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A Unified Transport Model for Correlated Disorder: Microfacets, volumes, porous materials, and beyond

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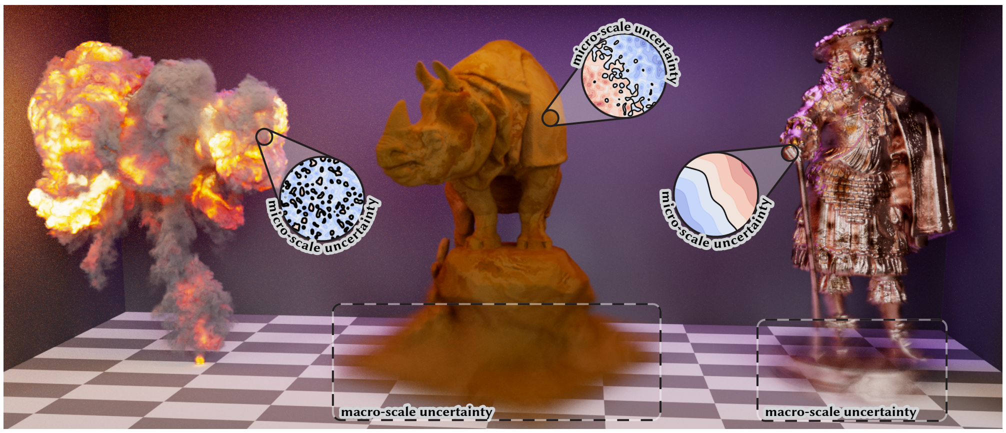

In this work, we will describe our recent developments [1, 2] to unify the distinct stochastic appearance models used in computer graphics for surfaces and volumes. By representing scene geometry as the zero crossings of a Gaussian random field, our theory subsumes Beckmann microfacet surfaces, classical participating media, and an exciting new continuum in between, including non-classical media with arbitrary heterogeneity and porous aggregates with correlated microstructures. Each object shown above is represented as a 3D volume that encodes the mean and covariance of a non-stationary Gaussian process. The insets show example realizations of the process. Note how the appearance of the stochastic geometry transitions from volumetric (left) to hard-surface (right) as the correlations in the process are strengthened. Increasing the *variance* of the process allows us to visualize uncertainty at the macro-scale (bottom).

To efficiently compute light transport in such correlated disorder (*without homogenizing to classical models*) we interweave the Monte Carlo transport process with "just-in-time" random sampling of 1D slices of the Gaussian process along rays. We also establish a formal connection between Gaussian processes and specific forms of procedural noise commonly used in computer graphics. This allows sampling realizations without expensive linear system solves, all while maintaining precise control over spatial correlations.

We believe our approach, while initially designed for computer graphics applications, holds potential for fields like reactor engineering and remote sensing where dense, correlated, porous media are prevelant.

References

[1] D. Seyb, E. d'Eon, B. Bitterli, W. Jarosz. "From microfacets to participating media: A unified theory of light transport with stochastic geometry." *ACM Transactions on Graphics*, 43(4), July 2024.

[2] K. Xu, B. Bitterli, E. d'Eon, W. Jarosz. "Practical Gaussian process implicit surfaces with sparse convolutions." *ACM Transactions on Graphics*, 44(6), December 2025.