Rigid Fluid

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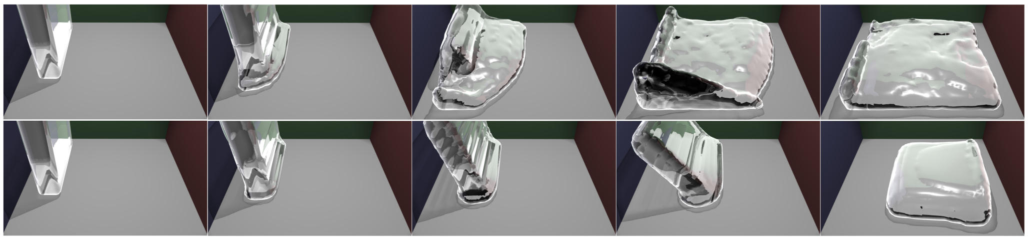

Figure 1: *Top: all particle positions are updated based on fluid motion, bottom: plastic operator is applied.*

1 Introduction

We present a framework for modeling solid-fluid phase change. Our framework is physically-motivated, with geometric constraints applied to define rigid dynamics using shape matching. In each simulation step, particle positions are updated using an extended SPH solver where they are treated as fluid. Then a geometric constraint is computed based on current particle configuration, which consists of an optimal translation and an optimal rotation. Our approach differs from methods such as [Carlson et al. 2004] in that we solve rigid dynamics by using a stable geometric constraint [Müller et al. 2005] embedded in a fluid simulator.

2 Our Approach

Our approach extends the smoothed particle hydrodynamics (SPH) technique with multiple position relaxation steps in every time step. A particle at position $\mathbf{X}_i^t$ is moved to $\mathbf{X}_i^{t+1}$ after two types of relaxation schemes (Figure 2): fluid step, and rigid step. The fluid step uses a prediction-relaxation scheme, where particle

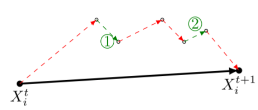

Figure 2: *Relaxations: fluid step (red) and rigid step (green)*

clustering and surface tension effects are handled. The rigid step is a geometric operation, in that energy conservation is replaced by displacement of current particle configuration to goal configuration. Given the initial configuration, C_0, and predicted configuration, C_t, of a collection of particles, the rigid operator, r^* (Equation (1)), solves for an optimal transformation (translation, $\mathbf{T}$, and rotation, $\mathbf{R}$), new position, $\mathbf{x}$ and velocity, $\mathbf{v}$, to match C_0 to C_t.

$$\{\mathbf{T}, \mathbf{R}, \mathbf{x}, \mathbf{v}\} \leftarrow r^*(C_0, C_t) \tag{1}$$

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In our framework, the fluid step induces large deformation, and we observe difficulty in convergence using a single geometric relaxation step. We resolve this by using two geometric relaxations in every time step: once after particle prediction-position update, and once after fluid solver's double density field position update but before collision detection (i.e., ① and ② in Figure 2). This restoration of the rigidity invariant is similar to the projection step to restore the divergence-free fluid invariant.

In addition, we can introduce plastic deformation by adaptively updating the initial object configuration of the rigid operator after fluid particle collision, which we refer to as the plastic operator (Equation (2)). Figure 1 shows a frame-by-frame comparison of two simulations with the same system configuration, and the plastic operator introduces deformation at the surface where object contacts the boundary.

$$\{\mathbf{T}, \mathbf{R}, \mathbf{x}, \mathbf{v}\} \leftarrow r^*(C_{t-1}, C_t) \tag{2}$$

3 Phase Change

Phase change is supported in our framework. Based on the distance between the centers of the voxels and their closest neighbors to the mesh surface, a distance field can be computed during the voxelization process. In order to simulate melting process (rigid to fluid phase change) of an object from the outside to the inside, we treat the material state as a function of time and each particle's distance to the surface of the object mesh. The rigid operator is applied to the particle when flag is in the range $(0, 1]$, and fluid motion is applied to the particle when flag is 0. Figure 3 is an example of changing the rigidity property of the particles of a sphere through time.

Figure 3: *Rigid particles (green) turn into fluid particle (red)*

References

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