Interactive Summed-Area Table Generation for Glossy Environmental Reflections

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Overview

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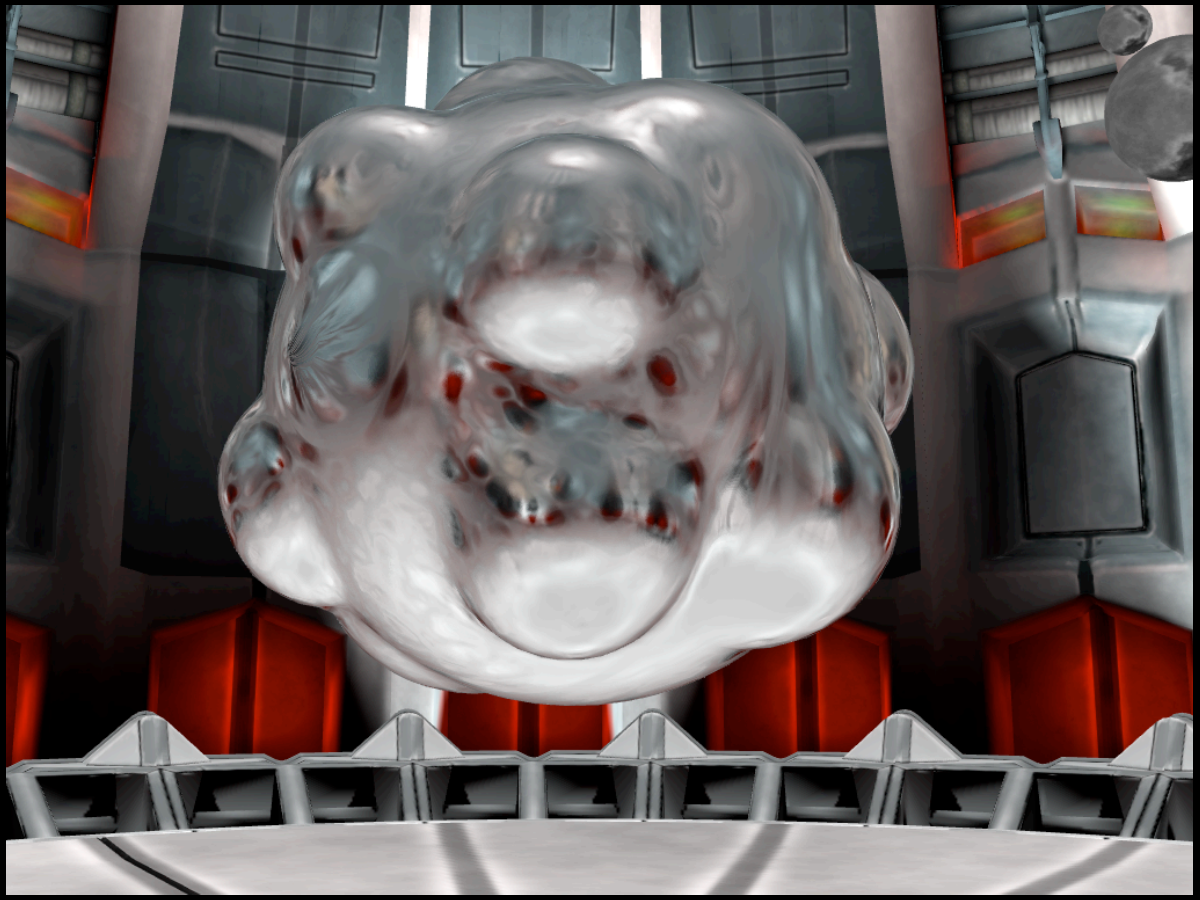
- Summed-area tables
  - Useful for averaging pixels
  - Efficient creation on GPU
- Rendering dynamic reflections with per-pixel glossiness using dual-paraboloid maps and summed-area tables



Summed-Area Tables (SATs)

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- Each element S_{mn} of a summed-area table S contains the sum of all elements above and to the left of the original table/texture T (for a left handed coordinate system) [Crow84]

$$S_{mn} = \sum_{i=1}^{m} \sum_{j=1}^{n} t_{ij}$$

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	1	2	3	4
4	0	7	2	4
3	1	4	1	2
2	6	1	2	0
1	0	3	5	2

input texture

	1	2	3	4
4	0	7	9	13
3	1	12	15	21
2	7	19	24	30
1	7	22	32	40

summed-area table

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summed-area table

Using a Summed-Area Table

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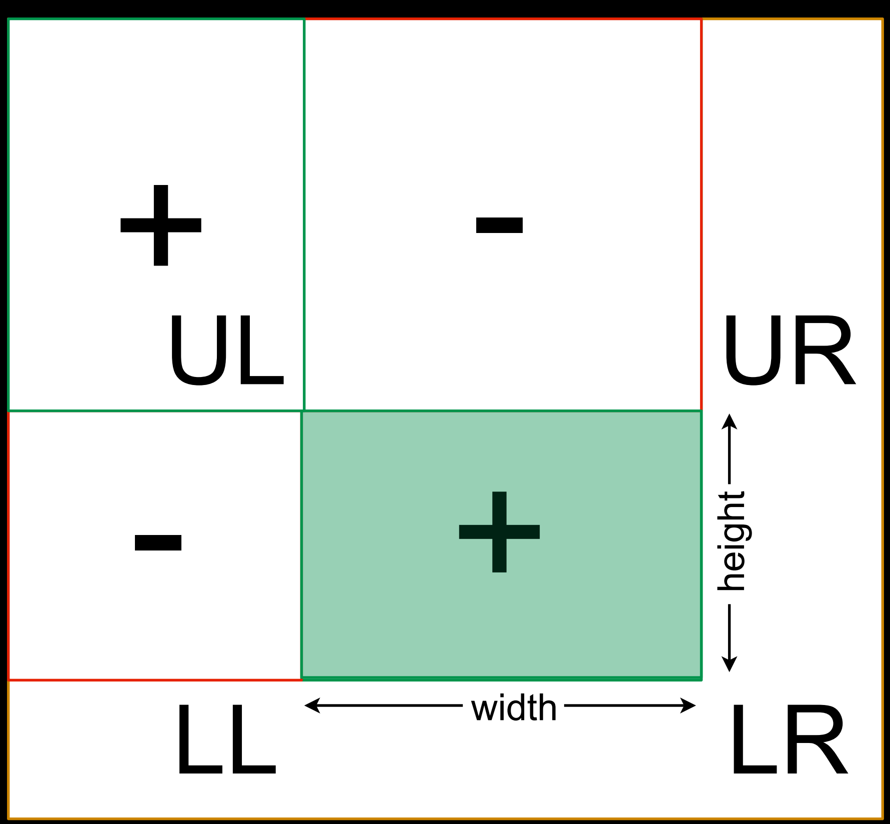
- Summed-area tables enable the averaging rectangular regions of pixel with a constant number of reads



$$average = \frac{LR - LL - UR + UL}{width*height}$$

Efficient Summed-Area Table Creation

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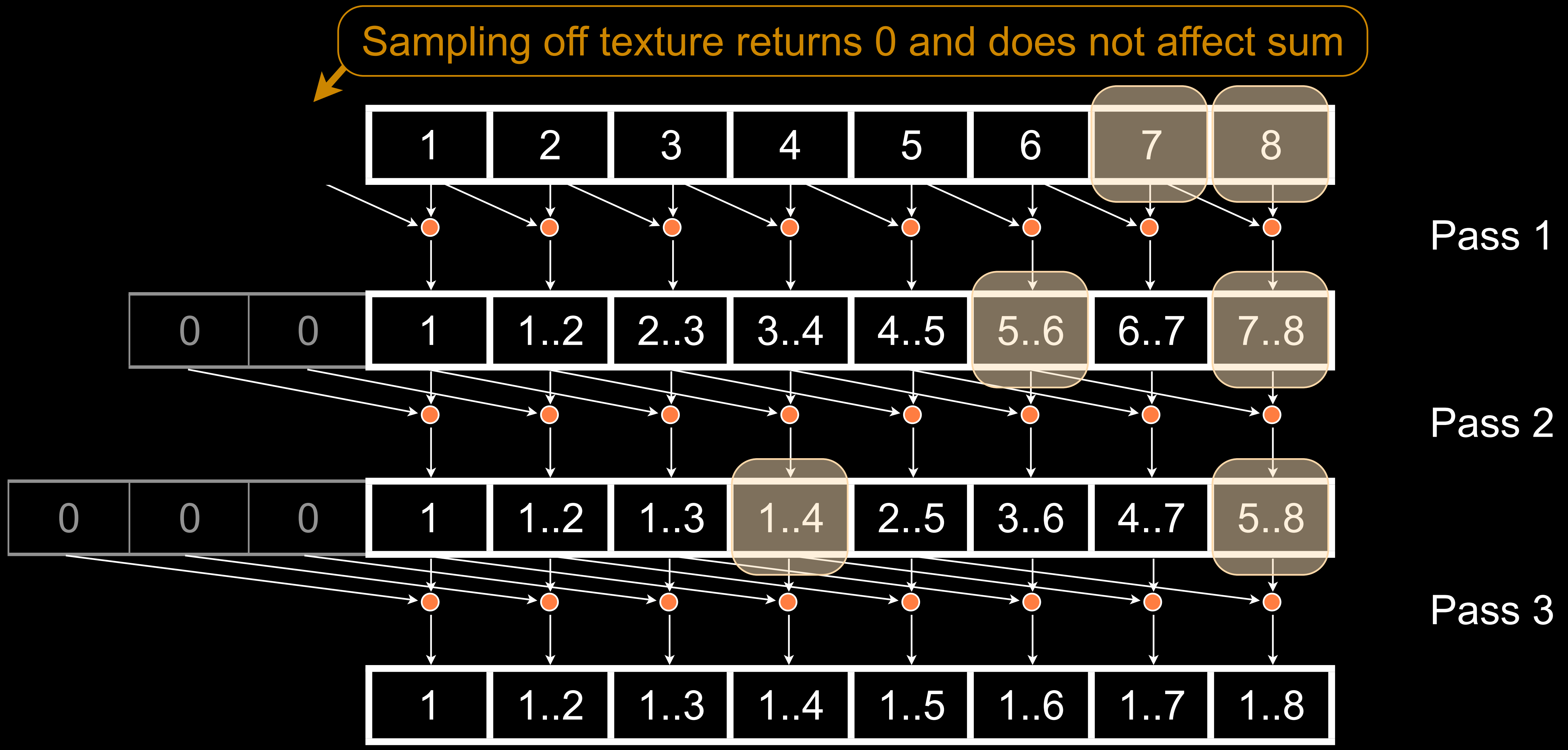
- Borrow technique from high performance computing - **recursive doubling**
- Summed-area table construction can be decomposed into horizontal and vertical phase each with *log_2(texture size)* passes
- Each pass adds two elements from previous pass.

Horizontal Phase:

$$P_i(x,y) = P_{i-1}(x,y) + P_{i-1}(x - 2^{passindex}, y)$$

Horizontal Phase



Boundary Conditions

- To make sure sampling off the texture does not effect the results we need to set up the correct texture clamping behavior
- Two possibilities:
  - Clamp to border color with a color of (0, 0, 0, 0)
  - Render a black border around the texture to be converted into SAT and set Clamp to Edge mode

Saving unnecessary texture reads

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- Reads off of the texture are wasteful
  - Texel cache ***should*** catch these reads
- Optimization:
  - Do not perform computation for *finished* texels
  - Reduce the size of the rendered quad each pass to only cover texels have not finished computation

Saving Render Passes

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- Two samples per pass requires 16 passes for a 256x256 texture → $2 * \log_2(256)$
- Reduce number of passes by adding more samples per pass
  - passes = $2 * \log_{\#samples}(\text{texture size})$
- Only need 4 passes to convert a 256x256 texture into a summed-area table if 16 samples / pass used
  - Trade extra work versus reducing context switches

Precision Requirements

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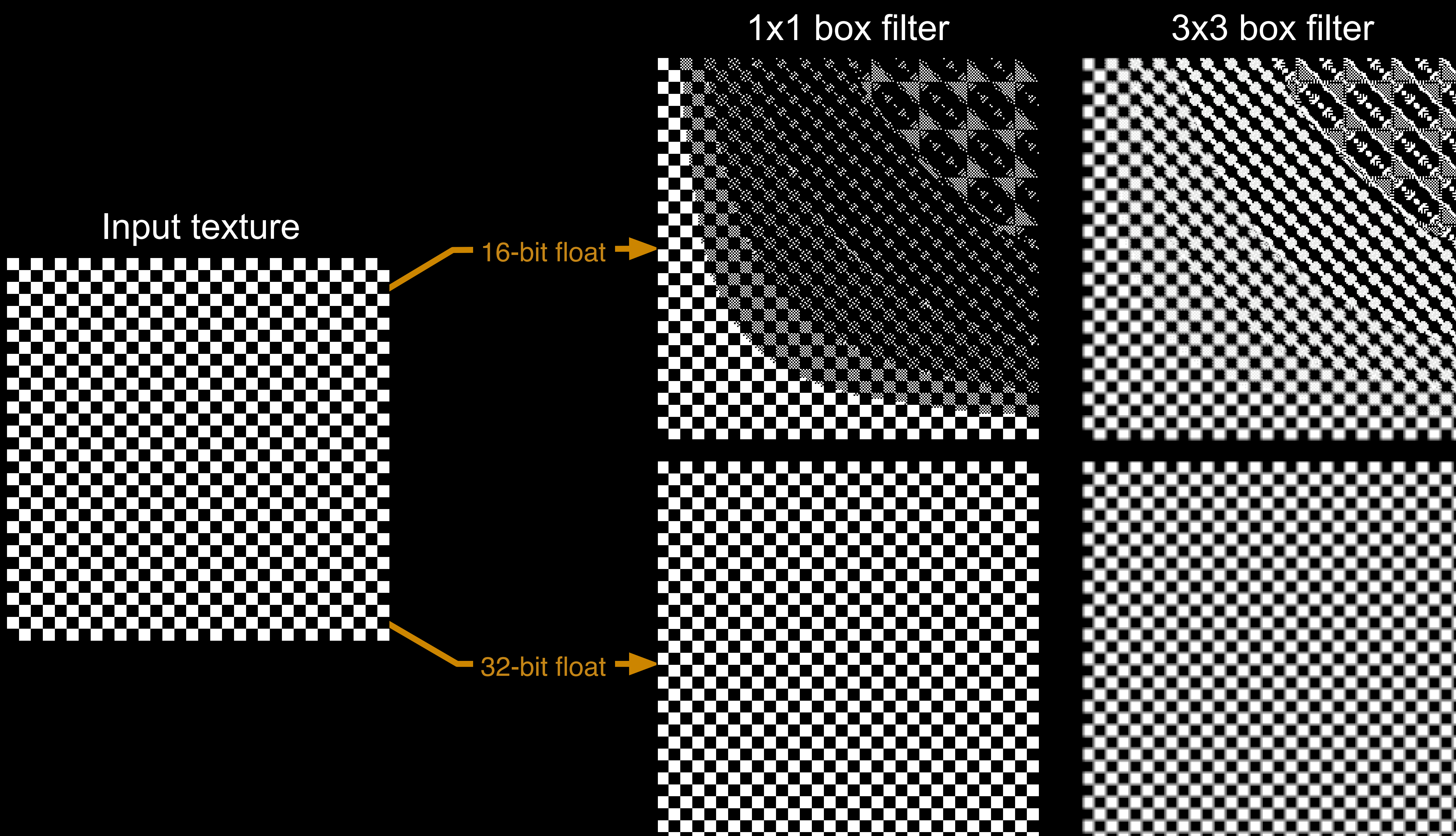
- For proper reconstruction:

$$table\ precision = log_2(w)+log_2(h) + b$$

- A 256x256 8-bit input texture requires 24-bits of precision per component
- Use 32-bit floats to compute and store summed-area tables
- Precision errors average out as you use larger box filter kernels

Effects of Precision Loss



Effects of Precision Loss
24-bit floats

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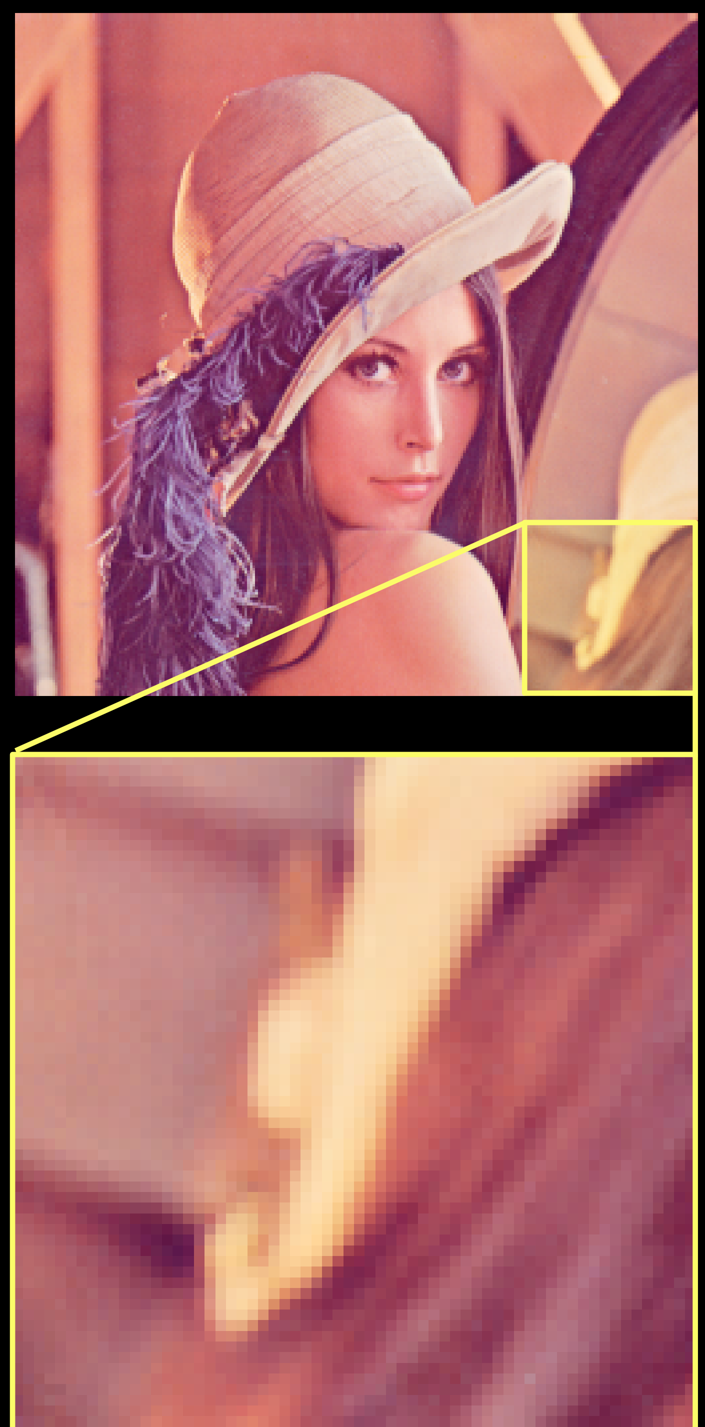
Input texture



1x1 box filter reconstruction

Improving Precision Requirements (1/2)

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- Summed-area tables store a positively increasing monotonic function
  - Construction requires the addition of a value that is at least zero
- **Construct table using offsets instead of absolute values**
  - Function no longer monotonic
  - Removes DC component of signal

Improving Precision Requirements (2/2)

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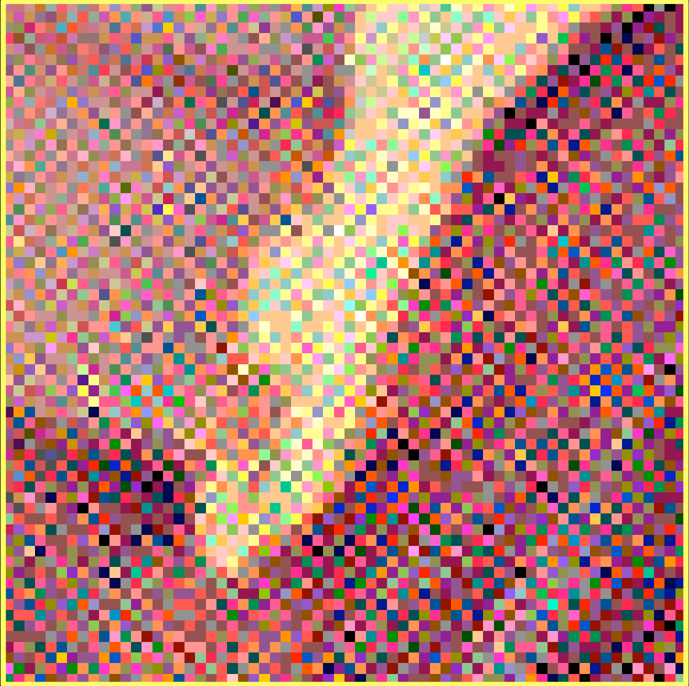
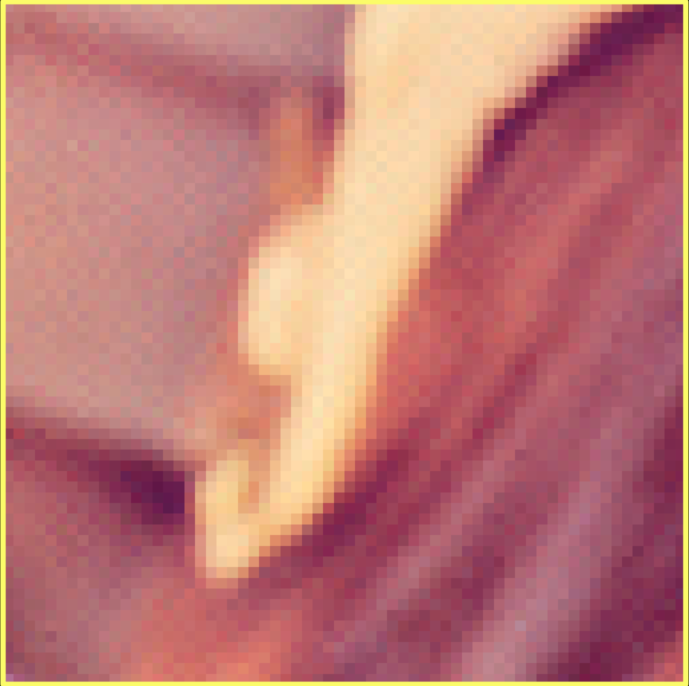
- Bias input texture by -0.5 before generating table
- Reconstruct samples from table by adding 0.5 to final result
  - For best results, use actual image mean
- Particularly useful on hardware with limited pixel pipeline precision

Original summed-area table

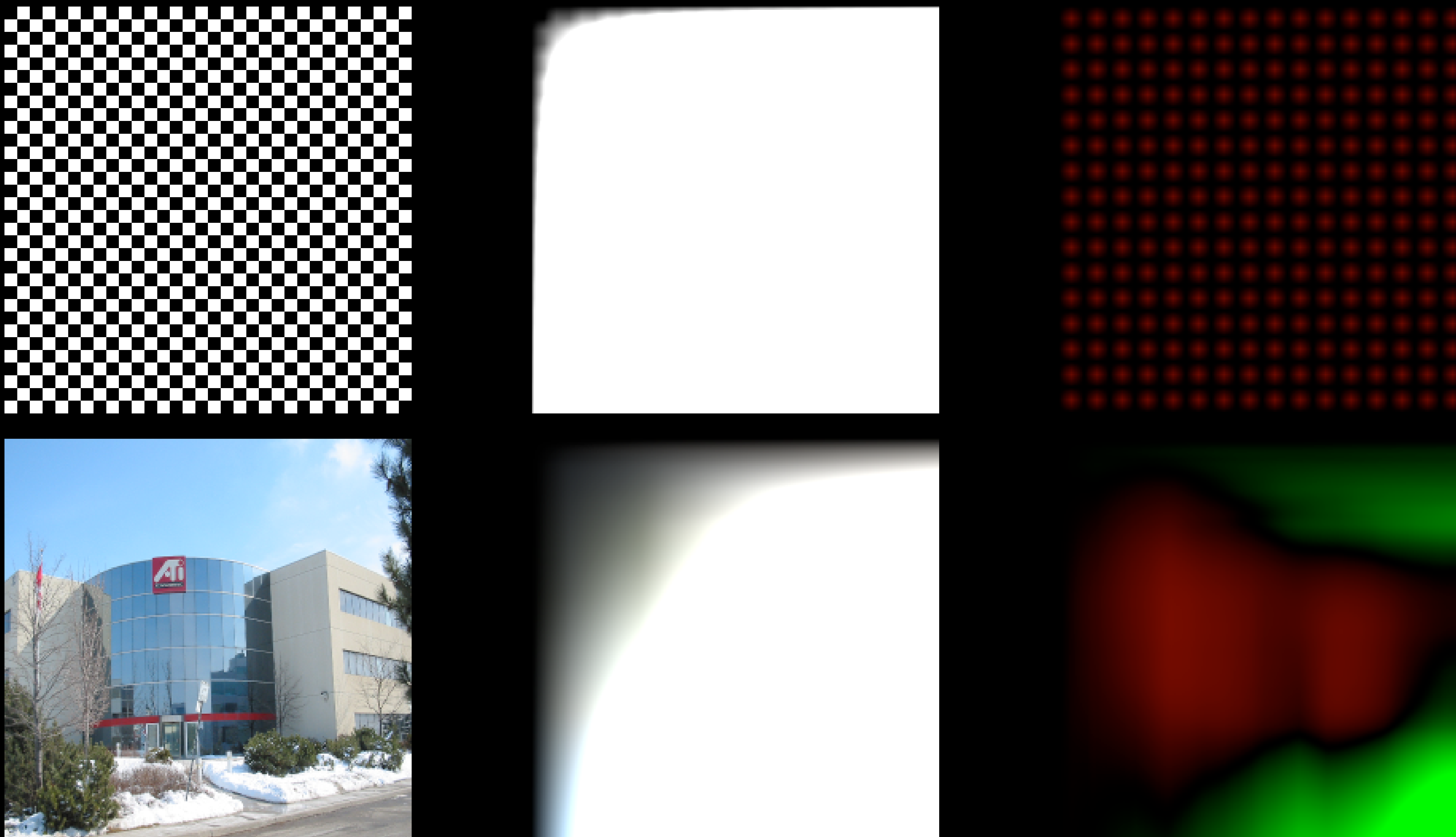


With precision improvement



Offset Summed-Area Tables

input texture | original summed-area table | **this work**



Dynamic Glossy Reflections Outline

- Render dynamic cubemap
- Convert to dual-paraboloid map
- Convert dual-paraboloid map faces to summed-area tables
- Apply summed-area table Dual-paraboloid map to glossy object
- Sounds like a lot of work, but is actually quite fast on modern hardware
  - Real-time demo later

Dual-Paraboloid Maps

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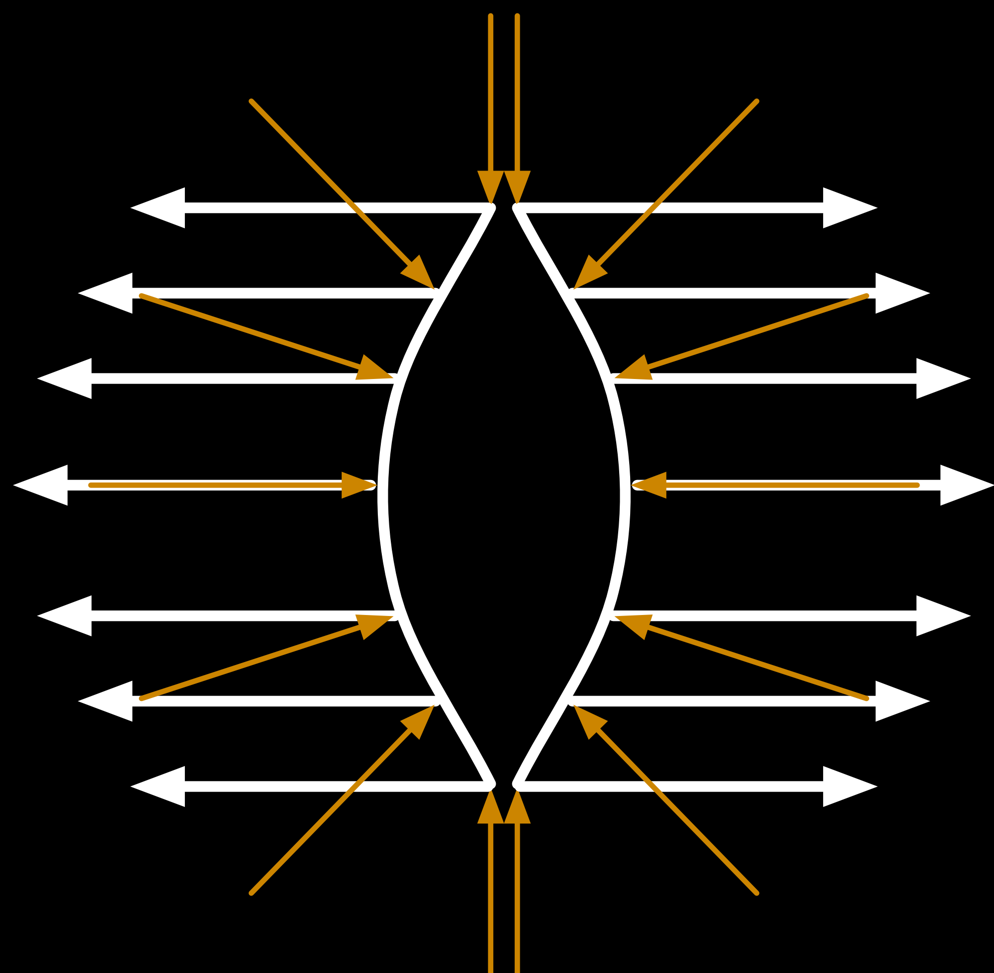
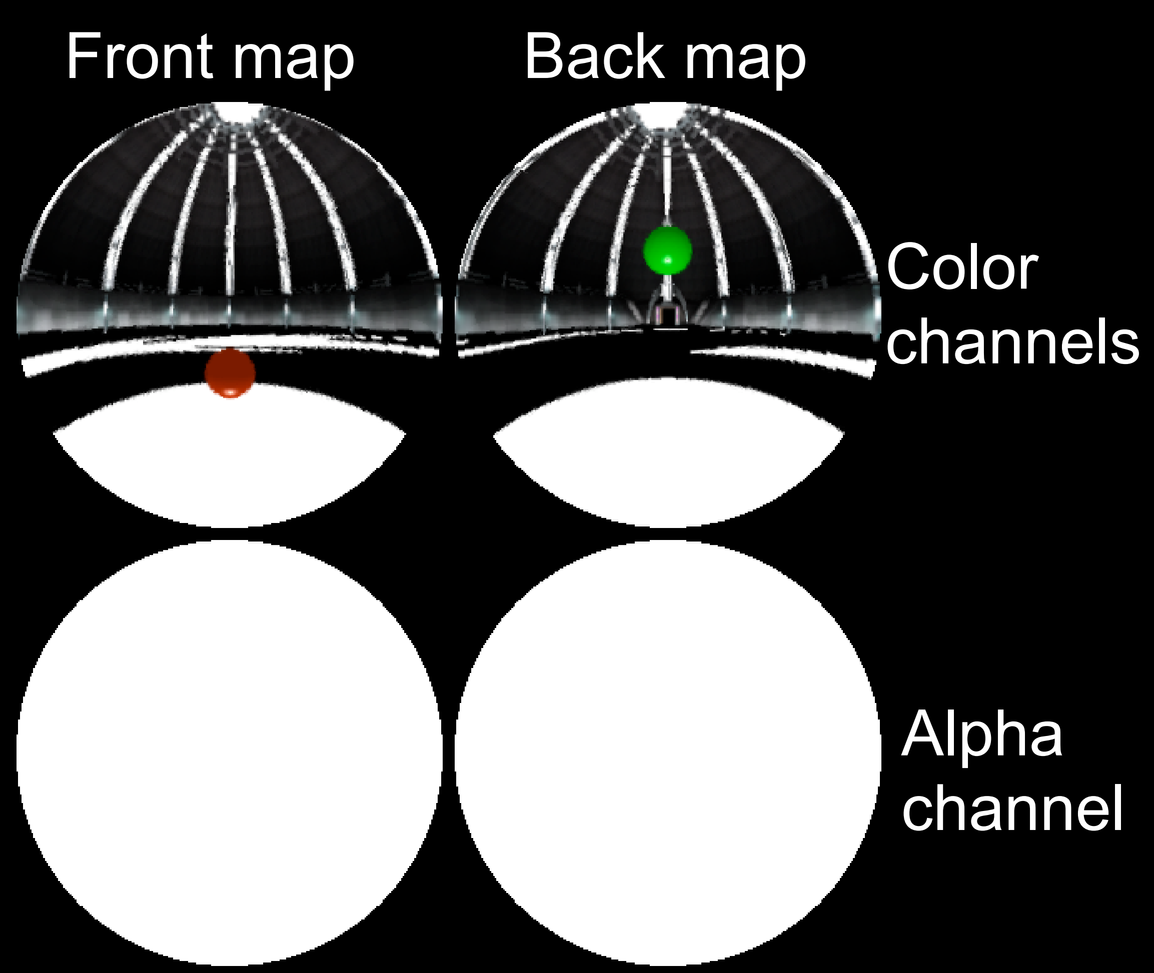
- A set of two textures that store an environment as reflected by a pair of parabolic mirrors





Cubemap to DP Map Conversion

- Convert uv position on DP map face to 3D vector using: (from [Blythe99])

Front face: $$R = \begin{pmatrix} \frac{2u}{u^2+v^2+1} \\ \frac{2v}{u^2+v^2+1} \\ \frac{-1+u^2+v^2}{u^2+v^2+1} \end{pmatrix}$$

Back face: $$R = \begin{pmatrix} \frac{-2u}{u^2+v^2+1} \\ \frac{-2v}{u^2+v^2+1} \\ \frac{1-u^2-v^2}{u^2+v^2+1} \end{pmatrix}$$

- Do the math on the fly or precompute lookup textures:

Front lookup texture

Back lookup texture

Why Bother With DP Mapping?

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- Summed-area table concept does not map well to cubemaps
  - Filtering across face boundaries is problematic
  - Potentially forced to read from all six of the cubemaps faces for large kernels
- Filtering in image space with a dual-paraboloid map incurs less error then cubemaps and spherical maps (ref [Kautz00])

Putting it All Together

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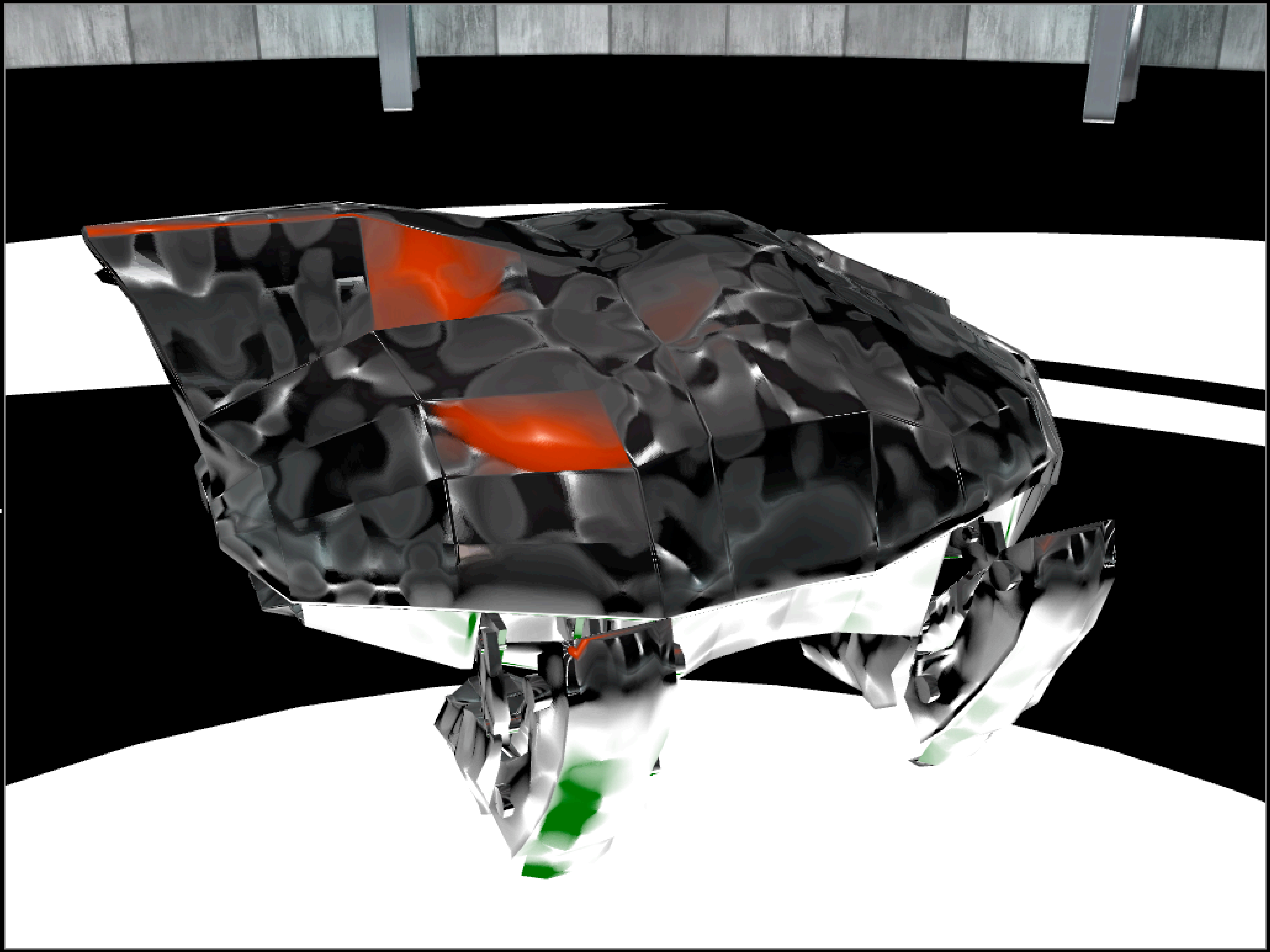
1. Render cubemap
2. Render dual-paraboloid map
3. Generate summed-area tables
4. Render scene with per- pixel glossy reflections



Direct DP Face Rendering

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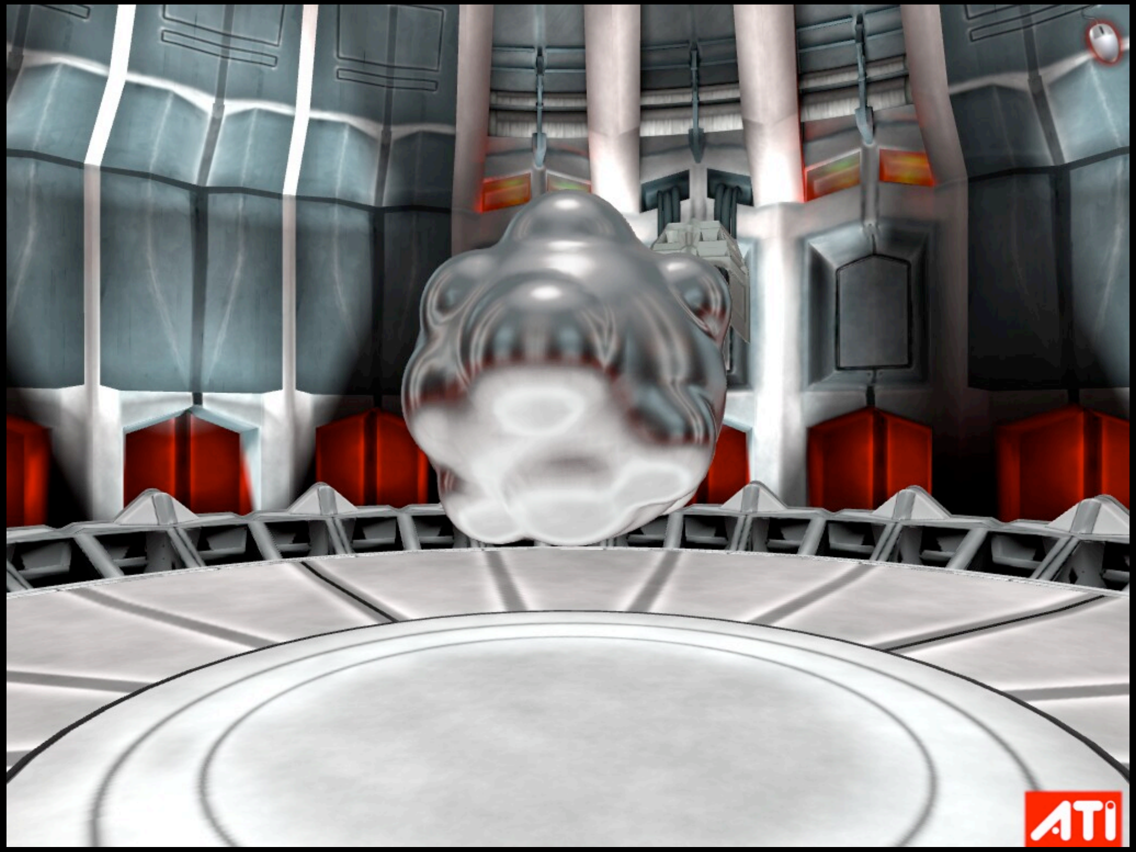
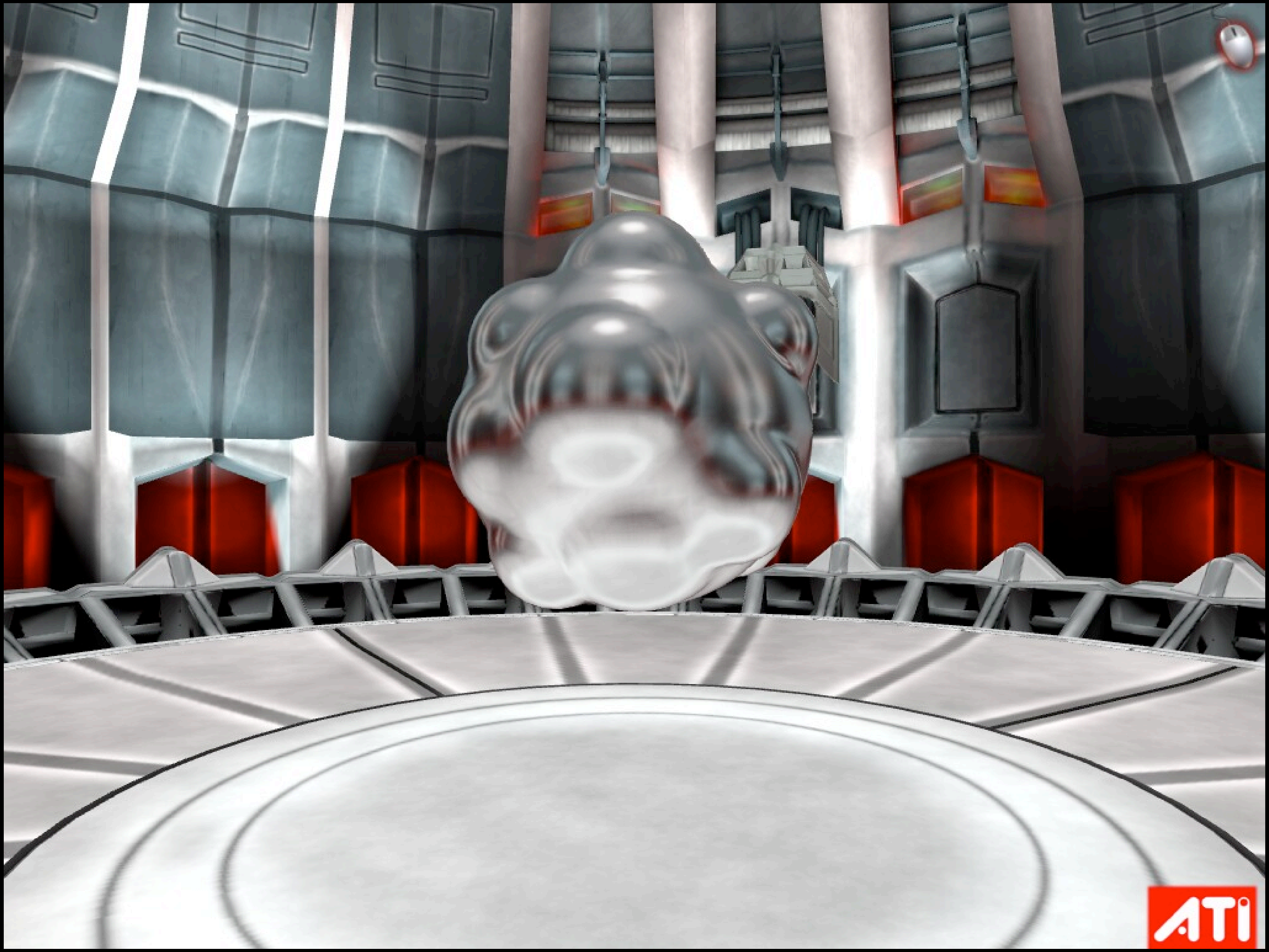
- Alternative to rendering cubemap, then converting to DP map:
  - Transform environment using parabolic projection function and render directly into DP faces
- Unfortunately parabolic projection is non-linear and maps lines to curves
  - Might be acceptable if your geometry is tesselated highly enough
- See [Coombe04] for details

Other Possibilities

- Average several box-filtered environment map samples to approximate smoother blur filter kernels
- Approximate a Phong BRDF by combining samples from the normal direction and the reflection direction



Real-time Demo



Disadvantages of technique

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- Precision requirements for summed-area tables
- Automatic bilinear filtering not supported for float32 textures
  - Not so much of an issue for larger filter kernels
  - Can perform bilinear filtering manually

Conclusion

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- Summed-area tables for constant time filtering of textures
- Efficient summed-area table generation scheme using the GPU
  – Does not require reading from and writing to the same texture
- Use summed-area tables and dual-paraboloid mapping together to achieve dynamic glossy environment reflections

Additional Information

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- Upcoming Eurographics'05 paper
  - Covers additional applications for fast summed-area table generation
- In depth implementation information in upcoming ShaderX4

Acknowledgments

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Questions?

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