Review of Position-Based Dynamics

In the field of physically animation, finding new methods to simulate physical phenomena is becoming more popular. Instead of focusing on accuracy, the new methods should be stable, robust, fast, and most importantly effective where the result should remain visually plausible. The traditional approach deals with force, therefore, at the beginning of each time step, the internal forces and external forces are accumulated. The more desirable approach is to have direct control over positions of the objects or vertices of a mesh. The method that is being proposed, position-based dynamics, has the following advantages:

- The simulation takes control over explicit integration and remove instability problems.
- The positions of vertices and part of objects can be manipulated during simulation.
- General constraints in the position-based setting will be handled.
- The position-based solver is easy to understand and implement.

In order to simulate a dynamic object, suppose there is a set of vertices and constraints, where a vertex has mass, position, and a velocity. First, using Euler integration step, positions for new locations of the vertices can be computed. Then the iterative solver manipulates the positions, so they satisfy the constraints. After that, the positions of vertices are moved to the optimized estimates while the velocities get updated at the same time. In this method, the velocity is the bridge that allows working with external forces possible if they cannot be converted to positions. This also allows the simulation to define damped velocities, if necessary, collision, and friction. By being able to move the vertices to a physically valid configuration makes this method unconditionally stable.

The result of one of the experiments is very satisfying. When simulating an object bending, the proposed method only depends on the dihedral angle of adjacent triangles, not the edge lengths, which allows the bending and stretching to be chosen independently. Another experiment is using the method to simulate both one way and two way coupled attachment constraints. This simulation is done on three stripes with a fixed constraint on the top and configured them to look like they swing and twist. The next experiment is a cloth laying on the floor where the simulation includes, self-collision detection, collision handling and rendering. The fourth experiment shows a piece of cloth that is torn open by an attached cube and ripped apart by a thrown ball. This is completed by selecting vertices when the stretch exceeds a specific threshold value and put a split plane through the vertex.

As a result, position-based dynamics proves that it can handle general constraints. Because it can manipulate the objects directly during simulation, this makes it easy to handle collisions, attachment constraints, explicit integration, and direct control of animated scene.

Review of As-rigid-as-possible solid simulation with oriented particles

In interactive applications, physics-based simulation is a very important technique, which is why producing visually convincing and stable deformation, robustness and efficiency of deformation simulations are extensively studied. There have been a few simulation techniques that are developed to compute positions directly instead of doing any integration on velocities and accelerations. Two of the methods are position-based dynamics (PBD), which deals directly with mesh vertices, and meshless deformation, which deals with rotations and translation of mesh vertices. These techniques are believed to be stable and efficient as they do not depend on the time step size. To further improve the PBD method, two of many approaches stand out. The first approach is to employ a simplified structure with small number of oriented particles to simulate the complex geometry of meshes. The second approach is to reformulate the integration of deformation dynamics as energy minimization in a variational form. This approach can specify the material stiffness independently of the solution methods. The two approaches are found to be complementary to each other as they can be combined and the deformation energy and momentum potential energy can be reformulated. The new combined method, as-rigid-as-possible (ARAP), is extremely stable and easy to implement. It can deal with one-dimensional, two-dimensional, and three-dimensional models.

In order to apply the method, suppose there is a particle that is transformed from the rest position and orientation to its current position and orientation. To compute the deformations from a deformation graph, a linear blend skinning is employed. In other word, the influences of the oriented particles are blended so the deformed position becomes a weighted sum of its positions after applying rigid transformations. To measure the rigidity of deformation, the ARAP deformation energy, the sum of the local rigidity energy defined at each node, is applied as it measures the squared distance between the actual deformed positions and deformed positions under the local grid. Momentum potential energy can be formulated based on projective dynamics. Direct manipulation of the deformable body is supported through both position and direction constraints.

The first experiment in this article is about showing the proposed method to simulate one-dimensional models. In this case, it is an elastic bar twisted and manipulated using both position and direction constraints. The second experiment is to demonstrate the material stiffness using different stiffness constants. Unlike the original oriented particles approach which requires a large iteration count to simulate a stiff bar, the proposed method is independent of the iteration count and the time step size. The third experiment is to demonstrate a restoration of a dinosaur. With the help of energy minimization, the dinosaur was able to return to its rest pose from its extremely deformed pose. Shape matching also helps with extreme deformation as well by rectifying a negative eigenvalue. The next experiment is about a dinosaur falling down on the floor. The collisions between the ellipsoidal particles and the floor were handled by pushing them back so they touched the floor. Each time step was divided into three sub-steps where the collisions and the frictions, which can be defined by changing the velocities, at the end of each sub-step. The two-dimensional models can be simulated with the proposed method by using position constraints as the experiment of a deformable sheet attached to a stiff rod and a deformable bunny lying on a deformable sheet. The final experiment was to test the effectiveness of the method by simulating all of the models from the previous experiments. The results showed that the simulation was robust and responsive.

As a result, using an ARAP approach for real-time simulation with oriented particles can be used with one-dimensional, two-dimensional, and three-dimensional models robustly and effectively. The results show that hundreds of deformable models can be simulated in real-time using thousands of particles. The method employs Euler integration scheme, as energy minimization, to find optimal positions and directions using local/global optimization solver. In addition, the material stiffness is independently from the iteration and time step size. Minimization of ARAP deformation energy is key to enforce the shape matching constraint for the rigidity. The method is not about the physical correct simulations but about obtaining visually plausible real-time deformation. Even though the method currently only supports isotropic materials but it definitely haves a great potential to support other materials as well in the future.

Comparison Between the Two Literatures

Both literatures describe methods that can be used in graphics simulation with robustness, effectiveness, and stability as main focuses. As mentioned in the first article, PBD is one of the studied methods that satisfies the conditions earlier. The method is proven to be stable and easy to implement since it works directly with positions instead of velocities and accelerations. The second article is about ARAP method which is a combination of PDB and energy minimization methods. Since the ARAP is practically derived from PDB, it also has been proven to be stable and robust. In addition to defining new optimized positions of vertices, ARAP method adds energy minimization to define rigidity of the objects. This way the ARAP can easily simulation many different types of models and more responsive. Overall, both methods have the same goals and are proven to achieve them. For comparison, ARAP method would be considered to be a better method as it can simulate more complex objects than the PDB.

Citations

- Müller M, Heidelberger B, Hennix M, Ratcliff J. Position based dynamics. In: Proceedings of virtual reality interactions and physical simulations; 2006. p. 71–80.
- Min Gyu Choi, Jehee Lee. As-rigid-as-possible solid simulation with oriented particles; 2018. p. 1–7.