*Journal of Integrative Agriculture* 2018, 17(2): 306–314

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RESEARCH ARTICLE

# Collision detection of virtual plant based on bounding volume hierarchy: A case study on virtual wheat

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**Abstract**

Visualization of simulated crop growth and development is of significant interest to crop research and production. This study aims to address the phenomenon of organs cross-drawing by developing a method of collision detection for improving vivid 3D visualizations of virtual wheat crops. First, the triangular data of leaves are generated with the tessellation of non-uniform rational B-splines surfaces. Second, the bounding volumes (BVs) and bounding volume hierarchies (BVHs) of leaves are constructed based on the leaf morphological characteristics and the collision detection of two leaves are performed using the Separating Axis Theorem. Third, the detecting effect of the above method is compared with the methods of traditional BVHs, Axis-Aligned Bounding Box (AABB) tree, and Oriented Bounding Box (OBB) tree. Finally, the BVs of other organs (ear, stem, and leaf sheath) in virtual wheat plant are constructed based on their geometric morphology, and the collision detections are conducted at the organ, individual and population scales. The results indicate that the collision detection method developed in this study can accurately detect collisions between organs, especially at the plant canopy level with high collision frequency. This collision detection-based virtual crop visualization method could reduce the phenomenon of organs cross-drawing effectively and enhance the reality of visualizations.

**Keywords:** wheat, collision detection, bounding volume hierarchy, virtual plant, morphology

## 1. Introduction

Collision detection in virtual environments is of considerable importance in computer animation, physical simulation, and robotics (Lin and Gottschalk 1998; Jimenez *et al*. 2001). Several collision detection methods have been proposed, such as space partitioning tree (Naylor *et al*. 1990; Vaněček 1991), biomimetic pattern recognition (Xiao *et al*. 2015), distance computations between convex objects (Van Den Bergen 1999), bounding volume hierarchy (BVH) (Van Den Bergen 1997; Klosowski *et al*. 1998; Wilson *et al*. 1999), and interference detection using graphics hardware and image space (Knot and Pai 2003). BVH is considered an effective collision detection algorithm due to its extensive application and robustness. Different methods have been used for the development of BVHs such as sphere (Wilson *et al*. 1999), Axis-Aligned Bounding Box (AABB) (Van Den Bergen 1997), Oriented Bounding Box (OBB) (Gottschalk *et al*. 1996), and K-Discrete Orientation Polytopes (Klosowski *et al*. 1998).

Received 21 January, 2017 Accepted 8 August, 2017
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doi: 10.1016/S2095-3119(17)61769-6

These BVH methods have strengths and weaknesses, and should be selected according to the intended application (Möller *et al*. 2008).

The use of virtual plants was first proposed approximately 20 years ago and can be applied in research, education/extension, and decision support in relation to plant breeding and management, landscape architecture, entertainment, and art (Room *et al*. 1996; DeJong *et al*. 2011). Currently, many studies on plant visualization focus on the development of organ geometric models and 3D visualization (Zhang *et al*. 2013, 2017). The phenomenon of plant organ intersection often occurs during the process of 3D visualization of plant morphology and reduces the realism of plant visualization. Thus, collision detection of plant organs is very important for accurate visualization of the characteristics of plant morphology and canopy structure.

Several previous studies on collision detection of virtual plants that avoid intersection of plant organs have been proposed. Fowler *et al*. (1992) presented a collision-based model of spiral phyllotaxis for detecting and eliminating collisions between neighboring primordia, however this method cannot be used in a complex plant canopy. Wu *et al*. (2011) studied collision detection of leaves in gramineous crop using the K-Discrete Orientation Polytopes method, but detection precision still should be improved. Qin *et al*. (2012) presented a collision detection method for maize using a combined OBB based on triangular data obtained from a digitizer to improve the accuracy and reliability. However, the methods for OBB construction and intersection detection are generally time-consuming. Thus, methods on collision detection among plants canopy need to be improved with regard to accuracy, computing speed, and practical application.

The objectives of this study are: 1) to optimize computing efficiency and detection accuracy by developing a collision detection method based on BVH for plant visualization according to the characteristics of 3D plant morphology and canopy structure; 2) to apply the method of collision detection to wheat visualization at the organ, individual and population scales, and evaluate the effects on the visualization.

## 2. Materials and methods

### 2.1. Visualization of wheat crop

The morphological models of wheat used in this study were developed based on simulation dynamics of leaves (Chen *et al*. 2007), leaf sheaths and internodes (Zhu *et al*. 2009), panicle morphology (Tan *et al*. 2006) and stem-sheath angle (Zhang *et al*. 2011), and leaf color in relation to thermal time (Zhu *et al*. 2008). Using the OpenGL library, geometric models for visualization of different organs were developed using geometric shapes (e.g., cylinder) and non-uniform rational B-splines (Wu *et al*. 2009). The dynamic visualization of wheat at the organ, tiller, and population scales was developed (Tang *et al*. 2008; Wu *et al*. 2009; Lei *et al*. 2011) and improved (Tang *et al*. 2011) by integration of morphological models and geometric models.

### 2.2. An overview of the procedures of wheat collision detection

A overview of the procedures of wheat collision detection in this study is presented in Fig. 1. First, the triangular data of leaves are generated with the tessellation of non-uniform rational B-splines surfaces (Wu *et al*. 2009). Second, triangle-triangle intersection detection is performed by the interval overlap method (Möller 1997), and then BVs and BVHs of leaves were constructed based on the leaf morphological characteristics using the Separating Axis Theorem (Ericson 2004). Third, the collision detection of two leaves was performed by using the depth-first search algorithm (Ericson 2004). Finally, the BVs of other organs (ear, stem, and leaf sheath) in virtual wheat plant were constructed based on their geometric morphology, and the collision detections were conducted at the organ, individual, and population levels.

### 2.3. Leaf tessellation

Tessellation, also called surface subdivision, is the subdivision of concave polygons or polygons with intersecting edges into convex polygons (Mölleret *et al*. 2008; Shreiner 2009). Using the OpenGL utility library, non-uniform rational B-splines objects are compartmentalized into lines and triangles (or polygons). Vertices data can be obtained through non-uniform rational B-splines surface mesh division with a callback function in OpenGL. Fig. 2-A and B show a normal wheat leaf and a meshed leaf based on existing leaf morphological modeling (Wu *et al*. 2009).

### 2.4. Efficiency of triangle-triangle intersection detection

Collisions among leaves detected by meshed triangles on the leaf surface are highly accurate at the final stage of collision detection based on BVHs. The interval overlap method presented by Möller (1997) is used to detect triangle-triangle collision. However, the detection efficiency between plant organs still needs to be improved. For two leaves, supposing that the numbers of triangles are $N_1$ and $N_2$ after tessellation and the detection time for a pair of triangles is Costi, the total detection time (TDT) is calculated by the