Contact Point Generation for Convex Polytopes in Interactive Rigid Body Dynamics

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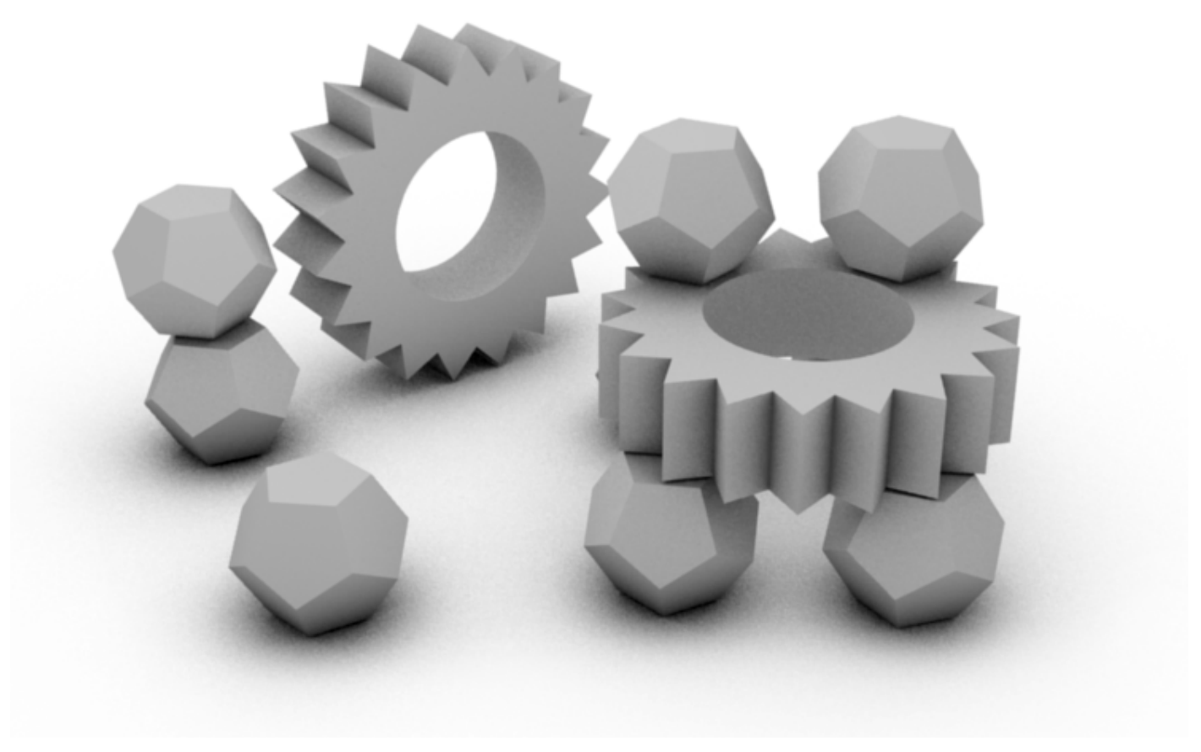
Abstract

WITH this paper, we address an issue which is of major impact on the animation quality, when using iterative contact force computation methods. The issue is robust generation of contact points for convex polytopes. A novel contact point generation method is presented, which is based on growth distances and Gauss maps. We demonstrate improvements when using our method in the context of interactive rigid body simulation.



A Practical and Robust Method

In the following we will describe our approach to contact point generation. Taking a top-down approach, we first outline the method and then elaborate on the details in the following subsections. The method:

1. Compute a contact normal $\mathbf{n}$ using the GJK–GD algorithm
2. Use the normal $\mathbf{n}$ to obtain the geometric features of the contact, using a Gauss mapping
3. Obtain contact points and distance measures using the feature intersection approach described in the following.

Contact Normal Using Growth Distances

We define the growth distance problem formally as

$$\mathbf{p}_G = \arg\min\left\{\alpha : \mathcal{A}_\alpha \cap \mathcal{B}_\alpha \neq \emptyset\right\} \tag{1}$$

where $\mathcal{A}_\alpha = \alpha(\mathcal{A} - \mathbf{p}_A) + \mathbf{p}_A$ is the contraction of $\mathcal{A}$ around contraction point $\mathbf{p}_A$. $\mathcal{B}_\alpha$ is defined analogously. The contraction points $\mathbf{p}_A$ and $\mathbf{p}_B$ have to be in the interior of $\mathcal{A}$ and $\mathcal{B}$ respectively.

$$\mathbf{p}_G = \arg\min\left\{\alpha : \underbrace{\left(1 - \frac{1}{\alpha}\right)}_{t}(\mathbf{p}_A - \mathbf{p}_B) \in \mathcal{A} - \mathcal{B}\right\} \tag{2}$$

where the scaling factor $0 < \alpha \leq 1$ and $t \in (-\infty, 0]$. Clearly, when $t = 0$ then $\alpha = 1$ and both $\mathcal{A}$ and $\mathcal{B}$ are unscaled. Equation (2) is a raycasting problem, which is well known and easy to solve, especially using the GJK distance algorithm. In the following we will refer to this method as the GJK–GD method.

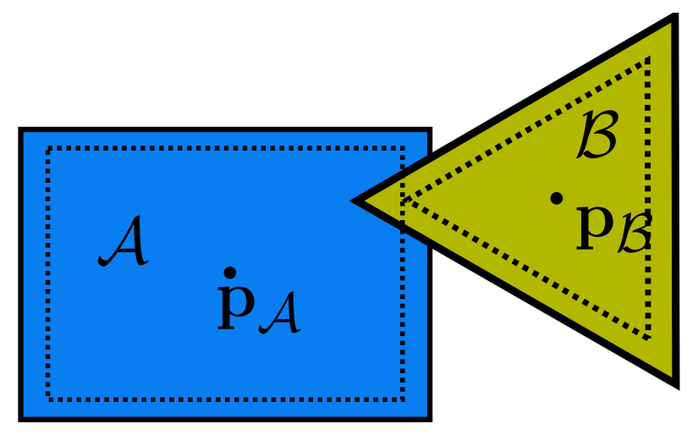


Figure 2: *The growth distance is defined as the amount that $\mathcal{A}$and $\mathcal{B}$ must be contracted, in order to be in touching contact. $\mathbf{p}_A$ and $\mathbf{p}_B$ are the chosen contraction points for $\mathcal{A}$and $\mathcal{B}$ respectively.*

Gauss Maps

A Gauss map is simply a mapping between surface normals and object features. Since all points on a facet have the same surface normal, the facet is represented as a single point on the Gauss map, observe Figure 3(b).

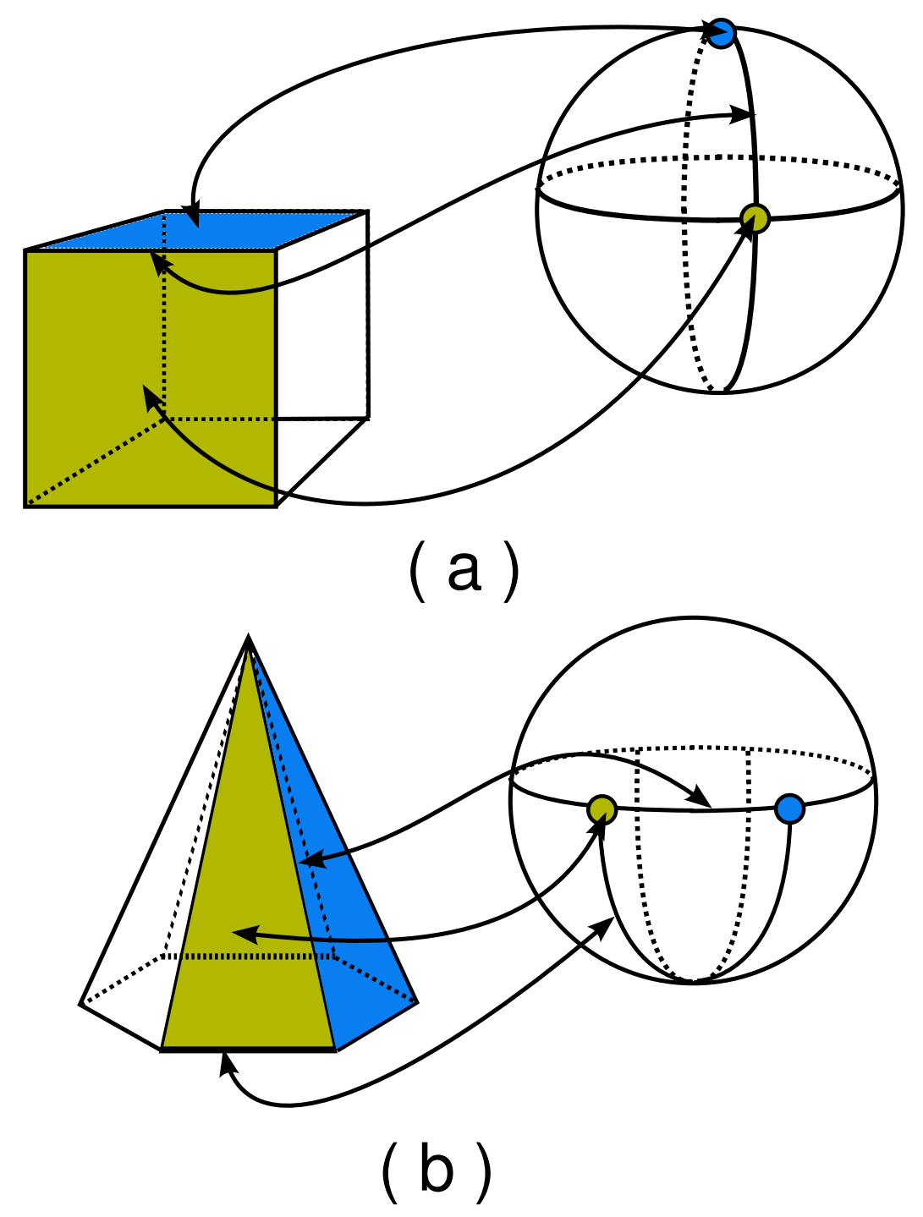
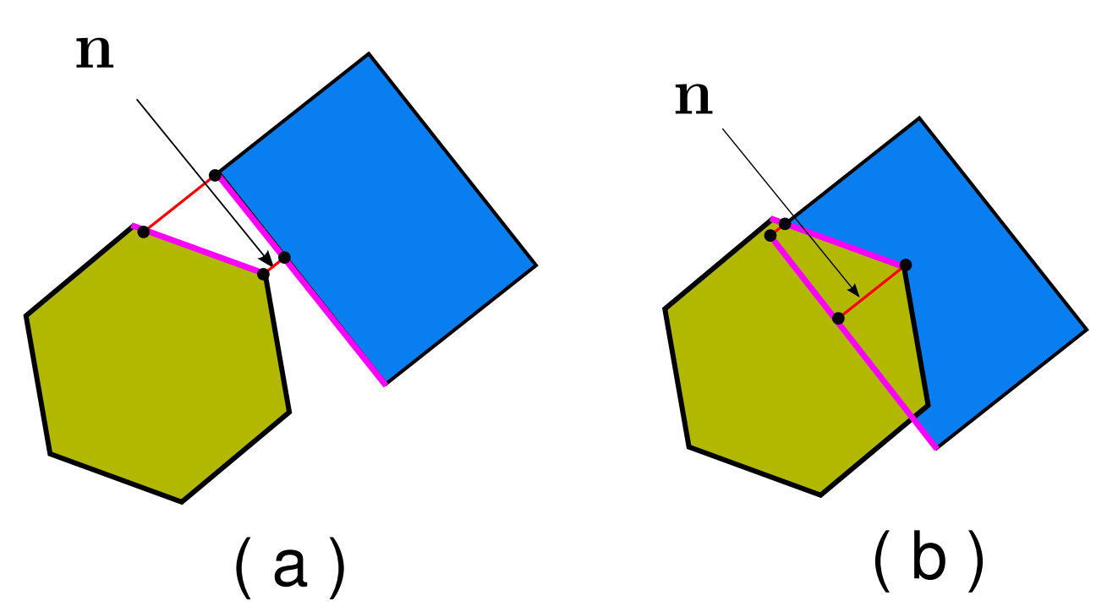

(a)
(b)

Figure 3: *Examples of Gauss maps. 3(a) The normal space of a box geometry is mapped onto a unit ball.*

Using a Gauss map allows us to expand a contact normal into a region and thereby in later steps allowing us to find all the contact points of the contact region.

Feature Intersection in The Contact Plane

After obtaining a contact normal using GJK–GD, we obtain one geometric feature from each Gauss mapping. To find the contact points, we project each feature onto the contact plane defined by the contact normal, and take their intersection in the plane.



(a)
(b)

Figure 4: *By way of the contact normal $\mathbf{n}$, the corresponding faces (highlighted in pink) are found using the Gauss map. The faces are intersected along the contact normal.*

Results

We perform interactive tests where user must carry out a specific task. Contact point generation has significant impact on the users ability to succeed in performing such tasks. For comparison we used a well-known contact tracking method.

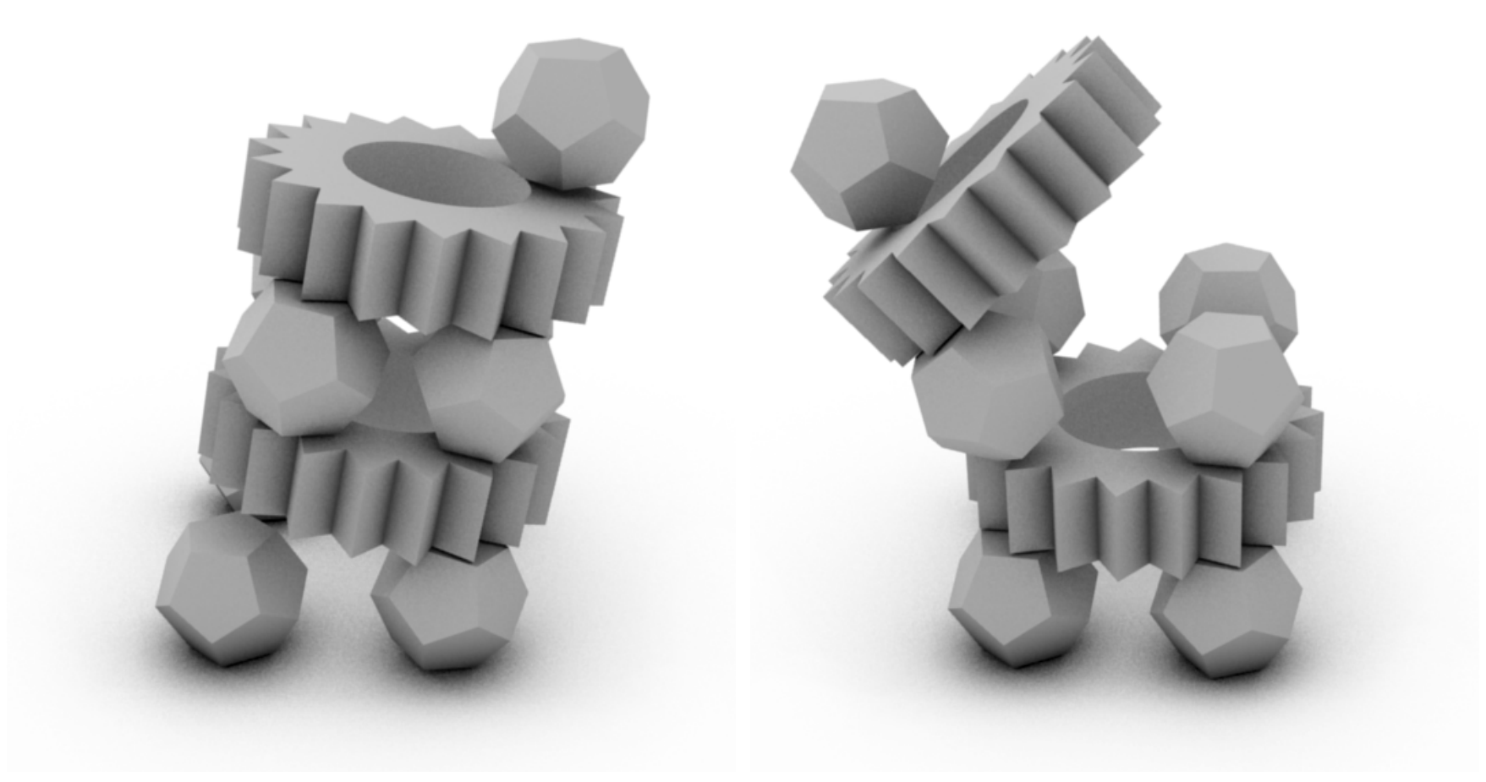


Figure 5: *Interactive test scenario of 9 convex objects and 2 gears (composites of convex objects). The user is asked to build a small tower and tilt it by applying a downward force to the top-most object.*

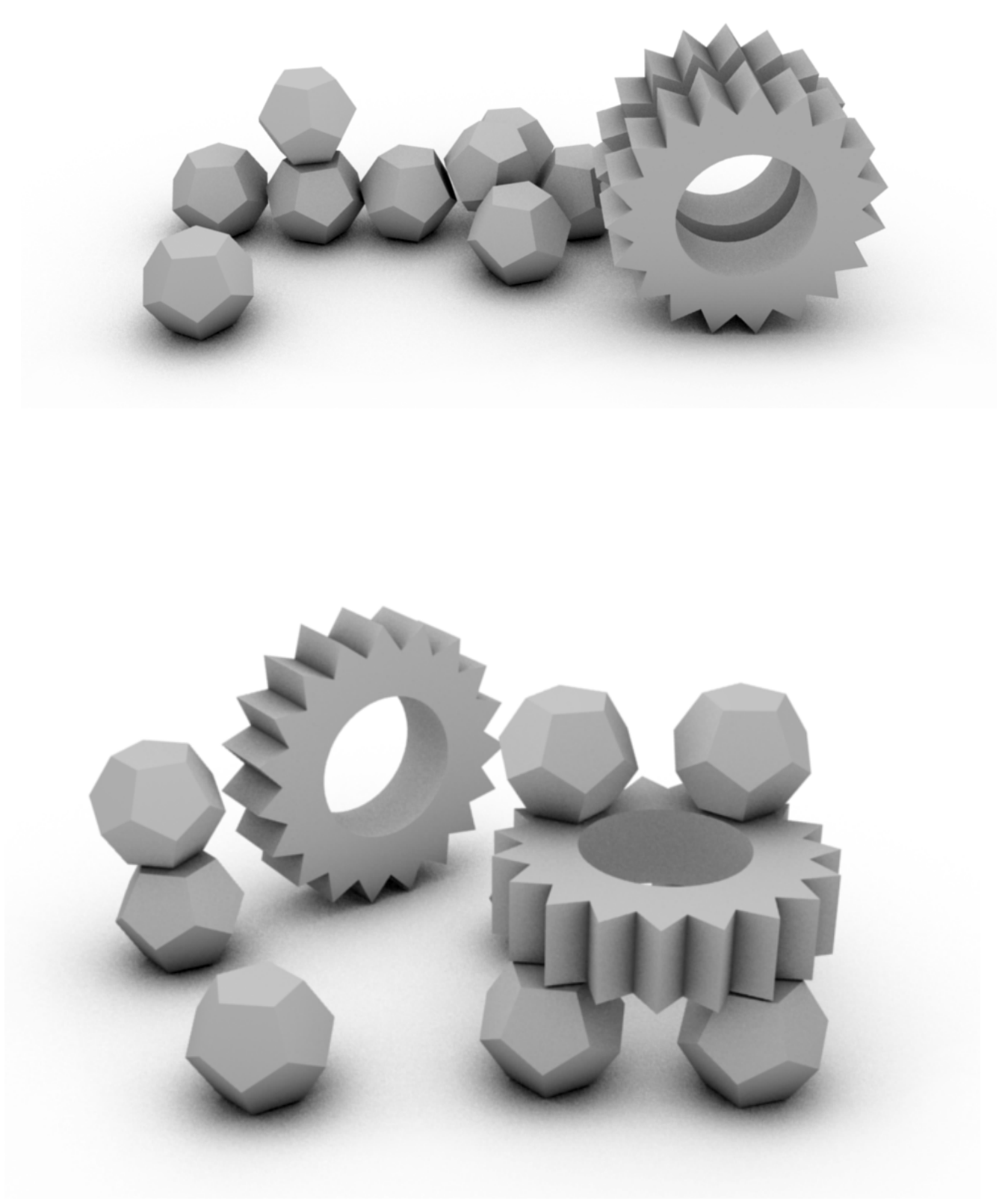


Figure 6: *Interactive test scenario of 9 convex objects and 2 gears(composites of convex objects). The user is asked to build a small tower and tilt it by applying a downward force to the top-most object.*

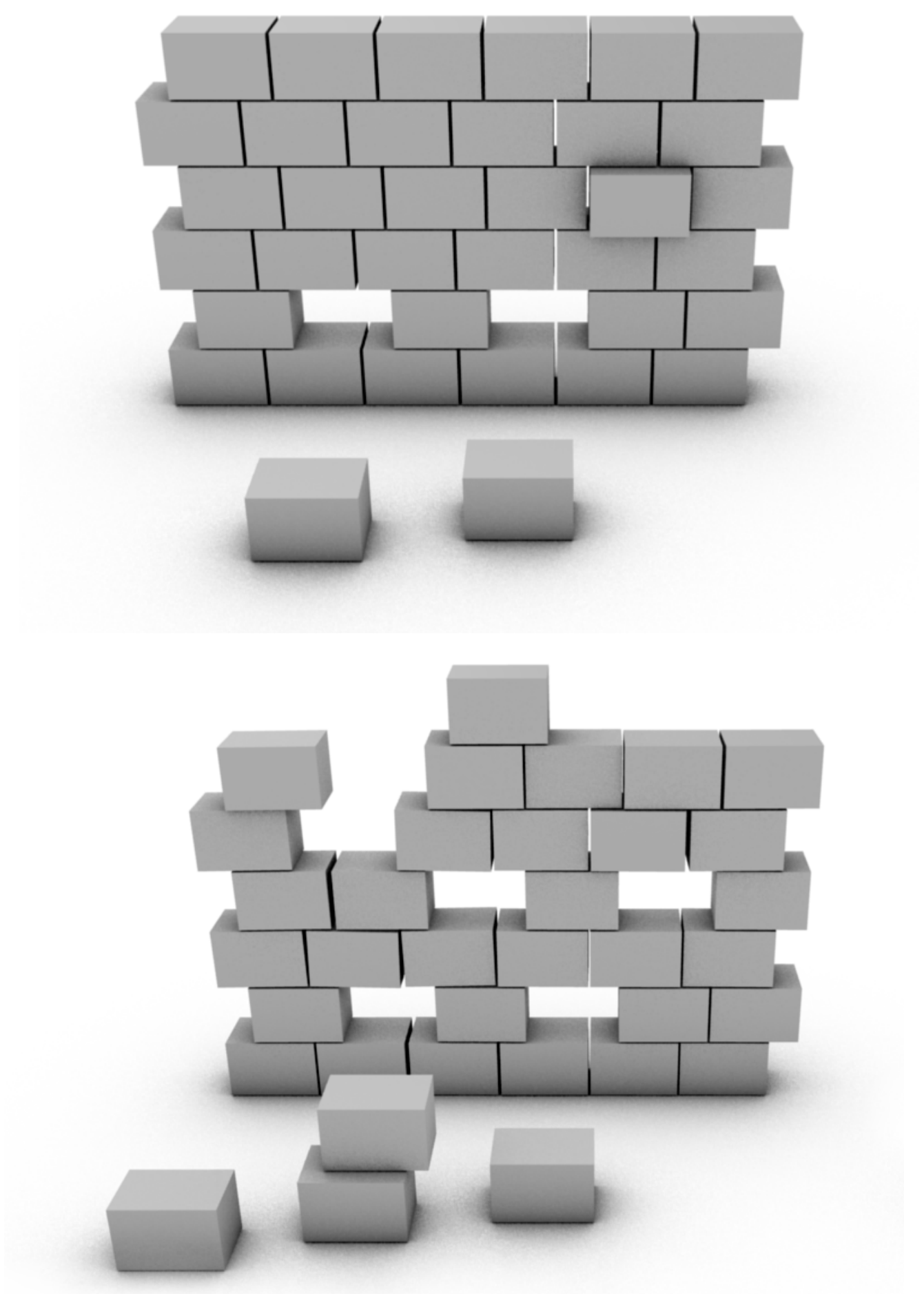


Figure 7: *Interactive test where bricks are removed one by one from a brick wall. Notice that our contact point generation method produces very stable animation results*

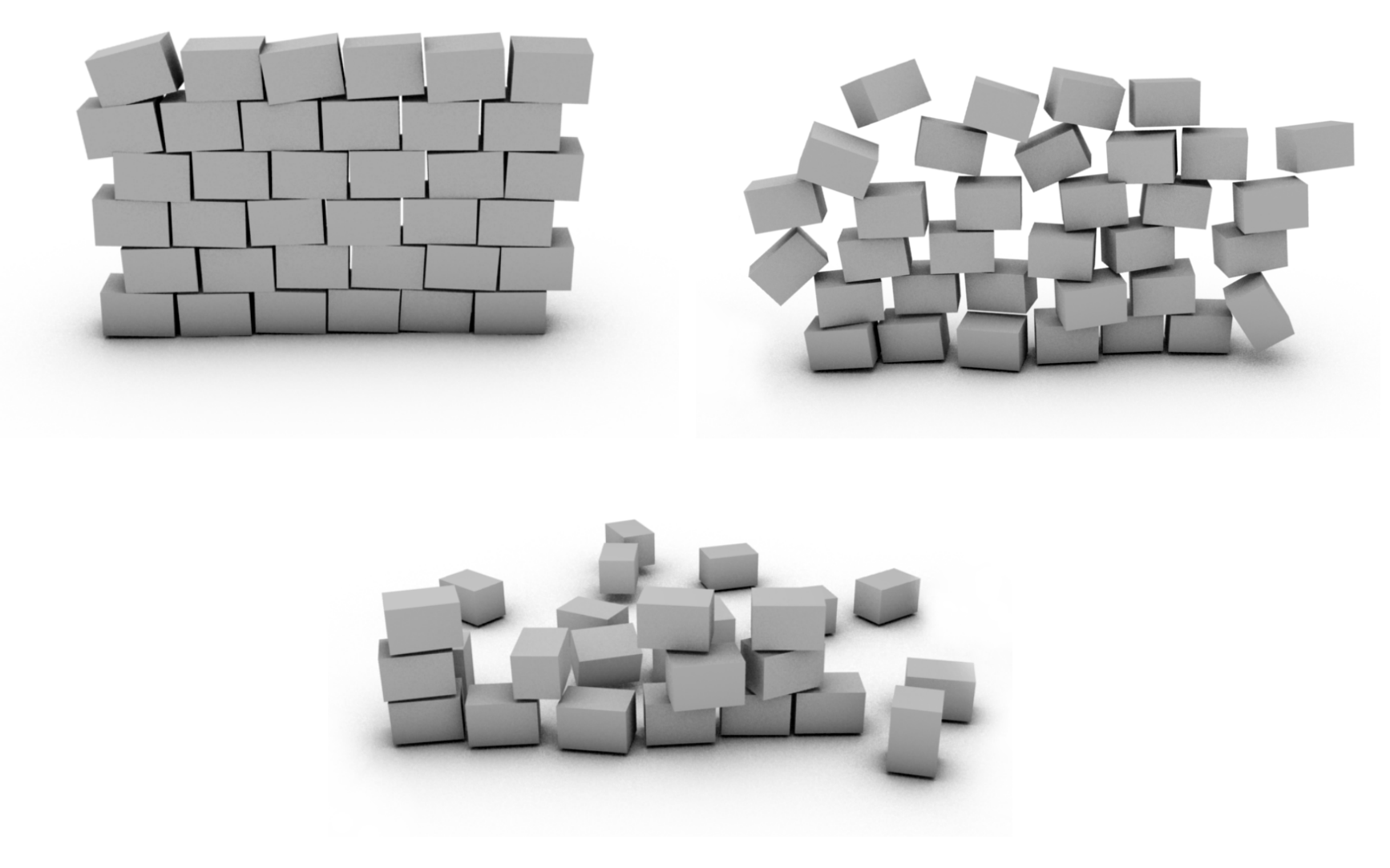


Figure 8: *Interactive test where bricks are removed one by one from a brick wall. In this case, unstable contact point generation (contact tracking) performs very poorly, and prevents the user from carrying out the task all together*

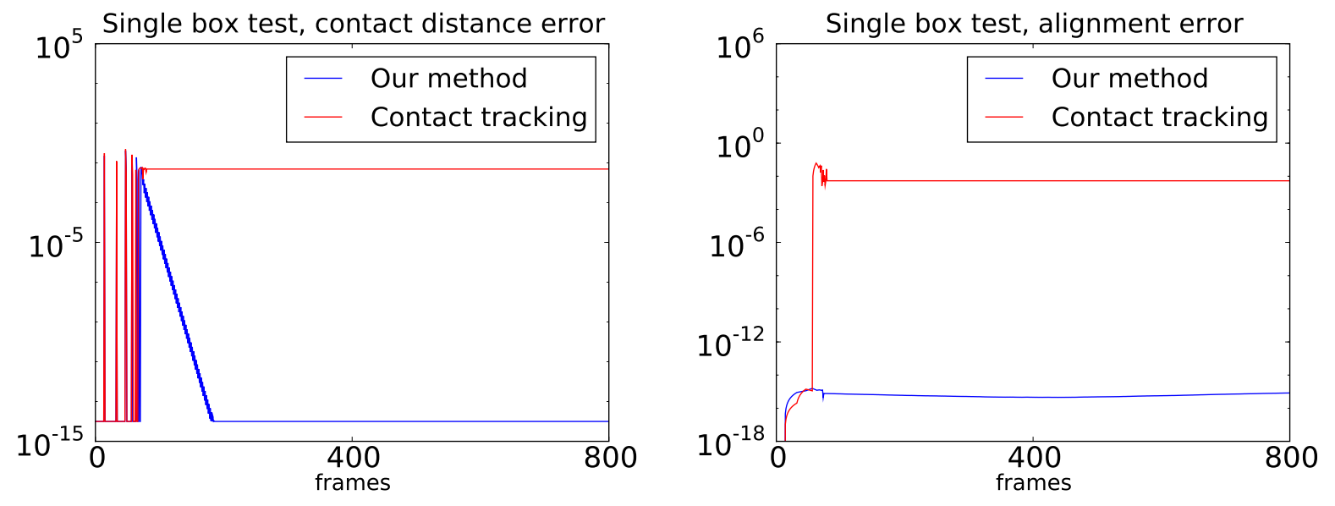


Figure 9: *Comparison of animation quality measures, our method versus the state-of-the-art method (contact tracking). Based on an interactive test, of dropping a box onto a plane. Observe, our method delivers less oscillatory behavior and shows several orders of magnitude lesser constraint violation and alignment errors during the entire simulation. We speculate that the ability to keep alignment and penetration errors low is of great importance to the stability and plausibility of the final animation quality.*

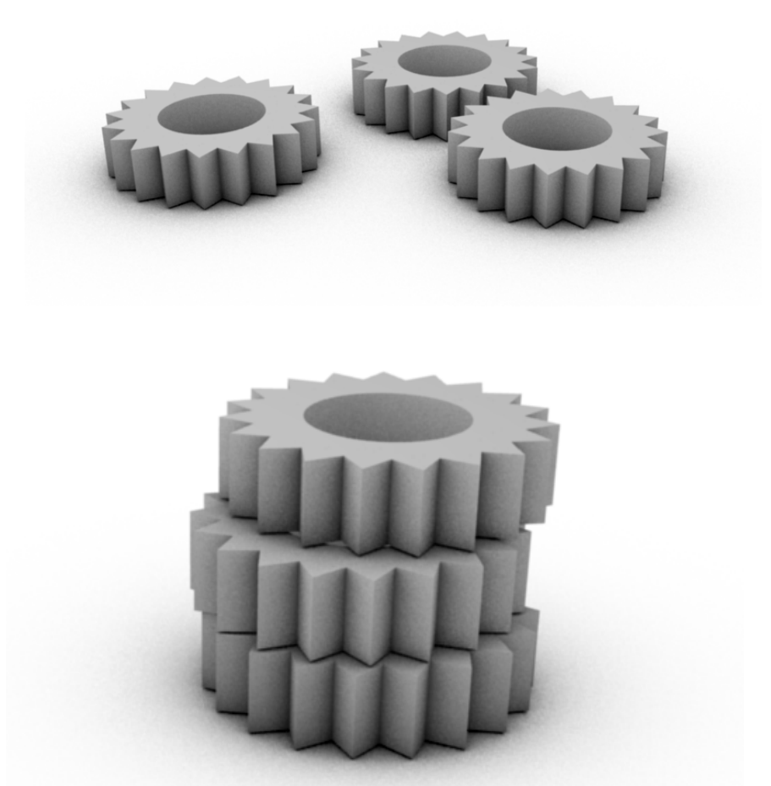


Figure 10: *Our method works with composite objects, made from multiple convex subparts*

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