Preface

Collision detection is a fundamental problem in many fields of computer science, including physically-based simulation, path-planning and haptic rendering. Many algorithms have been proposed in the last decades to accelerate collision queries. However, there are still some open challenges: For instance, the extremely high frequencies that are required for haptic rendering. In this book we present a novel geometric data structure for collision detection at haptic rates between arbitrary rigid objects. The main idea is to bound objects from the *inside* with a set of *non-overlapping* spheres. Based on such sphere packings, an "inner bounding volume hierarchy" can be constructed. Our data structure that we call *Inner Sphere Trees* supports different kinds of queries; namely proximity queries as well as time of impact computations and a new method to measure the amount of interpenetration, the *penetration volume*. The penetration volume is related to the water displacement of the overlapping region and thus, corresponds to a physically motivated force. Moreover, these penalty forces and torques are continuous both in direction and magnitude.

In order to compute such dense sphere packings, we have developed a new algorithm that extends the idea of space filling Apollonian sphere packings to arbitrary objects. Our method relies on prototype-based approaches known from machine learning and leads to a parallel algorithm. As a by-product our algorithm yields an approximation of the object's medial axis that has applications ranging from path-planning to surface reconstruction.

Collision detection for deformable objects is another open challenge, because pre-computed data structures become invalid under deformations. In this book, we present novel algorithms for efficiently updating bounding volume hierarchies of objects undergoing arbitrary deformations. The event-based approach of the kinetic data structures framework enables us to prove that our algorithms are optimal in the number of updates. Additionally, we extend the idea of kinetic data structures even to the collision detection process itself. Our new acceleration approach, the *kinetic Separation-List*, supports fast continuous collision detection of deformable objects for both, pairwise and self-collision detection.

In order to guarantee a fair comparison of different collision detection algorithms we propose several new methods both in theory and in the real world. This includes a model for the theoretic running time of hierarchical collision detection algorithms and an open source benchmarking suite that evaluates both the performance as well as the quality of the collision response.

Finally, our new data structures enabled us to realize some new applications. For instance, we adopted our sphere packings to define a new volume preserving deformation scheme, the *sphere-spring system*, that extends the classical mass-spring systems. Furthermore, we present an application of our Inner Sphere Trees to real-time obstacle avoidance in dynamic environments for autonomous robots, and last but not least we show the results of a comprehensive user study that evaluates the influence of the degrees of freedom on the users performance in complex bi-manual haptic interaction tasks.

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