Photon mapping to accelerate daylight simulation with high-resolution, data-driven fenestration models

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Modelling Complex Fenestration in RADIANCE

Exemplary fenestration

- Irregular scattering properties.
- Range from micro- to macro-structured, or combinations.
- Accurate control of transmission, often maintain directionality.
Modelling Complex Fenestration in RADIANCE
Possible approaches

- Geometric models and *secondary sources*.
  - Reformulate problem for deterministic ray-tracing.
- Geometric models and *photon mapping*.
  - Reverse simulation to avoid short-comings of ray-tracing.
- *Data-driven* models.
  - Hides internal complexity from simulation, populated by
    - interpolation of measurements (pabopto2bsdf, bsdf2ttree),
    - evaluation of formulae (e.g. bsdf2ttree), or
    - ray-tracing (e.g. genBSDF).
- How to efficiently employ data-driven models in simulation?
An exemplary data-driven model
From measured Bidirectional Scattering Distribution Function (BSDF) of a Laser Cut Panel (LCP)

- Incident light (green) is deflected (red) by sample of LCP.
- Scanning gonio-photometer allows to measure BSDF at varying incident and outgoing directions.
- Data-driven model replicates sample characteristics as a surface property in RADIANCE.
Sampling data-driven models in RADIANCE
Backward ray-tracing

\[ E \approx \int \text{rays} \]

- Illuminance \( E \) by integrating random rays.
Sampling data-driven models in RADIANCE
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- Even less – depending on the BSDF – reach the sun.
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- Illuminance \( E \) by integrating random rays.
- Only a fraction of these rays hit the fenestration.
- Even less – depending on the BSDF – reach the sun.
- Requires high amount of random rays \( \rightarrow \) slow!
Sampling data-driven models in RADIANCE
Backward ray-tracing: Time-step simulation with LCP

▶ "Splotchy" sampling artefacts.
▶ No sharp contours of shadows.
▶ $t = 103116$ s.
Sampling data-driven models in RADIANCE
Forward photon distribution

- Photons start at the light source.
- Photon ports optional clip distribution to fenestration.
- Caustic photons after directional transmission.
- Global photons after subsequent diffuse scattering.
Sampling data-driven models in RADIANCE
Forward photon distribution

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Sampling data-driven models in RADIANCE
Photon gather

▶ Local photon density by counting within search radius.
Sampling data-driven models in RADIANCE

Photon gather

\[ E \approx N_{\text{photons}} \]

- Local photon density by counting within search radius.
- Density evaluates to diffusely scattered illuminance.
Sampling data-driven models in RADIANCE
Photon gather

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Sampling data-driven models in RADIANCE
Photon gather

- Local photon density by counting within search radius.
- Density evaluates to diffusely scattered illuminance.
- Directional scattering is added by backward ray-tracing.
Sampling data-driven models in RADIANCE
Photon mapping: Time-step simulation with LCP

- Photon noise.
- Sharp contours of shadows.
- $t = 2482$ s.
Outlook: Climate-Based Daylight Modelling
Calculation of the solar component

- Directly compute solar component.
- Combine with Three-Phase-Method result for sky component.
- Simplified work-flow when compared to Five-Phase-Method.
Conclusions

- Data-driven modelling allows to directly transfer measurements into simulation.
- About $40 \times$ faster than backward ray-tracing with caustic photons and indirect visualization of global photons.
- Even $\approx 130 \times$ faster than backward ray-tracing with caustic and precomputed global photons (see proceedings).
- Photon Mapping supports both geometric and data-driven modelling of complex fenestration.
- Typical artefacts, e.g. noise, are visible – but typically will not effect visual comfort assessment.
Further information and acknowledgements

Measured BSDF and data-driven model of the LCP: doi:10.5281/zenodo.3375294

LO Grobe (2019). Photon mapping in image-based visual comfort assessments with BSDF models of high resolution. *Journal of Building Performance Simulation*. doi:10.1080/19401493.2019.1653994

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