PIVOT: Proximity Information From Voronoi Techniques

Department of Computer Science **University of North Carolina at Chapel Hill** **February 2002**

The Challenge

Many applications of computer graphics or computer simulated environments require spatial or proximity relationships between objects. In particular, dynamic simulation, haptic rendering, surgical simulation, robot motion planning, virtual prototyping, and computer games often require many different proximity queries simultaneously at interactive rates. Algorithms for determining collisions, intersections, and minimum separation distances have been extensively researched, but computing proximity queries for non-convex, dynamically deformable objects with no precomputation or knowledge of object motion remains an outstanding research challenge.

Highlights

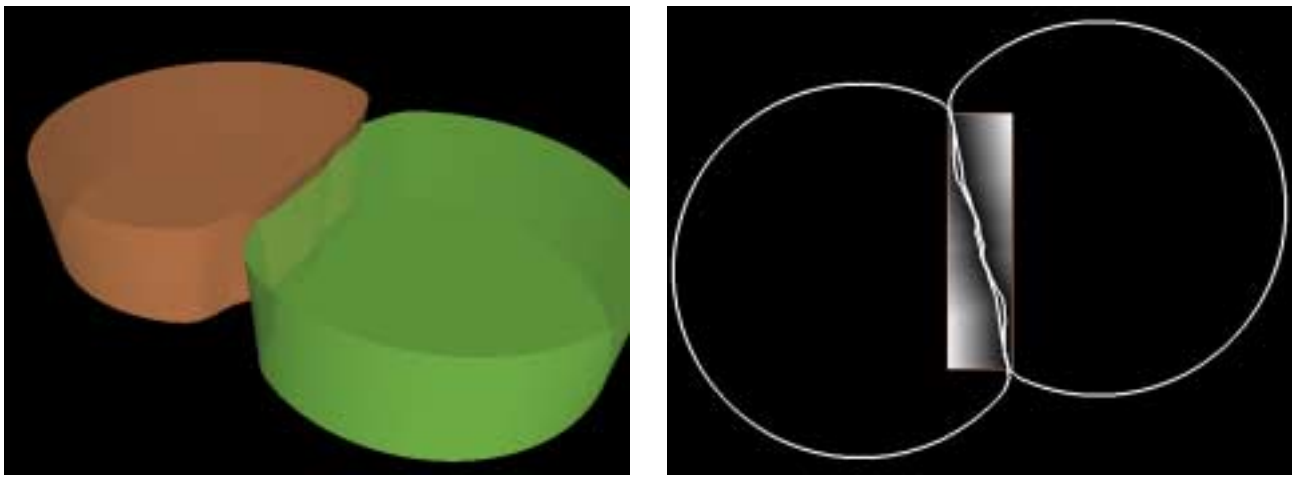
- **Computation of generalized proximity information using graphics hardware.**
- **Generality, simplicity, efficiency, no precomputation, robustness, bounded error approximation, and portability.**
- **A hybrid geometry and image-based approach that balances computation between the CPU and graphics subsystems.**

The Approach

We present a new approach for computing generalized proximity information of arbitrary objects using graphics hardware. Using multi-pass rendering techniques and accelerated distance computation, our algorithms perform proximity queries not only for detecting collisions, but also for computing intersections, separation distance, penetration depth, and contact points and normals.

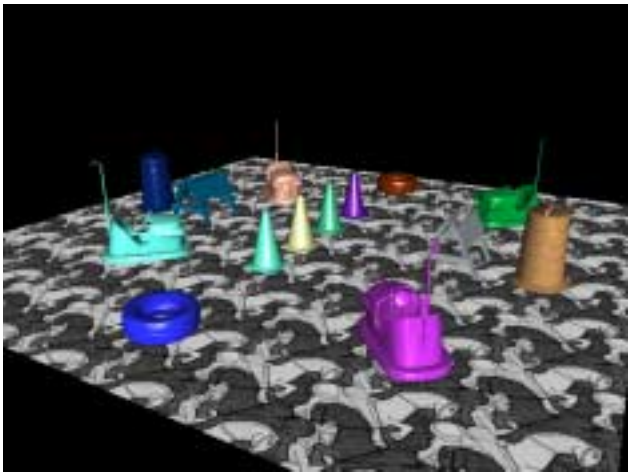
Our algorithms use a hybrid geometry and image-based approach that balances computation between the CPU and graphics subsystems. Geometric object-space techniques are used to coarsely localize potential intersection regions between two objects, and image-space techniques compute the low-level proximity information in these regions. Our algorithm relies on the computation of graphics hardware-accelerated distance fields using multi-pass rendering techniques.

The main features of our approach include a unified framework for all proximity queries, generality to non-convex objects, no required precomputation or complex data structures, computational efficiency allowing interactive queries on current PCs, robustness requiring no special-case handling of degeneracies, portability across various CPU/graphics combinations, and error-bounds on approximations. We have implemented our algorithm on PC and SGI platforms, and have demonstrated its performance in computing collision responses in both rigid- and deformable-body dynamic simulations.



Large deformable bodies, continuous contact. Here we show proximity information being used for collision response between dynamically deformable bodies. The left image shows force reactions between two objects that were initially overlapping by a large amount. The right image shows the distance field around the contact area.

Large non-convex objects in frequent close contact. Our approach computes proximity information for non-convex objects without decomposing the object into convex pieces.



Non-convex objects in frequent simultaneous contact. Our algorithm can process many simultaneous non-convex collisions at once.

Project Leaders

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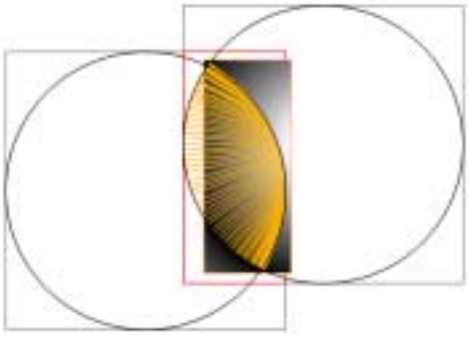
Selected Publications

Hoff, K., A. Zaferakis, M. Lin, and D. Manocha. "Fast and Simple 2D Geometric Proximity Queries Using Graphics Hardware," *Proc. ACM Interactive 3D Graphics Conference*, March 2001.

Hoff, K., T. Culver, J. Keyser, M. Lin, and D. Manocha. "Interactive Motion Planning Using Hardware-Accelerated Computation of Generalized Voronoi Diagrams," *Proc. IEEE International Conference on Robotoics and Automation*, 2000.



Points on the boundary of the left circle penetrating the right circle. A tight-fitting bounding box around the points; the distance field of the right object shown in black; the gradient vectors of the penetrating points shown in yellow.

Hoff, K., T. Culver, J. Keyser, M. Lin, and D. Manocha. "Fast Computation of Generalized Voronoi Diagrams Using Graphics Hardware," *Proc. ACM SIGGRAPH '99*, 277–285.

Key Words

Proximity queries; collision detection; penetration depth; graphics hardware acceleration; multi-pass techniques

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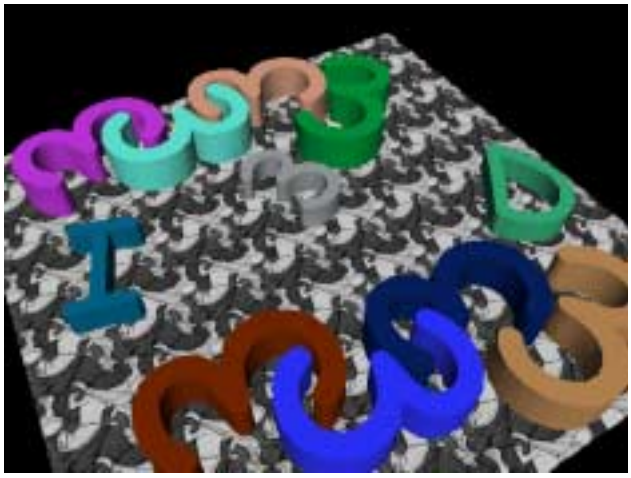

Non-convex objects in frequent simultaneous interlocking contact. Collision response for some specialized 3D scenes, such as those whose objects collide only in a 2D plane, can be computed using our approach.