STOCHASTIC LAYERED ALPHA BLENDING

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  - (Some) greedily use memory
  - Often use complex locking and atomics
- Takeaway:
  - Current solutions not ideal; many minimize use of transparency

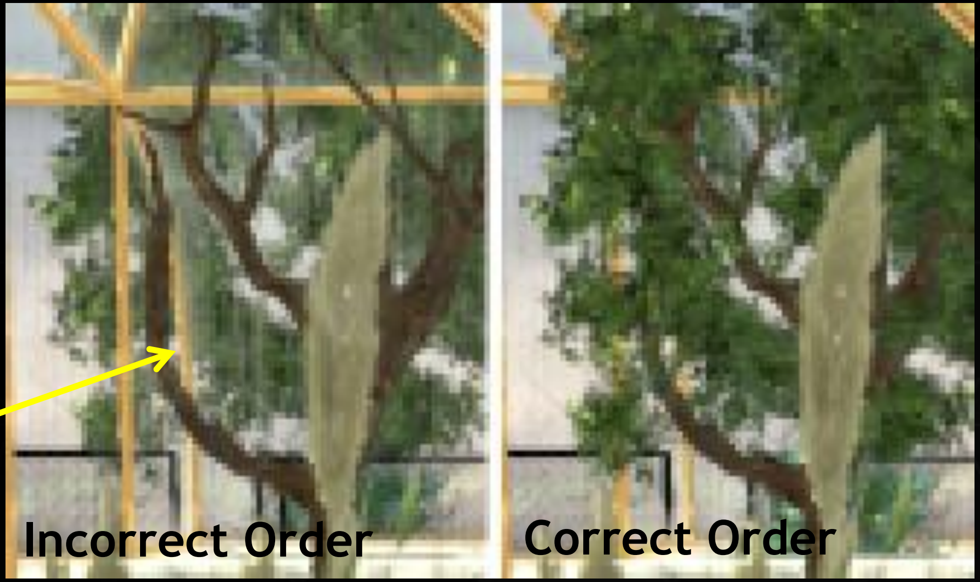
WHAT'S THE PROBLEM?

- [Porter and Duff 84] outlined numerous common compositing operations
  - The "over" operator, using multiplicative blending, describes most real interactions:

$$c_{result} = \alpha_0 c_0 + (1 - \alpha_0)\alpha_1 c_1$$

  - For streaming compute, you need to sort geometry *or* keep all α_i and c_i around

Merge two fragments then later try to insert one in between?



WHAT'S THE PROBLEM?

- Sorting geometry in advance can fail
  - May be no "correct" order for triangles
- Keep a list of fragments per pixel (i.e., A-Buffers [Carpenter 84])
  - Virtually unbounded** GPU memory
  - *Still* need to sort fragments to apply over operator in correctly
- Not just a raster problem; affects ray tracing, too
  - Unless it guarantees ray hits returned perfectly ordered

*** You can define a very conservative upper bound, but it's quite unhelpful.*

RECENT WORK: OIT CONTINUUM

** See my High Performance Graphics 2016 paper*

Algorithm	Memory Limit	Insertion Heuristic	Merge Heuristic	Normalize?	Use Alpha or Coverage?
A-buffer [Car84]	none	always	no merging	no	either†
Alpha Testing	1 layer	if $\alpha >$ thresh	discard furthest	no	alpha
Alpha Compositing [PD84]	1 layer	always	*over* operator	no	alpha
Screen-Door Transparency [FGH*85]	k z-samples	always	z-test, discard occluded	no	coverage
Z^3 [JC99]	k layers	always	merge w/closest depths	no	alpha
Deep Shadow Maps [LV00]	k line segments	always	merge w/smallest error	no	alpha
Depth Peeling [Eve01]	1 layer	if closest	discard furthest	no	either†
Opacity Shadow Maps [KN01]	k bins	always	α-weighted sum	no	alpha
Density Clustering [MKBVR04]	k bins	always	k-means clustering	no	alpha
k-Buffers [BCL*07]	k layers	always	merge closest to camera	no	alpha
Sort-Independent Alpha Blending [Mes07]	1 layer	always	weighted sum	no	alpha
Deep Opacity Maps [YK08]	k bins	always	α-weighted sum	no	alpha
Multi-Layer Depth Peeling [LHLW09]	k layers	if in k closest	discard furthest	no	either†
Occupancy Maps [SA09]	k bins	always	discard if bin occupied	renormalize alpha	alpha
Stochastic Transparency [ESSL10]	k samples	stochastic	z-test, discard occluded	α-weighted average	coverage
Fourier Opacity Maps [JB10]	k Fourier coefs	always	sum in Fourier domain	no	alpha
Adaptive Volumetric Shadow Maps [SVLL10]	k layers	always	merge w/smallest error	no	alpha
Transmittance Function Maps [DGMF11]	k DCT coefs	always	sum in DCT basis	no	alpha
Adaptive Transparency [SML11]	k layers	always	merge w/smallest error	no	alpha
Hybrid Transparency [MCTB13]	k layers	always	discard furthest	α-weighted average	alpha
Weighted Blended OIT [MB13]	empirical func	never	discard all	α-weighted average	alpha
Multi-Layer Alpha Blending [SV14]	k layers	always	merge furthest	no	alpha
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Interesting note

So what is
Stochastic Layered Alpha Blending?

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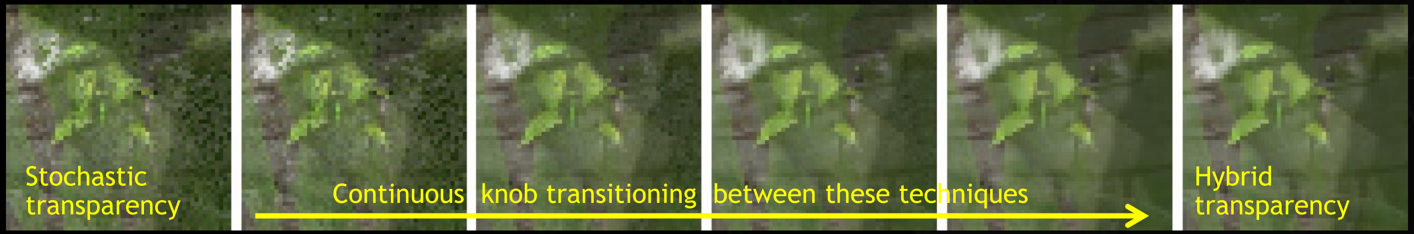
WHAT IS STOCHASTIC LAYERED ALPHA BLEND

- Shows how to use *stochasm* in a *k*-buffer algorithm
  - I.e., allows stochastic insertion of fragments
- Shows stochastic transparency ≡ *k*-buffering
- How?
  - By providing an explicit parameter that transitions
    - Stochastic transparency [Enderton 10] ↔ hybrid transparency [Maule 13]



To Understand:
Start With Stochastic Transparency

WHAT IS STOCHASTIC TRANSPARENCY?

- When rasterizing frag into k-sample buffer:
  - Stochastically cover $\alpha \cdot k$ samples

WHAT IS STOCHASTIC TRANSPARENCY?

- When rasterizing frag into k-sample buffer:
  - Stochastically cover α • k samples
  - Let's look at an example pixel with 16x MSAA
    - *(MSAA pattern simplified for display)*

Values represent current depth sample

1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0
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Set 8 samples to red; depth test each

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  - Second: draw blue fragment, z = 0.7, α = 0.5

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0.5	1.0	0.7	0.5
0.7	0.5	0.5	0.7
0.5	0.7	0.5	0.5
1.0	0.5	0.7	1.0

Set 8 samples to blue; depth test each

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Values represent current depth sample

0.5	0.3	0.7	0.3
0.7	0.5	0.5	0.3
0.5	0.3	0.3	0.5
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Set 8 samples to green; depth test each

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  - Third: draw green fragment, z = 0.3, α = 0.5
  - Fourth: draw yellow fragment, z = 0.9, α = 1.0

Values represent current depth sample

0.5	0.3	0.7	0.3
0.7	0.5	0.5	0.3
0.5	0.3	0.3	0.5
0.3	0.3	0.7	0.3

Set 16 samples to yellow; depth test each

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- 2nd pass accum. color using this as depth oracle

Values represent current depth sample

0.5	0.3	0.7	0.3
0.7	0.5	0.5	0.3
0.5	0.3	0.3	0.5
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OBSERVATIONS

- Can lose surfaces (like yellow one)
  - But it still converges; surface loss is *stochastic*

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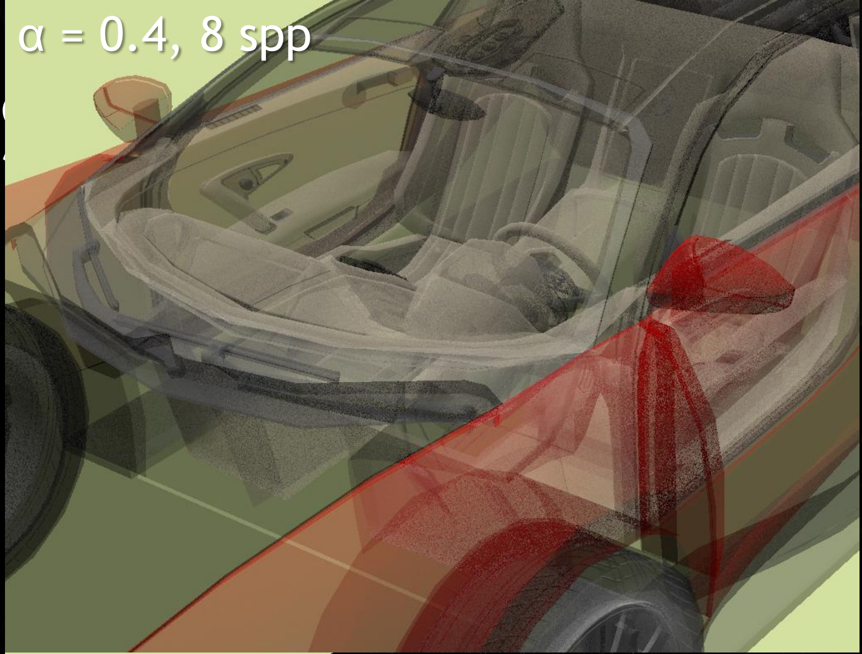
  - Also noticed in my experiments
    - Dashboard and seat noisier with high alpha than low!



Note: Even uses stratified sampling!

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        - Dashboard and seat noisier with high alpha than low!
- Seems wasteful to store 8 copies of z = 0.3 **
    - Why not store one copy of z = 0.3 and a coverage mask?

** *Glossing over some details here; feel free to ask later.*

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- Seems wasteful to store 8 copies of z = 0.3 **
  - Why not store one copy of z = 0.3 and a coverage mask?
- *Implicitly* layered – stores (<u>up to</u>) 16 surfaces per pixel (for 16x MSAA)
  - Also wasteful to store just 3 layers in a structure that can hold 16

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0.7	0.5	0.5	0.3
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Stochastic Layered Alpha Blending (SLAB)

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  - Merging: if > k layers, simply discard the furthest
- Identical results to k spp stoc. transparency, if k ≥ b
  - *<u>But</u>* can independently change values of k and b
    - Useful since stoc. transp. rarely stores k surfaces in a k-sample buffer
    - Also can explicitly increase b much further → reduce noise on existing layers

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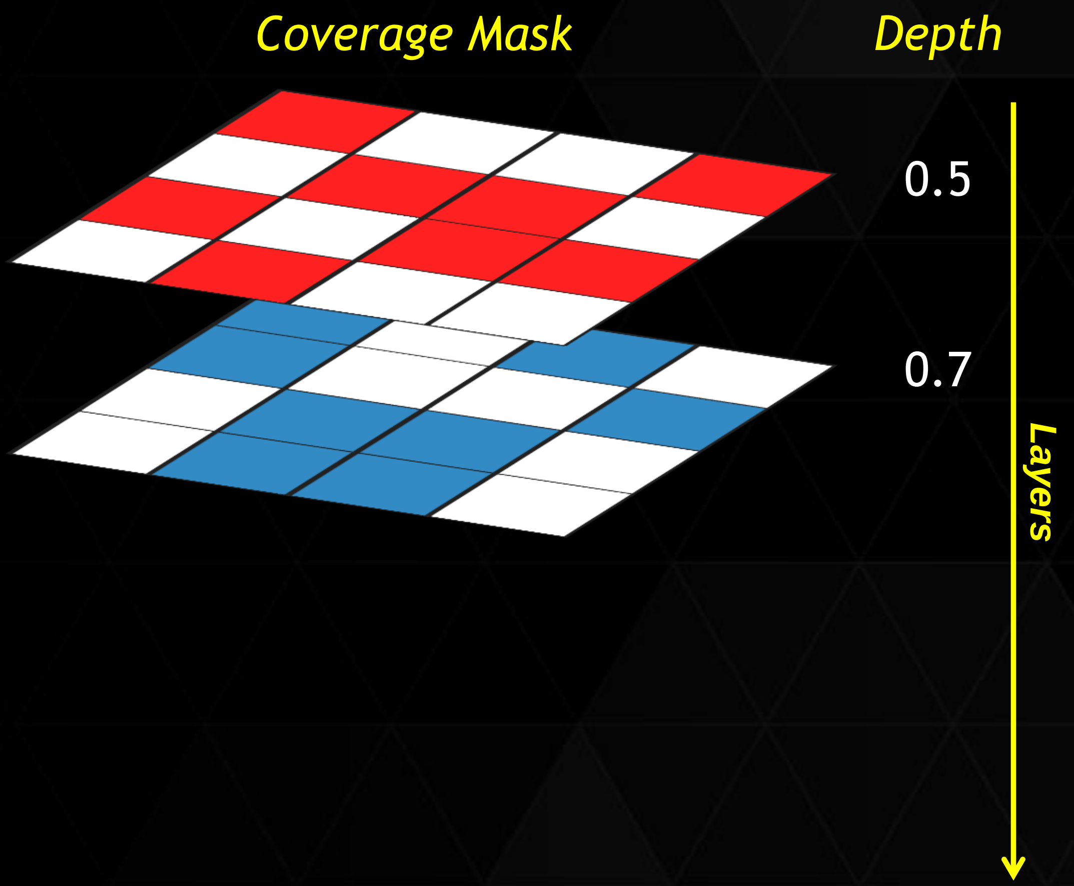

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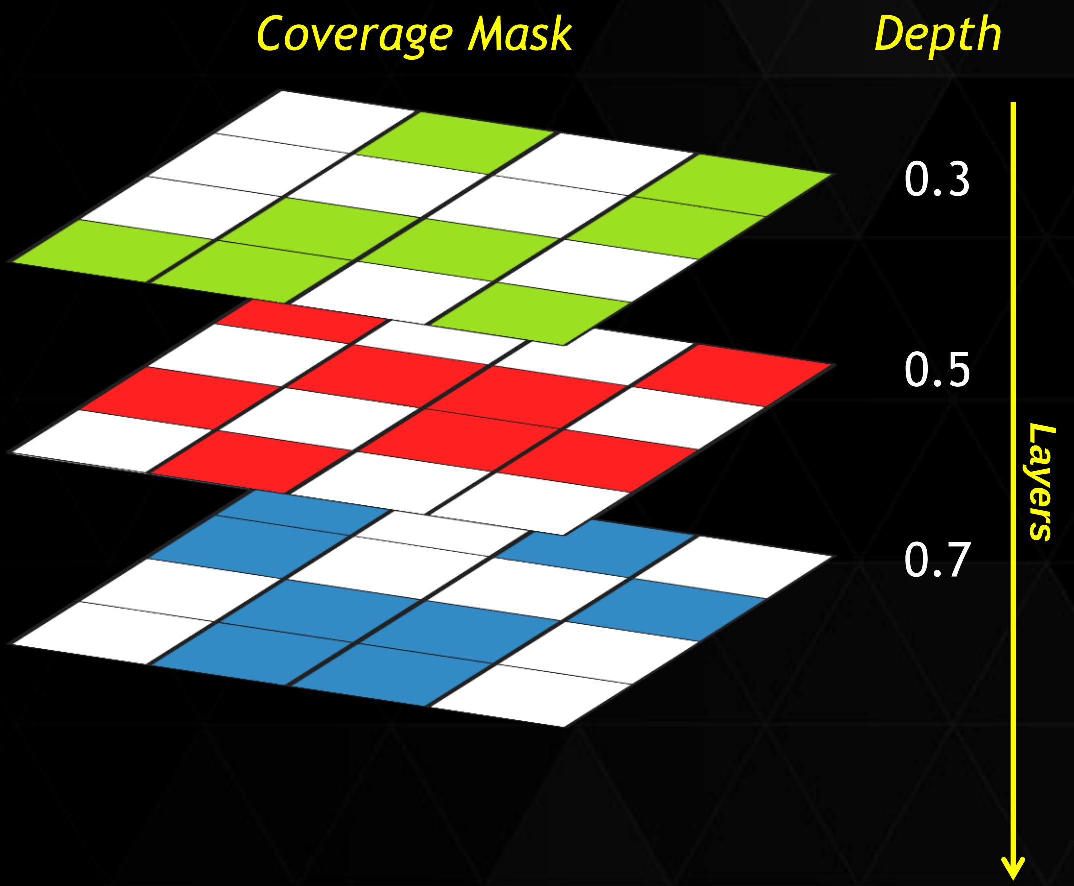

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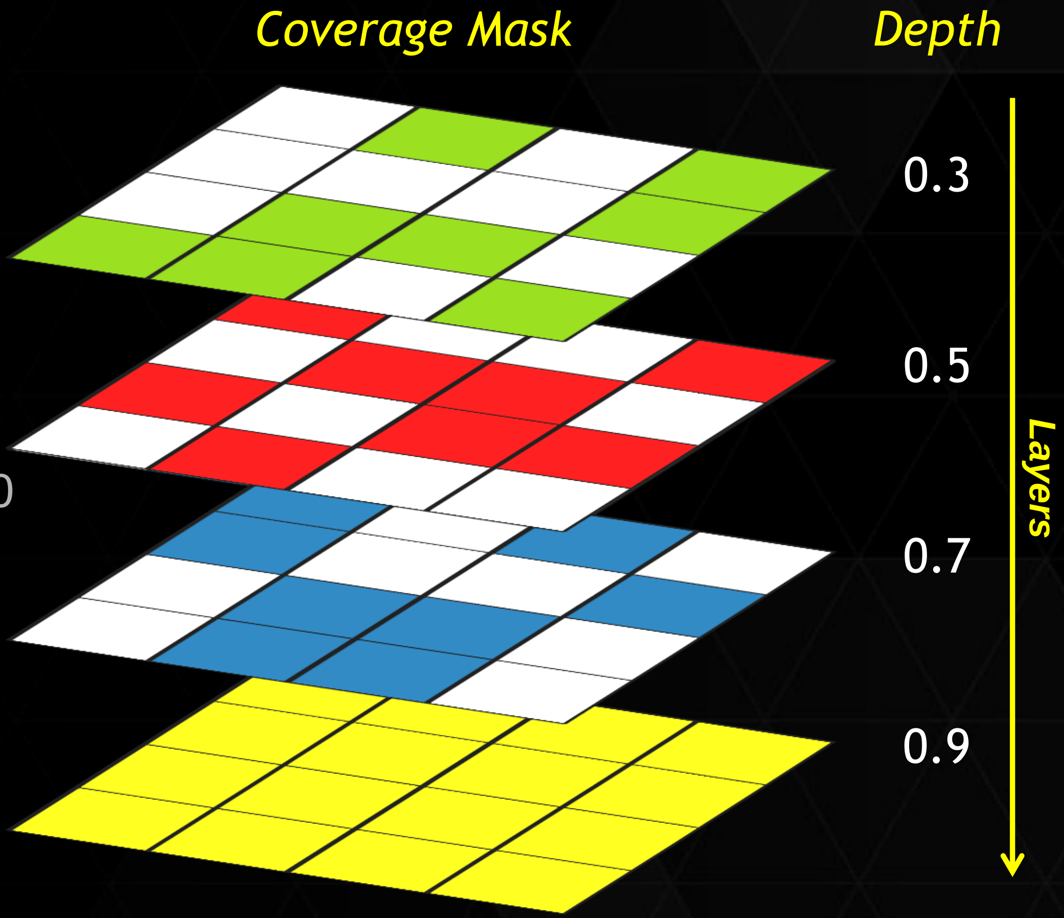

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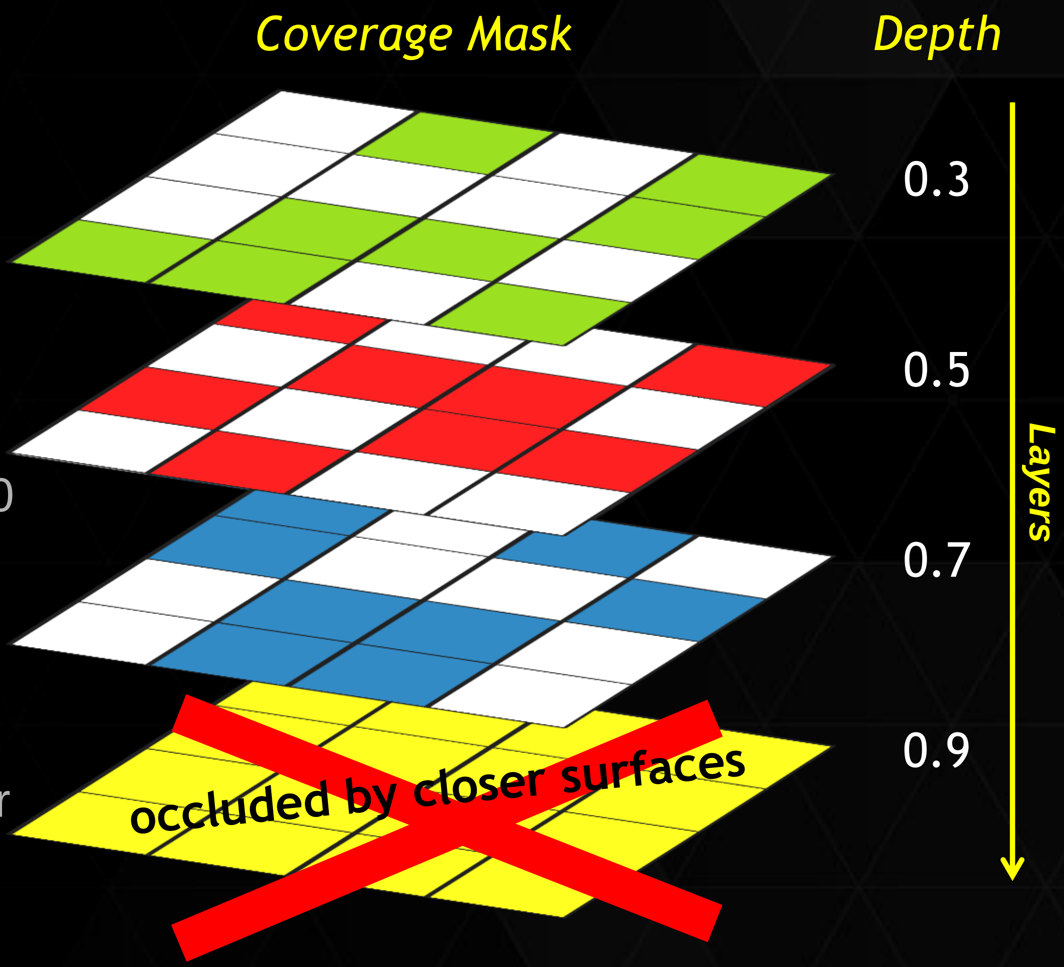
- Layers get inserted only if not occluded
  - Adds stochasm, if masks randomly chosen
  - Different random masks might keep this layer



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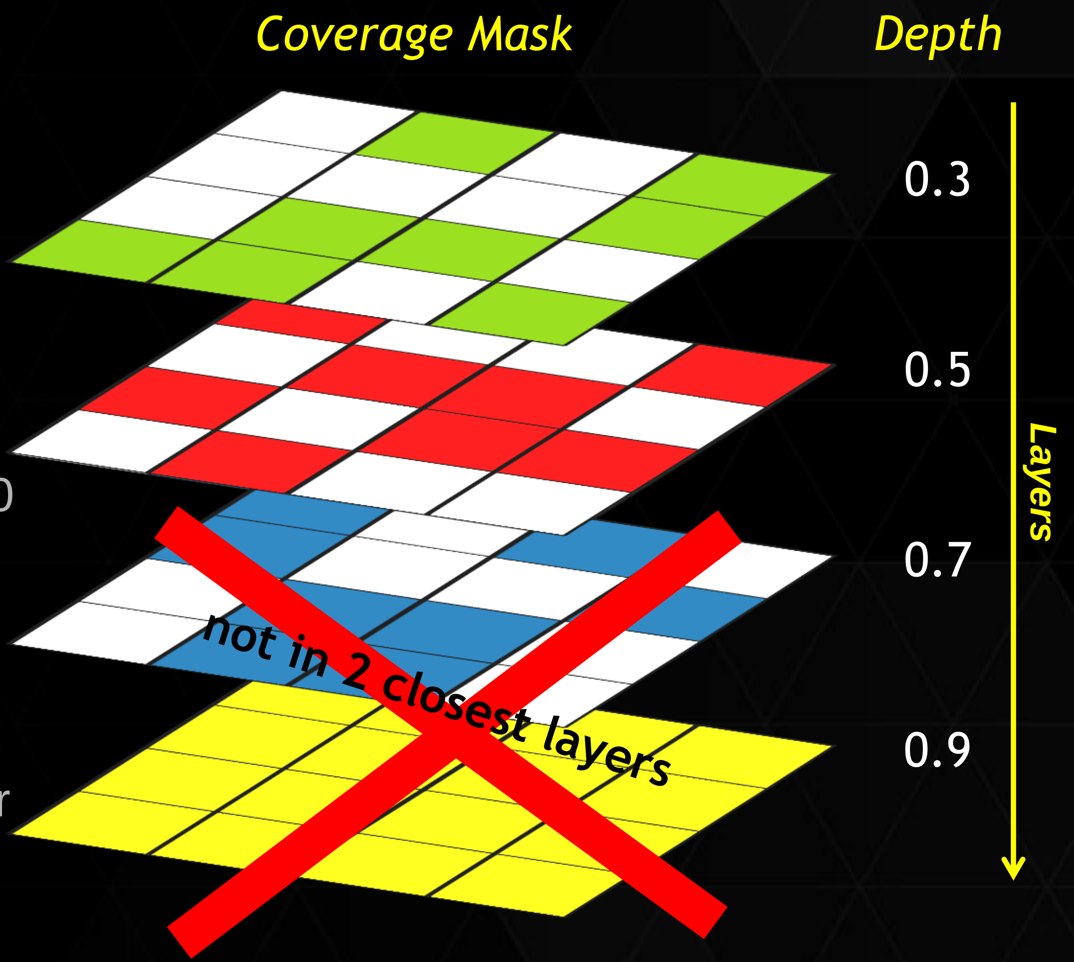
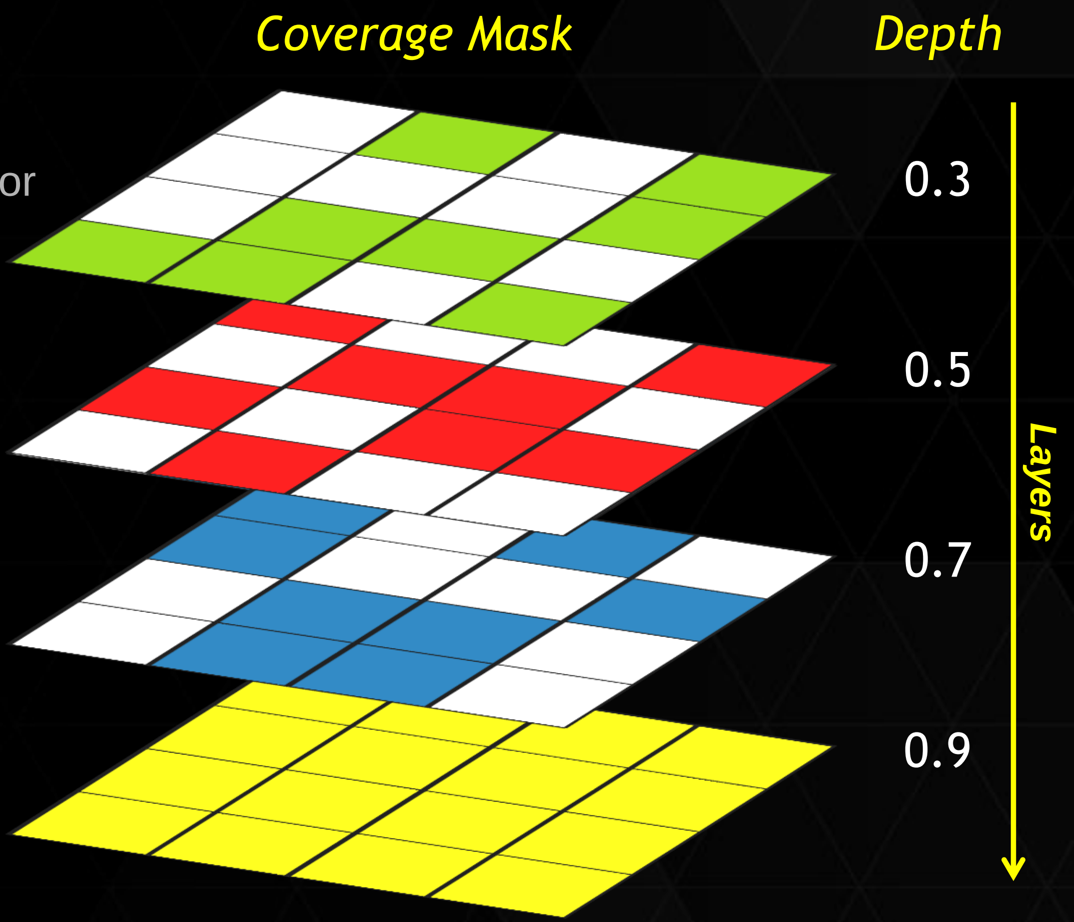
- If k = 2, layers beyond 2nd get discarded



ADJUSTING PARAMETERS

- Aim to reduce noise
  - One way: avoid discarding layers that impact color



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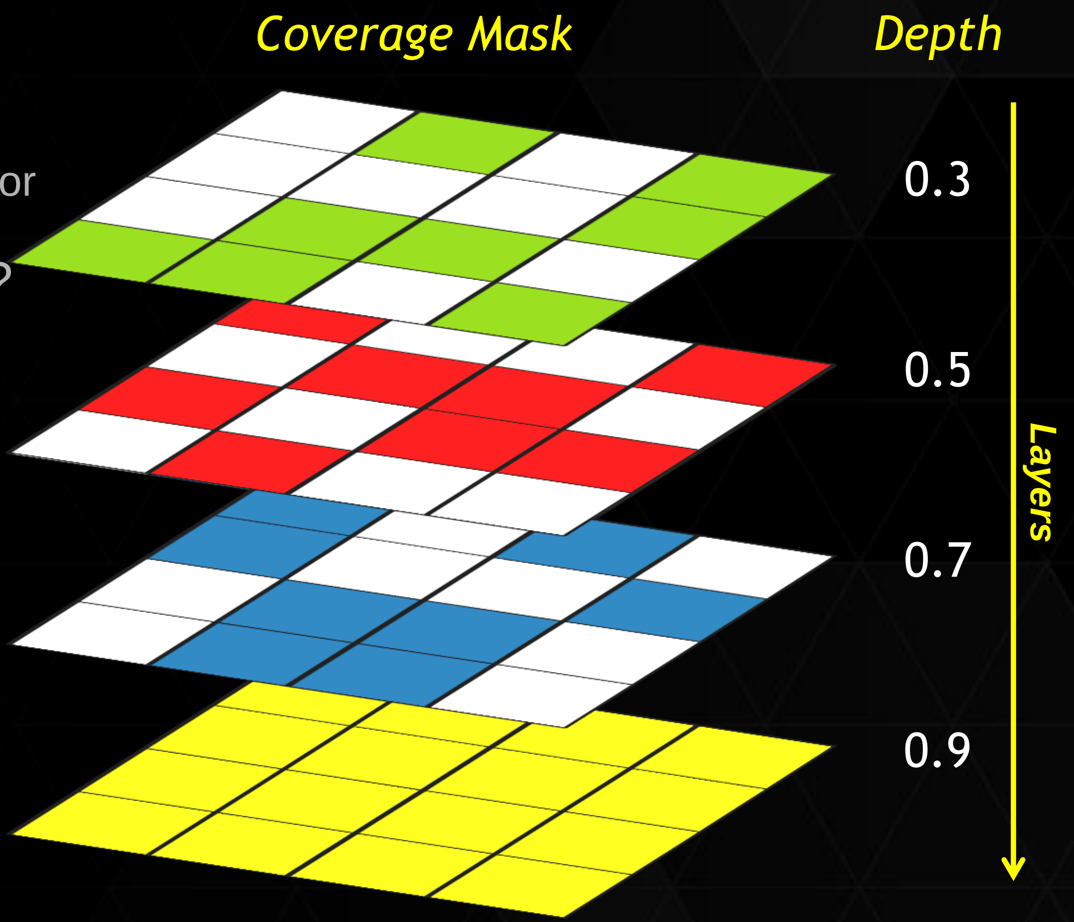

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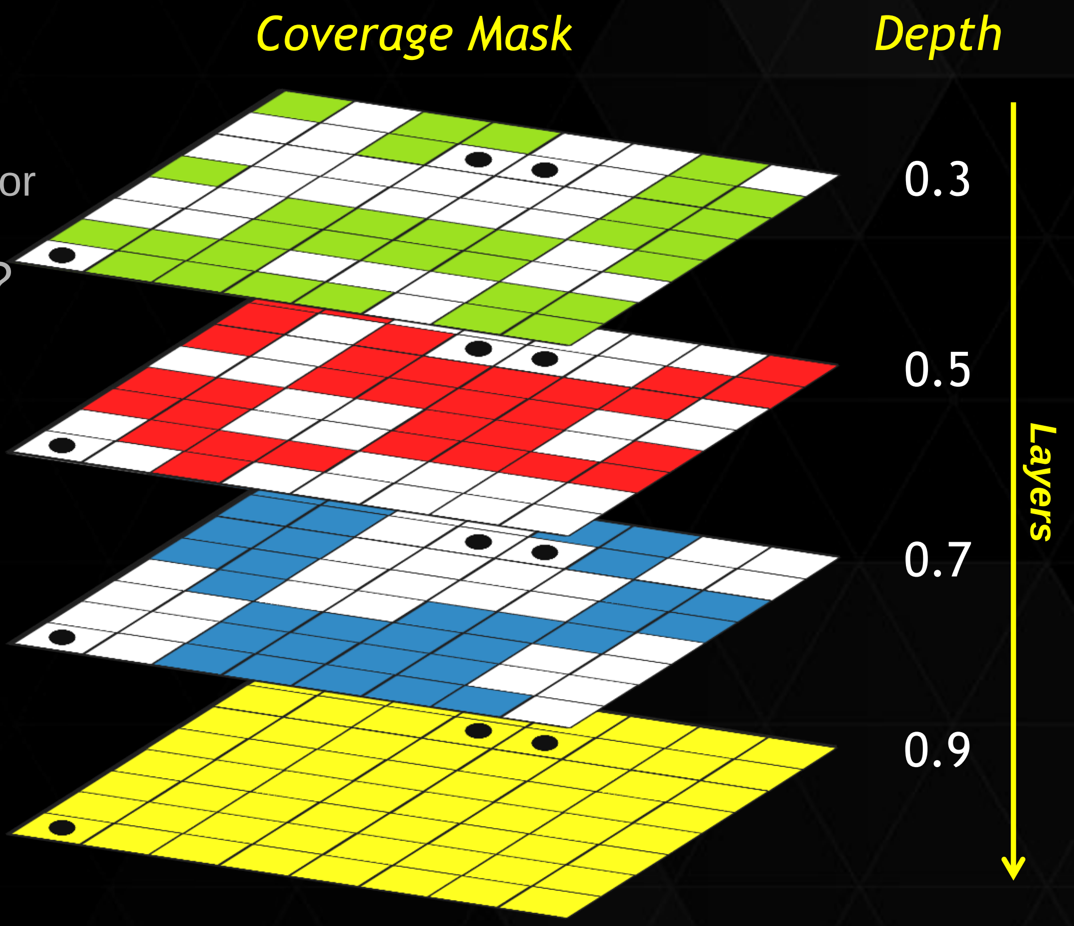

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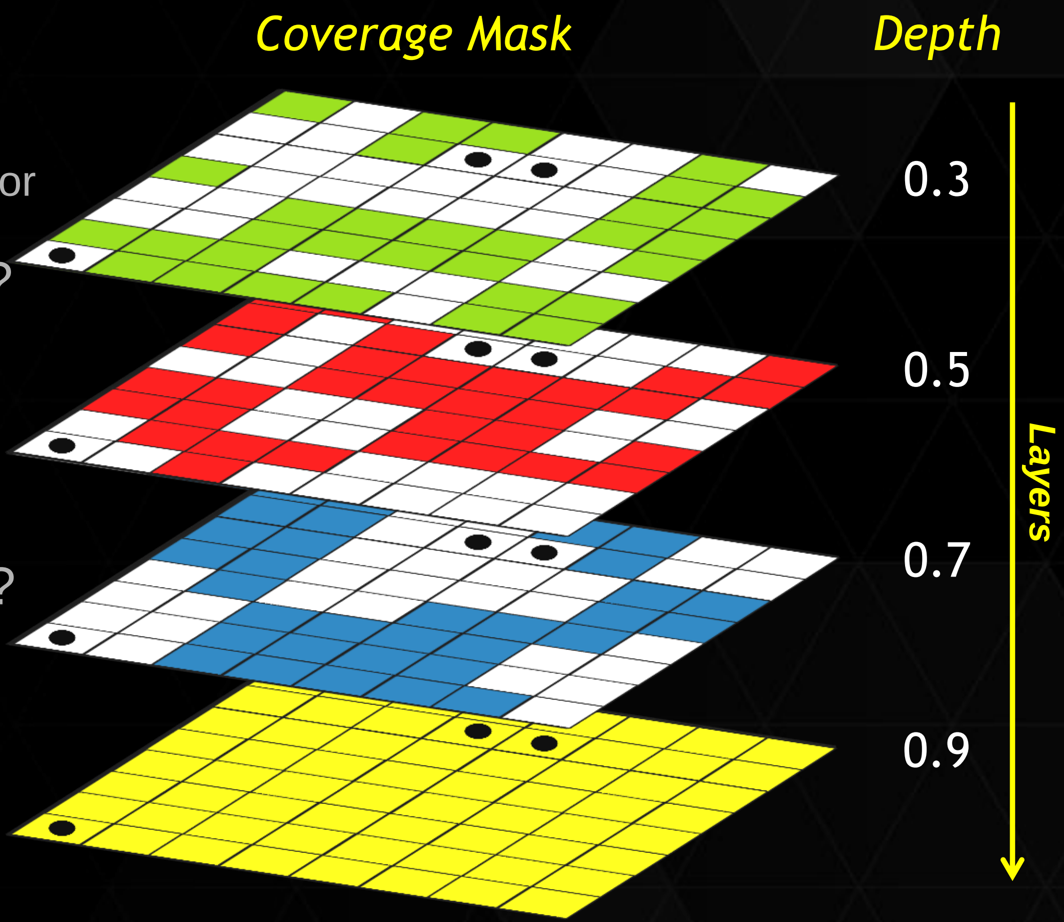
- Larger coverage masks → lower noise
- What happens as # coverage bits increases?



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- How to increase chance to store yellow frag?
  - Increase number of bits in coverage mask
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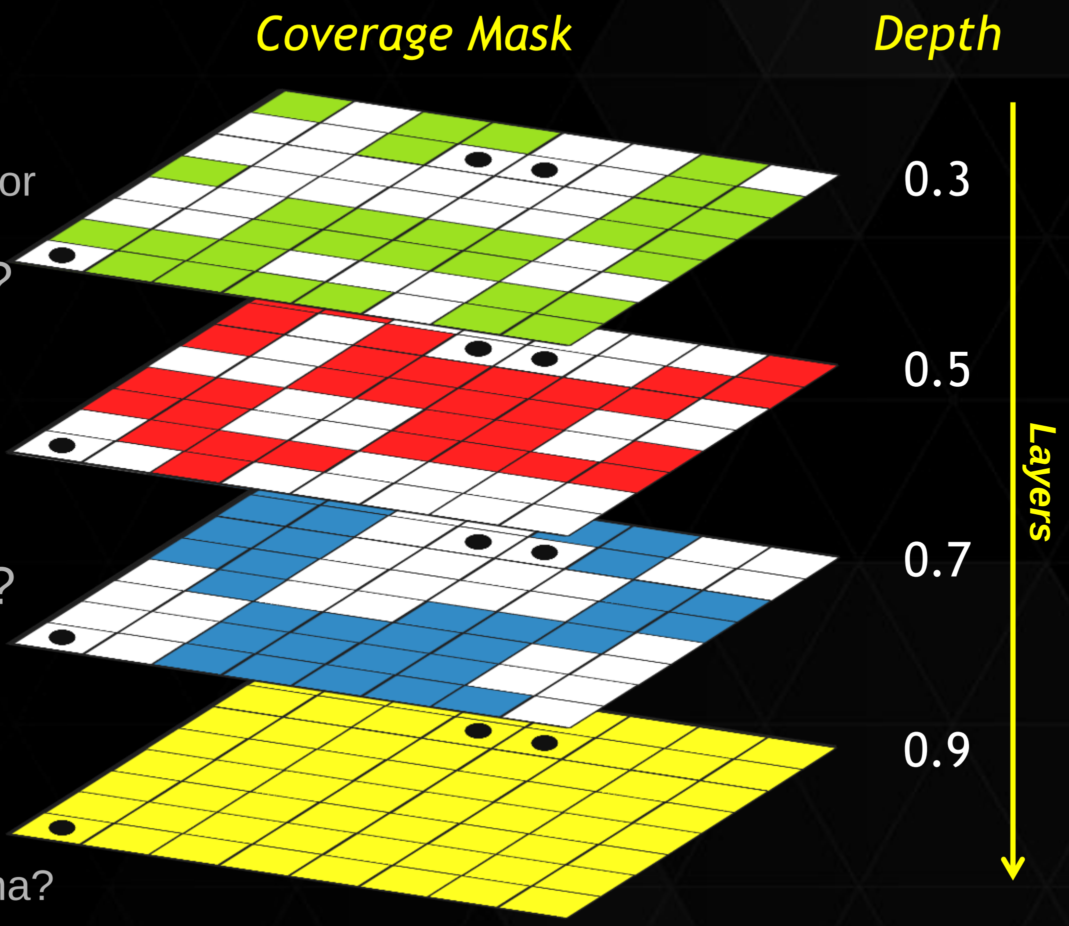
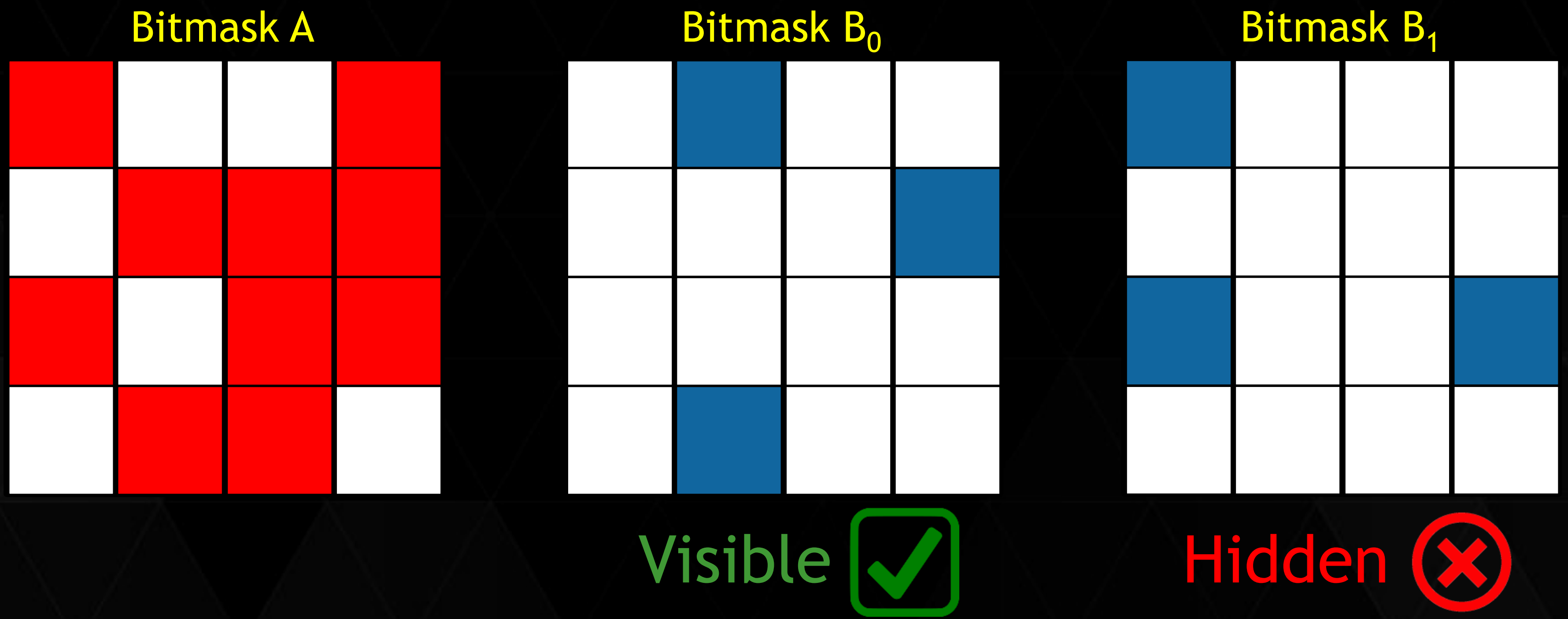
- What happens as # coverage bits increases?
  - Starts to behave as alpha
- Interesting to ask:
  - Can we stochastically insert fragments using alpha?



SLAB USING IMPLICIT COVERAGE

- Let's compute an insertion probability
  - Q: What's the chance random bitmask B is visible behind random bitmask A?



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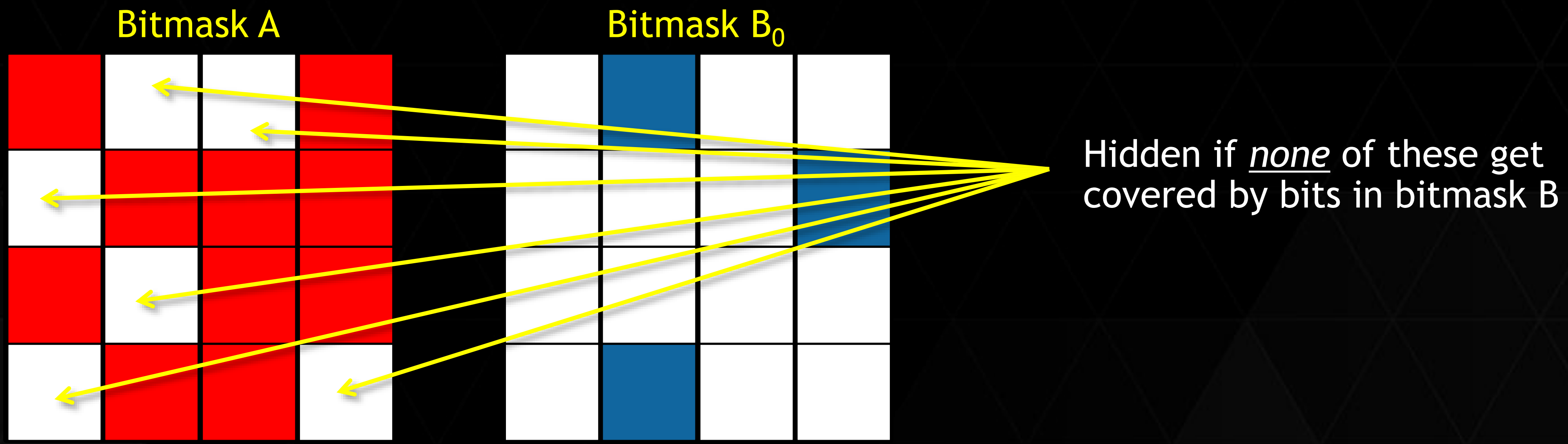

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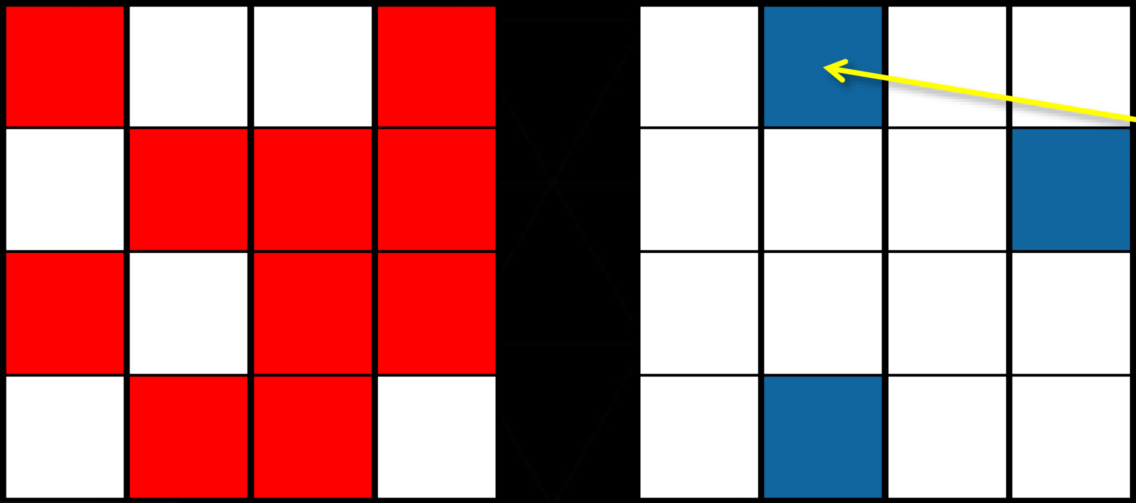
Bitmask A

Bitmask B_0



Naïve random sampling:

Covered with probability α_B

Uncovered with prob $(1 - \alpha_B)$

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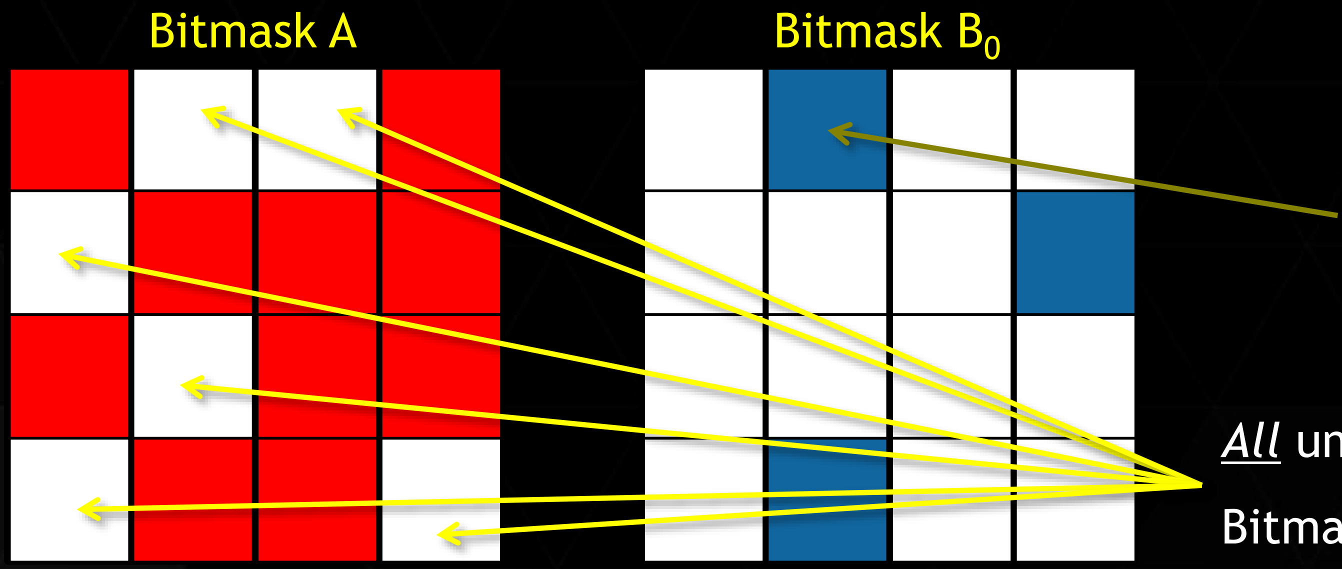

<u>Naïve random sampling:</u>

Covered with probability α_B

Uncovered with prob $(1 - \alpha_B)$

<u>*All*</u> uncovered with prob: $(1-\alpha_B)^6$

Bitmask B visible with prob: $1-(1-\alpha_B)^6$

SLAB USING IMPLICIT COVERAGE

- Let’s compute an insertion probability
  - Q: What’s the chance random bitmask B is visible behind random bitmask A?

$$P_b(\beta_A, \beta_B) = 1 - \left(1 - \frac{\beta_B}{b}\right)^{(b-\beta_A)}$$

Or

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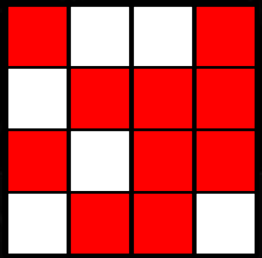
Bitmask A



$\beta_A \equiv$ # bits covered

$\beta_A = \lfloor \alpha_A b \rfloor$ or $\lceil \alpha_A b \rceil$

for b bits in bitmask

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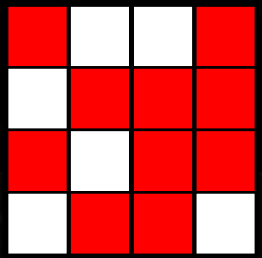
Or

$$P_b(\beta_A, \alpha_B) = 1 - \underbrace{(1 - \alpha_B)}_{\text{prob of leaving 1 bit uncovered}}{}^{\overbrace{(b-\beta_A)}^{}}$$

number of bits that must be uncovered

Bitmask A



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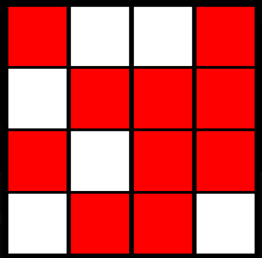
SLAB USING IMPLICIT COVERAGE

- Let's compute an insertion probability
  - Q: How about for random masks using stratified samples?

$$P_b(\beta_A, \beta_B) = \begin{cases} 1 - \frac{\beta_A!(b-\beta_B)!}{b!(\beta_A-\beta_B)!} & \text{if } \beta_B \le \beta_A \\ 1 & \text{if } \beta_B > \beta_A \end{cases}$$

Bitmask A



$\beta_A \equiv$ # bits covered

- Based on combinatorics
  - Choosing dependent probabilities so all mask bits in B are covered by A

WAIT! NOT USING INFINITE # BITS?

- Both equations require a number of bits *b* in the coverage mask

$$P_b(\beta_A, \beta_B) = \begin{cases} 1 - \frac{\beta_A!(b-\beta_B)!}{b!(\beta_A-\beta_B)!} & \text{if } \beta_B \le \beta_A \\ 1 & \text{if } \beta_B > \beta_A \end{cases}$$

using stratified random samples

$$P_b(\beta_A, \beta_B) = 1 - \left(1 - \frac{\beta_B}{b}\right)^{(b-\beta_A)}$$

using naïve random samples

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- Going back to our continuum
  - When b = k, SLAB is equivalent to stochastic transparency
  - When $b \rightarrow \infty$, SLAB is equivalent to hybrid transparency (a variant of k-buffer)

Stochastic Transparency [ESSL10]	k samples	stochastic	z-test, discard occluded	α-weighted average	coverage
Hybrid Transparency [MCTB13]	k layers	always	discard furthest	α-weighted average	alpha
(NEW) Stochastic Layered Alpha Blending	k layers	stochastic	discard furthest	α-weighted average	either‡

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    - Using deterministic insertion based on random coverage masks

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  - Need to use $k \leq b < \infty$
  - Can do this with an *explicit* coverage mask with b random bits
    - Using deterministic insertion based on random coverage masks
  - Can do this with an *implicit* coverage (i.e., alpha) using b *virtual* bits
    - Using stochastic insertion using probability functions
    - *b* only controls distance along the k-buffer ↔ stoc transp continuum

Let’s demonstrate

FOLIAGE MAP

(From Epic's Unreal SDK)

FOLIAGE MAP

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FOLIAGE MAP

(From Epic's Unreal SDK)

Stoc transp, 8 spp | SLAB, k = b = 8 | SLAB, k = 8, b = 32 | SLAB, k = 8, b = 128 | SLAB, k = 8, b = 32 using alpha | Hybrid Transparency

FOLIAGE MAP

(From Epic's Unreal SDK)

Stoc transp, 8 spp | SLAB, k = b = 8 | SLAB, k = 8, b = 32 | SLAB, k = 8, b = 128 | SLAB, k = 8, b = 32 using alpha | Hybrid Transparency

STOCHASTIC TRANSPARENCY TO K-BUFFERS

Stochastic Layered Alpha Blending, k=b=4

Stochastic Transparency, 4 spp

STOCHASTIC TRANSPARENCY TO K-BUFFERS

Stochastic Layered Alpha Blending, k=4, b=32

Stochastic Transparency, 4 spp

STOCHASTIC TRANSPARENCY TO K-BUFFERS

Stochastic Layered Alpha Blending, k=4, b=8
(using alpha rather than coverage)

Stochastic Transparency, 4 spp

STOCHASTIC TRANSPARENCY TO K-BUFFERS

Stochastic Layered Alpha Blending, k=4, b=32
(using alpha rather than coverage)

Hybrid Transparency, 4 layers

Summary

SUMMARY

- Proposed new algorithm
    - Stochastic layered alpha blending (SLAB)

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- Proposed new algorithm
  - Stochastic layered alpha blending (SLAB)
  - Key takeaways:
    - K-buffers need not be deterministic
    - Stochastic transparency and k-buffering are similar; transition via bit count
    - “Stochastic” need not mean random bitmask generation
    - Algorithms connecting others useful; here, allow trading noise for bias
    - SLAB with alpha values can stratify samples in z (between layers)
      - (Not really discussed in this talk)

QUESTIONS?

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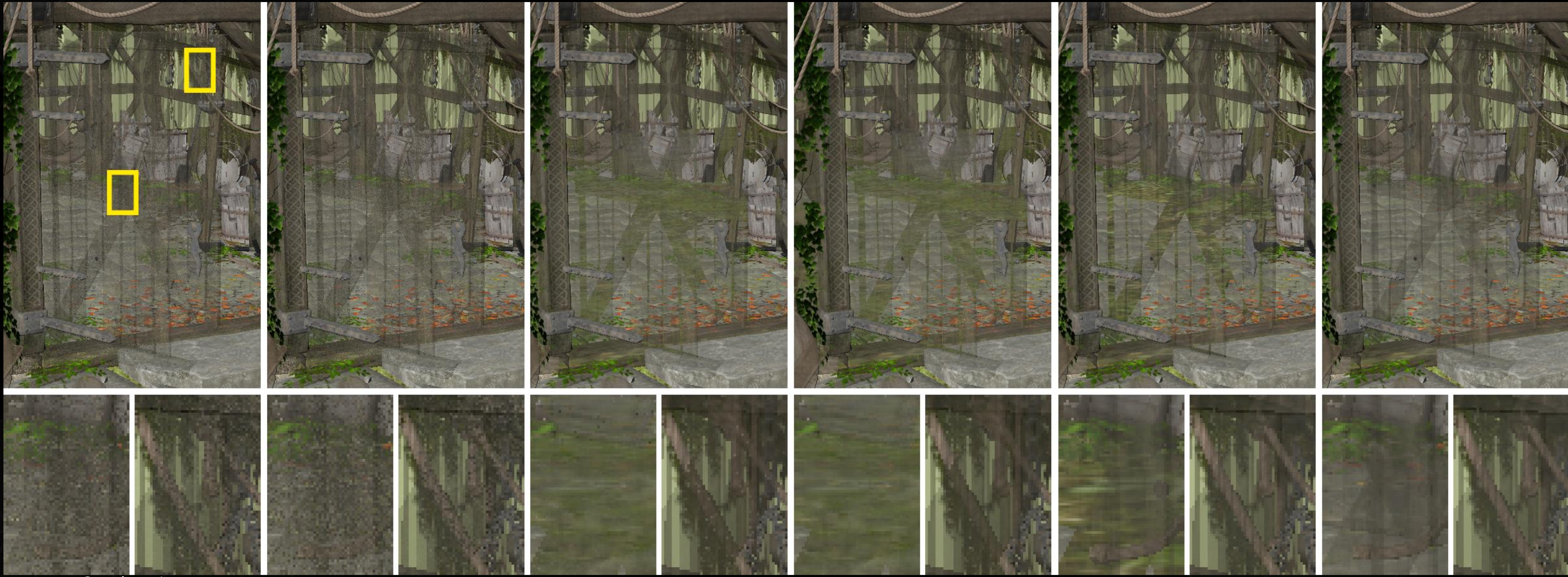
Paper PDF:

Blacksmith building, from Unity's "The Blacksmith" demo



Stochastic transparency 4 spp	SLAB k = 4, b = 4	SLAB k = 4, b = 16 using alpha	Hybrid transparency 4 layers	Multi-layer alpha blending 4 layers	Ground truth (A-buffer)