Precomputed Dynamic Appearance Synthesis and Rendering

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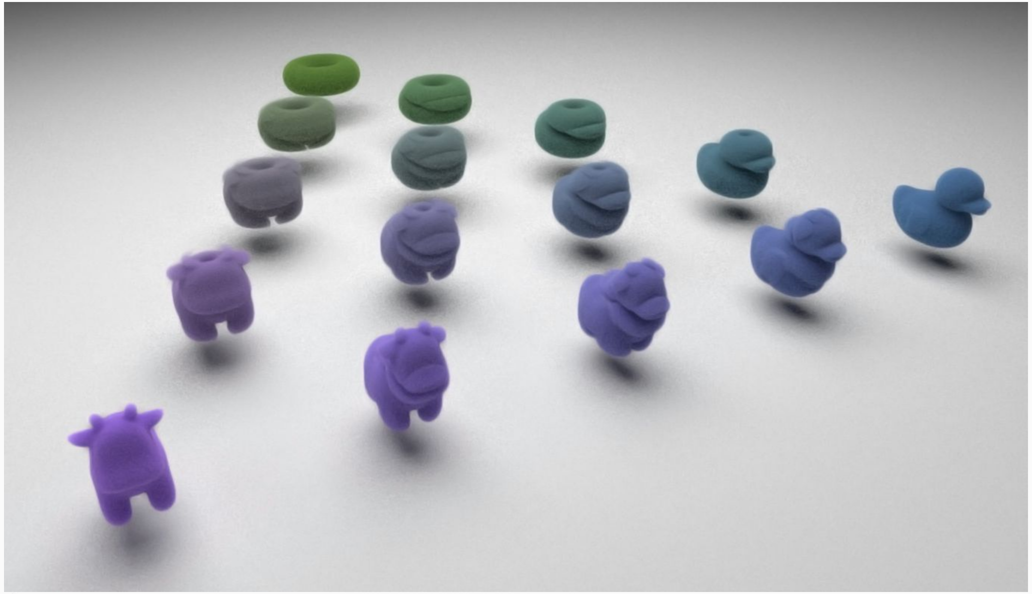
Teasers



Background

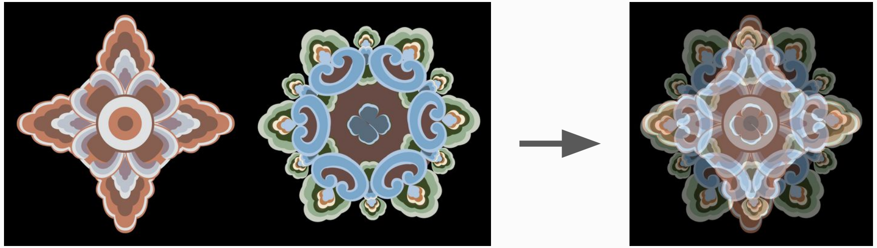
Appearances

Appearance in computer graphics: textures, volumes, BRDFs, etc.

Appearance synthesis: interpolating existing appearances to create additional materials.

Existing issues:

- Ghosting artifact;
- Efficiency;
- Storage.



Motivation & Target

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Our goal:

Integrating a **general**, efficient, and cross-dimensional **natural** appearance blending and rendering solution into traditional renderers.

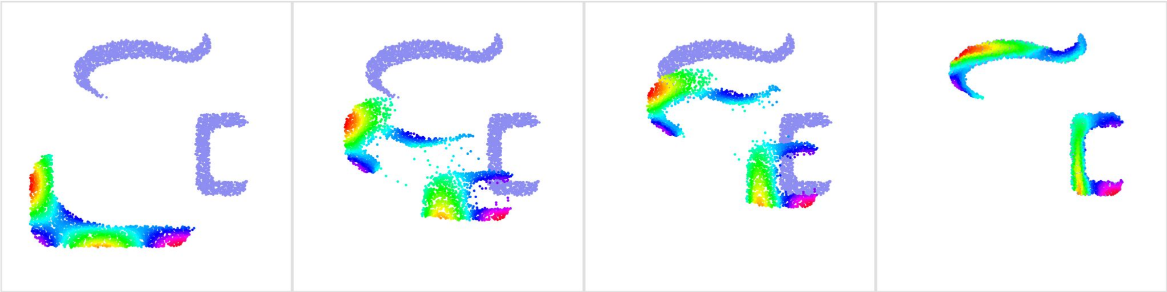
Requirements:

- Natural distribution interpolation;
- High performance;
- Point-sample and/or importance-sample capability;
- No full data reconstruction needed: local query;
- Varying interpolation weights.

Optimal Transport (OT)

Mathematical tool:

- Offers promising solutions for natural interpolation between distributions;
- Provide CLOSEST distances between distributions:
  - minimum sum of moving distance
  - total “weight” conservation
- Discrete or continuous;
- Dimension-agnostic.



OT in Rendering

Existing OT solvers:

- Computationally intensive;
- No existing point query support for OT;
- Rendering integration:
  - Monte Carlo point-sampling structure
  - work with discrete point sets
  - one-to-one mapping

Our Method

Our Method

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Step 1: Precomputation:

- A common proxy distribution;
- Calculate OT between each input and the proxy.

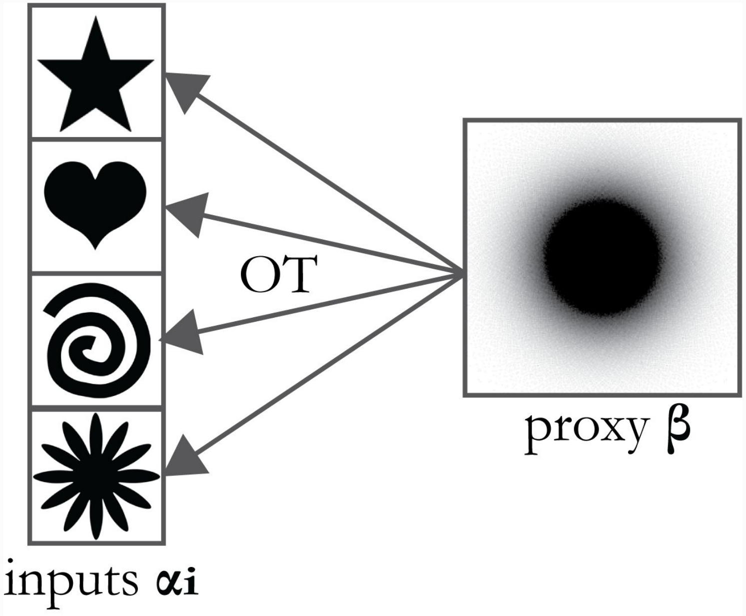
Step 2: Runtime renderer integration:

- Construct hierarchical query structure;
- Point query or range query to quickly find mapping;
- Interpolation based on blending weight.

Step 1: Precomputation

Target:

- From common proxy distribution **β** to different inputs **α**i
  - one-to-one discrete sample mapping

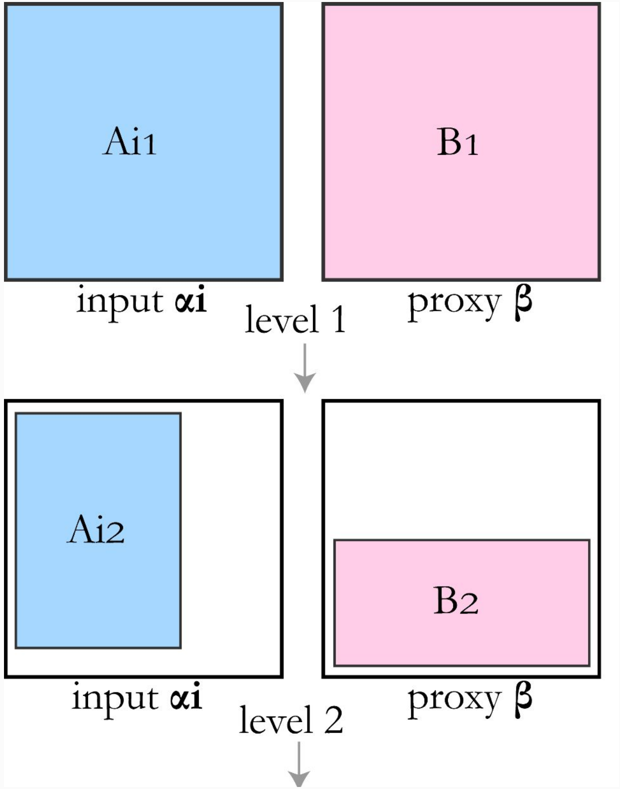


OT solver:

- Geomloss: by Feydy et al.;
- Runs on GPU;
- Discrete one-to-one point mapping.

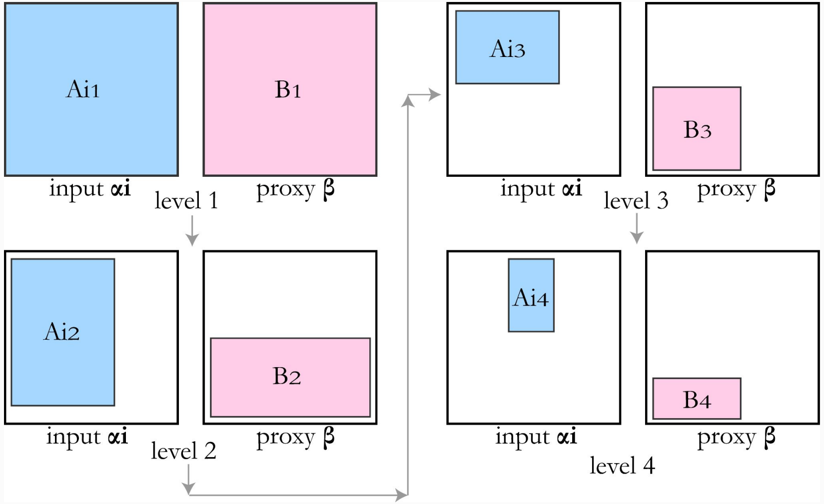
Step 2-1: Hierarchical Query Structure

- Inspired by bounding volume hierarchy (BVH);
- Each level contains:
  - two axis-aligned AABB bounding boxes for samples *Aij* (*j* stands for the *j-th* hierarchical level)
  - all samples in αi (*i* stands for the *i-th* input) and β inside the bounding box
  - two children pointers



Step 2-1: Hierarchical Query Structure

- Level subdivision on **β**:
  - based on the longest Euclidean distance of samples of one dimension
  - divide the proxy bounding box *Bj* in half
  - find mapped samples from input **α**i
  - calculate input bounding box *Aij*



- Subdivision until only one sample;

- Facilitates range queries calculation.

Step 2-1: Hierarchical Query Structure

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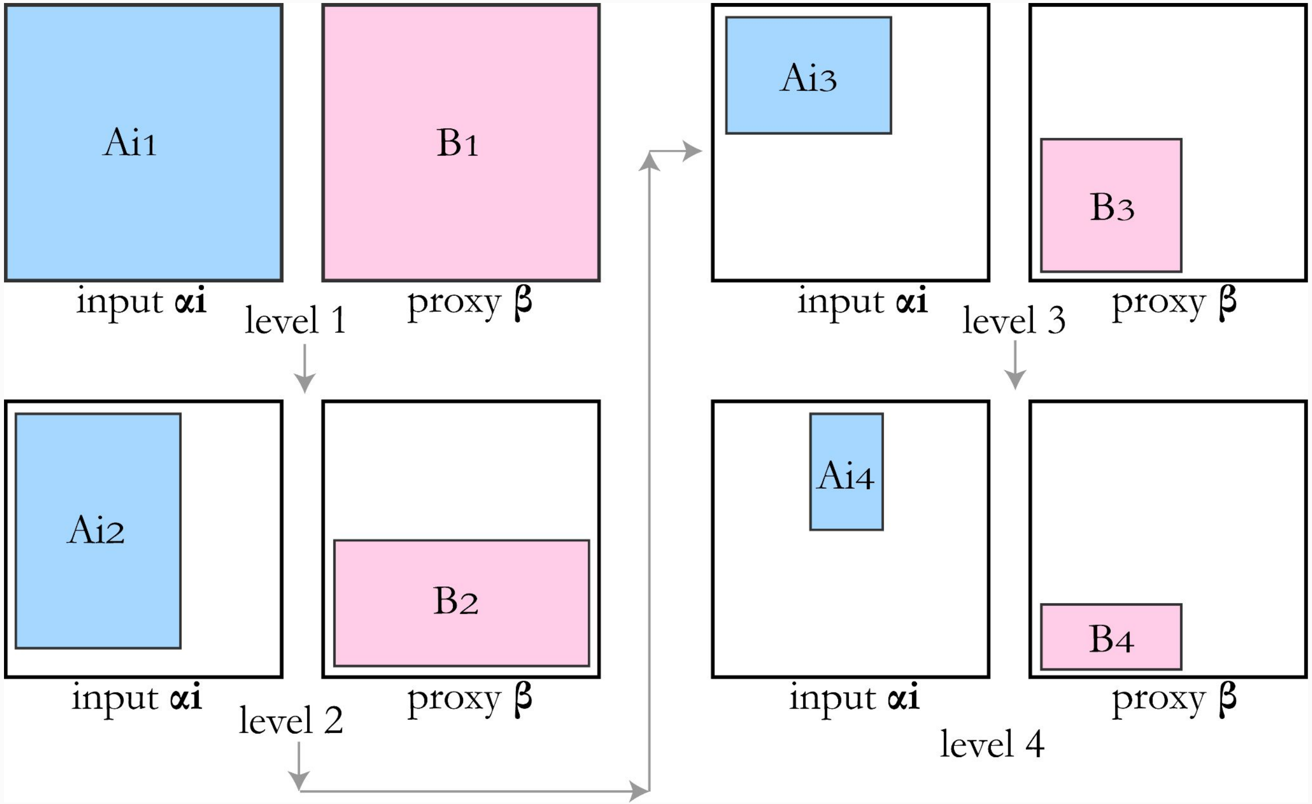
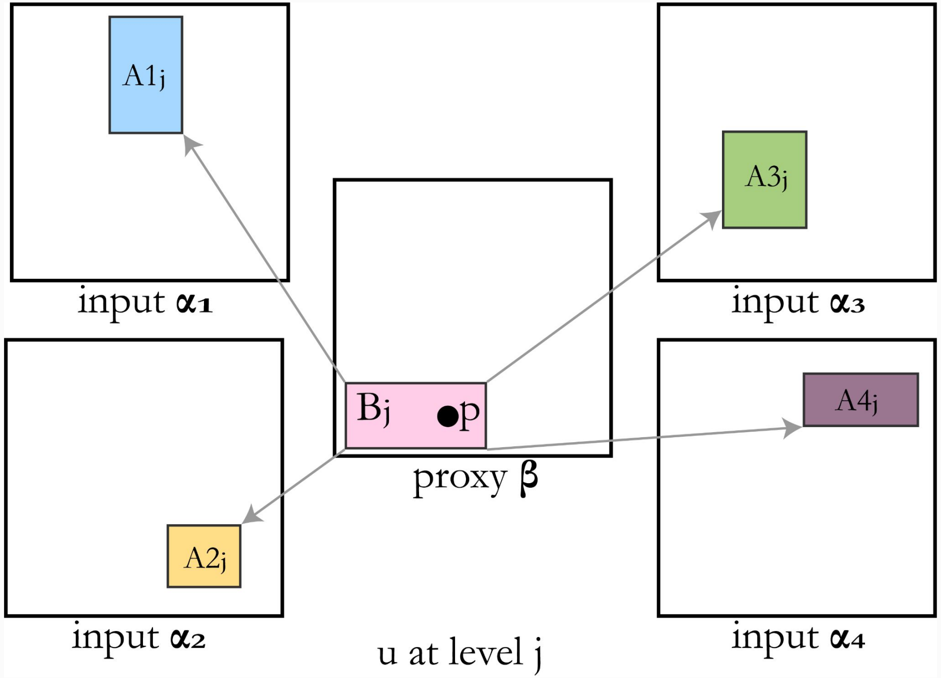


Step 2-2: Runtime Blending

- For a spatial point *p* that takes blending weight *u*:
  - traverse the hierarchical structure
  - find mapped bounding box at level *j*
  - point query: find the leaf nodes and perform blending
  - range query: find the largest covered bounding box and perform blending



Step 2-2: Runtime Blending

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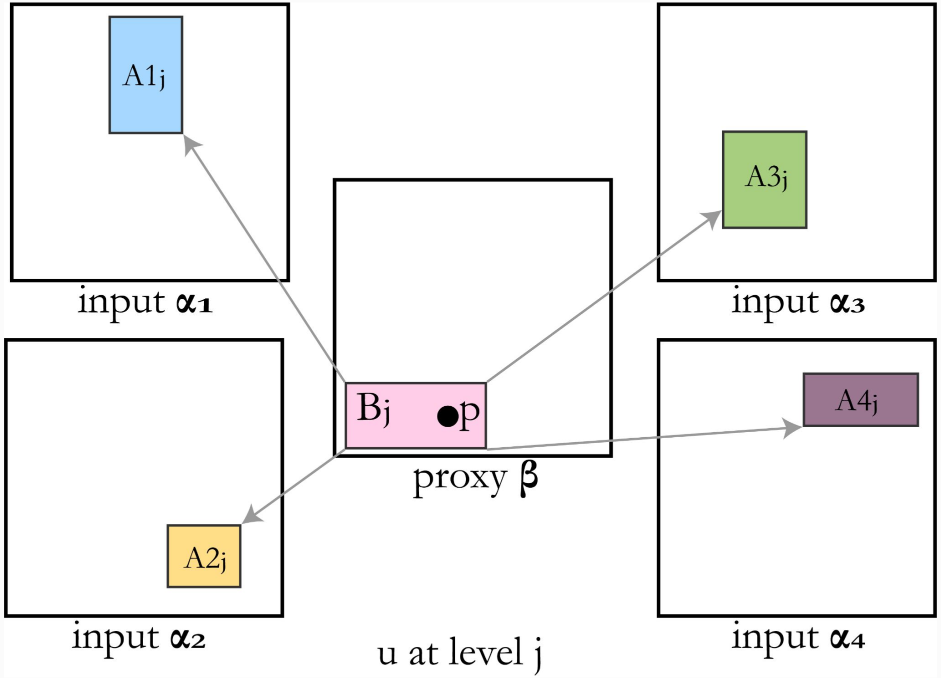
- No limitation on amount of inputs given proper *u*;
- Flexibility to switch inputs;
- Query allows data generation only around the spatial point *p*.



Proxy Selection

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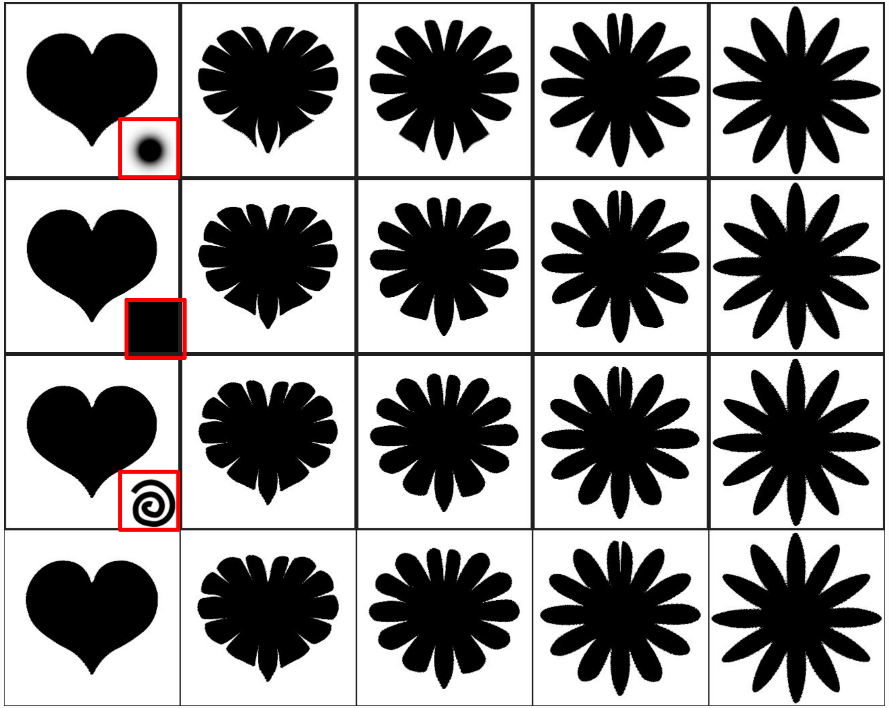
- Different proxies:
  - Gaussian
  - Uniform
  - Spiral
  - No proxy

- The differences in using different proxies or without proxy are minimal.



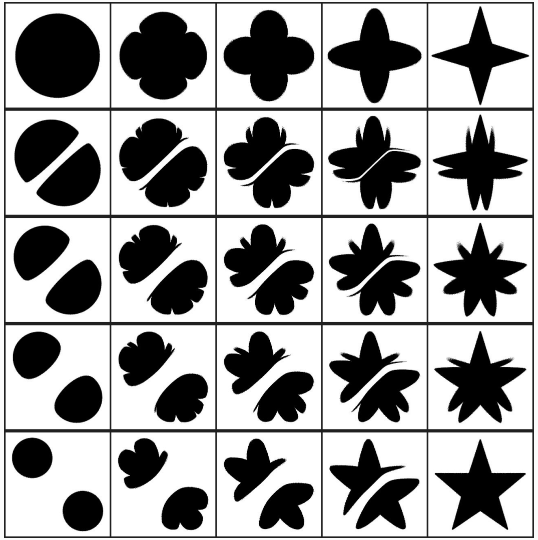
Implementation

- Geomloss OT solver by Feydy et al.:
  - on GPU
  - precomputation only
- Mitsuba renderer:
  - on CPU
  - minimum revision to the renderer
  - revision to the eval() function
- Storage
  - 1 million 2D texture samples with colors: 19 MB
  - 1 million 3D volume samples without color: 11 MB

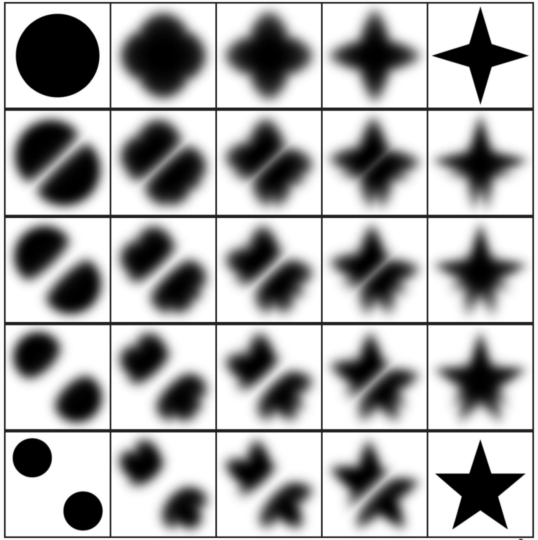
Results & Comparisons

2D Texture Blending

- Comparison with Solomon et al.;
- Less runtime, and sharper results;
- Feydy et al. provides a sharper but different solver.



Ours. Pre.: 834.7s
Query: 7.3s



Convolutional Wasserstein
ϵ = 0.005, 21.2s

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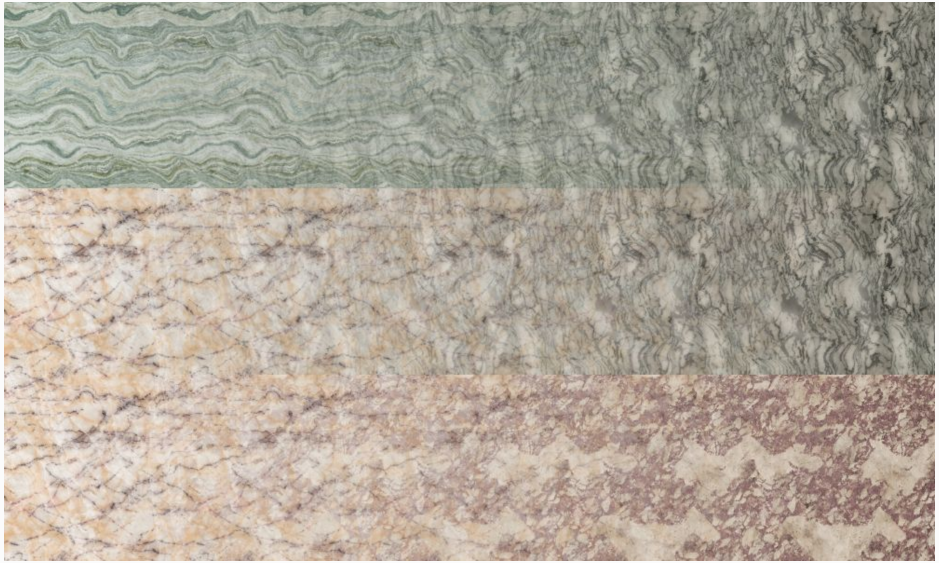
2D Tileable Texture Blending

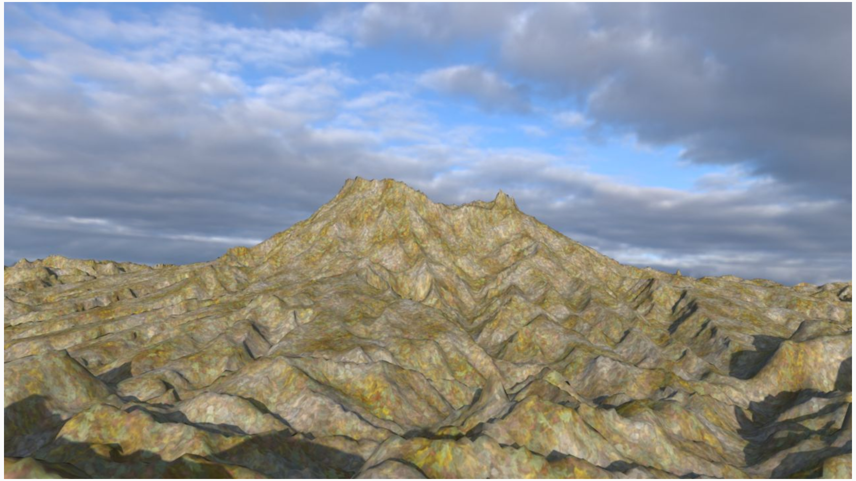
- Inspired by Matusik et al.;
- Textures from Adobe Substance 3D Asset;
- Also included rendering results.

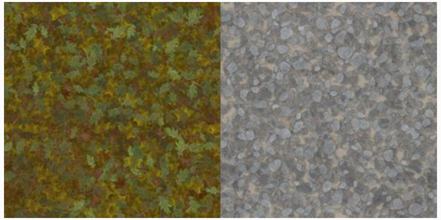


2D Tileable Texture Blending

Tileable Texture Blending with Perlin Noise

- Extension to tileable blending and query structure;
- Perlin noise provide the blending weight;
- Query structure allows focusing on blending a small range of data instead of generating the whole chunk of data;
- Seamlessly and infinitely extendable.





Tileable Texture Blending with Perlin Noise

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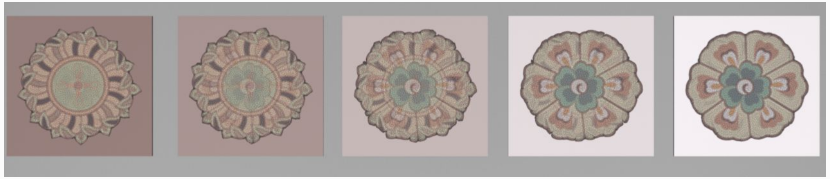
Level-of-Detail (LOD) and Range Query

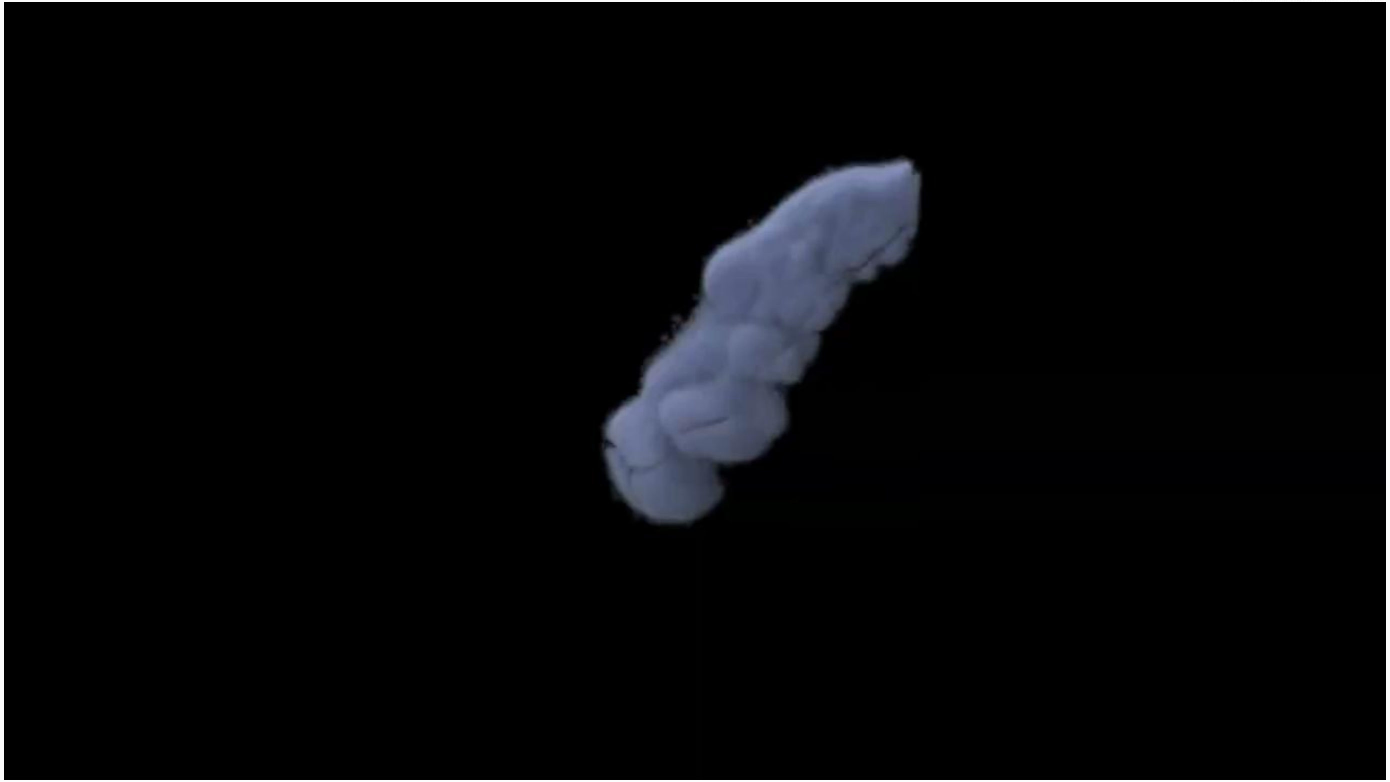
- LOD: detail decreases as the model moves away from the viewer;
- Range query: less traversal, less details, higher efficiency;
- Move the middle three textures away from the camera along the viewing direction.



Closer view
512 spp, time = 33.17 mins

Further view
512 spp, time = 27.51 mins

3D Volume 2-Way Interpolation



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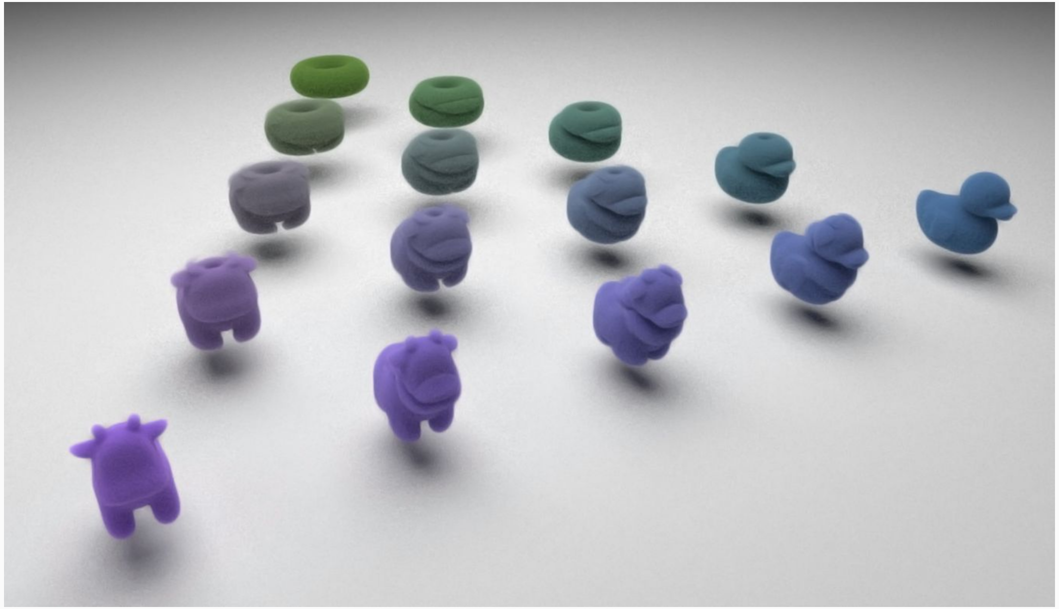
3D Volume 3-Way Interpolation

- 3-way volume blending inspired by Solomon et al.;
- Inputs are on the corners.



BRDF 4-Way Blending

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- Measured BRDF from the MERL database;
- Inputs on the corners, and the blending weight starts at 1.0 for each BRDF on the corner and decreases by 0.2 with each step;
- Blending materials with different roughness, metallic, or Lambertian values.

BRDF 4-Way Blending

Interpolating BRDF

Conclusion & Limitations

Conclusion

A **general**, efficient, and cross-dimensional **natural** appearance synthesis and rendering solution into traditional renderers.

- Precomputation:
  - OT calculate maps between a proxy distribution and each input distributions
- Runtime:
  - hierarchical point or range query structure
  - cross-dimensional multiple-way blending
  - generation of necessary data only

Limitations

- Lack a theoretical analysis about proxy selection;
- Lack a analysis about sample density analysis;
- Require further study of using proxy vs without proxy.

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Thank you so much!