Abstract: Semantic Diffusion Processes for High-Fidelity 3D Fuel Cloud Generation

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This project introduces a novel approach that utilizes diffusion processes to generate structurally and segmentation-aware point clouds for wildland fire science. Traditional 3D fuel models often lack the granular detail necessary for accurate fire spread prediction; our method ensures that generated point clouds not only represent the overall morphology of vegetation but also understand and delineate its constituent parts, such as canopy, ladder fuels, and ground litter.

The key innovation lies in the integration of individual conditional variables for each point within the cloud, allowing for precise control over the synthesis of specific fuel components with enhanced structural accuracy. We demonstrate the impact of these variables by comparing guided diffusion, where environmental constraints remain constant, with unguided diffusion, which introduces stochasticity to simulate the natural randomness of fuel accumulation.

Comparative analysis reveals how these conditional variables influence diffusion dynamics and the resulting fidelity of the 3D representations. By creating more detailed and semantically meaningful 3D fuel beds, this approach opens new possibilities for high-resolution fire behavior modeling, forest management, and the development of digital twins for fire-prone ecosystems.