Path Tracing
Path Tracing

\[ L \approx \frac{1}{n} \sum_{i=1}^{n} \]

Number of samples, n=1 in q2vkpt
Main challenges

- Better Sampling $\rightarrow$ less noise
- Denoising
Q2VKPT

- Research prototype to evaluate current state of real-time path tracing
- Open source https://github.com/cschied/q2vkpt
- Entirely raytraced
- Real-time path tracing (one indirect bounce)
- C99, Vulkan, GLSL, RTX
https://www.youtube.com/watch?v=vrq1T93uLag
Denoising
Path tracer output (1spp)
Denoising (A-SVGF)

Figure 1: Our filter takes (left) 1 sample per pixel path-traced input and (center) reconstructs a temporally stable 1920x1080 image in just 10 ms. Compare to (right) a 2080 samples per pixel path-traced reference. Insets compare our input, our filtered results, and a reference on two regimes, and show the impact filtered global illumination has over just direct illumination. Given the noisy input, notice the similarity to the reference for glossy reflections, global illumination, and direct soft shadows.
Denoising (A-SVGF)

Spatiotemporal Variance-Guided Filtering: Real-Time Reconstruction for Path-Traced Global Illumination

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Figure 1: Our filter takes (left) 1 sample per pixel path-traced input and (center) reconstructs a temporally stable 1920x1080 image in just 10 ms. Compare to (right) a 2048 samples per pixel path-traced reference. Insets compare our input, our filtered result, and a reference on two regimes, and show the impact filtered global illumination has over just direct illumination. Given the noisy input, notice the similarity to the reference for glossy reflections, global illumination, and direct soft shadows.

Gradient Estimation for Real-Time Adaptive Temporal Filtering

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Fig. 1. Results of our novel spatio-temporal reconstruction filter (A-SVCF) for path tracing at one sample per pixel (cyan inset in frame 410) with a resolution of 1280x720. The animation includes a moving camera and a flickering, blue area light. Previous work (SVCF [Schied et al. 2017]) introduces temporal blur such that lighting is still present when the light source is off and glossy highlights leave a trail (magenta box in frame 412). Our temporal filter estimates and reconstructs sparse temporal gradients and uses them to adapt the temporal accumulation factor α per pixel. For example, the regions lit by the flickering blue light have a large α in frames 406 and 412 where the light has been turned on or off. Glossy highlights also receive a large α due to the camera movement. Overall, stale history information is rejected reliably.
Main concepts of SVGF

Analyze input over time
• Temporally unstable → blur more
• Temporally stable → blur less

Filter hierarchically, starting small
• Estimate temporal stability after each filter iteration
→ Strong blur more likely in early iterations
SVGF

Path Tracer → Remove Textures → Denoising Filter → Reapply Textures → Temporal Antialiasing

- Temporal Accumulation
- Variance Estimation
- À-trous wavelet filter
Edge-avoiding À-trous Wavelets

\[ \hat{c}_{i+1}(p) = \frac{\sum_{q \in \Omega} h(q) \cdot w(p, q) \cdot \hat{c}_i(q)}{\sum_{q \in \Omega} h(q) \cdot w(p, q)} \]

In q2vkpt:
• 3x3 box kernel
• 5 iterations
https://www.youtube.com/watch?v=Fv-jStEsCpE&t=48s
Gradient Estimation for Real-Time Adaptive Temporal Filtering

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Fig. 1. Results of our novel spatio-temporal reconstruction filter (SVGF) for path tracing at one sample per pixel (cyan inset in frame 400) with a resolution of 1280x720. The animation includes a moving camera and a flickering, blue area light. Previous work (SVGF) [Schied et al. 2017] introduces temporal blur such that lighting is still present when the light source is off and glossy highlights leave a trail (magenta box in frame 412). Our temporal filter estimates and reconstructs sparse temporal gradients and uses them to adapt the temporal accumulation factor \( \alpha \) per pixel. For example, the region lit by the flickering blue light has a large \( \alpha \) in frames 400 and 412 where the light has been turned on or off. Glossy highlights also receive a large \( \alpha \) due to the camera movement. Overall, stale history information is rejected reliably.

Temporal Accumulation

Variance Estimation

Ä-trous wavelet filter

Reconstruction Filter

Reapply Textures

Temporal Antialiasing

SVGF
Denoising (A-SVGF)

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Fig. 1. Results of our novel spatio-temporal reconstruction filter (A-SVGF) for path tracing at one sample per pixel (cyan inset in frame 412) with a resolution of 1280×720. The animation includes a moving camera and a flickering, blue area light. Previous work (SVGF) [Schied et al., 2017] introduces temporal blur such that lighting is still present when the light source is off and glossy highlights leave a trail (magenta box in frame 412). Our temporal filter estimates and reconstructs sparse temporal gradients and uses them to adapt the temporal accumulation factor α per pixel. For example, the region lit by the flickering blue light have a large α in frames 404 and 412 where the light has been turned on or off. Glossy highlights also receive a large α due to the camera movement. Overall, stale history information is rejected reliably.
Screen-space Reprojection

\[
\hat{c}_i(x) = \alpha \cdot c_i(x) + (1 - \alpha) \cdot \hat{c}_{i-1}(\vec{x})
\]
Adaptive Temporal Filtering

\[ \hat{c}_i(x) = \alpha \cdot c_i(x) + (1 - \alpha) \cdot \hat{c}_{i-1}(x) \]

• Set \( \alpha \) according to changes of the shading function
  • Moving shadows, glossy highlights, flickering light sources, ...

• Make \( \alpha \) per-pixel weight for local adaptivity

• Need information about changes of shading (temporal gradient)
Path tracer output
1 sample per pixel
Difference of luminance
green positive
red negative
Path tracer output
1 sample per pixel
Difference of luminance
green positive
red negative
Path tracer output
1 sample per pixel
(correlated samples)
Difference of luminance (correlated samples)
green positive
red negative
Adaptive temporal filter weight

- Sample and reconstruct temporal gradient
- Change $\alpha$ according to relative rate of change
https://www.youtube.com/watch?v=HP4Xwp0ETfc
Treat each triangle of light meshes as individual area light
Light selection / sampling

Tried:

• Light hierarchy

Issues:

• Speed
• Inconsistent quality under animation
Light selection / sampling for static lights

Mesh

Potentially visible lights

Simplified BRDF and projected solid angle

CDF

Stochasticly selected subset
Light selection / sampling for **dynamic lights**

No culling

All dynamic lights

Simplified BRDF and projected solid angle

Stochastically selected subset

CDF
Light selection

Static light

Dynamic light

Sample by contribution
Path tracer

- One path per pixel
- One indirect bounce
- Two shadow rays

No special treatment for mirrors/glass
Mirror reflection
- No transmission
- Demodulate indirect albedo
- Fixed lower mip-level for texture sampling

No explicit Environment Map sampling
- Use indirect bounce
- No illumination for indirect bounce (missing raycast)

Constant Blinn-Phong BRDF for everything
Sampling Pattern

Blue noise dither mask
Blue noise

blurred

Source: http://momentsingraphics.de/?p=127
Magnitude of Fourier Transform

White noise

Blue noise

Residual noise

Removed by lowpass filter

Source: http://momentsingraphics.de/?p=127
Acceleration structures

- Top-Level
  - Bottom-Level Static geometry: Built once on map-load
  - Bottom-Level Dynamic geometry: Rebuilt from scratch per frame
Forward / Backward projection

• Required for Adaptive Temporal Filtering

• Visibility buffer for forward projection

• Map instances between frames
Conclusion

• Real-time path tracing is possible (in the near future)

• Transition difficult
  • Random access to everything
  • Tweaking of assets

• Need more research specifically tailored towards real-time rendering
  • Fast and robust importance sampling
  • Denoising
Thanks!

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Stephan Bergmann
Tobias Zirr

NVIDIA
id Software

Q2VKPT uses a texture addon collected by Tosher including original work by D Scott Boyce (@scobotech), released under Creative Commons Attribution-NonCommercial-ShareAlike 2.0

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