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Interactive Wood Fracture

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Abstract

We propose a new approach for the simulation of wood as an anisotropic material that takes its inherent fiber structure into account. Our approach is based on the Position-based Dynamics framework. We use the Shape Matching approach as the basis for modeling the isotropic attribute of wood. For simulating anisotropic behavior we employ a fiber model based on Cosserat rod theory. Our approach supports dynamic fracturing and captures typical breaking patterns of wood.

CCS Concepts

• ***Computing methodologies*** → ***Interactive simulation; Physical simulation;***

1. Introduction

The realistic modeling of vegetation plays an important role in visual computing with applications in domains such as urban modeling, visual effects, or motion planning for autonomous agents. Moreover, wood as a material is commonly used, for example, in construction, furniture, musical instruments, and therefore part of many objects in everyday scenes. Many approaches exist to model the surface structure and visual appearance of wood. Only recently, physically-based approaches that simulate the motion of plants and their interaction with the environment have been explored in greater detail [PNH*14] [ZB13] [HBDP17] [LRBP12] [PJH*17].

Modeling the fracturing of wood poses two main challenges: first, the animation of wood as a highly stiff material and second, the ability to capture diverse fracture patterns when the material breaks. Methods that discretize a volume with particles are capable of simulating material-specific behaviours like elasticity, plastic deformation and effects such as heat transfer or melting [SSP07] [CMM16]. More recent work focuses on the simulation of anisotropic materials using the Material Point Method [WCL*20]. However, this method is not well suited for interactive applications due to its computational complexity.

In this paper we introduce a novel approach for simulating wood as an anisotropic material with the ability of producing plausible fracture patterns. The kinetic behavior is simulated with Position-based Dynamics (PBD) of connected particles. For the simulation of wood fibers we employ the Cosserat rod method [KS16]. Individual particles are connected using the Shape Matching approach [MC11]. The discretization of the wood volume with particles allows us to measure stress within the material. The breaking of wood is simulated by evaluating material failure due to stress and updating particle connectivity accordingly. Our approach is computationally efficient and allows us to simulate whole trees at interactive rates.

Our approach requires as the input only a watertight mesh and information of the wood fiber distribution and orientation within the material. The fiber information can be provided in the form of vectors, which can be either defined by a user or generated procedurally. Based on the input geometry and fiber description we procedurally fill the mesh volume with particles and rods. In summary our key contributions are: (1) we propose a new particle-based method for simulating wood as an anisotropic material. (2) we provide a user friendly method that is able to procedurally approximate the material structure by particles and rods. (3) our approach is able to efficiently simulate characteristic fracture patterns of wood.

2. Overview

Figure 1 provides an overview of our approach. Input to our method is a watertight mesh, as well as fiber metadata that describe the distribution and orientation of fibers within the wood. The fiber information can either be defined manually by a user or generated procedurally. In the Position-based Dynamics [MHTG05] framework objects are represented as particles with constraints that define the dynamics. A model based on Cosserat theory [KS16] has been proposed for the simulation of elastic rods within the PBD framework.

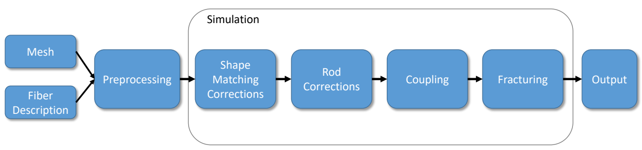

Figure 1: *Overview of the system pipeline.*

We employ the Cosserat method for simulating the anisotropic nature of wood by adding sampling the mesh volume with rods in the preprocessing step (Section 3). The rods are procedurally generated, based on the input mesh and fibers information. Each individual rod consists of at least three particles, connected by edges (Fig 2 b). Each edge carries an orientation that the defines an orthonormal frame between the attached particles. We use the shape matching approach [MC11] as a basis for modeling the isotropic part of wood. The previously generated particles of the discretized domain are grouped into one or more overlapping shape matching groups (Fig 2 a).

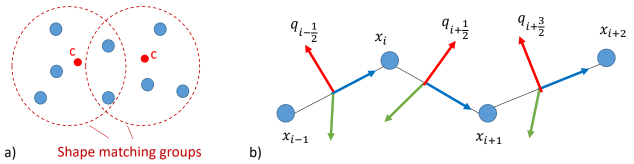

Figure 2: ***a)*** *Two overlapping shape matching groups with mass centers* ***c***. ***b)*** *A Cosserat rod discretization, consisting of three particles and edges between them with an attached orthonormal frame.*

The simulation loop consists of the application of shape matching and rod constraints respectively. Afterwards, we apply constraints for the coupling of the rod and shape matching dynamics. The individual steps of the simulation loop are described in Section 4. The last step is to test the fracture condition for each shape matching group, as described in Section 5. If the fracture condition is met we update particle connectivity and shape matching group membership accordingly.

3. Preprocessing

We propose a procedural method for generating rods and shape matching groups within the input mesh. In the following, we describe the creation of fibers for an input tree mesh. For trees, the fiber direction inside the wood is assumed to follow the centerline of the branches. Initially, the mesh volume is filled randomly with particles. Then, we iteratively create new particles at positions of the previously created ones by advancing in fiber direction and create an edge between them. This is performed until all particles reach the ground (Figure 4 a-c). If a newly created particle is colliding with an existing particle, the previous particle is deleted. As a result we obtain a continuous rod fiber sampling throughout the tree volume (Figure 4 d).

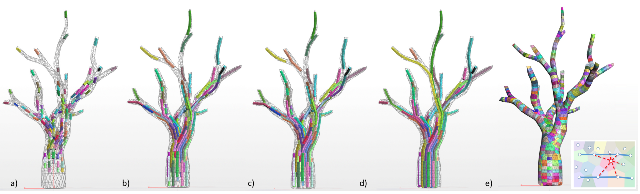

Figure 4: *a-d) Shows the procedural generation of rods inside the mesh. e) The particles of the rods are used to create Voronoi fracture mesh and shape matching groups. Shape matching groups are created for each particle and contain the particle itself and its Voronoi neighbours.*

The final step is the generation of a Voronoi mesh from the original mesh and creation of rod constraints and shape matching groups. For each particle one shape matching group is created, containing the particle itself and its one-ring Voronoi neighbors (Figure 4 e). The Voronoi mesh is animated by linear blend skinning using the adjacent particles.

4. Simulation

The typical simulation sequence in PBD consists of the following steps: prediction, correction, update. In the prediction step particle and rod attributes are evolved in time independently from each other. During the correction step shape matching and rod constraints are iteratively applied. In the update step the corrected attributes are applied and velocities updated.

The first step is to predict attributes of particles and rod elements. Particles are defined by a position, orientation, velocities and other quantities, such as mass. A rod segment is defined by two particles and the edge between them. Edges are defined by an orientation and angular velocity. We advance the particle position, orientation, linear and angular velocity, as well as the rod segment orientation and angular velocity using an explicit forward Euler integration scheme. The solver then iteratively applies constraint corrections for rods and shape matching groups, respectively. Coupling and collision constraints are applied afterwards.

Rod corrections. Stretch and shear constraints minimizes the stretch and shear for a rod element which is formed by two adjacent particles with positions and and the orientation, stored as a quaternion, between them. Bend and twist constraints couple two adjacent rod elements and minimizes bend and twist, with respect to the rest configuration, between them.

Shape Matching corrections. Polar decomposition for each shape matching group is performed to determine the least squares optimal rotation of the original shape into the current deformed configuration, which is used to correct particle positions and orientations.

Coupling constraints. Particles can be part of a rod, as well as shape matching groups. This means that changes of rod element orientations (e.g. due to rod twisting or bending) should affect the orientation of attached particles and vice versa. We, therefore, couple particle and rod orientations by minimizing their relative orientations with respect to the rest configuration. Finally, we update particle positions and orientations, as well as rod orientation from their intermediate corrected values. The linear and angular velocities are then computed from the new and old positions and orientations.

5. Wood Fracture

Jones et al. [JML*16] and Choi [Cho14] propose methods for simulating elastoplastic deformations and fracturing with the shape matching approach. We extend upon this work by adding support for anisotropic fracture conditions. For each shape matching group we compute the Green strain ε_g by a polar decomposition [Cho14]. We then convert the strain into local coordinates, which are relative to the fiber orientation, by

$$\varepsilon_g' = R\varepsilon_g R^{-1},$$

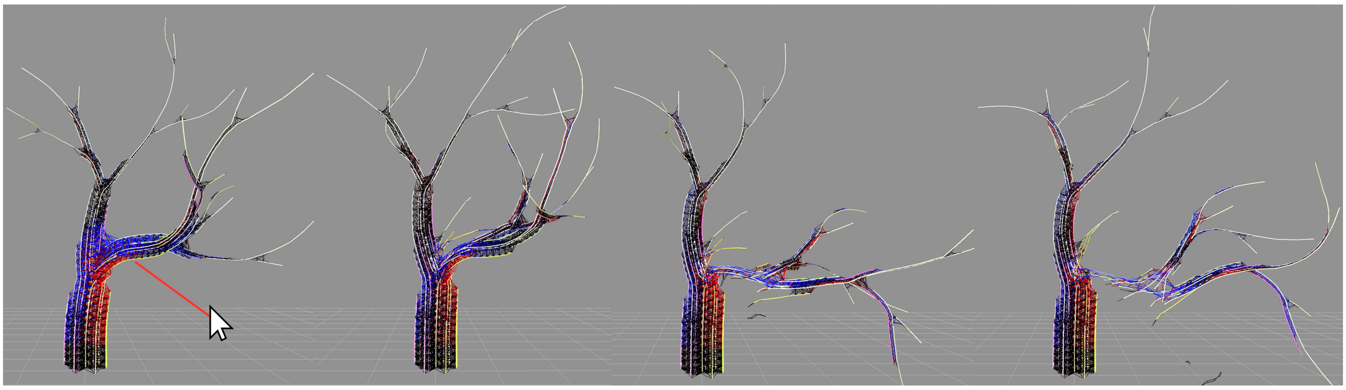

Figure 3: *Branch breaking after the user is pulling the branch to the right side. Compression of wood is visualized as red, tension as blue.*

where R is the current shape matching group orientation. We employ the fracture criterion similar to Gharib et al. [GHVB17], whereby we determine the parameters of the compliance matrix and fracture thresholds empirically. If the fracture criterion is satisfied we know that failure occurred in either the radial, tangential or fiber direction. We use this direction as the normal of the fracture plane that passes the shape matching center. Connectivity of shape matching group members that pass the fracture plane, as well edges defined by rod elements are consequently removed. Updates for the Voronoi mesh are performed similar to Choi [Cho14].

6. Implementation and Results

We implemented the preprocessing algorithm in Houdini. The simulation part is realized in C++ using OpenGL for rendering. Figure 3 shows a result of our simulation, where a user is pulling a branch of the tree to the right side. As soon as the fracture condition is met the branch starts to break. The simulation is performed at interactive rates on a workstation with an Intel Xeon CPU at 3.00 Ghz, 128 GB RAM and a GeForce GTX 1080 graphics card.

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