Real-Time Path Tracing and Denoising in *Quake II*

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OUTLINE

Part I: Q2VKPT
- Path Tracing Overview
- Denoising with A-SVGF
- Sampling

Part II: Quake II RTX
- Improvement Process
- Final Renderer Overview
q2vkpt
Quake 2
Vulkan
Path Tracer

http://brechpunkt.de/q2vkpt

Christoph Schied
@c_schied
Path Tracing
Path Tracing

Number of samples, \( n=1 \) in q2vkpt

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

- Better Sampling → 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
<table>
<thead>
<tr>
<th>Category</th>
<th>Time (ms)</th>
</tr>
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<tbody>
<tr>
<td>Frame time</td>
<td>15.24</td>
</tr>
<tr>
<td>Instance geometry</td>
<td>0.02</td>
</tr>
<tr>
<td>BVH update</td>
<td>0.52</td>
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<tr>
<td>ASVGf gradient samples</td>
<td>0.28</td>
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<tr>
<td>Path tracer</td>
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<tr>
<td>ASVGf full</td>
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<tr>
<td>ASVGf reconstruct gradient</td>
<td>0.27</td>
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<tr>
<td>ASVGf temporal</td>
<td>0.68</td>
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<td>ASVGf atrous</td>
<td>2.16</td>
</tr>
<tr>
<td>ASVGf TAA</td>
<td>0.32</td>
</tr>
</tbody>
</table>

Resolution: 2560x1440, RTX2080 Ti
Denoising
Denoising (A-SVGF)

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

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**Gradient Estimation for Real-Time Adaptive Temporal Filtering**

CHRISTOPH SCHIED, CHRISTOPH PETERS, and CARSTEN DACHSBACHER, Karlsruhe Institute of Technology, Germany

Fig. 1. Results of our novel spatio-temporal reconstruction filter (A-SVGF) for path tracing at one sample per pixel (cyan inset in frame 404) 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 $\alpha$ per pixel. For example, the regions lit by the flickering blue light have a large $\alpha$ in frames 406 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.
Denoising (A-SVGF)

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Figure 1: Our filter takes (left) 1 sample per pixel path-traced input and (center) reconstructs a temporally stable 1520×1080 image in just 10 ms. Compare to (right) a 2000 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.

Gradient Estimation for Real-Time Adaptive Temporal Filtering

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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 404) 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 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 $\rightarrow$ blur more
  • Temporally stable $\rightarrow$ blur less

Filter hierarchically, starting small
  • Estimate temporal stability after each filter iteration
  $\rightarrow$ 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
One sample per pixel (input)
SVGF

Fig. 1. Results of our novel spatio-temporal reconstruction filter (A-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] [Scheid 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 $a$ per pixel. For example, the regions lit by the flickering blue light have a large $a$ in frames 400 and 412 where the light has been turned on or off. Glossy highlights also receive a large $a$ due to the camera movement. Overall, stale history information is rejected reliably.
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 410) 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 $\alpha$ per pixel. For example, the regions lit by the flickering blue light have a large $\alpha$ in frames 406 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.
Screen-space Reprojection

\[ \hat{c}_i(x) = \alpha \cdot c_i(x) + (1 - \alpha) \cdot \hat{c}_{i-1}(\hat{x}) \]
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
Video in quake with gradients?
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

Stochastically selected subset
Light selection / sampling for dynamic lights

No culling

CDF

Simplified BRDF and projected solid angle

All dynamic lights

Stochastically selected subset
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
No explicit Environment Map sampling
• Use indirect bounce
• No illumination for indirect bounce (missing raycast)

Constant Blinn-Phong BRDF for everything

Mirror reflection
• No transmission
• Demodulate indirect albedo
• Fixed lower mip-level for texture sampling
Sampling Pattern

Blue noise dither mask
White noise

blur

Source: http://momentsinographics.de/?p=127
Blue noise

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

White noise

Removed by lowpass filter

Residual noise

Blue noise

Removed by lowpass filter

Residual noise

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

- Top-Level
- Bottom-Level
  - Static geometry: Built once on map-load
  - 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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Christoph Peters
Florian Reibold
Johannes Hanika
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

http://brechpunkt.de/q2vkpt
https://github.com/cschied/q2vkpt
schied@brechpunkt.de
@c_schied
Quake II RTX
Alexey Panteleev
Original Q2VKPT Image
Textures from Quake 2

- Skylight is too dim
- Inconsistent reflections
- Doesn’t blend in
- Very dark shadows
Fixing the Sky

- Desaturate the env-map
- Increase skylight intensity
- Not so dark now!
- Shadows are missing :(
Environment Noise

Original environment map

Bright environment map
Environment Noise
Textures and Tone Mapping

- Smoother, more natural ambient
- Separate emissive parts
- Fixed texture color space
Add Sunlight and Denoiser Channels

- Sunlight brings back contrast
- Adds visible diffuse GI
- Denoiser channels bring back shadows
- Sunlight brings back contrast
Materials

- Metallic and roughness maps
- Emissive maps
- Normal maps
Environment

- Procedural environment map
- Volumetric lighting
- HDR sky dome lighting
- Natural sunlight color
Path Tracer Output
Direct Diffuse
Direct Diffuse (Denoised)
Indirect Diffuse
Indirect Diffuse (Denoised with SH)
Indirect Specular
Indirect Specular (Denoised)
Irradiance Channels Combined
Quake II RTX Rendering Pipeline

- Path Tracer
  - Primary Rays
  - G-buffer
  - Indirect Diffuse
  - Direct Diffuse
  - Specular
  - Sp-Temp Filter
  - + Spherical Harmonics
  - A-SVGF
  - Temporal Filter
  - Composition

- Q2VKPT

- Transparent / Emissive

- GodRays
  - TAA
  - FLOW
  - Bloom
  - Tone Mapper
Path Tracer Overview

1. Primary
Path Tracer Overview

1. Primary
2. Reflection...
Path Tracer Overview

1. Primary
2. Reflection or refraction
Path Tracer Overview

1. Primary
2. Reflection or refraction
3. Direct sun shadow
Path Tracer Overview

1. Primary
2. Reflection or refraction
3. Direct sun shadow
4. Direct diffuse light shadow
Path Tracer Overview

1. Primary
2. Reflection or refraction
3. Direct sun shadow
4. Direct diffuse light shadow
5. Bounce (diffuse or specular)
Path Tracer Overview

1. Primary
2. Reflection or refraction
3. Direct sun shadow
4. Direct diffuse light shadow
5. Bounce (diffuse or specular)
6. Indirect sun shadow
Path Tracer Overview

1. Primary
2. Reflection or refraction
3. Direct sun shadow
4. Direct diffuse light shadow
5. Bounce (diffuse or specular)
6. Indirect sun shadow
7. Indirect diffuse light (no shadow)
Development Team

- Q2VKPT to keynote version: 6 weeks (Feb-Mar 2019)
- A group of passionate engineers and artists:

  Adam Moss  Gavriil Klimov  Liam Middlebrook
  Alex Dunn  Gregor Kopka  Manuel Kraemer
  Alexey Panteleev  Grigoriy Odegov  Matthew Rusch
  Andrew Reidmeyer  Ivan Fedorov  Matthijs De Smedt
  Dane Johnston  James Jones  Nuno Subtil
  Eric Werness  Johnny Costello  Oleg Arutyunyan
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  • Arthur “Turic” Galactionov for the weapon models
  • D Scott Boyce for some of the textures
  • Potentially others whose assets found their way into Quake II RTX through a chain of mods

• We’d also like to thank id Software for the original Quake II
QUESTIONS
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