Pre-stabilization for Rigid Body Articulation with Contact and Collision

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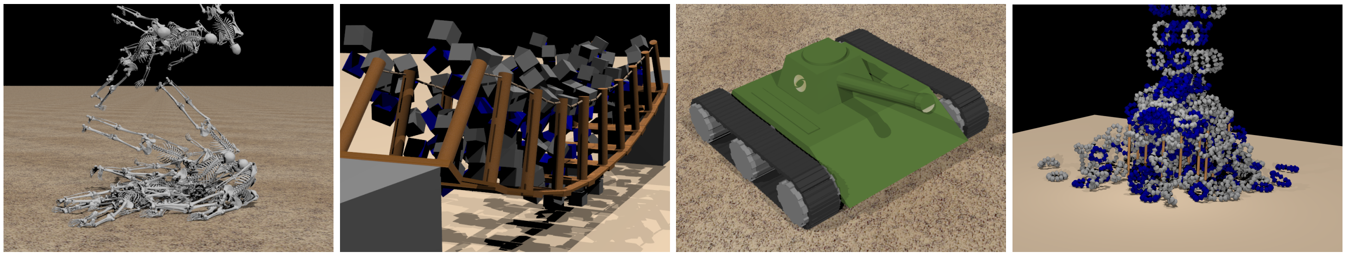

Figure 1: The ability to articulate rigid bodies allows animators to build more complex physical systems.

Introduction

We propose a novel approach for dynamically simulating articulated rigid bodies undergoing frequent and unpredictable contact and collision. Many practitioners solve these types of problems using reduced coordinate (or generalized coordinate) formulations that parameterize the degrees of freedom in a manner consistent with the constraints of articulation, effectively reducing the overall degrees of freedom, eliminating those that could violate the constraints. However, consistency conditions are required to ensure that closed loops are actually closed adding a nonlocal constraint to the system. Moreover, unpredictable contact and collision can pose serious difficulties. We have found it easier to design algorithms that treat closed loops and frequent contact and collision in maximal coordinates, and propose a novel maximal coordinates approach that builds on the previous work of [Guendelman et al. 2003]. Our approach works with any black box method for specifying valid joint constraints, and no special considerations are required for arbitrary closed loops and/or branching. Moreover, our technique is linear both in the number of bodies *and* in the number of auxiliary contact and collision constraints, unlike many other methods that are linear in the number of bodies but not in the number of auxiliary constraints.

Algorithm

Our pre-stabilization method relies on the ability to target any desired joint state. One simply temporarily evolves a pair of rigid bodies forward in time to obtain a predicted joint state, and then uses any black box joint model to determine the closest allowable or desired joint state as input to our nonlinear solver. This entails solving a $6n$ degree of freedom nonlinear equation where n is the number of joints in the articulated rigid body, and the situation is compounded by contact and collision. Thus, we take an iterative approach similar to and commensurate with the approach for contact and collision proposed in [Guendelman et al. 2003], i.e. we apply impulses one joint at a time. Furthermore, we iteratively solve the 6 degree of freedom nonlinear system for each joint using Newton iteration on smaller systems of 3 equations by first finding and applying a linear impulse to satisfy the positional constraint, and then finding and applying an angular impulse to satisfy the orientation constraint.

The primary benefit of our impulse based pre-stabilization technique is the seamless integration of the impulses used to enforce the position and orientation articulation constraints with those in an impulse based contact and collision algorithm. We integrate our algorithm with [Guendelman et al. 2003] as follows:

- Process Collisions (followed by Velocity Post-Stabilization)
- Integrate Velocities (followed by Velocity Post-Stabilization)
- Resolve Contacts & Articulation Pre-Stabilization
- Integrate Positions (followed by Velocity Post-Stabilization)

Since processing collisions and integrating the velocity forward in time both change the values of the velocity field, a velocity post-stabilization technique is used after each of these steps. Pre-stabilization is tightly integrated with the contact processing algorithm by using the same contact graph for the contact stage to process articulation constraints. A similar process is used for shock propagation, although we remove the infinite inertia aspect of the shock propagation algorithm *only* when computing the impulses due to articulation (otherwise, it is used as usual). Finally, the positions and orientations are integrated forward in time using the velocities calculated by applying all the impulses necessary to handle both the contact and articulation constraints. This has enabled the treatment of large stacks of articulated bodies with robust contact *and* articulation handling. Note that we do not apply velocity post-stabilization before integrating the positions forward in time, since the velocities obtained during contact processing and pre-stabilization should not be modified until the positions and orientations are corrected for contact and constraint enforcement. However, after moving the bodies, we again apply velocity post-stabilization to ensure velocities are valid for the next step.

Conclusions

Our method readily handles complicated contact, collision and articulation scenarios such as a tank with gears driving treads or twenty skeletons dropping into a pile (with over 20 million triangles). No special treatment is required for branching, closed loops, contact, collision, friction, stacking, etc. The algorithm is quite efficient, linear in the number of bodies and auxiliary constraints, and necessitated only a small overhead comprising about 5% of the overall computation time. As future work, we will consider adapting our impulse based approach to a generalized coordinates model for articulated bodies.

References

GUENDELMAN, E., BRIDSON, R., AND FEDKIW, R. 2003. Nonconvex rigid bodies with stacking. *ACM Trans. Graph. (SIGGRAPH Proc.) 22*, 3, 871–878.

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