Stabilizing Impossible Collisions with Loki

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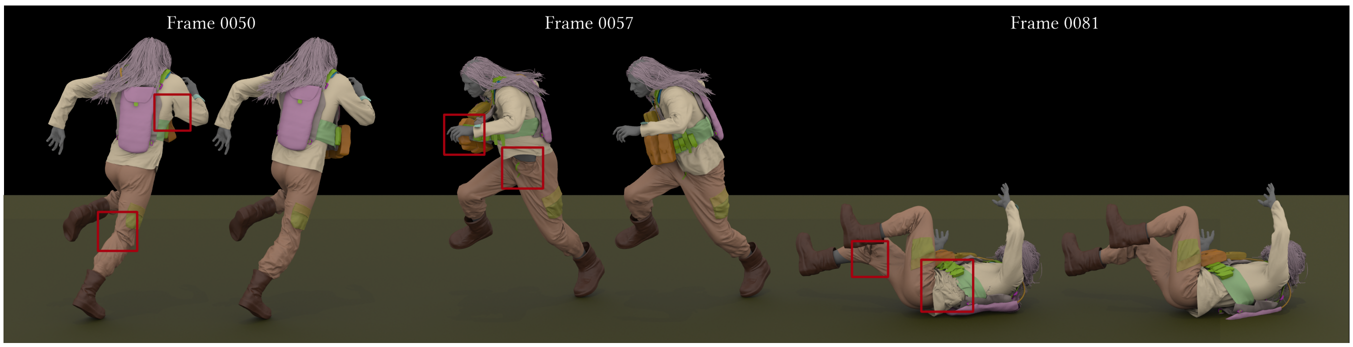

Figure 1: Character animation often suffers from nonphysical pinching (e.g., at armpits and knees) which can destabilize costume simulation (left, red boxes). Our proposed methods (right) stabilize collisions without changing the animation. ©Wētā FX.

Abstract

We present a suite of techniques from our in-house simulation framework, Loki, addressing the pervasive challenge of collision instabilities in character effects, particularly in cases where non-physical pinching prevents collision resolution. We introduce a proximity-tolerant mode for contact projection that trades collision residual for stability, a compliant kinematic mechanism for on-demand gap expansion, and contact-aware strain limiting to prevent penetrations while enforcing target edge lengths. Additionally, we showcase our tools for collider management, including hierarchical collision exclusion, one-sided collision handling, and paintable collision thickness maps. These techniques collectively demonstrate a robust and intuitive workflow for combining physically based collisions with challenging production animations.

CCS Concepts

• **Computing methodologies → Physical simulation**.

Keywords

contact mechanics, physically based animation

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1 Motivation

Collision handling in tricky animation scenarios has long been an industry-wide challenge. From a solver's perspective, no correct solution exists when upstream animations fail to provide sufficient gaps for collision resolution. Unfortunately, this predicament is common in practice, as animators often cannot accurately predict the necessary clearances for downstream processes. Moreover, procedural gap-opening deformers typically fall short of achieving the realism offered by physics-based simulation. This tension between animation constraints and simulation robustness necessitates innovative solutions to enhance collision handling in production environments.

We present several strategies that we have developed within Loki [Lesser et al. 2022] to make collision handling more adaptable and resilient when faced with challenges of this type. These include a proximity-tolerant mode for hard contact projection which strategically trades collision residual for stability; a compliant kinematic mechanism that offers on-demand gap expansion; and a constitutive strain-limiting approach that mitigates penetrations from edge shrinking. Additionally, we showcase an array of front-end controls that empower artists to manage collision interactions. These intuitive tools encompass hierarchical collision exclusion, enabling

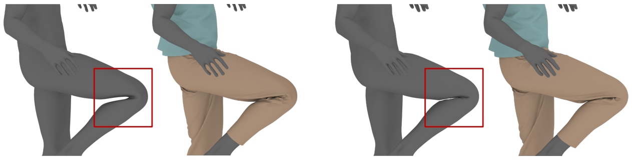

Figure 2: Comparison of gap expansion upfront (left) and on-demand (right). ©Wētā FX.

multi-scale control at object type, object pair, and vertex levels; one-sided collisions for seamless de-penetration of stuck colliders; and paintable collision thickness maps that create vital slack space for folding. These advancements collectively transform Loki into a more forgiving solver, capable of blending stable physics with production animation, enhancing efficiency by reducing the need for manual intervention.

2 Collision Handling Strategies

Proximity-tolerant Mode for Contact Projection. Loki assigns a thickness value to each colliding primitive (vertices, edges, or faces), defining an extruded proximity region. Ideally, these regions should not overlap when collisions are fully resolved. In practice, however, this is not always the case. Primitives may enter proximity of others at the beginning of a timestep, especially when multiple colliders stack up. Attempting to separate primitives in proximity can cause a cascade of collision violations, many of which may be impossible to resolve without creating more contacts. This contact chain quickly becomes unmanageable. Rather than attempting to push colliders outside each others' proximity, our method tolerates the overlaps and projects their velocities to a state where they cease approaching each other. This strategy effectively breaks the chain of escalating contacts and ensures a feasible solution within a few collision iterations, resulting in fewer artifacts and pops.

Compliant Kinematics. Character animation often presents challenges in pinching areas such as armpits, elbows and knees. Predicting the appropriate gap size for dynamic simulation in these areas is difficult: a small gap can lead to contact jitters or blowups, while a large gap may introduce unnatural and excessive deformation and fail to capture the desirable skin bulge, see Fig 2. To overcome this, we introduced compliant kinematics in Loki, allowing for dynamic gap adjustment. Artists paint a compliance map on the character mesh, which allows kinematic vertices (vertices of passive colliders) to deform without momentum when in contact. A restorative energy potential ensures gaps are created when pinched areas are formed, while deforming only negligibly otherwise. Further details are provided in the supplemental document.

Constitutive Strain Limiting. Real cloth and fur tend to have a superlinear relationship between stretching strain and the strength of the resulting forces. This is typically modeled by applying strain limiting as a post-collision pass in each simulation iteration. However, similar to proximity contacts, this approach can cause a cascade of collision violations and potentially destabilize the simulation. Inspired by Codimensional Incremental Potential Contact [Li et al. 2021], we replace the post-collision method with a constitutive approach, integrating strain limiting into our contact projection framework. This strategy ensures that the collision solver and strain limiting algorithm work in harmony, reaching a global agreement upon convergence. Derivation details are available in the supplemental document.

3 Collider Management

Multilevel Collision Exclusion. Our system offers a comprehensive suite of collision exclusion options. Users can fine-tune collision behavior by enabling or disabling each collider for various interaction types, including dynamic-dynamic, dynamic-kinematic, and self-contacts. The interface also allows for easy addition of exclusion rules for specific collider pairs. Additionally, we provide paintable maps on each collider for precise control of vertex-level contact visibility. For even more granular control, users can select sets of vertices within or between objects that will not collide with one another, but will collide with all other geometry as usual. This versatile toolkit empowers artists to manage collisions efficiently, often proving to be a faster and more cost-effective solution than rectifying animation imperfections.

One-sided Collisions. We implemented an optional one-sided approach that enabled collisions only towards the "outer" side of certain meshes, particularly beneficial for character skin and smaller pendants. This method is justified by the solid internal nature of these elements, where collisions from the inside are theoretically impossible but may occur due to factors such as early iteration termination in previous steps. In such anomalous situations, our system tolerates the artifact and continues the simulation, allowing the tunneling on the collider to potentially resolve to the "correct" side of the mesh. Importantly, this method is purely geometric and does not rely on SDFs, enabling one-sided collision resolution for both penetrating and open meshes. By defaulting to single-sided collisions on character skins, this forgiving approach facilitates most shots to complete in the first attempt with minimal or unnoticeable collision failures.

Paintable Collision Thickness Maps. To further enhance collision management, we use paintable maps for collision thickness. These maps allow artists to create extra slack space on wrinkles and folds by scaling the collision thickness on either the outer or inner side of any collider. It's crucial to note that collision thickness is distinct from material thickness, which plays a vital role in defining the stretching and bending behavior of a scene object. This feature provides an additional layer of control, allowing for more nuanced and stable collision behavior in complex folding regions.

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