Perception-Guided Global Illumination Solution for Animation Rendering

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Motivation

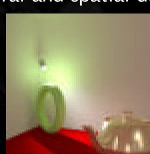
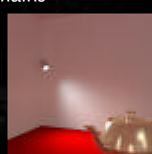
In the traditional approach to rendering of high quality animation sequences every frame is considered separately.

- The temporal coherence is poorly exploited:
  - redundant computations.
- The visual sensitivity to temporal detail cannot be properly accounted for:
  - too conservative stopping conditions,
  - temporal aliasing.

Focus

Indirect lighting in animated sequences

- Quite costly to compute
- Usually changes slowly and smoothly both in the temporal and spatial domains

Goal

Improve the performance of rendering and enhance the visual quality of resulting animations by:

- Better exploiting both the spatial and temporal coherence of indirect lighting.
- Applying perception-motivated stopping conditions to steer the computation.

Assumptions

- Dynamic environments
- Predefined animation paths for all objects and camera

Overview

- Previous work
- Indirect lighting solution
  - General framework
  - Spatio-temporal photon processing
  - Animation Quality Metric
- Results
- Conclusions

Previous work: global illumination for dynamic environments (1)

Interactivity

- Progressive radiosity:
  - Chen’90, George et al. ’90, Müller et al. ’95
- Hierarchical radiosity:
  - Pueyo et al. ’97, Drettakis and Sillion ’97, Schöffel and Pomi ’99
- Instant radiosity:
  - Keller ’97

Previous work: global illumination for dynamic environments (2)

High-quality animation rendering

- Early radiosity:
  - Baum et al. ’86
- Space-time hierarchical radiosity:
  - Damez et al. ’99, Martin et al. to appear in IEEE TVCG
- Global Monte Carlo radiosity:
  - Besuievsky and Sbert to appear in JCAV
- Range-image framework:
  - Nimeroff et al. ’96

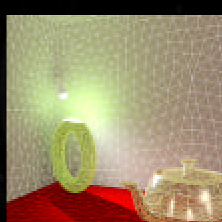
Previous work: perception-driven global illumination solutions

- Static environments
  - Bolin and Meyer ’98, Ramasubramanian et al. ’99, Volevich et al. ’00
- Dynamic environments
  - Yee et al. to appear in ACM TOG

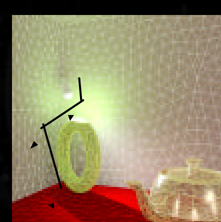
Possible problems

- Huge storage costs
- Fluctuations of accuracy between keyframes and inbetween frames (overlooked lighting changes)
- Popping effects

Our framework

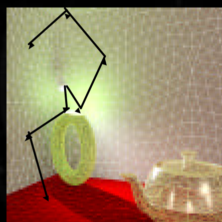


Our framework



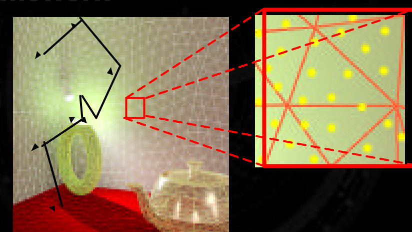
- View-independent light source photon tracing.

Our framework



- View-independent light source photon tracing.
- Photon-hit points are stored for possible re-use in neighboring frames.

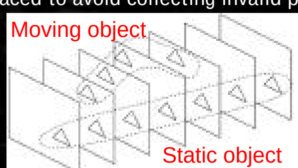
Our framework



- View-independent light source photon tracing.
- Photon-hit points are stored for possible re-use in neighboring frames.

Temporal photon processing: contradictory requirement

- Maximize the number of photons collected in the temporal domain to reduce the stochastic noise.
- Minimize the time interval in which the photons were traced to avoid collecting invalid photons.



Temporal photon processing: our solution

- Energy-based stochastic error metric
  - Steers the photon collection in the temporal domain
  - Computed for each mesh element and for all frames
- Perception-based animation quality metric
  - Decides upon the stopping condition
  - Computed once per animation segment

Energy-based error metric

- Problem: how to distinguish the actual changes in lighting from the stochastic noise?
- We assume that hitting a mesh element by photons can be modeled by the Poisson distribution.
  - For the mean number m of hit points the standard deviation $s = \sqrt{m}$ (for $m = 0$ we assume $s = 1$)
  - If the number of photons x hitting a mesh element does not satisfy the condition $m - ks \le x \le m + ks$ the photon collection for this mesh element is disabled (e.g., $k = 2$).

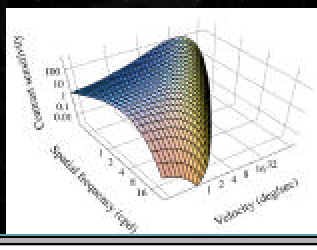
Perception-based error metric

Modeling important characteristics of the Human Visual System

- Weber's law-like amplitude compression
- Contrast Sensitivity Function
- Visual masking

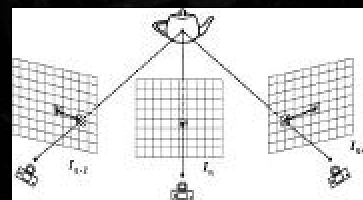
Spatio-velocity Contrast Sensitivity Function

- SV-CSF measured for traveling gratings of various spatial frequencies by Kelly (1960).

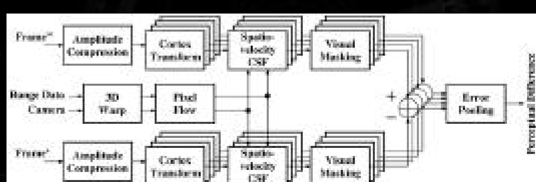


Estimating pattern velocity

- Pixel Flow derived via 3D warping provides velocity data as required by Kelly's SV-CSF model.

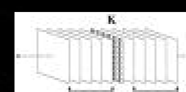


Animation Quality Metric (AQM)



- Perception-based Visible Differences Predictor for still images (Daly, 1993) was extended for animated sequences (Myszkowski et al., 2000).

AQM processing

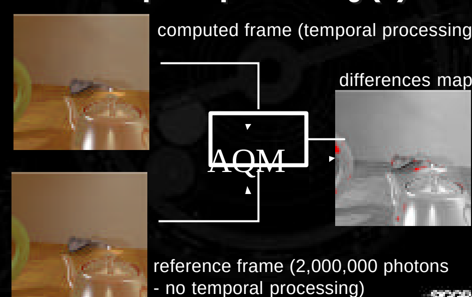


1. Select the central frame K for a given animation segment.
2. Split all photons collected in the temporal domain for this frame into two halves and compute two corresponding images.
3. Use the AQM to predict the perceivable differences between these two images.
4. If the noise is perceived for more pixels than a certain threshold value the number of photons is increased.

Algorithm

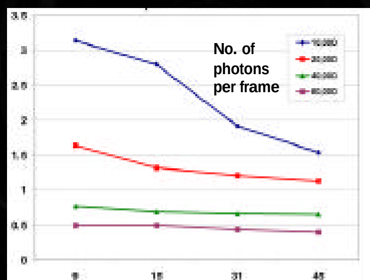
1. Initialization: determine the initial number of photons per frame.
2. Adjust the animation segment length depending on temporal variations of indirect lighting which are measured using energy-based criteria.
3. Adjust the number of photons per frame based on the AQM response to limit the perceivable noise.
4. Spatio-temporal reconstruction of indirect lighting.
5. Spatial filtering step.

Results: photon temporal processing (1)



Results: adaptive photon collection for each mesh element (2)

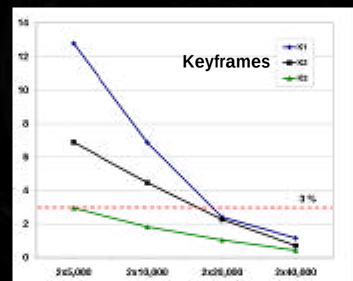
Pixels with the AQM predicted perceivable differences [%]



Number of frames in an animation segment

Perceivable noise reduction

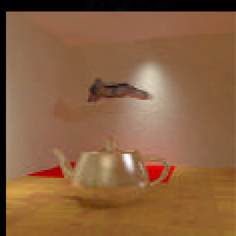
Pixels with the AQM predicted perceivable differences [%]

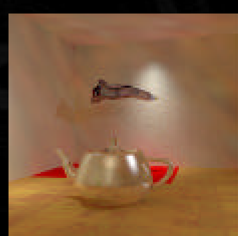


Number of photons per frame

Temporal processing:

ON *OFF*





10,000 25,000

photons per frame

Video

Timings [seconds]

Scene	Photon tracing	AQM	Temp. proc.	I/O MIN (MAX)	Total MIN
ROOM	2.57	0.27	0.32	0.72 (21.56)	3.88
ATRIUM	2.95	0.21	1.85	0.88 (26.93)	5.89

Timings of the indirect lighting computation for a single frame obtained as the average cost per frame for the whole animation (800 MHz Pentium III processor).

Summary

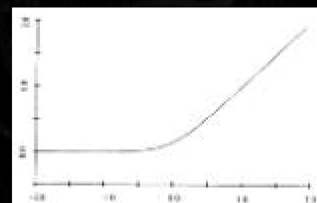
- We proposed an animation rendering technique with spatio-temporal photon processing.
- Our technique enables efficient computation of global illumination for dynamic environments and reduces temporal aliasing.

Future work

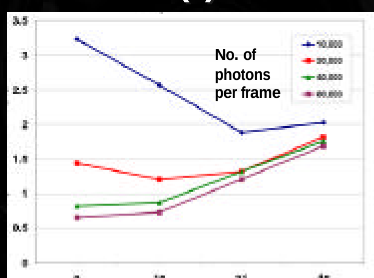
- We are currently working on a plug-in for 3D Studio MAX based on our technique.
- It would interesting to adjust our technique to compute only those lighting details that can be reconstructed for given settings of the MPEG compression.

Visual masking

Masking is strongest between stimuli located in the same perceptual channel, i.e., featuring similar spatial frequency.



Results: photon collection for fixed number of frames (2)



Histogram of mesh elements with maximum possible temporal expansion