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CAD-based Monte Carlo automatic modeling method based on primitive solid

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ABSTRACT

Monte Carlo method has been widely used in nuclear design and analysis, where geometries are described with primitive solids. However, it is time consuming and error prone to describe a primitive solid geometry, especially for a complicated model. To reuse the abundant existed CAD models and conveniently model with CAD modeling tools, an automatic modeling method for accurate prompt modeling between CAD model and primitive solid is needed. An automatic modeling method for Monte Carlo geometry described by primitive solid was developed which could bi-convert between CAD model and Monte Carlo geometry represented by primitive solids. While converting from CAD model to primitive solid model, the CAD model was decomposed into several convex solid sets, and then corresponding primitive solids were generated and exported. While converting from primitive solid model to the CAD model, the basic primitive solids were created and related operation was done. This method was integrated in the SuperMC and was benchmarked with ITER benchmark model. The correctness and efficiency of this method were demonstrated.

1. Introduction

In nuclear particle transport simulation, Monte Carlo method has been widely used. The geometry model which should be prepared before simulation can be described in several methods: half space (Briesmeister, 2000; Martz, 2013; Both et al., 2003; Fasso, 2005), primitive solid (Agostinelli et al., 2003; Yican et al., 2015; Song et al., 2014), mesh (Martz, 2013; Agostinelli et al., 2003), CAD model for directly transporting (Tautges et al., 2009), etc. With accurately modeling and intuitively understanding the model, the method mainly used in the Monte Carlo geometry definition is Constructive Solid Geometry method (CSG) (Requicha and Voelcker, 1982) which includes the half space method and the primitive solid method. The half space method constructs solid with half-space surfaces defined in mathematical equations and directions. The primitive solid method constructs solid with Boolean operation, position and rotation. Contract to the half space method, there are some benefits for using the primitive solid method, such as easy to handwrite and understand.

While describing, it is easy to establish a simple model which has less cells and less faces in each cell. But the situation was completely changed while establishing a complex model with many cells and many surfaces in each cell. It is hard to modeling manually which is time consuming and error prone. For reusing the abundant existed CAD model and convenient modeling with CAD modeling tools, an automatic modeling tool for accurate prompt modeling from CAD model is needed. Some previous researches (Grosse and Tsige-Tamirat, 2009; Nasif et al., 2012) of automatic modeling for Monte Carlo simulation had been studied, but most of them focused on half space model. In this paper a newly automatic modeling method for primitive solids was researched for the need of rapid development and various applications of Monte Carlo simulation.

The key conversion of the CAD model and a primitive solid model is the conversion between the boundary representation method (Braid, 1975) and the primitive solid method. The previous research into conversion from CAD model to a half space model is decomposing the CAD model to a convex solid set, and translate to half space geometry according to the boundary surfaces of the convex solids. While converting the CAD model to primitive solid model, the primitive solid can be created according to the boundary surface of the convex solid. While converting primitive solid model to CAD model, it is similar that creating of basic solid to the method of half space but different with movement and rotation.

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This method had been studied and integrated in the Super Monte Carlo Simulation Program for Nuclear and Radiation Process, named SuperMC. SuperMC was developed by FDS Team which is an interdisciplinary research team devoting to the research and development of advanced nuclear energy systems, mainly including nuclear reactor physics (Wu et al., 2009), nuclear reactor material (Wu et al., 2002; Wu, 2007; Wu and FDS Team, 2008), nuclear reactor engineering (Wu and FDS Team, 2008; Wu et al., 2011; Wu, 2007), numerical simulation and visualization (Wu et al., 1999; Wu and FDS Team, 2009), medical physics and environmental protection (Yican et al., 2008), etc. It is a CAD-based MC program for integrated simulation of nuclear system by making use of hybrid MC-deterministic method and advanced computer technologies. SuperMC 2.2, the latest version, can perform neutron, photon and coupled neutron and photon transport calculation and integrates automatic modeling and visualization (Wu and FDS Team, 2009; Wu et al., 2006; Hu et al., 2007; Long et al., 2010; Luo et al., 2010; Long et al., 2011; He et al., 2012; Tang et al., 2010). SuperMC/MCAM is the geometry and physics modeling part of SuperMC. Previous version SuperMC/MCAM 4.8 which modeling for MCNP was a mature and efficient modeling program which has been used widely (Li et al., 2007; Zheng et al., 2007; Huang et al., 2006; Lu et al., 2009).

In this paper, the conversion method was described in Section 2. Section 3 introduced the testing method and showed the results. At last, a brief summary was given in Section 4.

2. Conversion algorithm

2.1. CAD to primitive solid conversion

In SuperMC/MCAM, an automatic conversion method which converts CAD model to half space model was implemented. In this method which was based on the CAD model decomposing, a CAD model was imported and decomposed to several disjoint convex solid sets; and then the corresponding surface with direction was generated and transformed to a half space according to each surface of every convex solids. While creating surface based convex solid's surface, the equation of the surface and the direction would be record. Fig. 1 shows an example of a cube with a half cylinder. With this method, this solid would be decomposed into two convex models: a cube and a half cylinder. Then, these convex solids would be processed separately and each surface with its direction would be recorded, and saved in a half space format.

While converting to primitive solids, the improvement of the developing algorithm, which focused on the transform of surfaces of each convex solid, was done based on the above method. While processing a plane half space, a central point on the surface and the equation used to specify the half space would be given. And then the plane half space would be transform to XOY plane and the transform matrix would be recorded. At last a cube would be created and transformed by the inverse of transform matrix to make sure after the movement and rotation, the cube's top surface has the same equation and direction with the plane half space. While processing an inner cylindrical half space, some key parameters including the radius, cylindrical center point and axis would be given. And then a cylinder would be created based on some key parameters. While processing an outer cylindrical half space, some key parameters including the radius, cylindrical center point and axis would be given. And then a cylinder would be created based on some key parameters and a cube would be created with maximum length. Fig. 1 shows the processing of each surface. The processing of converting cone, sphere and torus was similar.

After these primitive solids were created, the Boolean relationships and the movement need to be recorded. The solid was posed at the center of the world after its creation from the half space, and

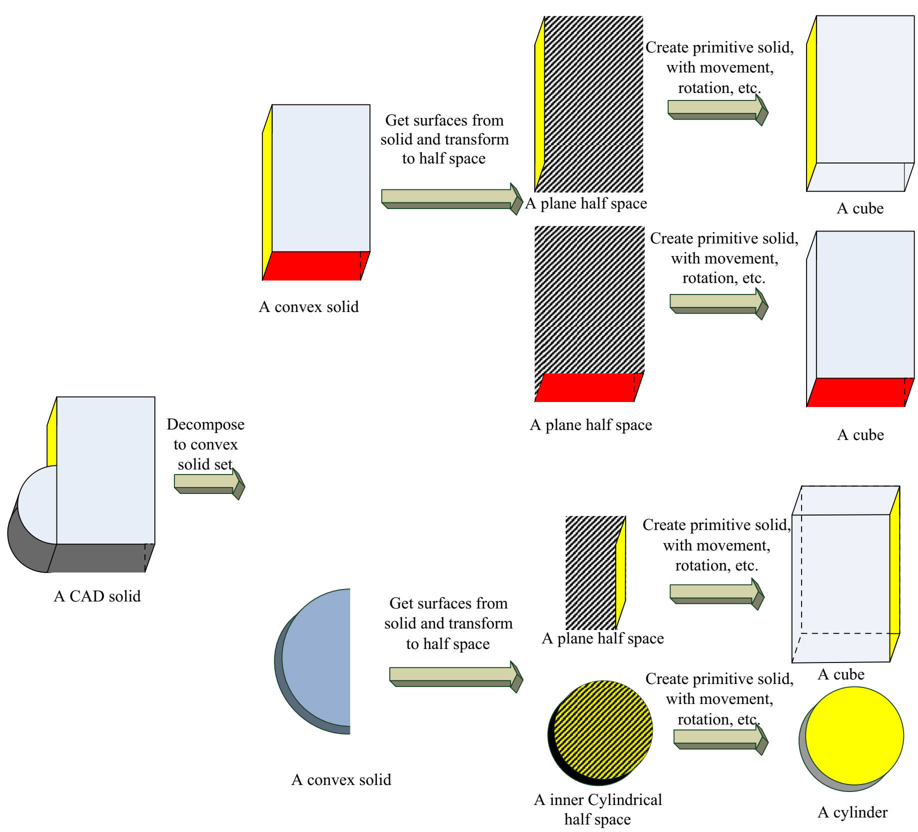

Fig. 1. The processing of each surface in convex solids.