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Combined strategy for efficient collision detection in 4D planning applications

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Collision detection is the most time consuming component of many geometric reasoning applications like CAD/CAM, robotics and automation, computer graphics, and virtual reality. Performance is also a crucial factor for 4D modeling and planning applications targeted at the scheduling of large industry projects by means of identifying and resolving of spatio-temporal clashes in complex dynamic scenes, containing thousands and millions of objects (Boskers and Abourizk, 2005).

Four fundamental approaches to the collision detection problem have been proposed and successfully implemented to deal with different statements and application peculiarities. These are exact interference detection, spatial decomposition, bounding volumes techniques and methods exploiting temporal coherence (Jimenez 2001; Lin 1998; Klosowski 1998; Cameron, 1990; Zachmann, 1994).

In this paper, we develop and analyze a combined strategy that exploits peculiarities of dynamic scenes arising from the 4D modeling and planning. As distinct from traditional project management systems (Meredith and Mantel, 1995) these applications enable the simulation of 'in progress' project activities taking into account spatio-temporal factor. For this purpose both 3D CAD models and scheduling data are consolidated to obtain more comprehensive visual representation for the project analysis and to allow early detection and resolution of clashes already at project design and planning phases rather than during its realization.

We consider that the scenes originating from 4D modeling and planning applications have the following characteristics:

High complexity: the scenes may consist of thousands and millions of objects with their own 3D model representations and dynamic behaviors.

Mixed geometry: the objects may be both solid bodies given by constructive solid geometry (CSG) or boundary representation (BRep) as well as shapes represented by analytical forms or approximated by polygons collections.

Pseudo-dynamic motion: All the object motions are discrete in time and known in advance (in contrast to real-time simulation in virtual reality environments or motion planning applications).

Regular forms and motions: A significant part of objects are constructed and displaced in the scene in accordance with regular patterns originated from the modeled project. Geometrical similarity is a quite constructive principle to minimize collision checks in large-scaled scenes by means of identifying groups of objects that exhibit similar behavior and undergo similar transformation.

In the main, our contribution is a collision detection strategy that focuses on the enumerated peculiarities of pseudo-dynamic scenes arising from 4D modeling and planning applications. The strategy combines spatial decomposition, bounding volumes and temporal analysis methods yielding substantially faster collision detection than previous known methods being applied separately or discordantly. Being based on a special spatio-temporal partition schema, the strategy allows efficient software implementations.

Figure 1 presents typical dependency plots of CPU time expressed in seconds costs from the number of objects. The plots illustrate significant performance benefits of the combined strategy reached at different degrees of the space occupation. For the investigated scenes an approximate performance gain of 5-25 times is demonstrated compared with traditional spatial decomposition and bounding volume methods being applied separately.

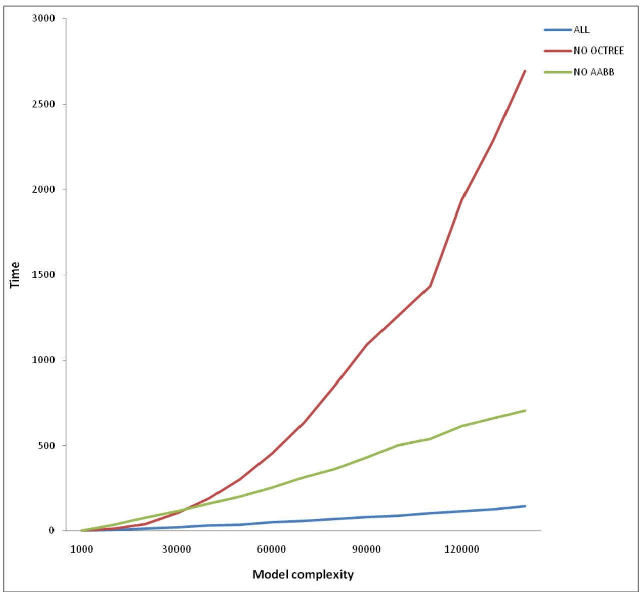

Figure 1. The dependency of CPU costs from the object numbers for different spatio-temporal strategies

It is important that under reasonable assumptions relating the characteristics of pseudo-dynamic scenes, the collision detection problem can be successfully resolved using the proposed strategy and the spatio-temporal partition schema. The derived theoretical estimates of the complexity as well as the conducted experiments prove its computation benefits. It gives rise to a wide potential use of the strategy in complex, large-scale industry projects.

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