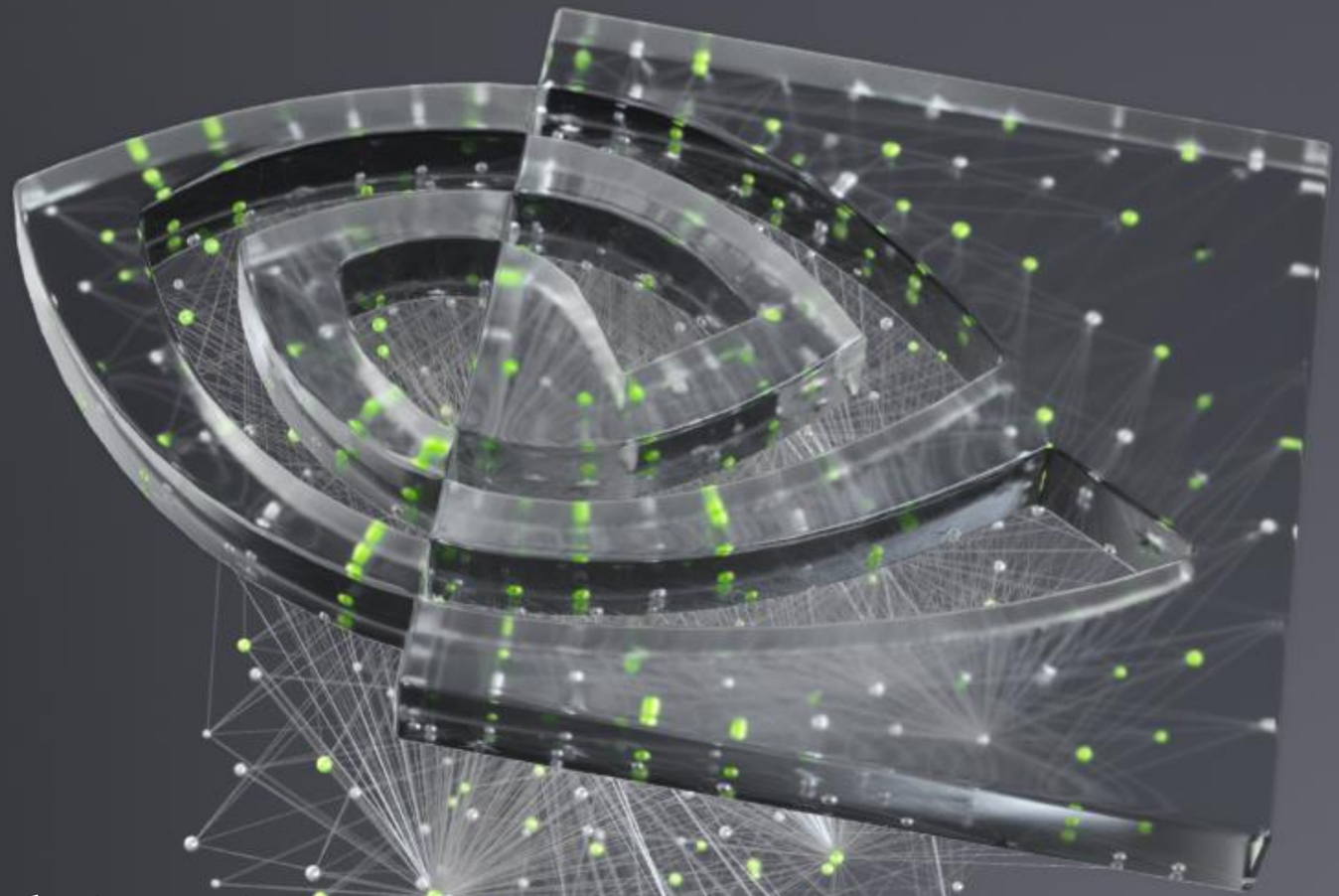


NVIDIA | GAME STACK LIVE

RTXDI: Details on Achieving Real-time Performance

Chris Wyman

Principal Research Scientist, NVIDIA

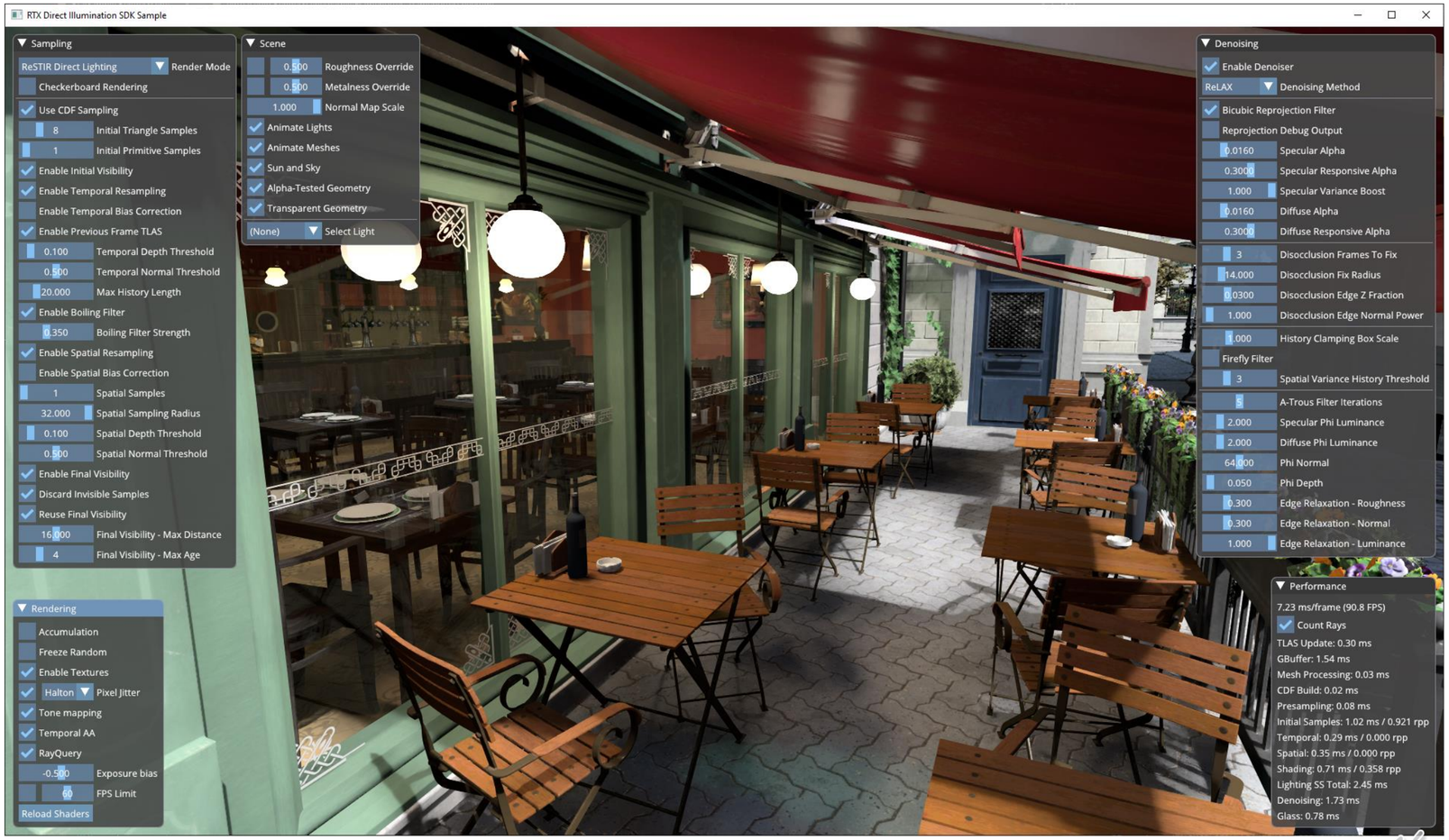
RECENTLY LAUNCHED RTX DIRECT ILLUMINATION (RTXDI)

https://developer.nvidia.com/rtxdi

- Render with millions of dynamic lights
  - Primitives of all sorts (triangles, spheres, cylinders, etc.), with or without IES profiles
  - Also textured and environment map emissives

SDK INCLUDES WHITE-BOX SOURCE

- Sample app demonstrates integration
- Led by Alexey Panteleev
- Go take a look!



TODAY: EXPLORE ALGORITHM DETAILS

A technical deep dive into how we made RTXDI fast

- Currently, RTXDI largely based on “ReSTIR”
  - Reservoir spatiotemporal importance resampling
- Presented basics a few times last year:
  - At SIGGRAPH 2020, “Spatiotemporal reservoir resampling for real-time ray tracing with dynamic direct lighting”
  - At GTC 2020, “Rendering games with millions of ray-traced lights”
  - At HPG 2020, “Reframing light transport for real-time”
- Will do a quick high-level review
- **Today’s focus: improvements to achieve real-time performance**

AGENDA

Quick Overview

What is RIS, ReSTIR, resampling? How does it help rendering?

Memory Coherence Issues

Coherence → big impact in ReSTIR; tackle with unusual approach

Intelligent Compute Refactoring

Leveraging or removing redundant compute in original research

PHYSICALLY-BASED RENDERING

Let’s start with basics: What is it?

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- Solve mathematical equations describing light interactions
- Different renderers may focus on *different aspects*

- Typically, the *rendering equation* is involved

$$L(x, \omega_o) = \int_{\Omega} \rho(x, \omega_i, \omega_o) L(x, \omega_i) \langle w_i \cdot N \rangle d\omega_i$$

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The two hard parts in raster

Not easier for ray tracing; incoming light still comes from everywhere

In DXR, just call TraceRay()

HANDLING HIGH-COMPLEXITY

How do you solve a tough integral?

HANDLING HIGH-COMPLEXITY

How do you solve a tough integral?

$$F = \int f(x)dx \approx \frac{1}{N} \sum_{1 \le i \le N} \frac{f(x_i)}{p(x_i)}$$

- Use Monte Carlo integration with *importance sampling*
  - Monte Carlo = numerically sampling the integral
  - Importance sampling = minimizing N with good choice of distribution $p(x)$

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- Use Monte Carlo integration with *importance sampling*
  - Monte Carlo = numerically sampling the integral
  - Importance sampling = minimizing N with good choice of distribution $p(x)$

- Can we do *perfect* importance sampling? I.e., get N=1

(APPROXIMATELY) PERFECT IMPORTANCE SAMPLING

- Perfect sampling means $p(x) \propto f(x)$, specifically:

$$p(x) = \frac{f(x)}{\int f(x)dx}$$

To perfectly sample $\int f(x)dx$, first need solution to $\int f(x)dx$…

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- Can *approximate* it, using more Monte Carlo integration:

$$F = \int f(x)\,dx \approx \frac{1}{N}\sum\left[\frac{f(x_i)}{\hat{p}(x_i)}\,\frac{1}{M}\sum\frac{\hat{p}(x_j)}{p(x_j)}\right]$$

resampled importance sampling; see Talbot et al.

WHY USE RESAMPLED IMPORTANCE SAMPLING

And what is ReSTIR?

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We need a color at our pixel

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We need a color at our pixel

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Reuse neighbor pixel samples to *improve* sampling at current pixel

WHY USE RESAMPLED IMPORTANCE SAMPLING

And what is ReSTIR?

$$F = \int f(x)\,dx \approx \frac{1}{M_0}\sum\left[\frac{f(x_{i_0})}{\widehat{p_0}(x_{i_0})}\,\frac{1}{M_1}\sum\left[\frac{\widehat{p_0}(x_{i_1})}{\widehat{p_1}(x_{i_1})}\frac{1}{M_2}\sum\left[\frac{\widehat{p_1}(x_{i_2})}{\widehat{p_2}(x_{i_2})}\cdots\right]\right]\right]$$

Resampling chain can continue indefinitely!

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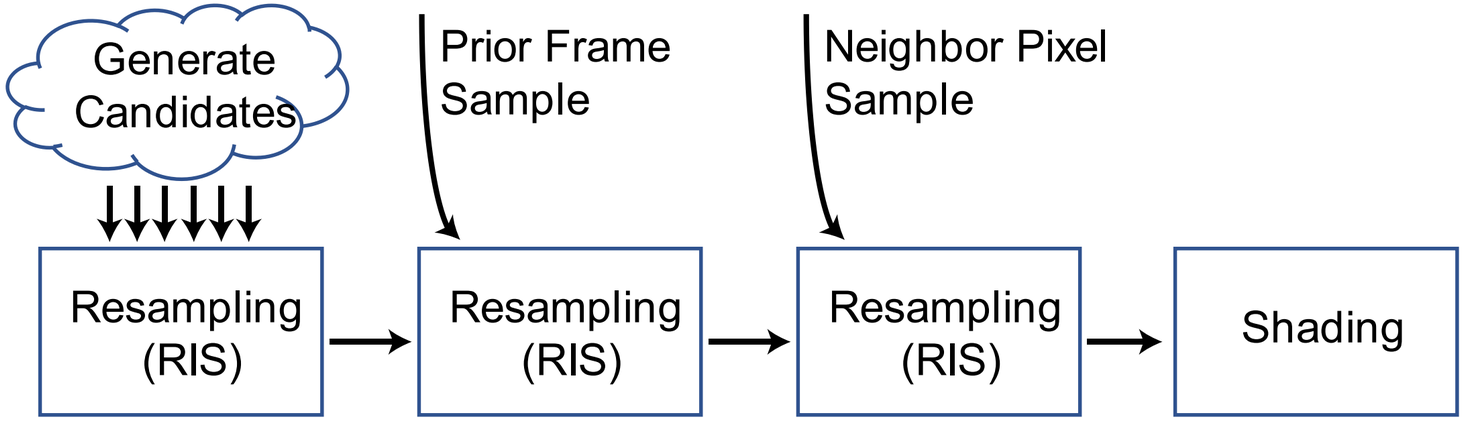
Resampling chain can continue indefinitely!

Feed spatial samples, temporal samples, etc., to improve current pixel samples

ReSTIR Pipeline:



WHAT DOES THIS GET US?

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Paper shows:
3 million emissive triangles
~50 ms

THAT’S NOT QUITE GAME PERFORMANCE…

SDK TARGET: IMPROVE PERFORMANCE

3 million emissives
Lighting: 4.6 ms

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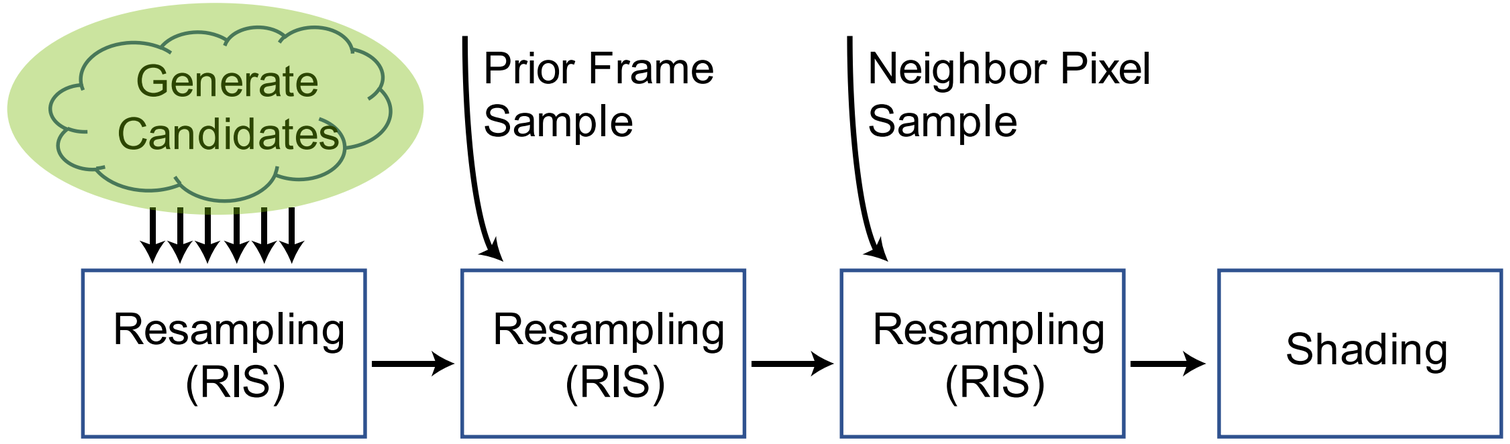

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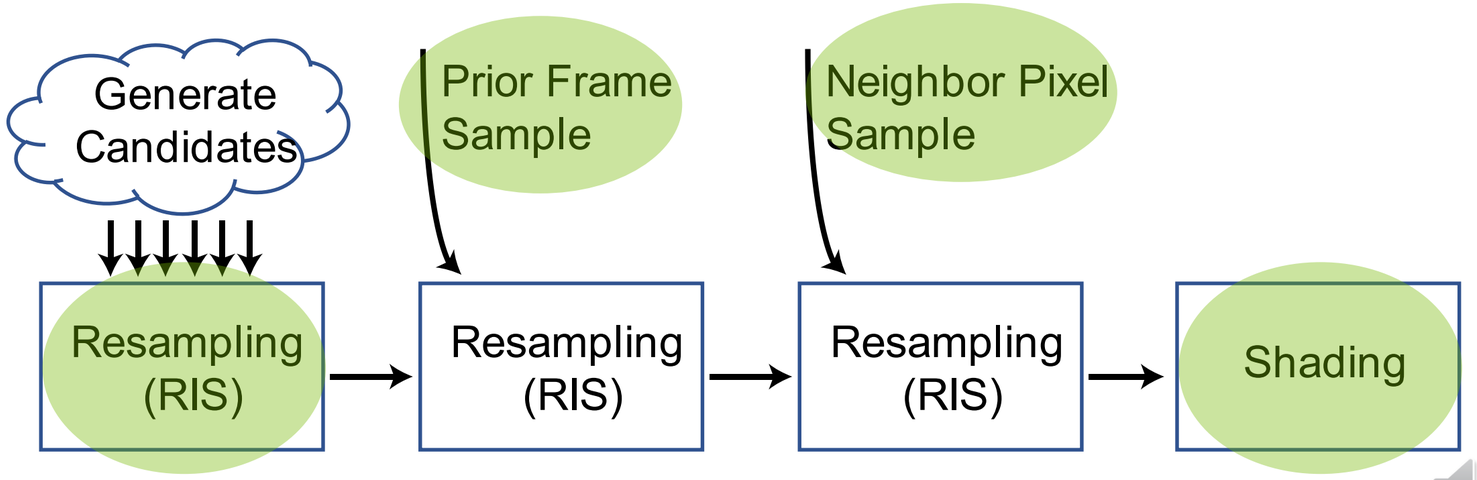

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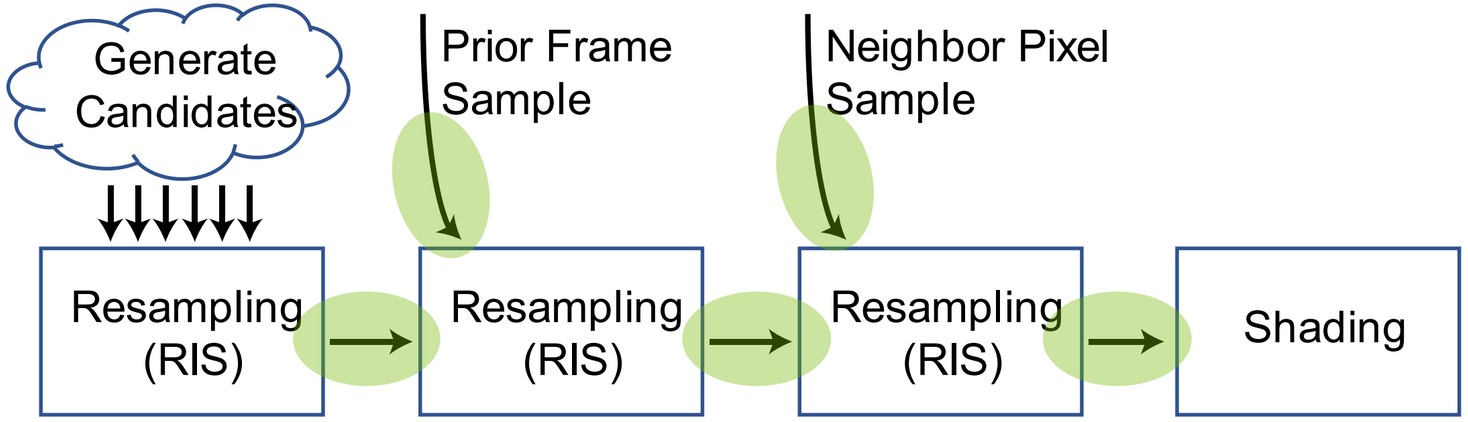

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Improve in standard ways:

- Compress to minimize bandwidth
- Merge kernels to minimize intermediate read/writes
- Minimize size of reservoir (i.e., number samples)

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  - Reading G-buffer data
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Some of our perf team:

Wondered why I'd design such an algorithm

So… Let's dive into this one

SAMPLING LIGHTS COHERENTLY

What’s the problem?

SAMPLING LIGHTS COHERENTLY

What's the problem?

- **Need** randomization for resampling (i.e., for correctness)
- Choosing small random subset from very large list ≡ incoherency
- Each pixel chooses a **different** random subset ≡ cache thrash
- Constant # lookups; costs vary >20x scene to scene

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- **Q: Can we "pre-randomize" to move incoherency out of inner loop?**

PRE-RANDOMIZING LIGHT SAMPLES

Key observation: Degenerate RIS steps allow ***reshaping*** computation

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$$\int f(x)\,dx \approx \frac{1}{N}\sum\left[\frac{f(x_i)}{p(x_i)}\,\frac{1}{M}\sum\frac{p(x_j)}{p(x_j)}\right] = \frac{1}{N}\sum\left[\frac{f(x_i)}{p(x_i)}\,\frac{1}{M}\sum 1\right]$$

- This is the standard Monte Carlo estimator…

*But in **two** steps: first select M samples, then pick N of those!*

PRE-RANDOMIZING LIGHT SAMPLES

Key observation: Degenerate RIS steps allow ***reshaping*** computation

- Pre-process (once per frame):
  - Create S_i sets of lights, each containing S_M lights
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  - Pixel blocks randomly sample the same set S_i of lights (i.e., pick random S_i per pixel block)
  - 8x8 blocks seem the sweet spot

PRE-RANDOMIZING LIGHT SAMPLES

Key observation: Degenerate RIS steps allow ***reshaping*** computation

Found 128 sets of 1024 lights
works across most or all scenes

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  - First pick **which** light type
  - Then pick **which light** of that type
  - Finally pick a **point on** that light
  - Leads to execution divergence
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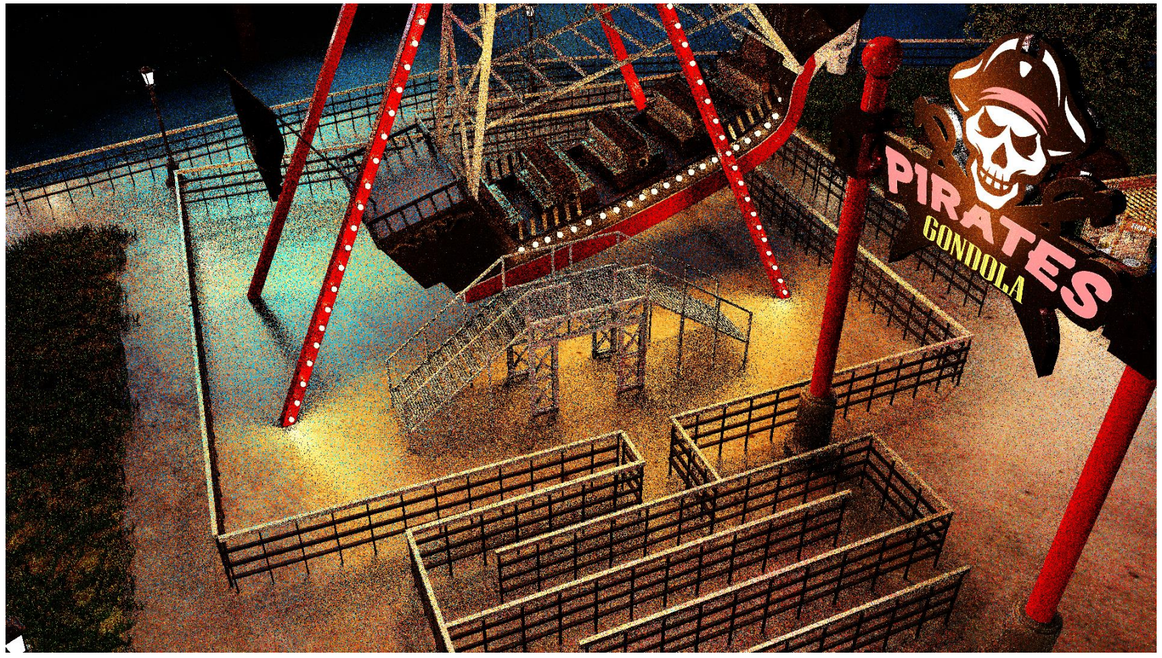
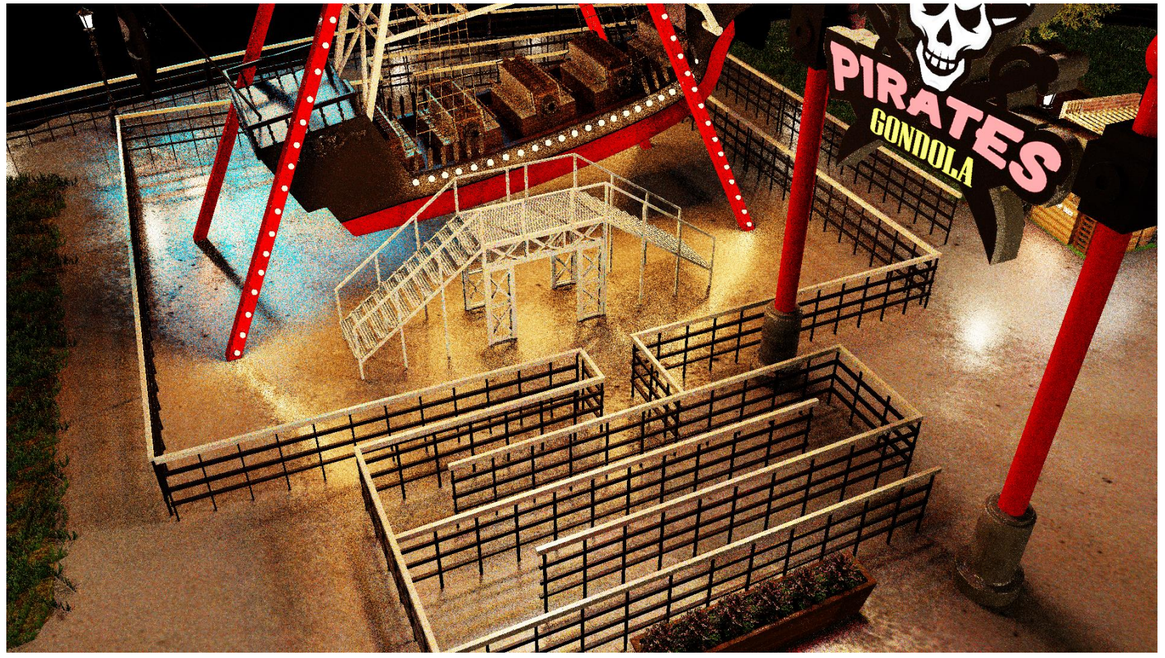
  - Pre-randomization moves this divergence out of inner loop
- Can reshape sampling multiple times
  - Sample per light type; then resample into our S_i light pools

IMPROVEMENT?

Going back to the Amusement Park



Before: ~20 ms initial light sampling
50 ms total lighting cost



After: ~0.8 ms for initial light sampling
4.6 ms for total lighting cost

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ONE GOAL: MINIMIZE RAY COUNTS

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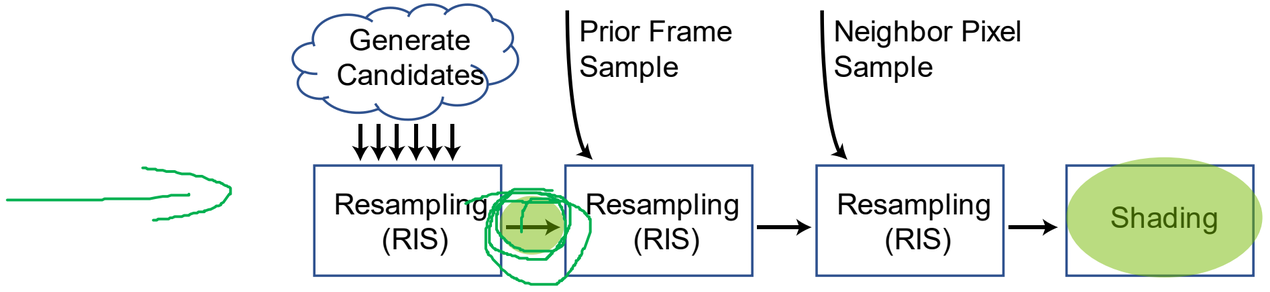
1 shadow ray
guides resampling

4 shadow rays
for final shading



ONE GOAL: MINIMIZE RAY COUNTS

ReSTIR paper uses 5 rays per pixel

1 shadow ray
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- Ponder: How important are all these rays? Particularly the last four…

WHAT DO THOSE RAYS DO?

Remember: Final shade rays are the N value in RIS

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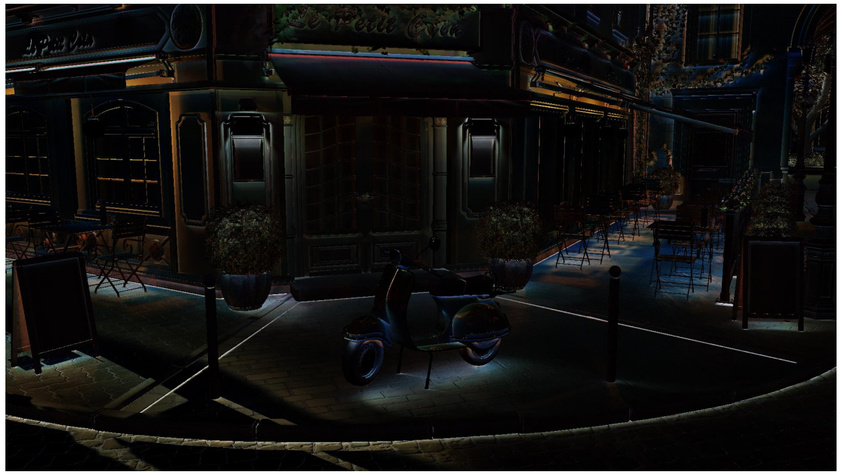
$$\int f(x)\,dx \approx \frac{1}{N}\sum\left[\frac{f(x_i)}{\hat{p}(x_i)}\frac{1}{M}\sum\frac{\hat{p}(x_j)}{p(x_j)}\right]$$

- Controls variance of $f(x_i)/\hat{p}(x_i)$. Is N = 4 really much better?

With final shadow rays

No final shadow rays



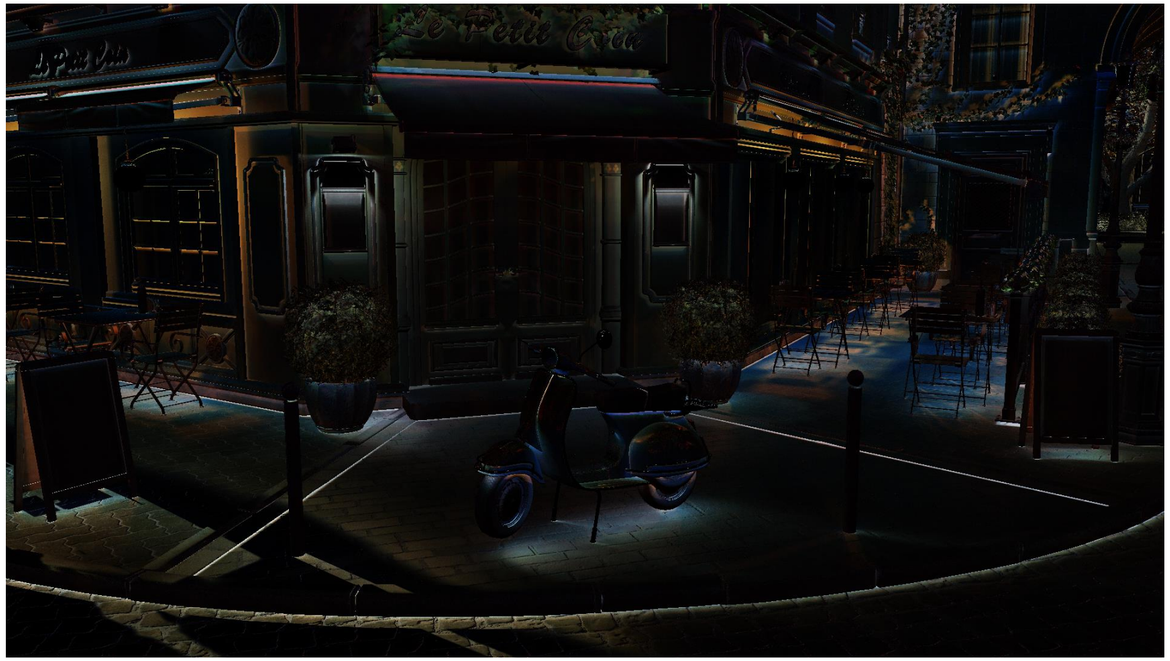
N controls variance of ***this***

LET DENOISER HANDLE THAT

- N = 1 is fine with a good denoiser
- Cuts budget to 2 rays per pixel

- Standard ways to cut further
  - Checkerboarding
  - Lower resolution reservoirs

- Plus some additional tricks



REUSING SAMPLES MORE INTELLIGENTLY

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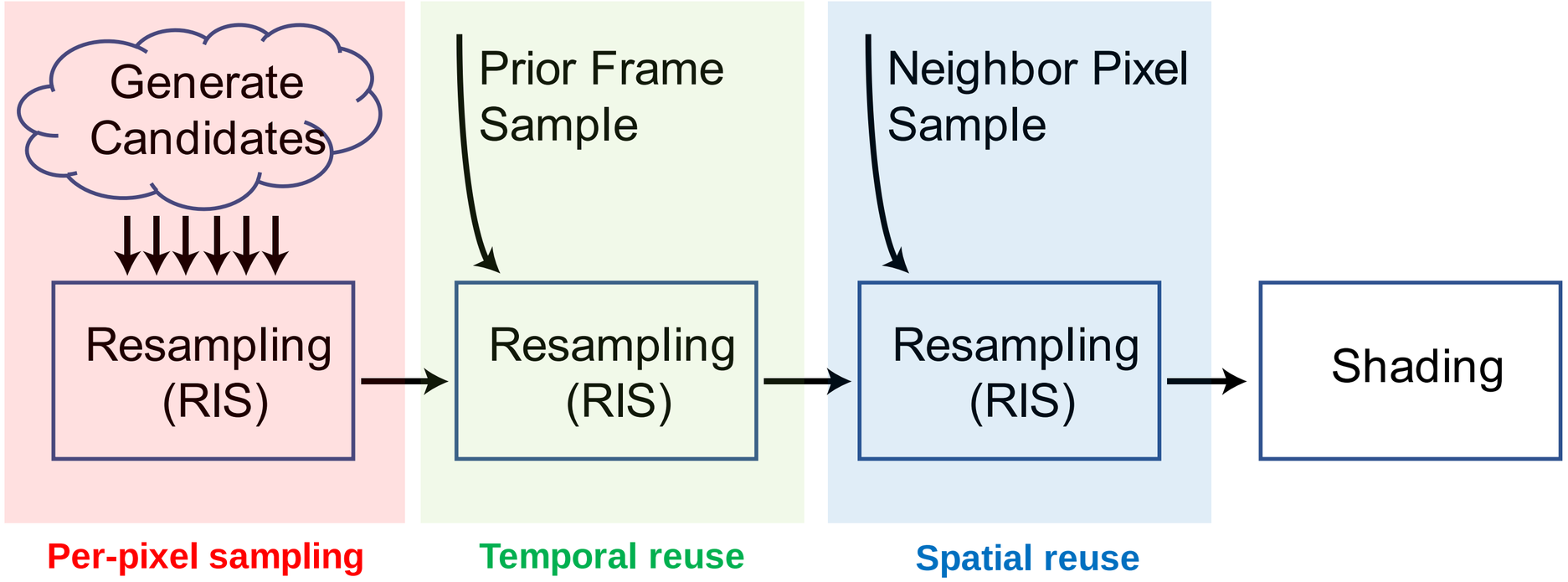
Consider the ReSTIR pipeline



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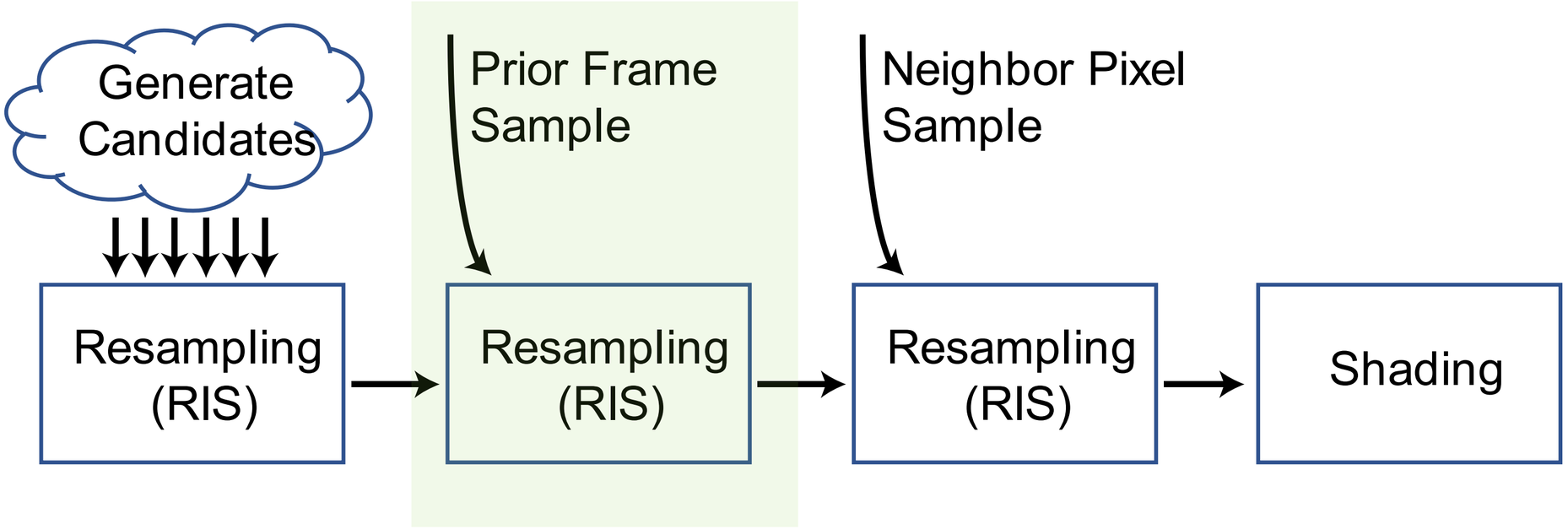
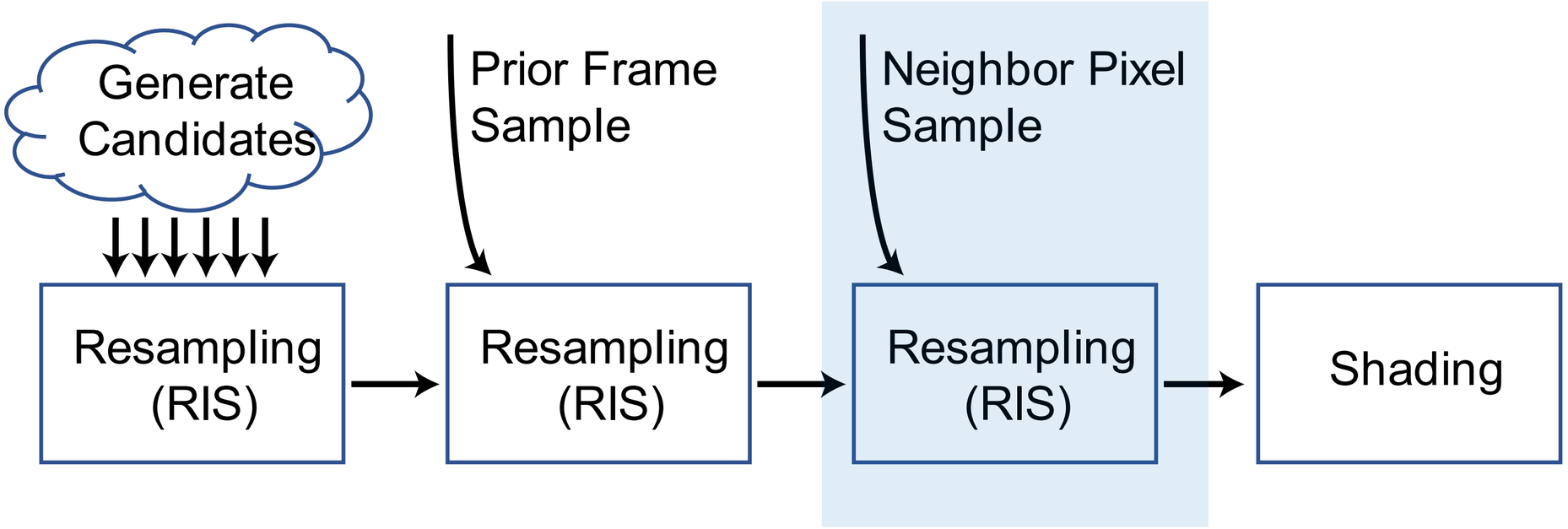


Interesting observation:
Temporal reuse most important


Initial Candidates Only
Spatial Reuse
Temporal Reuse
Both
MENU

REUSING SAMPLES MORE INTELLIGENTLY

Why use spatial reuse at all?



- Spatial reuse dithers out issues with temporal-only reuse
- Minimize this reuse; exactly one spatial tap seems sufficient (though 2 or 3 help with noise)

SHADING MORE INTELLIGENTLY

Other opportunities to reduce redundancy

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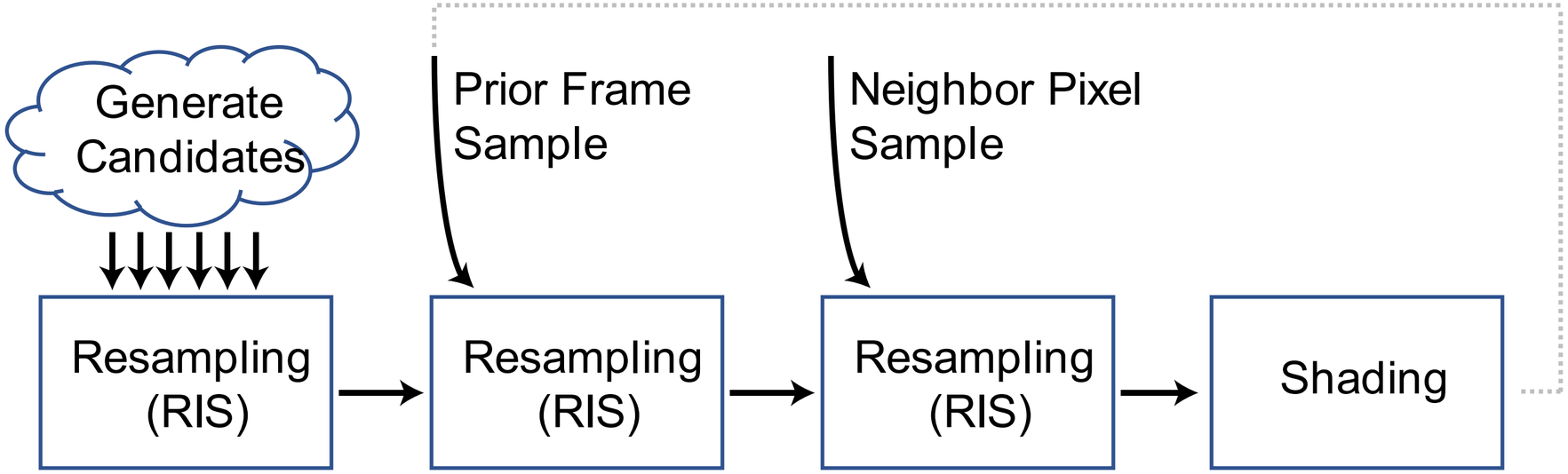
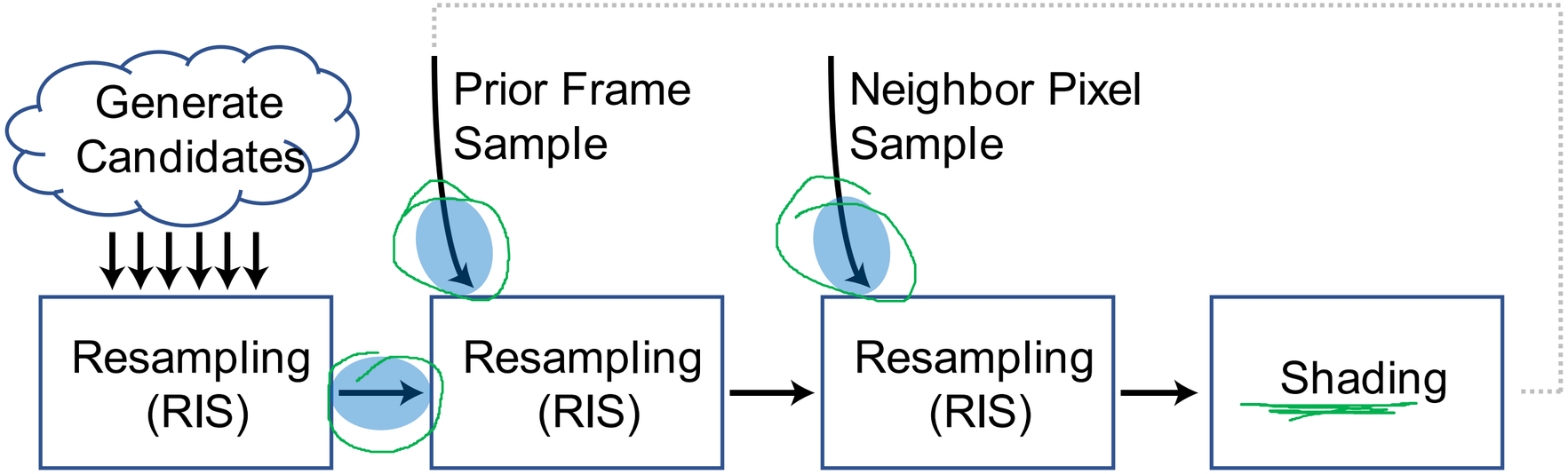


SHADING MORE INTELLIGENTLY

What's going on here?



- One of three samples is shaded

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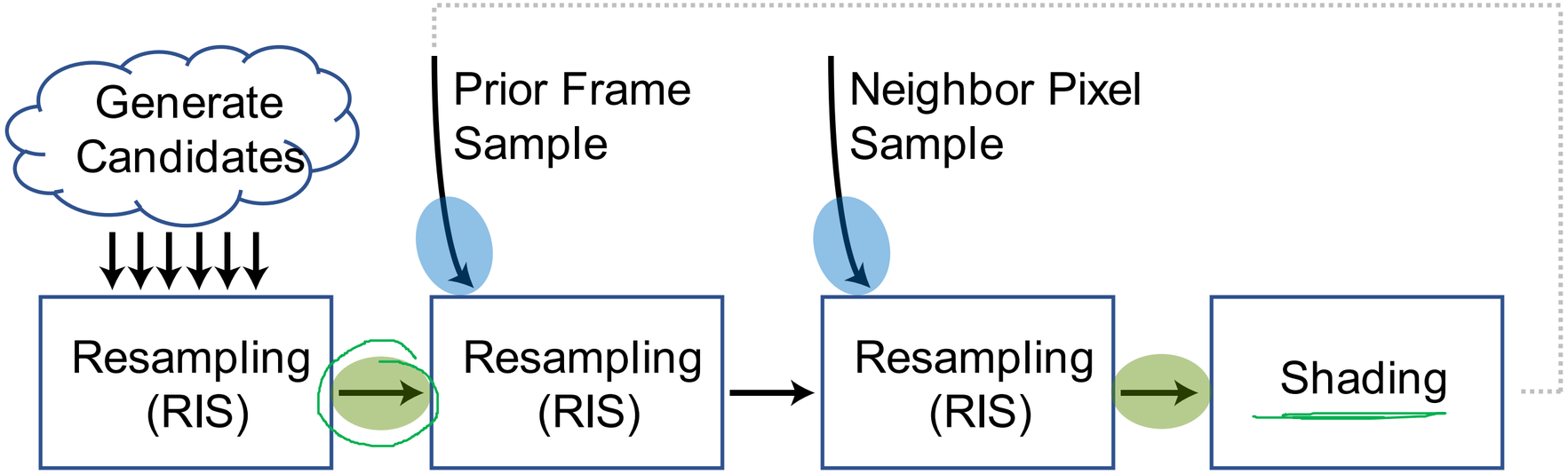

- One of three samples is shaded
- Two shadow rays traced (a reasonable chance they're duplicates)

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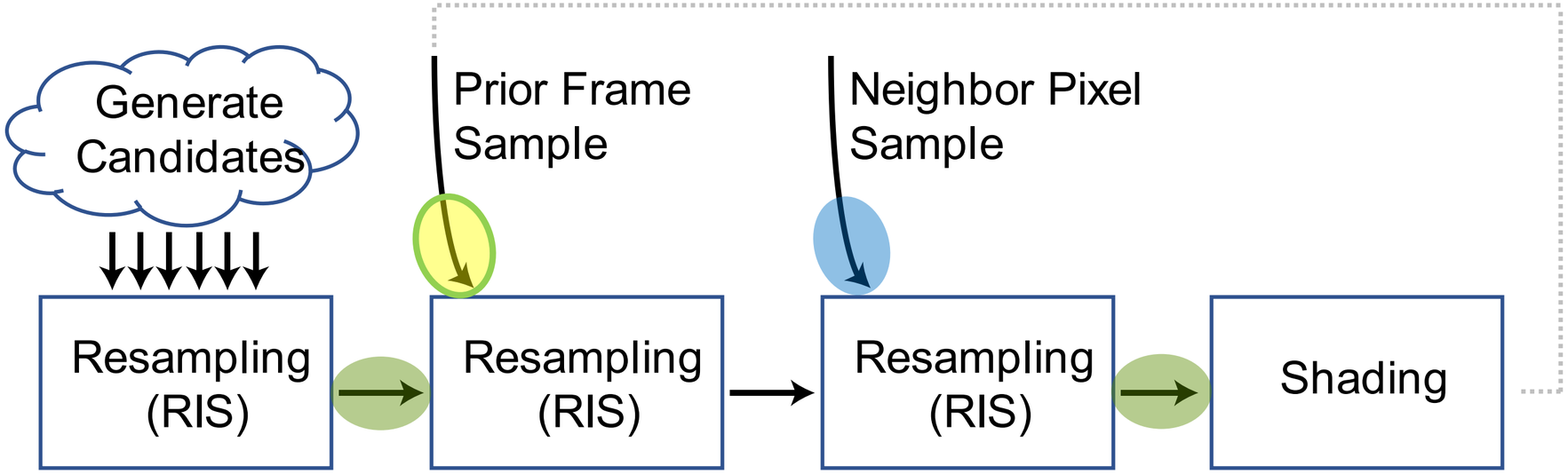
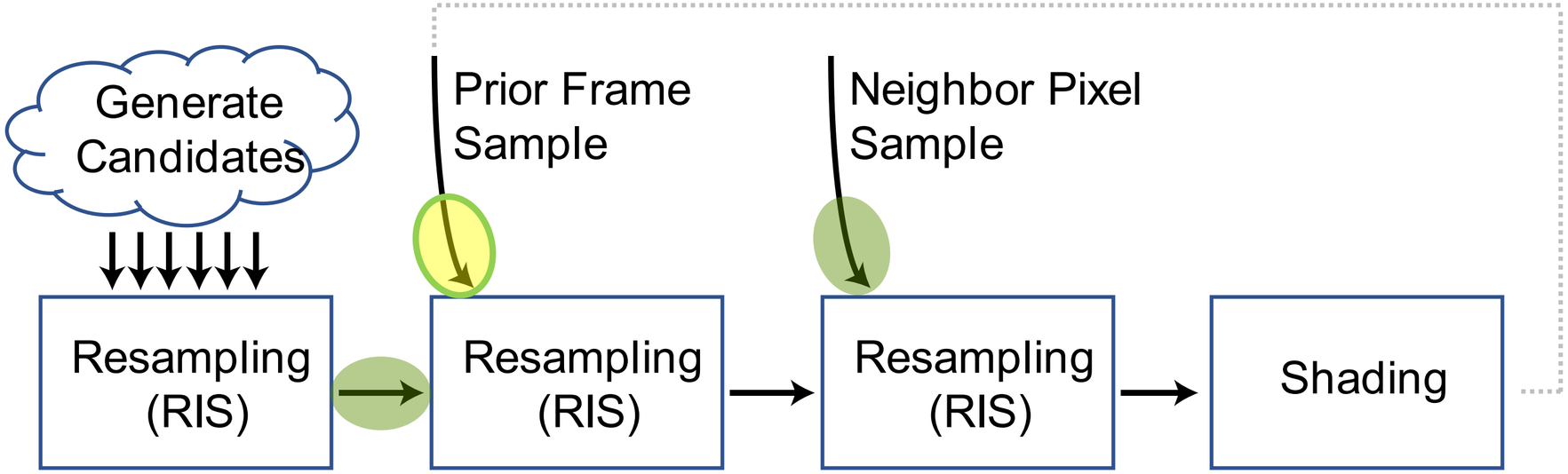


- One of three samples is shaded
- Two shadow rays traced (a reasonable chance they're duplicates)
- Have reasonable (if approximate) visibility from last frame

COULD WE REORGANIZE WHERE WE TRACE RAYS?



- Still 2 rays per pixel, but now has **3 shaded samples**

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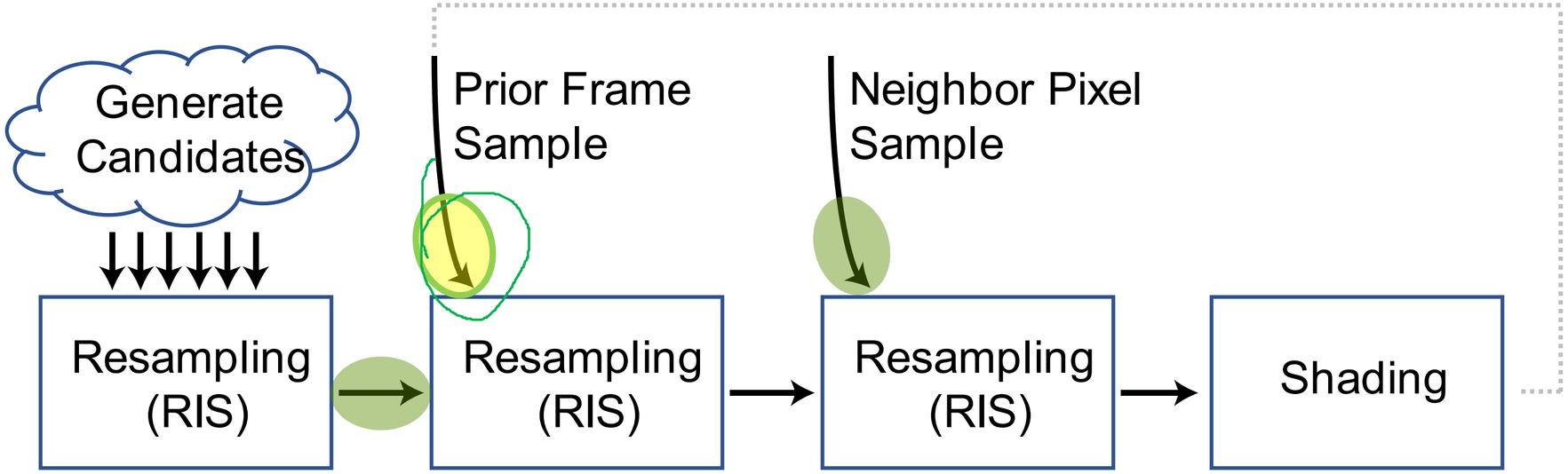

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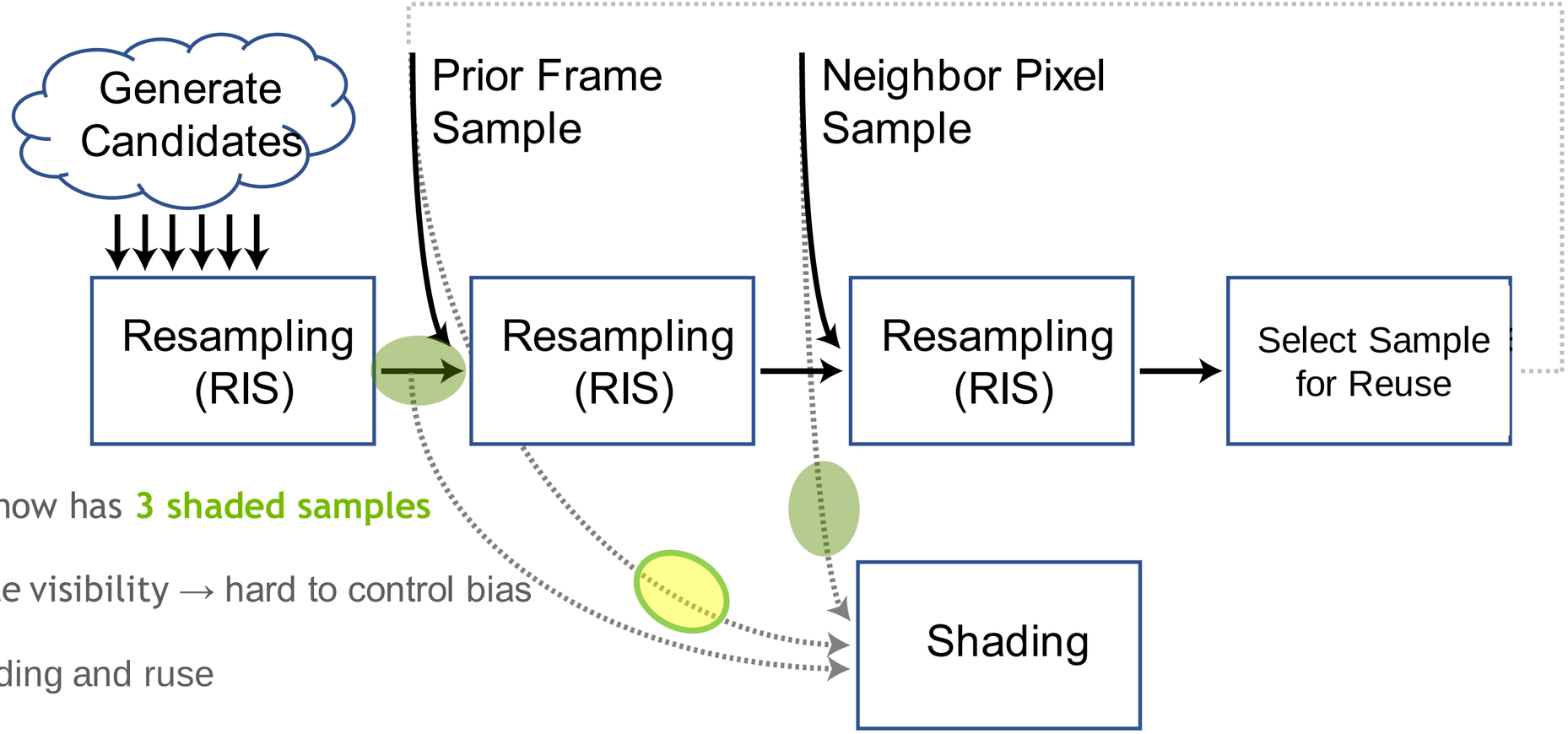
- Sadly, reusing approximate visibility → hard to control bias

IDEA: DECOUPLE REUSE AND SHADING

Visibility can be used ***differently*** for reuse and for shading



- Still 2 rays per pixel, but now has **3 shaded samples**
- Sadly, reusing approximate visibility → hard to control bias
- But we can **decouple** shading and ruse
  - Shading artifacts less noticeable; transient, just 1 frame

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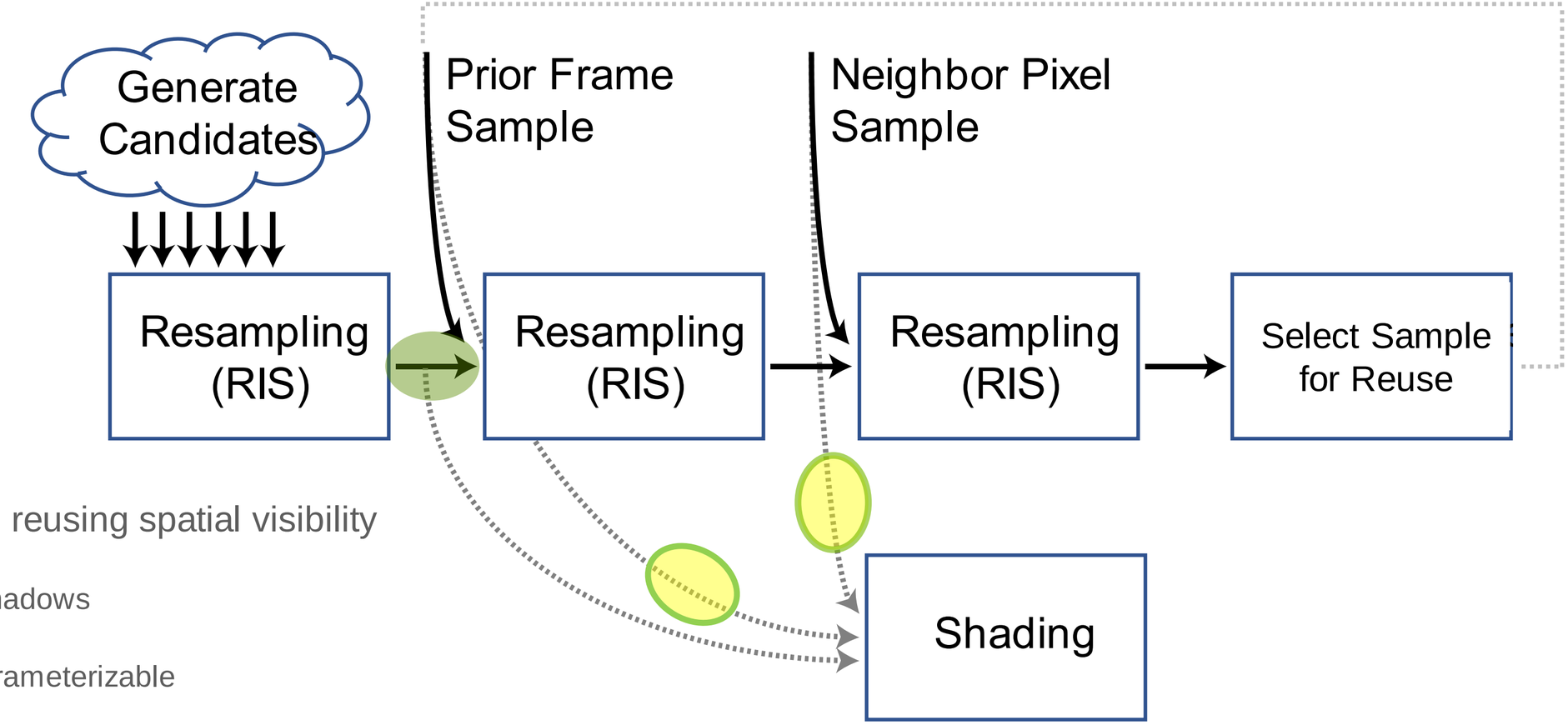
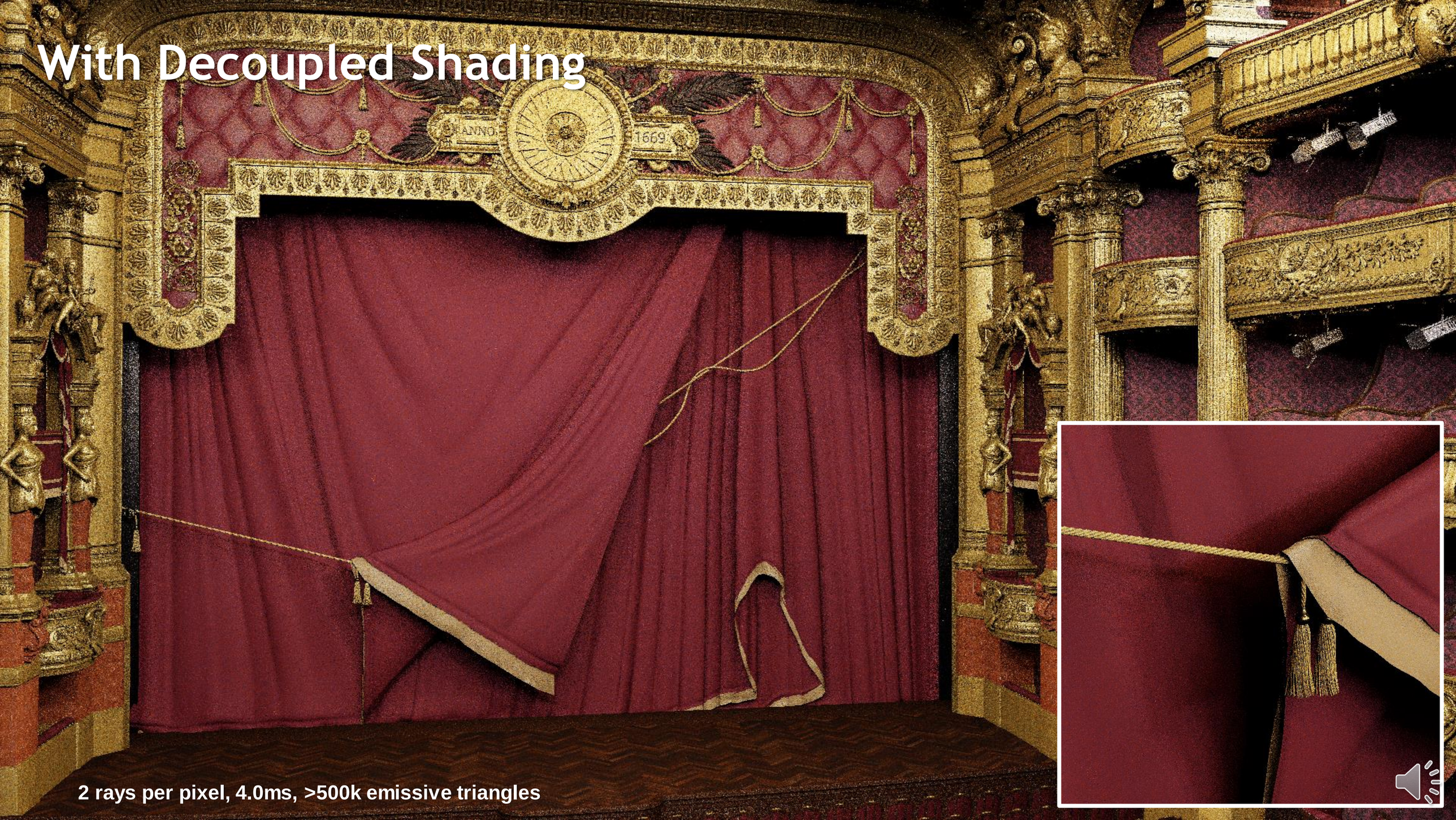


- Can be more aggressive, reusing spatial visibility
  - Noticeably lightens shadows
  - But degradation is parameterizable
  - Allows tuning down quality for fewer rays

Before Decoupled Shading

Paris Opera House, GoldSmooth from TurboSquid

With Decoupled Shading



2 rays per pixel, 4.0ms, >500k emissive triangles

SUMMARY

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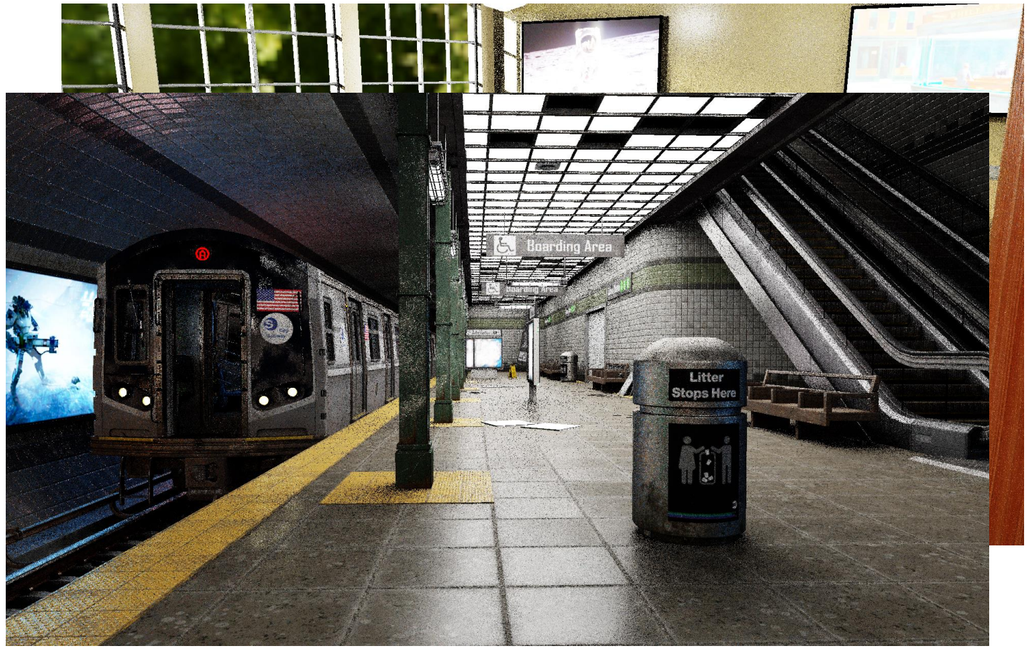
- RTXDI available now; take a look!

Classroom:
- 4 emissive meshes (13k tris) plus light probe
- 2 ms for lighting

SUMMARY

- RTXDI available now; take a look!

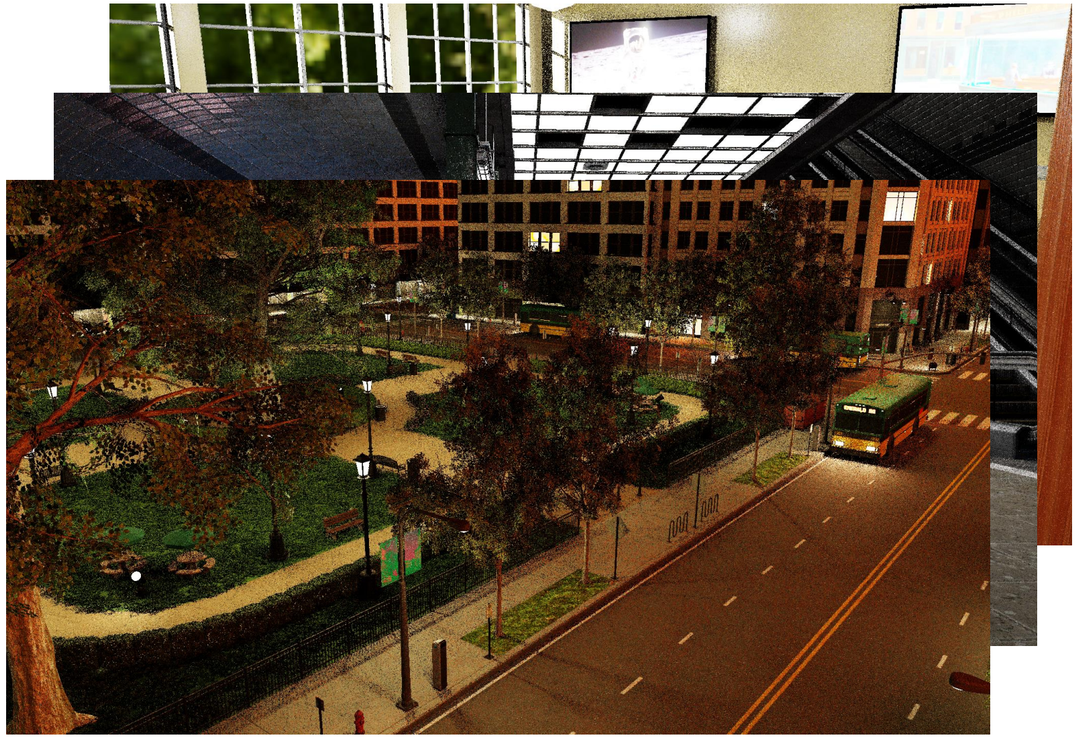
- We've seriously tuned perf since prior published numbers



Subway:
750 emissive meshes (25k tris)
2.2 ms for lighting

SUMMARY

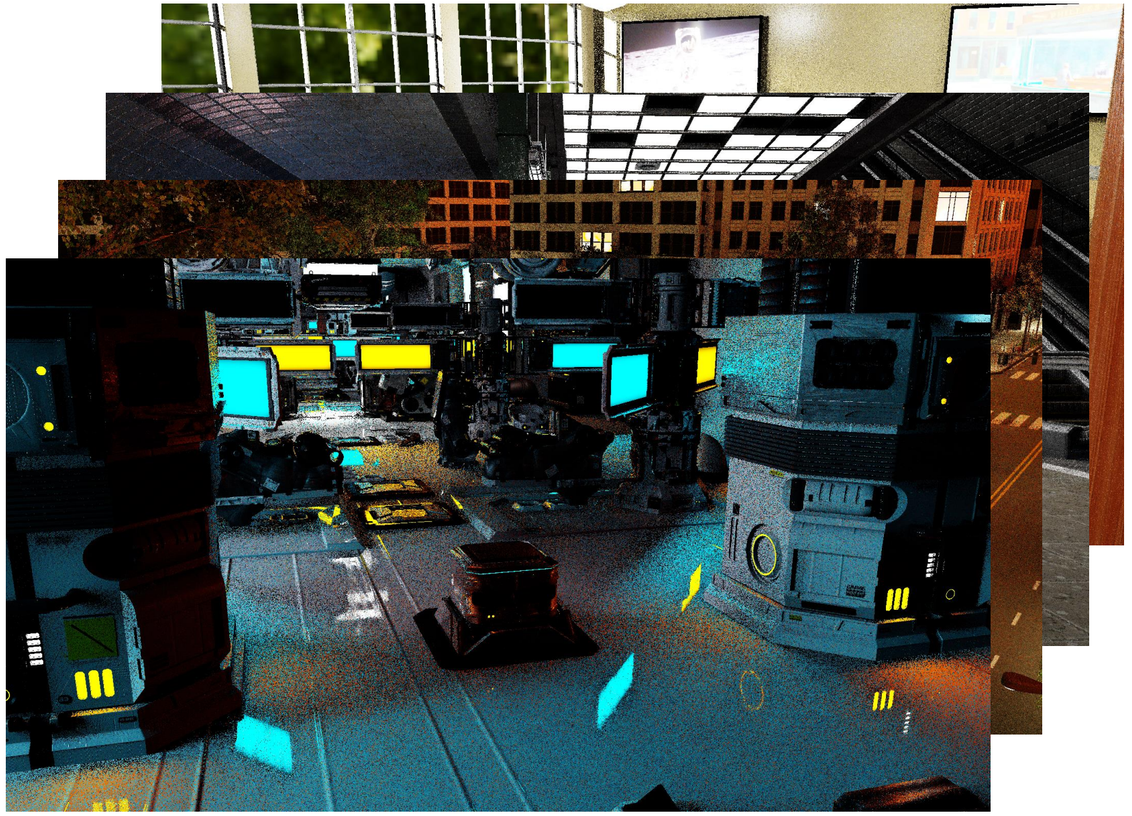
- RTXDI available now; take a look!
- We've seriously tuned perf since prior published numbers
- Big algorithmic changes:
  - Pre-randomize to reduce incoherency; remove from inner loop
  - Minimizing ray count
  - Improving quality at isoperf via decoupling



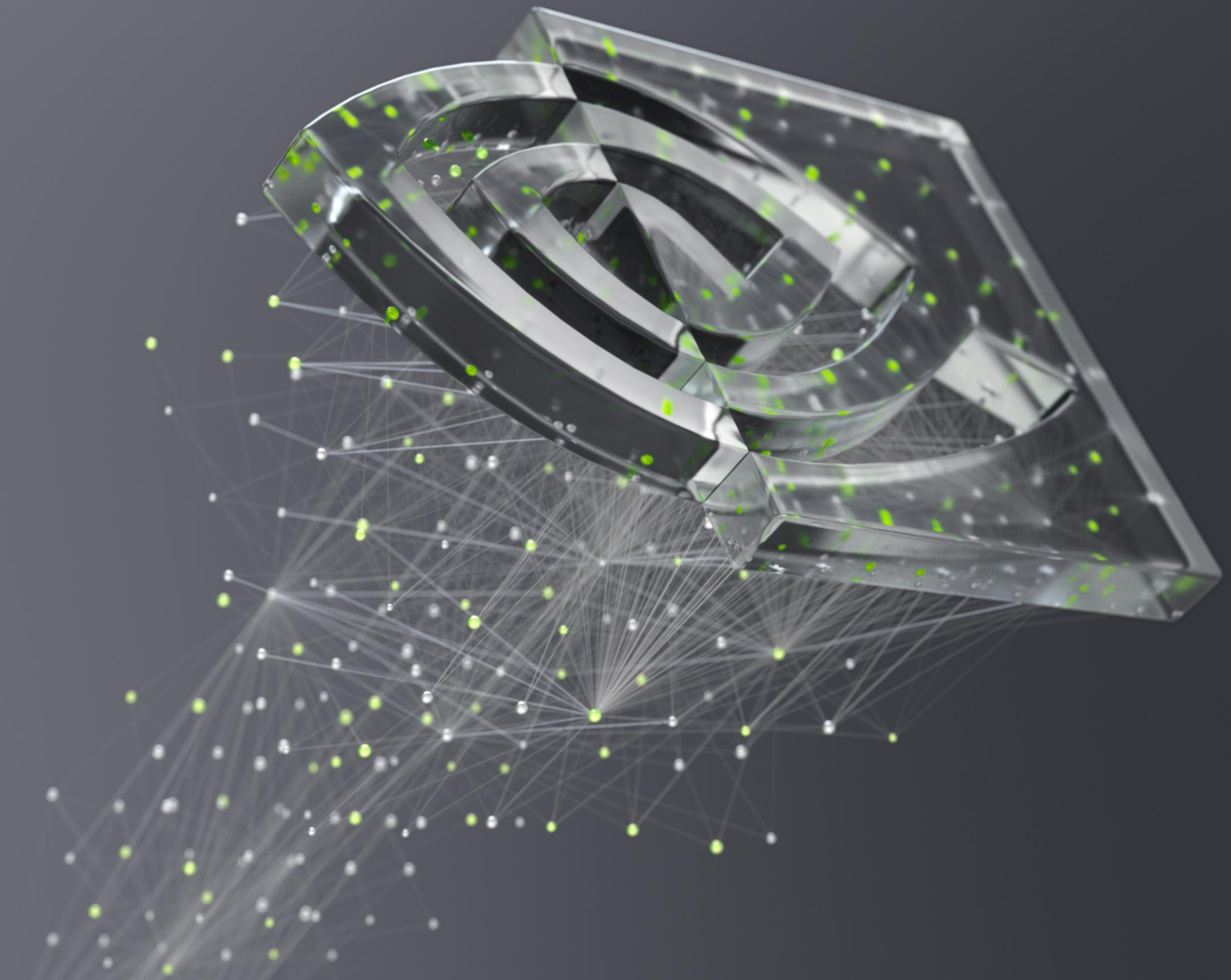
Emerald Square:
280 emissive meshes (89k tris)
5 ms for lighting

SUMMARY

- RTXDI available now; take a look!
- We've seriously tuned perf since prior published numbers
- Big algorithmic changes:
  - Pre-randomize to reduce incoherency; remove from inner loop
  - Minimizing ray count
  - Improving quality at isoperf via decoupling
- Remaining scene-to-scene perf deltas largely from ray cost



Zero Day:
384 emissive meshes (11k tris)
3 ms for lighting



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GAME STACK LIVE

NVIDIA