Robust Cloth Collision

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May 12, 2019

1 Overview

In this project, we try to implement a robust method to handle the collision and friction for cloth animations. We implement the method described by Bridson et al. [1]. As collisions form the major bottleneck in cloth animation, robust and fast handling of collisions is required. Here, we try to circumvent it, by implementing repulsions. Moreover, the method is a post processing corrective step and does not depend on the cloth internal dynamics or rigid body dynamics.

2 Algorithm

We first give a brief overview of the algorithm and then will go over each component in a different subsection.

1. Select a collision time step Δt and set $t^{n+1} = t^n + \Delta t$.
2. Advance the cloth positions to candidate positions to $\bar{x}^{n+1}$ and velocities to $\bar{v}^{n+1}$ using the cloth internal dynamics at time t^{n+1}. See section 2.1.
3. Advance the body configuration to candidate configuration to $\bar{x}_r^{n+1}$ and configuration velocities to $\bar{v}_r^{n+1}$ at time t^{n+1}. See section 2.1.
4. Compute the average velocity $\bar{v}_r^{n+1/2} = (\bar{x}_r^{n+1} - \bar{x}_r^{n+1})/\Delta t$.
5. Do proximity detection on $\bar{x}^n$ and then apply repulsion impulses and friction to get $\widetilde{v}^{n+1/2}$ for cloth. See sections 2.2 and 2.3.
6. Do proximity detection on $\bar{x}^n$ and then apply repulsion impulses and friction to get $\widetilde{v}^{n+1/2}$ for cloth and $\widetilde{v}_r^{n+1/2}$ for rigid body. See sections 2.2 and 2.3.
7. Check linear trajectories from $\bar{x}$ with $\widetilde{v}^{n+1/2}$ for collisions and resolving them with final mid step velocity $v^{n+1/2}$. See section 2.4.
8. Limit strain and strain rate for cloth. See section 2.5.
9. Compute the final position for cloth $\bar{x}^{n+1} = \bar{x}^n + \Delta t \widetilde{v}^{n+1/2}$ and Update the final velocity $\bar{v}^{n+1} = \widetilde{v}^{n+1/2}$.
10. Compute the final configurational velocities for rigid body as well.

2.1 Cloth Internal and Rigid Body Dynamics

We implement the cloth internal dynamics using the position based dynamics and apply the stretching and bending constraints as described in assignment 3. We also keep the pulling constraint in order to create small perturbations in the cloth, if necessary. We also assume that each vertex of triangular mesh has same mass. This gives the cloth extra weight at the boundary, to mimic the cloth seams.

For rigid body, we simply use the update equations from the assignment 2, to get the new configuration positions and velocities.

2.2 Proximity Repulsions

We use the axis-aligned bounding box to get the proximities for both point-triangle pairs and edge-edge pairs efficiently between both the cloth-cloth and cloth-rigid body. To stop the imminent collision, we apply an inelastic collision of magnitude $I_c = mv_N/2$, only if the points are approaching. If the points are separating and only if the normal component of relative velocity is $v_N \geq 0.1d/\Delta t$, we apply the spring based repulsion force of magnitude $I_r = -min(\Delta tkd, m((0.1d/\Delta t) - v_N))$, where d is the difference of distance between two points and the cloth thickness. Otherwise no impulse is applied.

Once computed, the impulse is added and used to change the final velocities using the barycentric coordinates of the two points either for edge-edge or face-point collision. For cloth-cloth interaction the equations are mentioned by Bridson et al[1]. For cloth-rigid body interaction, we calculate the exact impulse by making the relative velocity at the point of contact zero. The equations for updating velocities at cloth and body is then calculated as follows. We only show here the edge-edge collision equation. Face-point collision equation can be derived with similar barycentric coordinates. Equation for edge-edge (m_b is mass of body and m_c is mass of cloth) to get magnitude $\alpha =$

$$\frac{-v_{rel}\hat{n}}{(1-a)^2(1/m_b + rot(\theta)[I^{-1}[\bar{p_1}]_\times rot(-\theta)\hat{n}]_\times \bar{p_1}) + (a)^2(1/m_b + rot(\theta)[I^{-1}[\bar{p_2}]_\times rot(-\theta)\hat{n}]_\times \bar{p_2}) + (b^2 + (1-b)^2)(1/m_c)}$$

2.3 Friction

As mentioned in paper, we also use Coulomb's model for friction for both static and kinetic with single friction parameter μ. We estimate the impulse needed to make the tangential component of the relative velocity of the interacting points zero, in both cloth-cloth and body-cloth simulations. If the magnitude of this impulse is more than the $\mu F_N \Delta t$, we limit it to $\mu F_N \Delta t$, where $F_N = -F_R$ i.e. normal force is reverse of the repulsion forces from previous section. We then go on to apply the impulses in the tangential relative velocity direction using similar updates like in section 2.2.

2.4 Geometric Collisions and Rigid Impact Zones

Repulsion forces try to prevent the inter-penetrations that happen at only the discrete moments in time. To handle the inter-penetrations that happen between time steps with the new velocities, we again use the axis aligned bounding box hierarchy, but now generate box around the current position and the candidate position at the end of the time step. We then run section 2.2 and 2.3 again. This could result in new collisions, so we make this an iterative process. Even after multiple iterations, a cloth could have lumps which could result in newer collision in each iteration between same set of points. We use rigid impact zones as described by Bridson et al. [1] to handle such cases after few iterations of collision detection.

2.5 Limit Strain and Strain Rate

In order to get better viewing results, we also implement the a limit to change in strain as well as change in strain rate in each time step to maximum 10 % as done in the paper.

3 Implementation

We have provided how to generate specific interesting test cases in the README.md

3.1 Simulation Options

1. Cloth Filename: .clt file depicting the scale, thickness, mass scale, intial position and initial theta (will be multiplied by MPI inside
2. Scene Filename: .scn file same as in the assignment. Use blank.scn for just floor.
3. Scene Filename: .scn file same as in the assignment. Use blank.scn for just floor.
4. Cloth Internal Dynamics: Enable/disable the constraints and the weights

5. Rigid Body Dynamics: Newton Iteration Parameters, if body is fixed, body just moves with initial parameters.

6. Collision Handling: parameters to enable/disable repulsion, collision, friction, etc.

4 Limitations

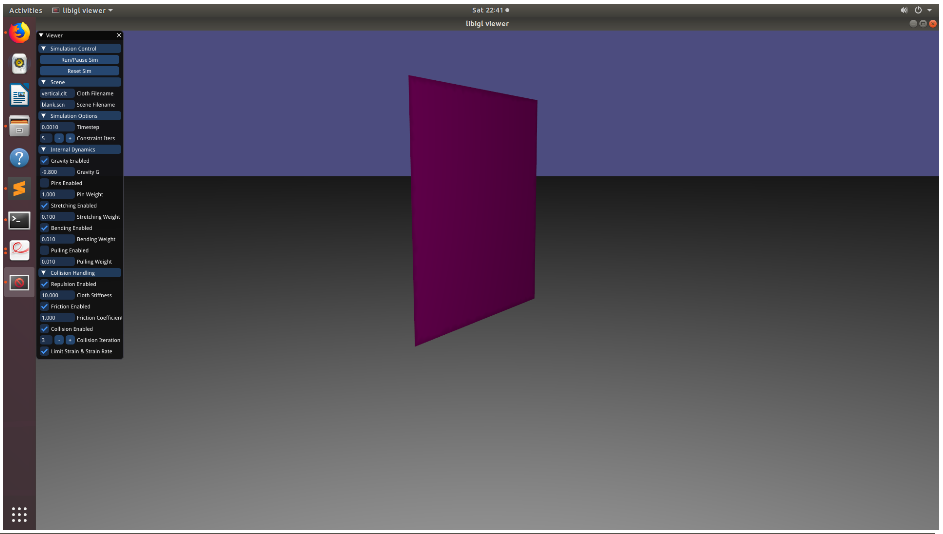
1. We have not handled rigid body-rigid body collisions, as it was not part of the scope of this project. 2. Similarly no friction between rigid body and floor. 3. Three simultaneous collision between cloth, floor and body is not handled properly. Ideal case would be to disable gravity to prevent it from happening.

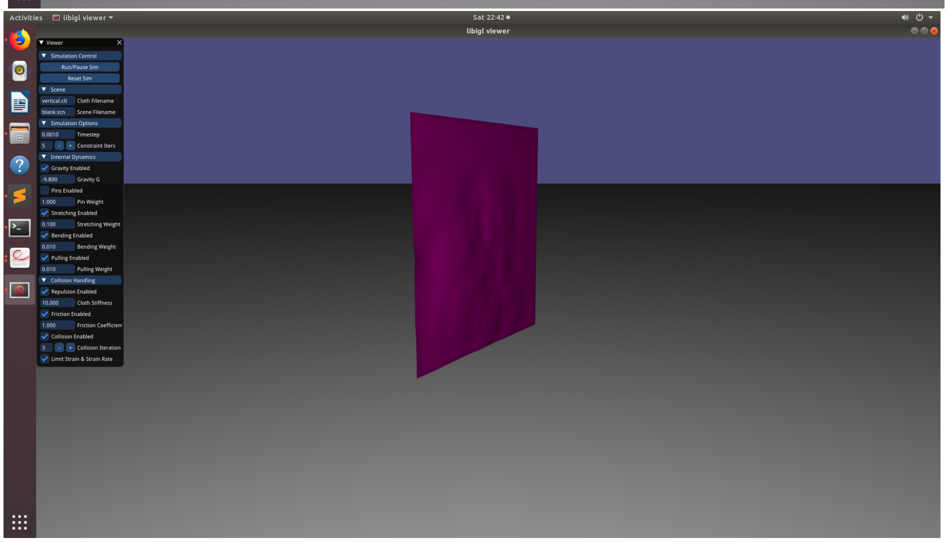
References

[1] Robert Bridson, Ronald Fedkiw, and John Anderson. Robust treatment of collisions, contact and friction for cloth animation. In *ACM Transactions on Graphics (ToG)*, volume 21, pages 594–603. ACM, 2002.

5 Example Test Cases

We now share some example test cases screen shots.





5.1 Folding on floor

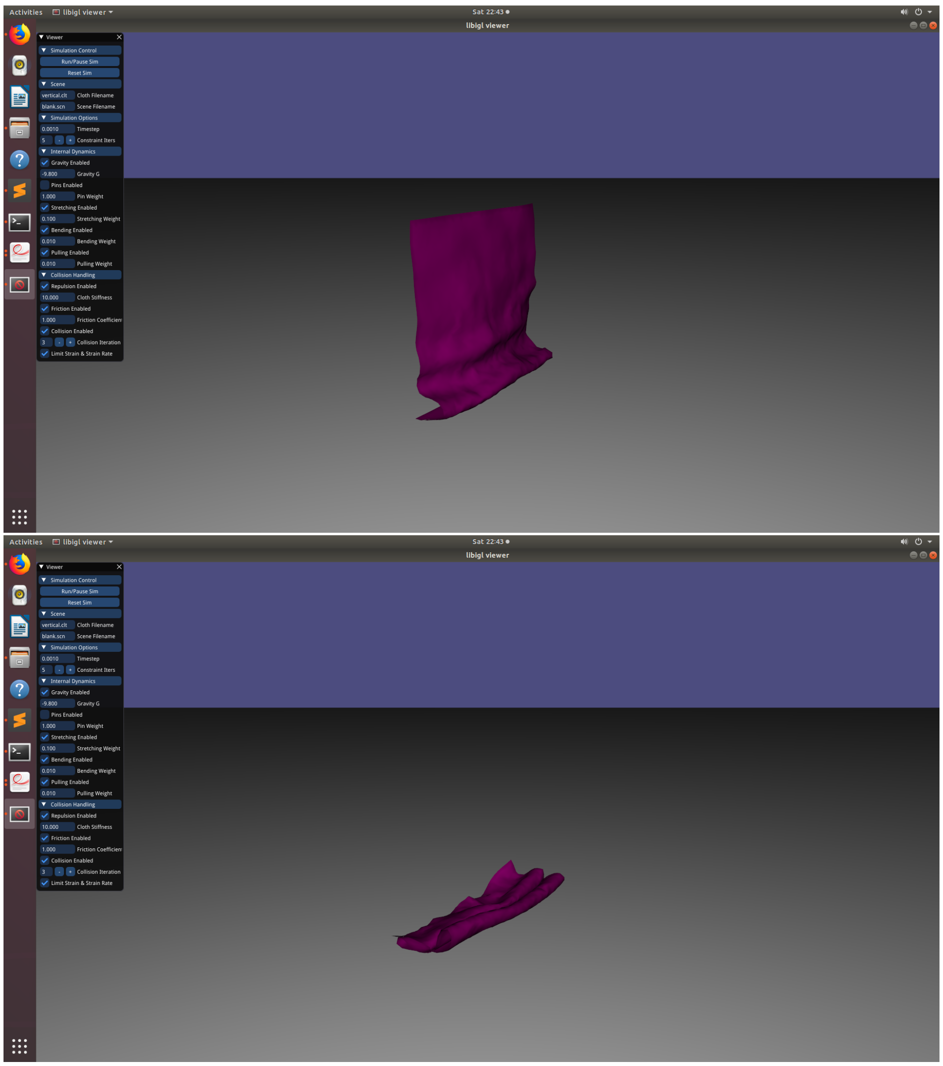
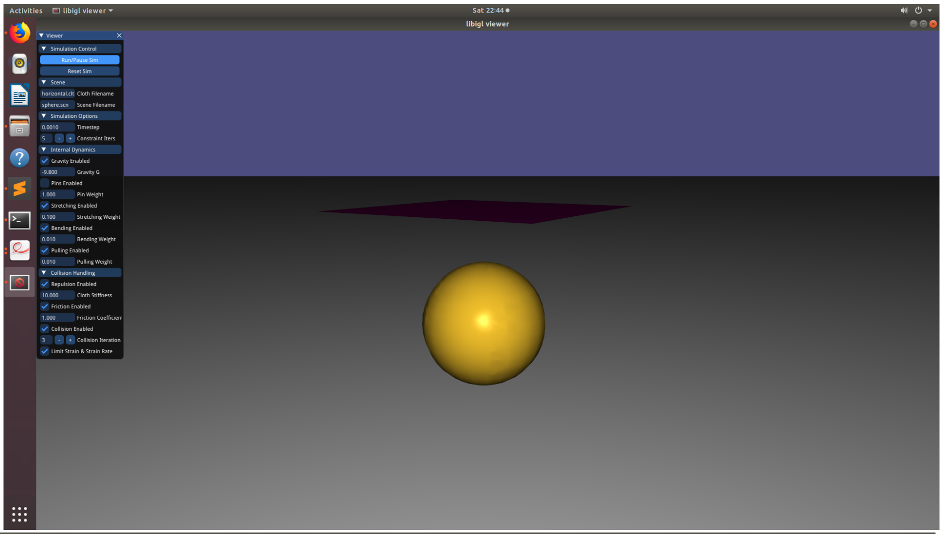
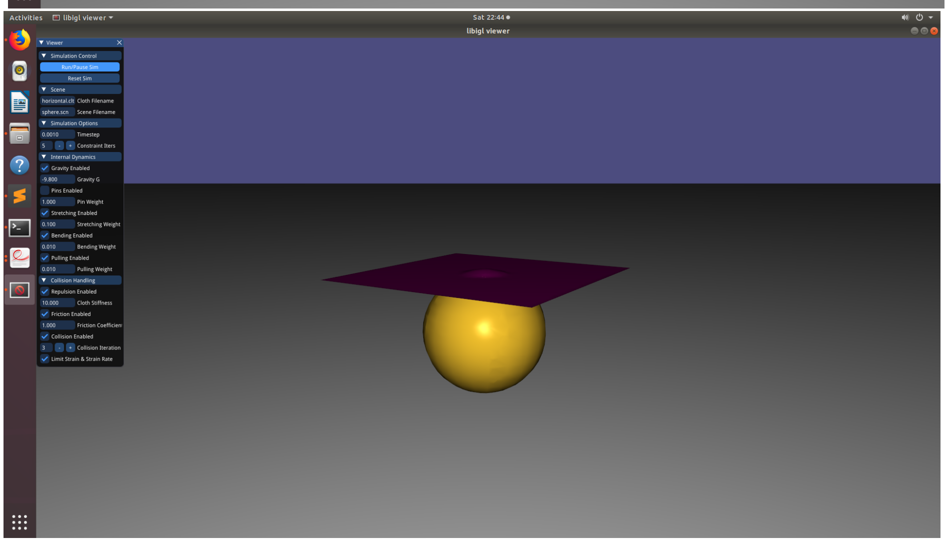


Figure 1: Folding on floor





5.2 Simple wrap on smooth surface

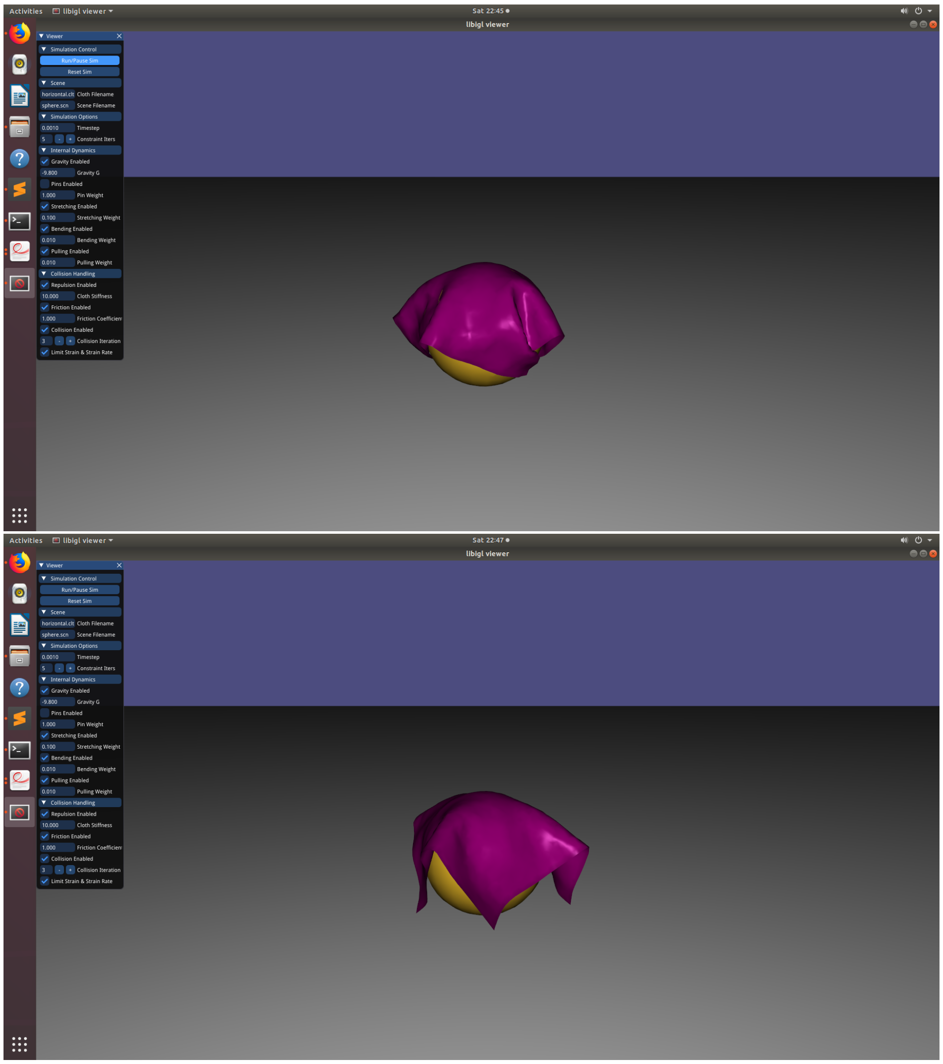
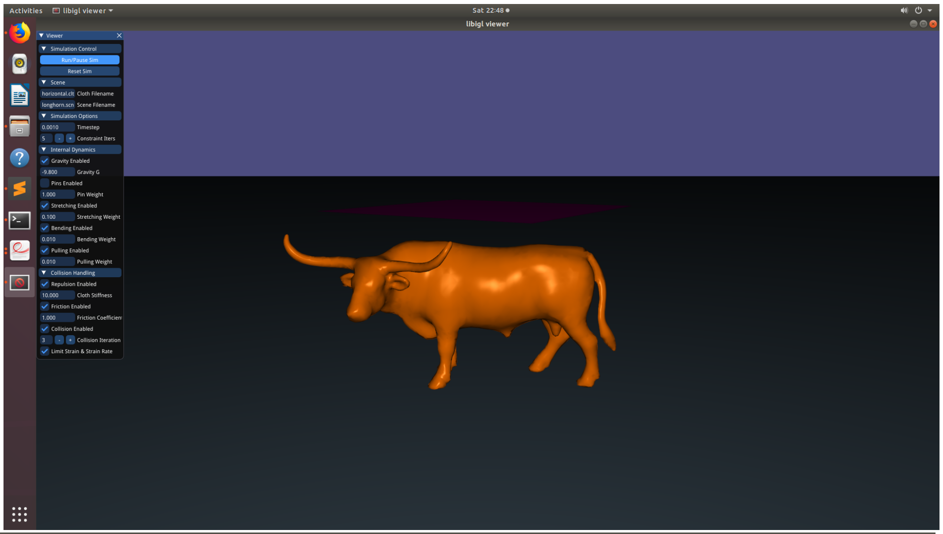
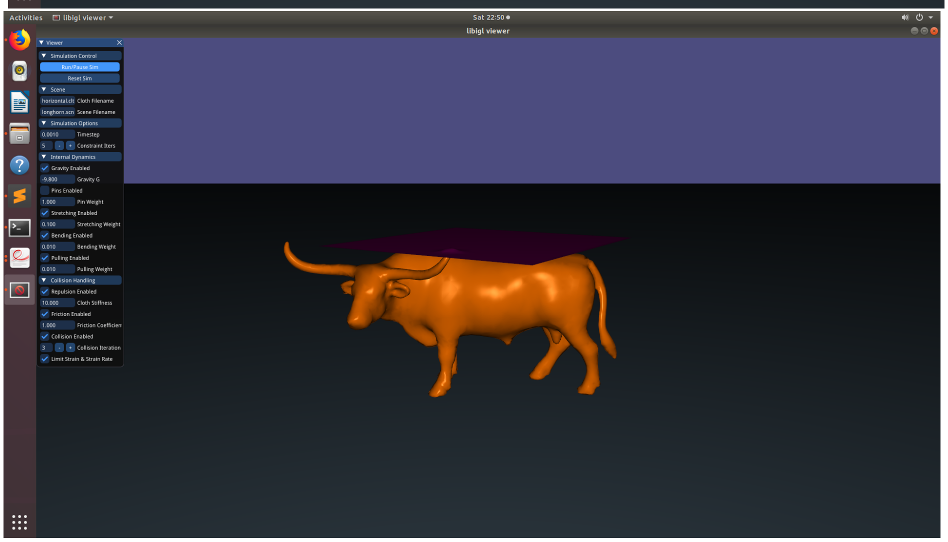


Figure 2: Wraps on spheres





5.3 Wrap on pointy surface

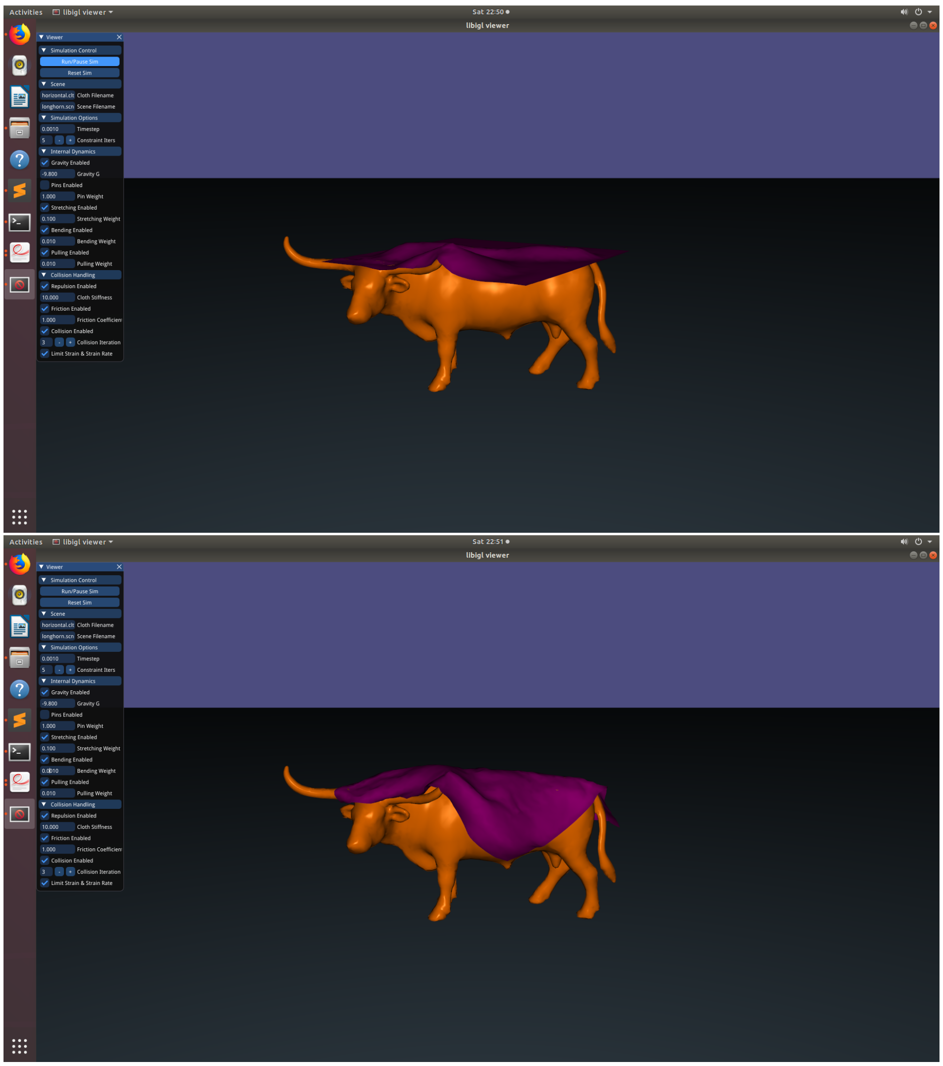
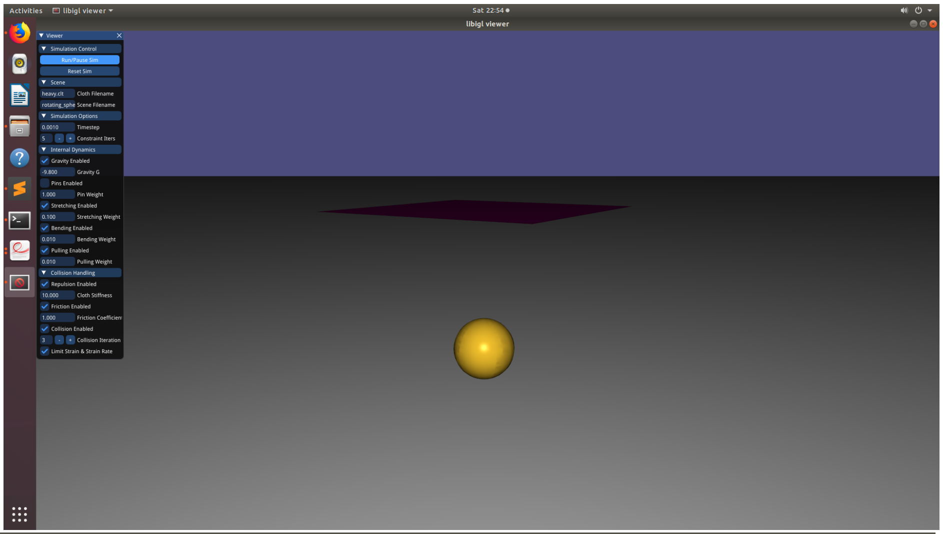
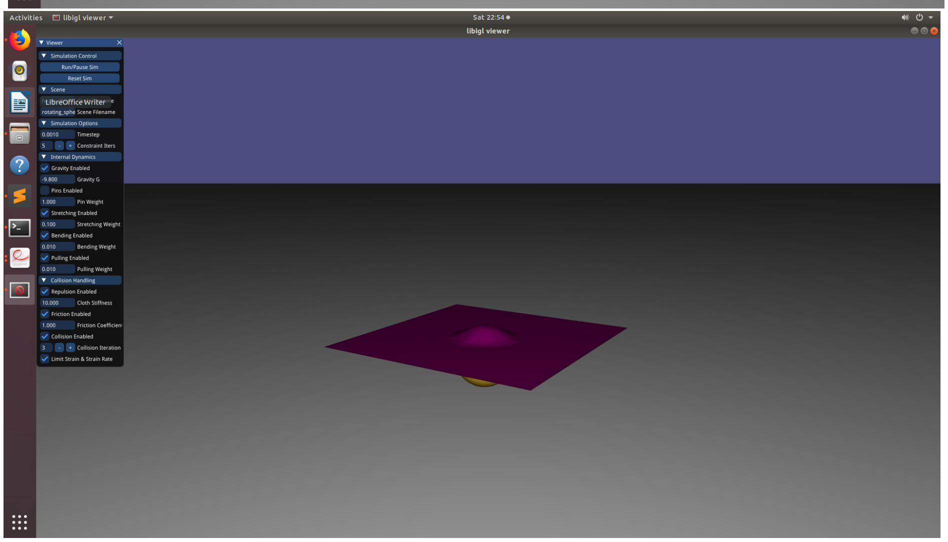


Figure 3: Wraps over the longhorn





5.4 Wringing on spinning ball

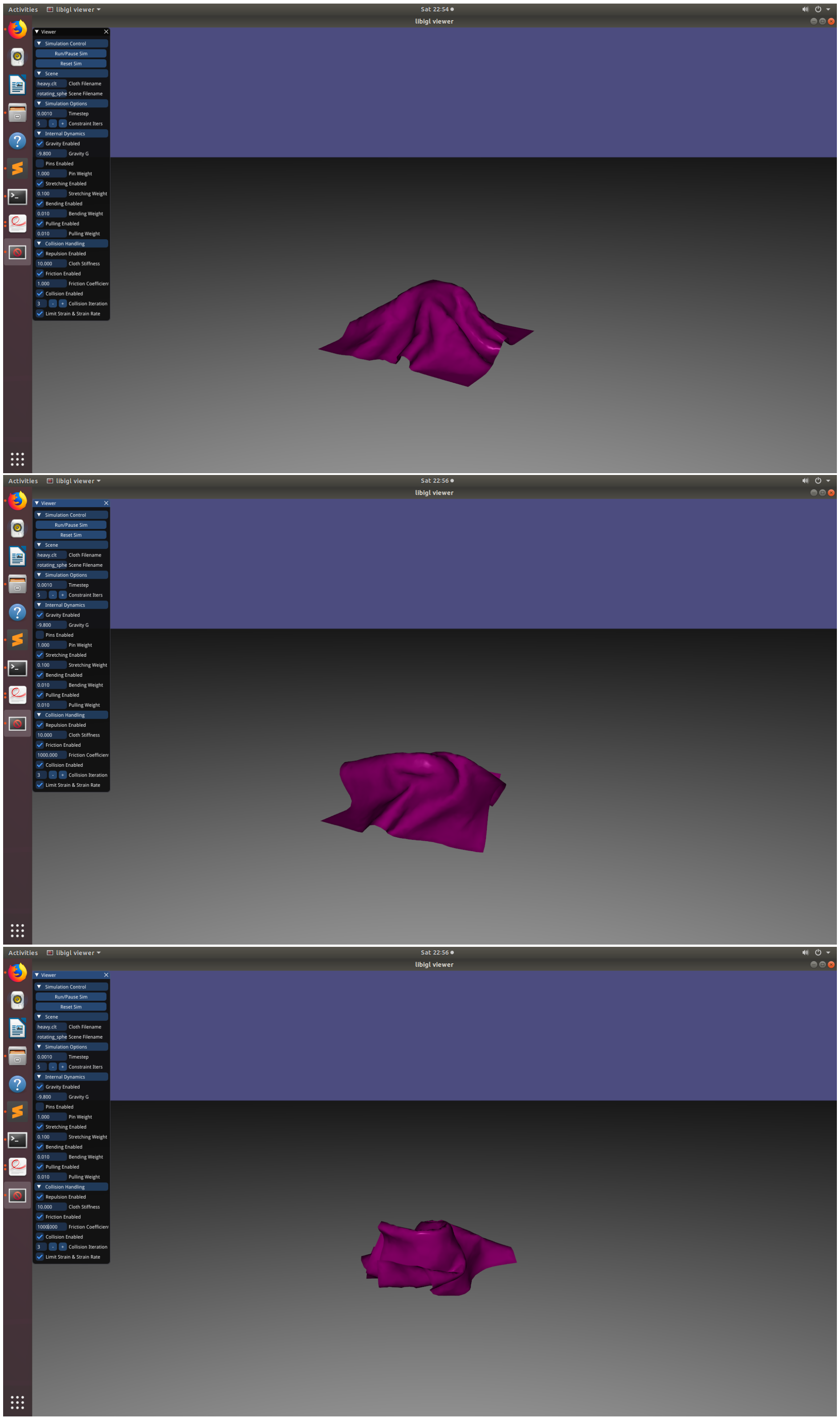


Figure 4: Wrings with the spinning ball. Test for friction