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MICADO: Models of Interactive Constraints for the Assembling of 1D Deformable Objects

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Abstract

This paper introduces a set of Lagrangian constraints, allowing most needed interaction and combinations of one-dimensional deformable elements for creating complex structures. The proposed tools can potentially be used with a large set of available 1D-models. All constraints formulation are compatible with linear, displacement-based, integration schemes. The proposed constraints allow for real-time complex structure simulation, and also novel interactions between simulated objects. Details can be found in [TG08]. Various examples are provided, illustrating the benefit of the proposed numerical tools.

Categories and Subject Descriptors (according to ACM CCS): I.3.5 [Computer Graphics]: Computational Geometry and Object ModelingPhysically based modeling ; I.3.7 [Computer Graphics]: Three-Dimensional Graphics and RealismAnimation

1. Introduction

In recent years thin elastic solids have become more and more used in the computer graphics community. An important research effort has been achieved on modeling such objects. It is now possible to handle deformations in an interactive, and mechanically accurate way. Such models can be used for modeling objects that obviously look like deformable lines (such as ropes [ST07], surgical threads [CDL*05], cables [GS07],etc.). They can also be used as an animation skeleton for more complex shapes (e.g. hair wisps [BAC*06], muscles...). Surprisingly, while the community has made a significant research effort on the mechanical models for 1D-objects, only few work has been done on the methods and tools for sophisticated interaction on these objects. Equally, numerical tools for tight coupling between such models, in order to create complex structures, have been somewhat ignored. Lagrangian constraints are known to be an efficient method for linking models together. They can also produce effects that classical collision-based methods can barely provide (e.g. static link between objects). However, it is difficult to find non-trivial examples of such

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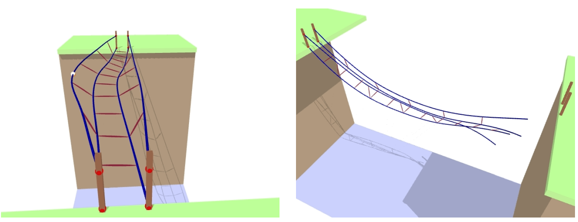

Figure 1: *A bridge modeled with 4 deformable ropes, linked with distance constraints. Such constraints improve efficiency, maintaining realistic visual behavior.*

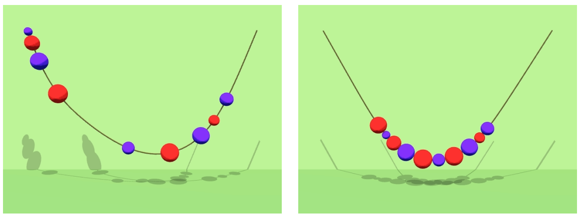

Figure 2: *Threading of a pearl necklace, illustrating the interaction between the 1D deformable model and the pearls.*

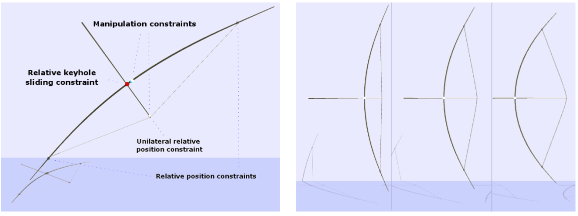

Figure 3: *Bow simulation: modeling by constraints and extension.*

Experiment	Absolute λ	Relative λ	cost
Bridge	32	21	1.7ms
Necklace	8	10	0.4ms
Bow	11	16	0.56ms
Cable bundle	7	35	1ms
Spider net	28	49	4.0ms
DNA	8	32	1.1ms

Table 1: *Practical computation cost of the proposed examples with our method.*

constraints in the computer graphics literature. Research on one-dimensional deformable models is probably still a hot topic in the field; such models are currently mature enough in the animation community for next step, that is combining them together. We propose here a set of constraints that are compatible with displacement-based backward integration methods [DSB99].

2. Applications and results

We have implemented the described constraints, and used them for a number of simulations. We base our examples on the 1D model described described in [TGDM07]. They were run on an Intel Centrino Duo laptop, with two 2Ghz processors and 1Gb of RAM. Constraint computation times are fast enough to provide relatively complex scenes at interactive rates

The second illustration is devoted to structures where "loops" are present: a rope bridge. In that structure, a large number of loops is involved. In the example shown, the ropes are linked (both for footpath and handrail linkage) using 21 distance constraints. Using such a constraint instead of a mechanical model provides a significant speed up, while maintaining realism (see figure 1).

Pearl constraints provide a smart and efficient way to simulate objects sliding on a string. We illustrate their use with the threading of a pearl necklace (see figure 2).

The final example illustrates a practical example that is classically not simulated using complete deformable sets: the mechanical system is composed of an arrow, and a bow. We reproduce the behavior of a bow that projects an arrow (see figure 3), using three 1D models for the limbs, the string and the arrow.

All these animations run at interactive rates, with an average cost of about 1ms per simulation step. Using unknown reordering described in the previous subsection, efficient solving is reached (see table 1).

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