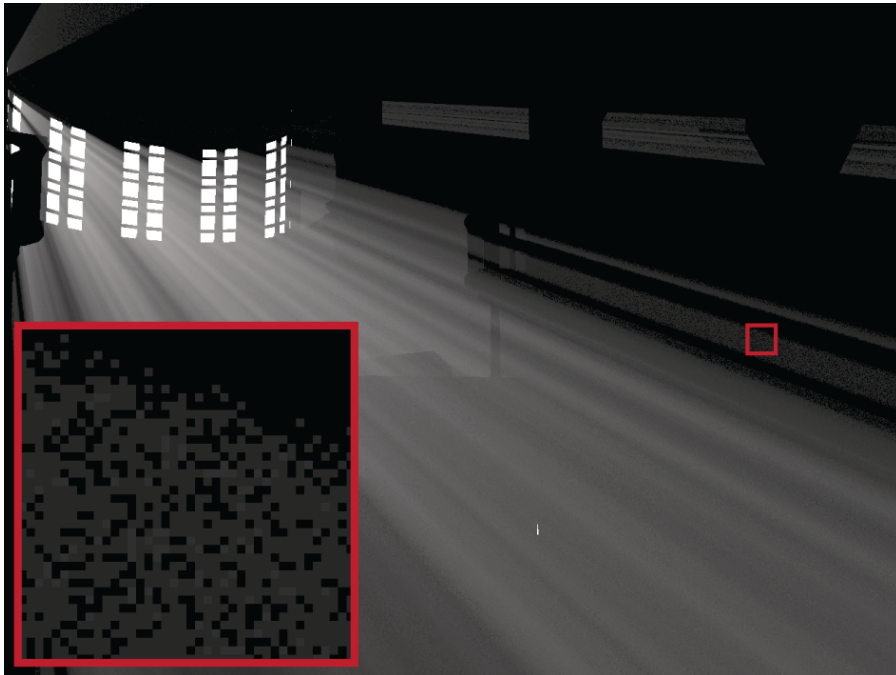
- Dynamic
- Stores interval sums computed *so far*

Equal time comparison: *Sibenik*

Screen resolution: 1280 x 960

Shadow map resolution: 4096 x 4096

NVIDIA GeForce 480 GTX



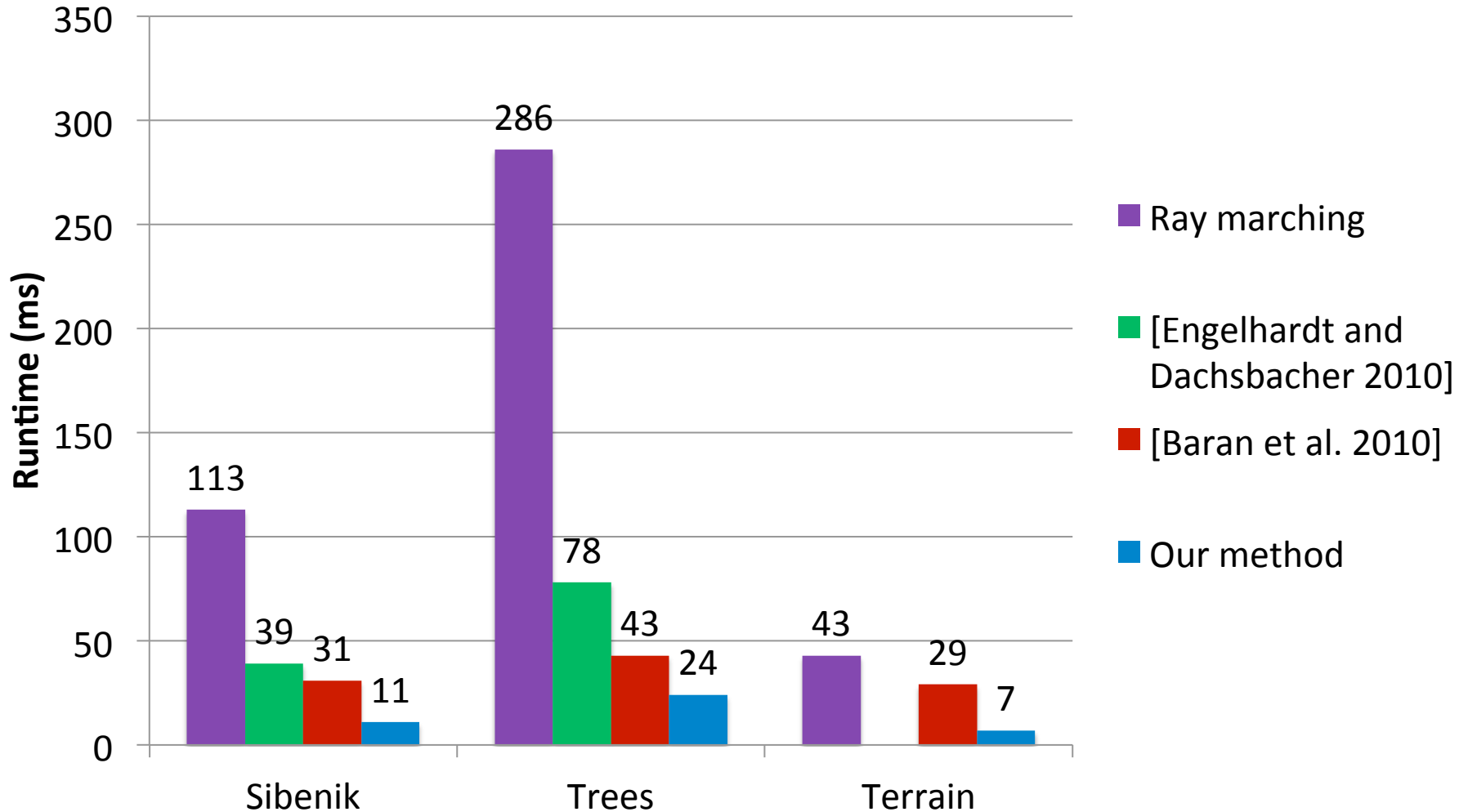
Ray marching at 11 ms



Our method at 11 ms

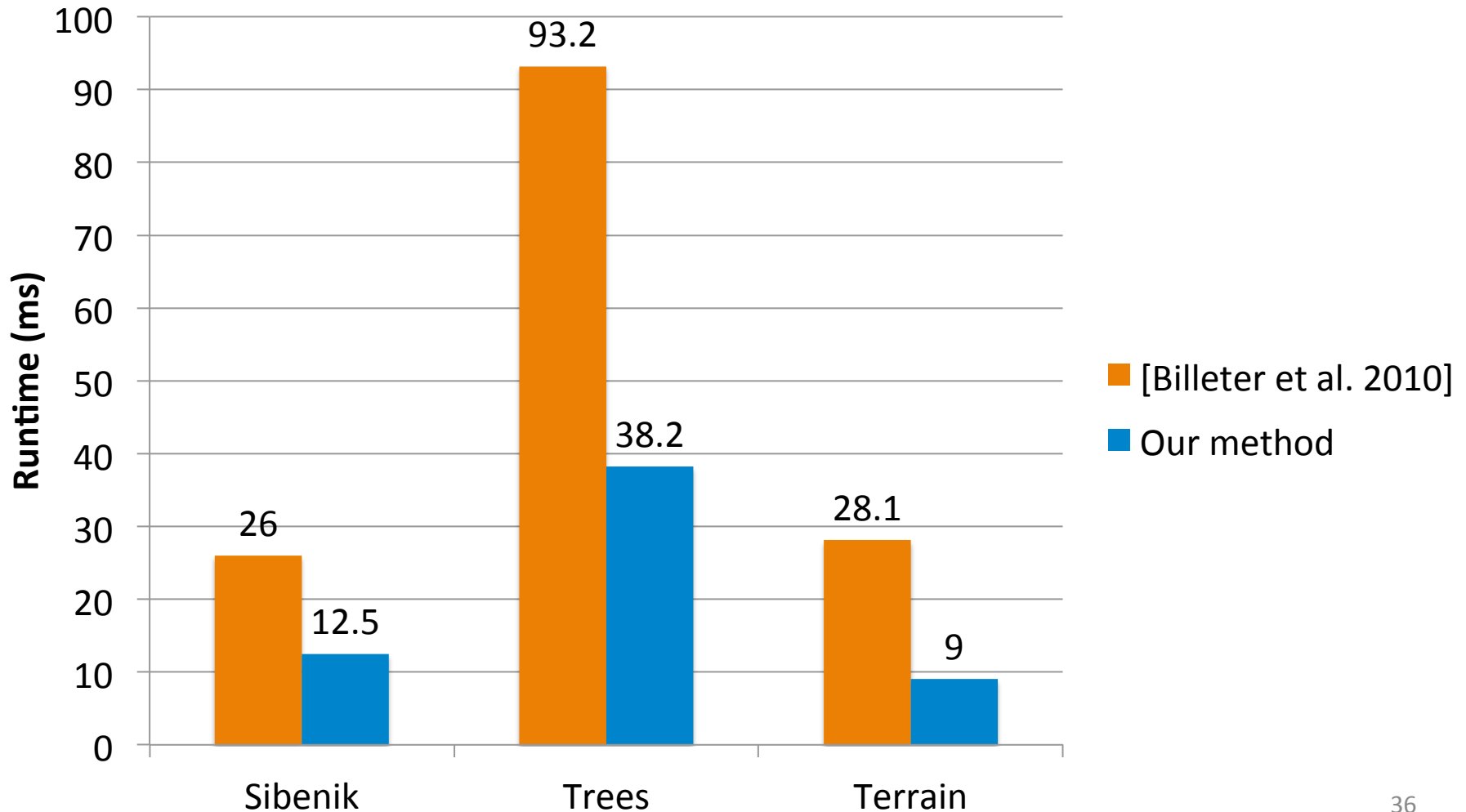
Performance comparison (lower is better)

Directional light, 4K shadow map



Performance vs. Billeter et al. [2010]

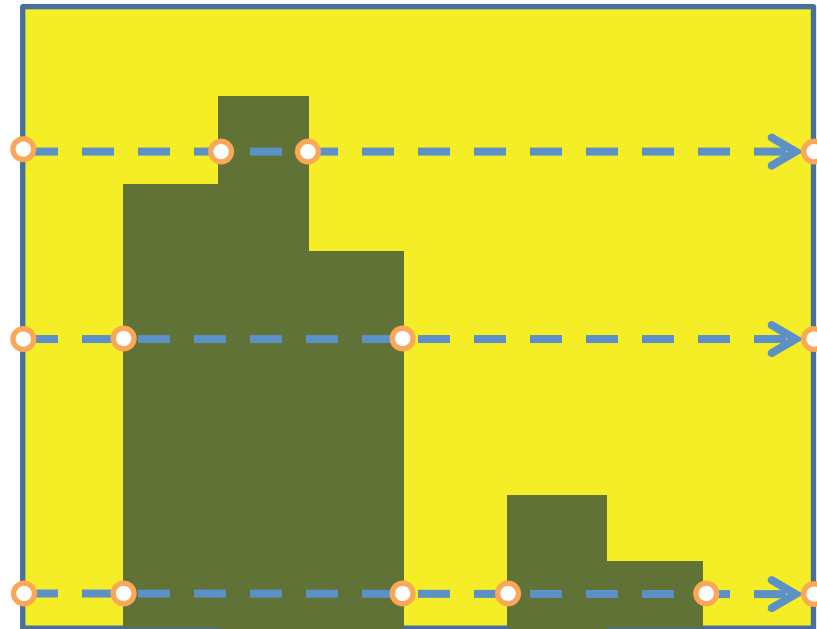
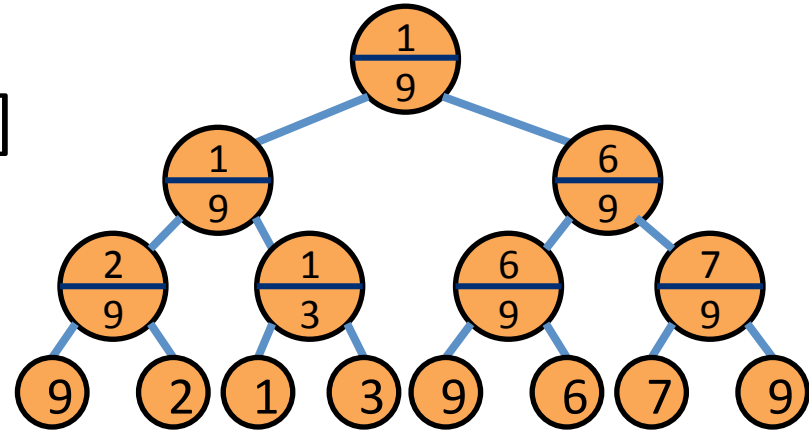
Spotlight, 4K shadow map





Discussion

- Compared to Billeter et al. [2010]
 - Do not need explicit height field geometry
 - One fragment per pixel
 - No processing for occluded light-shadow transitions
- Compared to Baran et al. [2010]
 - Static data structure
 - Parallel queries
 - Pixel shaders only



Conclusions and future work

- Volumetric shadows practical for games
- GPU algorithm design tradeoffs
- Inhomogeneous media

