A Volumetric Penetration Measure for 6-DOF Haptic Rendering of Streaming Point Clouds

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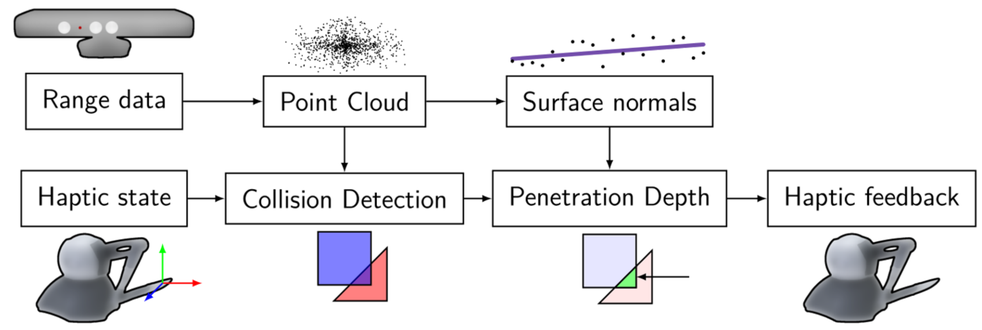
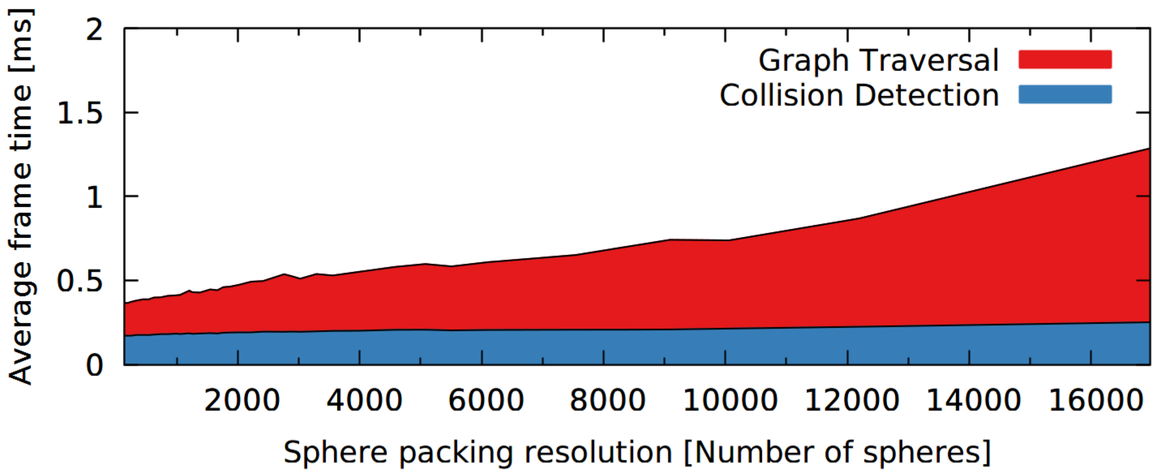
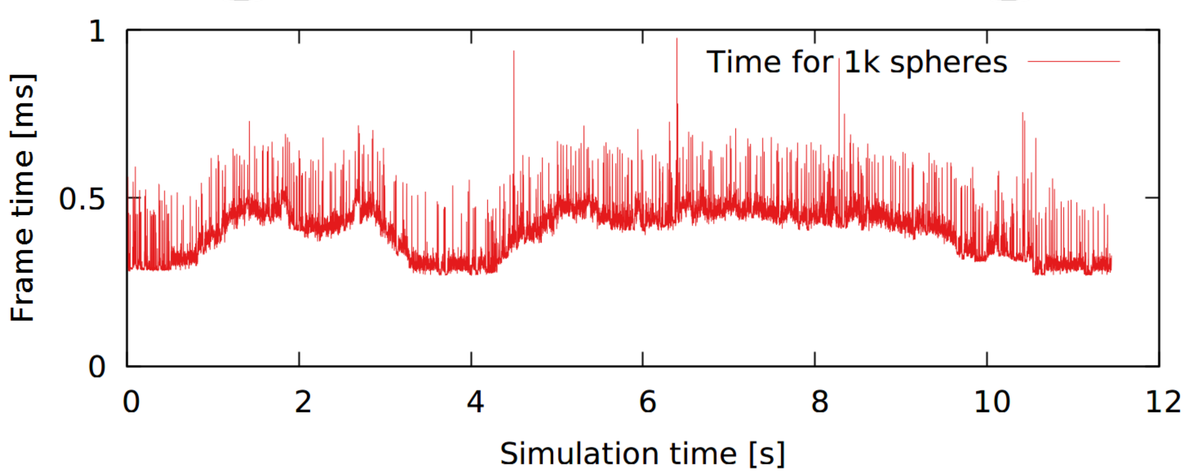
Massively-Parallel Implementation

- Concurrent kernels for asynchronous tasks
- Continuous forces and torques
- Performance: <1ms for 13k spheres



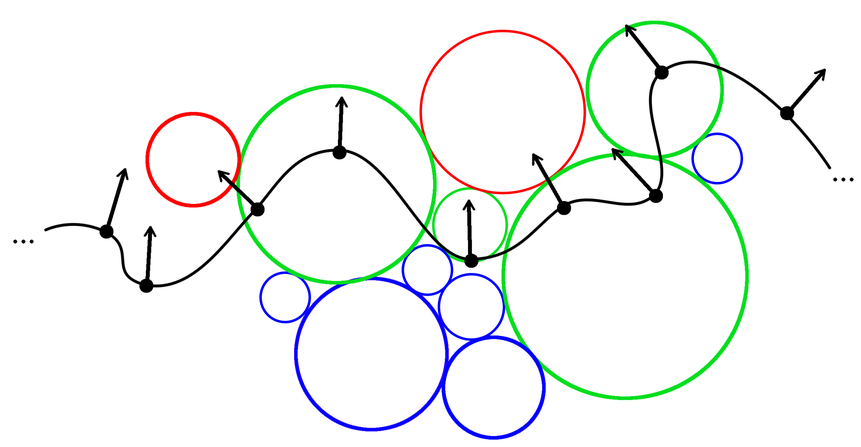




Penetration Measure

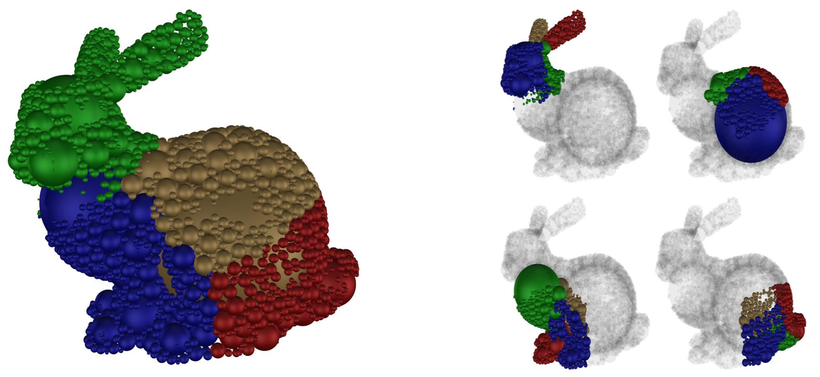
- Classify spheres with respect to point cloud
  - Outside, boundary, inside
- Complete penetration volume

$$V = \sum_i \frac{4}{3}\pi r_i^3 + \sum_j \frac{1}{3}\pi h_j^2 (3r_j - h_j)$$



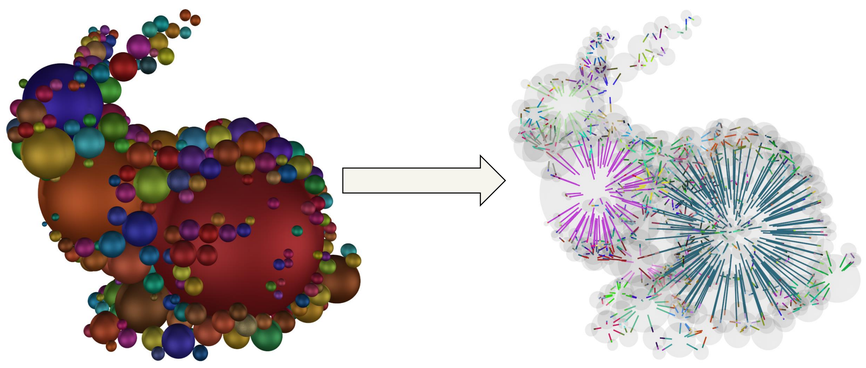
Inner Spheres Representation

- Polydisperse sphere packing
- BVH acceleration data structure
- Arbitrary degree of accuracy



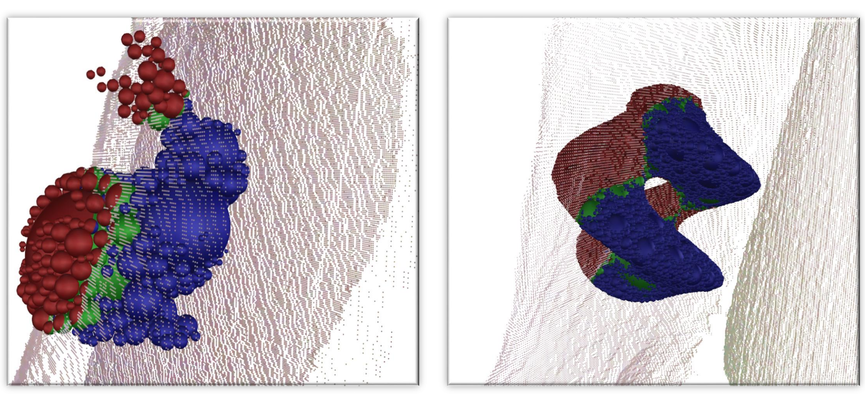
Proximity Graph on Leaves

- Graph between spheres
- Ensure connectedness with minimal edges
- Breadth-first traversal by proximity



Collision Detection

- Find boundary spheres by Inner Sphere Tree
- Parallelized on GPU with one thread per point
- Run-time complexity is output sensitive



Point Cloud Surface Estimation

- Online surface estimation by local PCA
- Point cloud extrapolation in haptic loop
- Simple outlier removal heuristic