H-Collide: A Framework for Fast and Accurate Collision Detection for Haptic Interaction

(completed 2000)

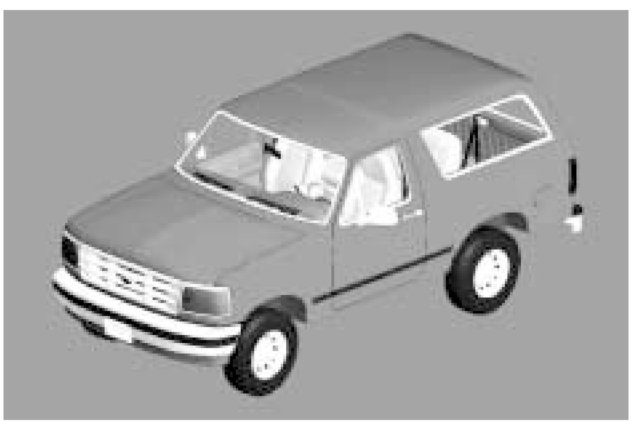
Department of Computer Science **University of North Carolina at Chapel Hill**

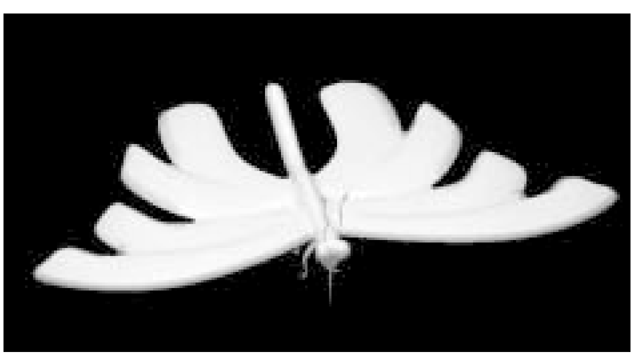
Motivation

Virtual environments require natural interaction between computer systems and users. Haptic rendering as an augmentation to visual display can improve perception and understanding both of force fields and of world models in synthetic environments. It allows users to reach into virtual worlds with their hands, so they can touch feel and manipulate simulated objects.

Haptic display often uses what is essentially a small robot arm used in reverse. Such devices are now commercially available for a variety of configurations (2D, 3D, 6D, specialized for laparoscopy or general purpose). The system used in this work was a 6DOF-in/3DOF-out SensAble Technologies PHANToM arm.

"Real-time" graphics applications have display update requirements somewhere between 15 and 30 frames/second. In contrast, the update rate of haptic simulations must be as high as 1000 updates/second in order to maintain a stable system. This rate varies with the spatial frequency and stiffness of displayed forces, and with the speed of motion of the user. Also, the skin is sensitive to vibrations greater than 500Hz, so changes in force at even relatively high frequencies are detectable.





Models tested with H-Collide. *Top:* a Ford Bronco composed of 18,439 triangles. *Above:* a butterfly of 78,846 triangles. We are able to achieve up to a factor of 20 times speed improvement on these models.

Highlights

- **Real time contact determination for haptic interface**
- **Novel hybrid hierarchical representation**
- **Enabling algorithms and system framework for virtual protyping and surgical training**

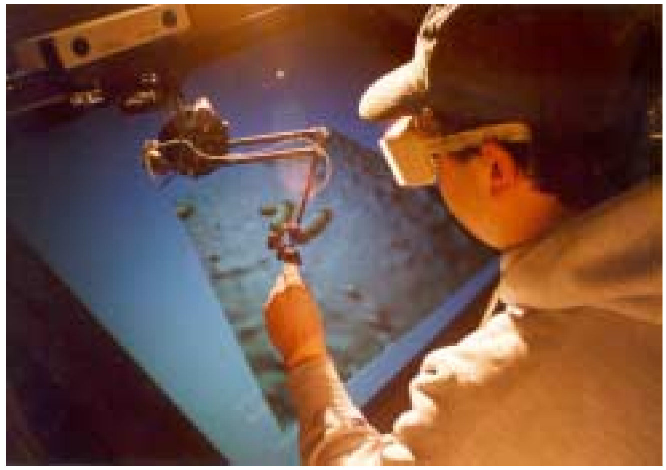
In order to create a sense of touch between the user's hand and a virtual object, contact or restoring forces are generated to prevent penetration. This is computed by first detecting if a collision or penetration has occurred, then determining the (projected) contact point on the object surface. Most existing algorithms only address the collision detection and contact determination problems for relatively small objects consisting of a few thousand polygons or a few surfaces. Our ultimate goal is to be able to achieve smooth, realistic haptic interaction with CAD models of high complexity (normally consisting of tens of thousands of primitives) for virtual prototyping applications. In addition, we aim to design algorithms that are easily extensible to support a wide range of force-feedback devices (including 6 degree-of-freedom arms) and deformable surfaces.

System Overview

H-Collide is a framework for fast and accurate collision detection for haptic interaction. It consists of a number of algorithms and a system specialized for computing contact(s) between the probe of the force feedback device and objects in the virtual environment. To meet the stringent performance requirements for haptic interaction, we use an approach that specializes many other earlier algorithms for this application. Our framework utilizes:

Spatial Decomposition: H-Collide decomposes the workspace into uniform grids or cells, implemented as a hash table to efficiently deal with large storage requirements. At run time, the algorithm quickly finds the cell containing the path swept out by the probe.

Bounding Volume Hierarchy Based on OBBTrees: An OBBTree is a bounding volume hierarchy and each node of the hierarchy corresponds to a tight-fitting oriented bounding box (OBB). For each cell consisting of a subset of the polygons of the model, we precompute an OBBTree. At



Far left: This model of a man contains 7,152 triangles. It can be "felt" in real time with a PHANToM using H-Collide with SensAble Technology's *GHOST* library. *Left:* a user of the nanoWorkbench examines a particle of tobacco mosaic virus on a representative surface. The surface tested with H-Collide had 12,482 triangles.

run time, most of the computation time is spent finding collisions between an OBBTree and the path swept out by the tip of the probe between two successive time steps. To optimize this query, we have developed a very fast specialized overlap test between a line segment and an OBB, that takes as few as 6 operations and only 36 arithmetic operations in the worst case (not including the cost of transformation).

Frame-to-Frame Coherence: Typically, there is little movement in the probe position between successive iterations. The algorithm utilizes this coherence by caching contact information from the previous step to perform incremental computations.

Implementation and Performance

H-Collide has been successfully implemented and interfaced with *GHOST* (a commercial haptic library) and used to find collisions between the probe of a 3DOF PHANToM arm and large geometric models (composed of tens of thousands of polygons). Performance varies based on the geometric model, the configuration of the probe relative to the model, machine configuration (e.g. cache and memory size) and the combination of techniques enabled. While not all our algorithms can guarantee greater than 1000 Hz performance for all models, the overall approach results in a factor of 2–20 speed improvement as compared to earlier algorithms and commercial implementations.

Project Leaders

Ming C. Lin, associate professor
Russell M. Taylor II, research associate professor

Past Researchers

Arthur Gregory, Stefan Gottschalk

Research Sponsors

Honda, Intel Corp., National Institutes of Health, National Center for Research Resources (NIH), National Science Foundation

Selected Publications

Publications available at: *www.cs.unc.edu/~geom/HCollide/*

Gregory, A., M. Lin, S. Gottschalk, and R. Taylor. "Real-Time Collision Detection for Haptic Interaction Using a 3-DoF Force Feedback Device," *Computational Geometry: Theory and Applications* (special issue on virtual environments), 15(1–3), February 2000, 69–89.

Gregory, A., M. Lin, S. Gottschalk and R. Taylor. "H-Collide: A Framework for Fast and Accurate Collision Detection for Haptic Interaction," *Proc. IEEE Virtual Reality Conference*, 1999.

Lin, M. C., A. Gregory, S. Ehmann, S. Gottschalk, and R. Taylor. "Contact Determination for Real-Time Haptic Interaction in 3D Modeling, Editing and Painting," *Proc. 1999 Workshop for PhanTom User Group*.

Key Words

Haptics; human-computer interaction; collision detection

For More Information

Dr. Ming C. Lin
Department of Computer Science
University of North Carolina at Chapel Hill
CB#3175, Sitterson Hall
Chapel Hill, NC 27599-3175
Phone: (919) 962-1974
Fax: (919) 962-1799
E-mail: lin@cs.unc.edu
Web: www.cs.unc.edu/~geom/HCollide/

Related Projects

www.cs.unc.edu/~geom/inTouch/
www.cs.unc.edu/~geom/collide.html
www.cs.unc.edu/Research/force/