Photon-Driven Manifold Sampling
Fei Lee, Jia-Wun Jhang, Chun-Fa Chang
Context – Caustic Sampling

- Sampling Caustic is hard ... really hard
  - Like playing the lottery
  - Only few or even one direction have contribution
  - So many prior works relied on specially designed techniques like Manifold Walk
Context – Manifold Walk [Jakob and Marschner 2012]

- Originally proposed as a mutation strategy for metropolis light transport.
- Later works find out that we can use manifold walk to find specular path (admissible path)
  - We just need give it a seed path containing a general guess
- And multiple different seed path leads to the same admissible path via manifold walk
  - This behavior is called basin of Convergence.

Taken from Mitsuba Documentation

Taken from Specular Manifold Sampling (Zelner et al. 2020)
Context – Manifold Walk

Manifold Next Event Estimation

Initialize seed path by connecting last vertex to the light

Specular Manifold Sampling

Generalize MNEE through random specular surface sampling

Manifold Next Event Estimation
Hanika et al. 2015

Specular Manifold Sampling
Zelner et al. 2020
Improving Manifold Sampling?

Specular Manifold Sampling
Zelner et al. 2020
Improving Manifold Sampling?

- Specular Manifold Sampling
  - Zelner et al. 2020

- Specular Manifold Bisection Sampling
  - Jhang and Chang 2022

Introduce large jump into manifold walk
Improving Manifold Sampling?

Specular Manifold Sampling
Zelner et al. 2020

Improving Manifold Walk

Specular Manifold Bisection Sampling
Jhang and Chang 2022

Importance Sampling According to Basin of Convergence
Improving Manifold Sampling?

Specular Manifold Sampling
Zelner et al. 2020

Improving Manifold Walk

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Jhang and Chang 2022

Importance Sampling According to Basin of Convergence

Manifold Path Guiding
Fen et al. 2023

Guide seed path direction using learned distribution

Admissible Path
Seed Path
Training Sample
Improving Manifold Sampling?

Specular Manifold Sampling
Zelner et al. 2020

Improving Manifold Walk

Importance Sampling According to Basin of Convergence

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Jhang and Chang 2022

Admissible Path

Manifold Path Guiding
Fen et al. 2023

Spatiotemporal Admissible Path Reuse
Xu et al. 2023

Reuse neighboring pixels' admissible path as seed path
Improving Manifold Sampling?

Specular Manifold Sampling  
Zelner et al. 2020

Specular Manifold Bisection Sampling  
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Improving Manifold Walk

Importance Sampling According to Basin of Convergence

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Neural Path Sampling  
Yu et al. 2024

*Predict seed path direction through neural network*
Improving Manifold Sampling?

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Photon-Driven Manifold Sampling

Specular Manifold Bisection Sampling
Jhang and Chang 2022

Improving Manifold Walk
Key Observations

• Lack of bidirectional information
  • All method start from the shading point
Key Observations

Specular Manifold Sampling
Zeltner et al. 2020

Randomly sample specular vertex as seed path
Key Observations

Seed Path

Admissible Path

Training Sample

Manifold Path Guiding
Fen et al. 2023

Guide seed path direction using learned distribution
Key Observations

Admissible Path

Seed Path

Other pixel's admissible path

Spatiotemporal Admissible Path Reuse
Xu et al. 2023

Reuse neighboring pixels admissible path as seed path
Key Observations

Admissible Path

Seed Path

Neural Path Sampling
Yu et al. 2024

Predict seed path direction through neural network
Key Observations

• Lack of bidirectional information

So, we use photons as our source of bidirectional information
Key Observations

- Lack of bidirectional information
- Similarity in neighboring area
Key Observations

• Lack of bidirectional information
• Similarity in neighboring area  This give us reason to use nearby photon’s information
Key Observations

• Lack of bidirectional information
• Similarity in neighboring area
• More random sampling leads to variance

Where is incoming light?
How many bounce?
What specular interaction?
Key Observations

- Lack of bidirectional information
- Similarity in neighboring area
- More random sampling leads to variance

So … we reuse everything
Key Observations

- Lack of bidirectional information
- Similarity in neighboring area
- More random sampling leads to variance
Algorithm Details

• Our method use a two pass approach.

Photon Pass

Eye Pass

Admissive path
Photon Pass

- In this pass we only want to collect caustic photons.
- So we sample first vertex directly on specular surface
Algorithm Details

• Our method use a two pass approach.
Eye Pass – Photon Selection

- Now we have a shading point, how do we select photons?
Eye Pass – Photon Selection

• Generally closer the better... but that’s not always the case
Eye Pass – Photon Selection

- Generally closer the better... but that’s not always the case
Eye Pass – Photon Selection

- So we employ a simple algorithm (linear search with update prob)

```plaintext
Algorithm 1 Photon selection process

given a photon population \( \{P_0, P_1, ..., P_k\} \), and a shading point \( x_D \)

\[
\text{photonIndex} \leftarrow \text{random}(0, k) \\
\text{photonDistance} \leftarrow \infty \\
\text{for } i \leftarrow 0 \text{ to } k \text{ do} \\
\quad d = ||P_i - x_D||^2 \\
\quad \text{if } d < \text{photonDistance} \text{ and } \text{rand()} < u \text{ then} \\
\quad\quad \text{photonIndex} \leftarrow i \\
\quad\quad \text{photonDistance} \leftarrow d \\
\quad \text{end if} \\
\text{end for} \\
\text{return photonIndex}
```
Eye Pass – Photon Selection

• So we employ a simple algorithm (linear search with update prob)
Eye Pass – Photon Reuse

- After selecting a photon, we reuse all its stored information to form our seed path.
Eye Pass – Photon Reuse

• After selecting a photon, we reuse all its store information to form our seed path.
  • We just reuse all the specular vertices in between.
Eye Pass – Photon Reuse

- After selecting a photon, we reuse all its stored information to form our seed path.
  - We just reuse all the specular vertices in between.
  - Also replace the old light vertex
Eye Pass – Photon Reuse

- After selecting a photon, we reuse all its stored information to form our seed path.
  - We just reuse all the specular vertices in between.
  - Also replace the old light vertex
Eye Pass – Photon Reuse

• Why replace the old light vertex?

Without light substitution

With light substitution
Eye Pass – Photon Reuse

• Why replace the old light vertex?
Eye Pass – Perturbation Cone

- Another problem...

We might miss some path here
Eye Pass – Perturbation Cone

- We also introduce a small perturbation to the photon path if needed
- Especially useful in low photon count

\[ x_0 \rightarrow s_i \rightarrow x_L \]
Eye Pass – Perturbation Cone

• We also introduce a small perturbation to the photon path if needed
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Eye Pass – Perturbation Cone

- We also introduce a small perturbation to the photon path if needed
- Especially useful in low photon count
• We also introduce a small perturbation to the photon path if needed
• Especially useful in low photon count
Eye Pass – Perturbation Cone

- smaller $\theta$ is more suitable for higher photon count, lower photon count require a wider cone.
- The wider the cone, the higher the variance
Eye Pass

• After all that, our seed path is ready for manifold walk process
  • Feed into manifold walk to find admissible path
  • Evaluate admissible path pdf with Bernoulli trial
  • Calculate final contribution
Let’s see some results
Results

<table>
<thead>
<tr>
<th>THREE SLABS</th>
<th>SPP</th>
<th>MPG</th>
<th>Ours</th>
<th>Reference</th>
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<tbody>
<tr>
<td></td>
<td>3</td>
<td>3+6</td>
<td>9</td>
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<tr>
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<td>0.080</td>
<td>0.029</td>
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</tbody>
</table>

National Taiwan Normal University
Results

**GLASS SHOES**

2 min

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<thead>
<tr>
<th></th>
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</tr>
</thead>
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<tr>
<td>MSE</td>
<td>0.137</td>
<td>0.039</td>
<td>0.025</td>
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</table>
### Results

<table>
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<tr>
<th>SMBS</th>
<th>MPG</th>
<th>Ours</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPP: 19</td>
<td>7+21</td>
<td>18</td>
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<tr>
<td>MSE: 0.113</td>
<td>0.147</td>
<td>0.121</td>
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</tr>
</tbody>
</table>

**SWIMMING POOL**

2 min
Results

THREE SLABS 2nd

PPM | PM | Ours | Reference

Photon Count: 96M | 10000 | 10000 |
Future Works

• Reciprocal probability estimation
• Photon Distribution
  • How to optimally distribute photon to important area?
• Photon Selection
  • How to select photon more efficiently?
• Guide and Reuse
  • Perturbation cone can be see as a form of guiding
  • Then can we mix both method together adaptively?
Conclusion

• We introduce an effective and unbiased method for multi-bounce caustic sampling, by introducing a bidirectional seed path sampling strategy.
• An efficient way to sample caustic photons.
• A photon reuse scheme for manifold walk process.
Thank you for listening!

Feel free to contact me via email!
Email: leefamily.dennys@gmail.com
I am actively seeking PhD opportunities :)}