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Explicit Integrators Analysis for a Simulation Engine

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Abstract

One of the most significant elements when dealing with particle based object modeling in virtual reality applications is the integrator used to compute the state of the particles, because it grants the deformation stability of the scene objects. This paper presents a study of the response achieved by a set of integrators applied to a multiresolution mass-spring model used in a virtual reality environment. The dynamic of the animation engine has been adapted to each one of the tested integrators, comparing the different responses obtained in each case taking into account the efficiency and the stability of the object dynamics.

Categories and Subject Descriptors (according to ACM CCS): I.3.6 [Computer Graphics]: Methodology and Techniques I.3.7 [Computer Graphics]: Three Dimensional Graphics and Realism I.3.m [Miscellaneous]:

1. Adaptive Multiresolution Mass-Spring Model

The multiresolution representation technique selected is a surface model that applies the wavelet transform to select the most suitable level of resolution for the scene representation needs. The multiresolution representation can be achieved both globally and locally. The model supports the definition of regions at different resolutions, allowing the existence of areas with finer levels of detail on the object as well as others with coarser levels of description to obtain a plausible response from the point of view of sensorial feedback [GPR05]. The magnitude of force $F_{t,j}$ applied to a particle at resolution level j is determined by the action of the external forces $F_{e,j}$, the internal forces $F_{i,j}$ (Hook's Law), and the dumping force $F_{a,j}$, so

$$F_{t,j} = F_{i,j} + F_{e,j} + F_{a,j} \tag{1}$$

The internal forces are computed using Hook's Law $F_h = -k(x - x_o)$ where F_h is the force produced by the spring, k is the elasticity constant of the spring, x_o is the equilibrium spring length and y x is the current length of the spring. In this case, $F_{i,j} = \sum_l F_{h,l} \mid l \in L_j$ where L_j is the set of springs that fall into m_j. The dumping force, defined as $F_{a,j} = -c_j \cdot v_j$ where c_j is the dumping factor, that is opposed to speed v_j of the particle m_j, stabilizes the system to recover the equilibrium point and models the friction force.

2. Animation Engine

The animation of the model can be summarized in four stages:

1. The external forces, which interact with the system, are calculated.
2. The internal forces, which affect each one of the system masses, are computed.
3. The displacements of the superficial deformable model masses are calculated.
4. The global movement of the system is calculated using the rigid skeleton particles.

To simulate the dynamics of the objects we have introduced Eq. 1 in the animation engine. The deformation is updated using one of the selected integrators. Selected integrators for testing are based on the Taylor Series expansion of the functions involved in the dynamics of the particle set: position and speed. The choice of the integrators is based on the remainder term order and the computational complexity required to program the integrator: Explicit Euler Integrator

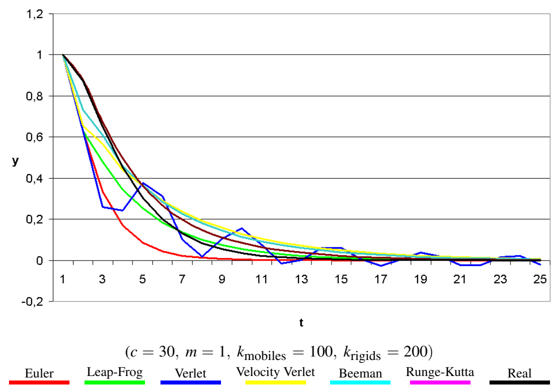

Figure 1: *Animation engine's stability.*

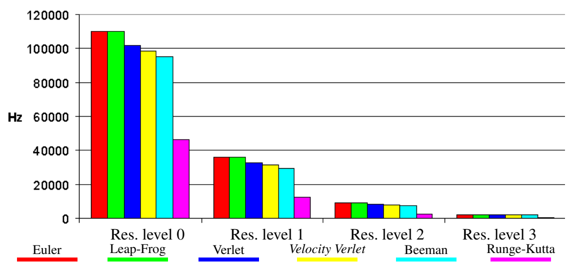

Figure 2: *Integrators' performance at different resolution levels.*

(**EEI**) [PFTV93], Leap-Frog Integrator (**LFI**) [HE88], Verlet Integrator (**VI**) [Ver67], Velocity Verlet Integrator (**VVI**) [SABW82], Beeman Integrator (**BI**) [Bee76] and Fourth Order Runge Kuta Integrador (**4RKI**) [PFTV93].

3. Experimental Results

Tests have been focused to check the response of the animation engine combining the multiresolution mass-spring model together with each one of the selected integrators. Specifically, it has been studied: The dynamic stability of the animation engine depending on the resolution level and the settings of the multiresolution mass-spring representation. and the efficiency achieved by each one of the integrators. Figure 1 shows a curve comparing the dynamics of the selected integrators fixing some values in the mass-spring model and considering resolution level $j = 3$. Figure 2 collects the animation engine's performance, measured as the number of iterations per unit time, depending on the resolution level defined in the object. The results are shown in Hz.

4. Conclusions

The choice of an integrator to be introduced in the animation engine of a virtual reality application is a very important decision focused on obtaining a realistic simulation. The choice must be taken considering both performance and stability in the animation loop. This decision depends on the system parameters and the computational restrictions. From a computational point of view, the most simple integrators, **EEI** or **LFI** achieve a better performance than higher order integrators. On the other hand, more complex integrators, **BI** of **4RKI**, have a more stable behaviour at all resolution levels of the deformable model. In the tests, **LFI** has emerged as a very good choice balancing stability and performance. The animation engine studied has in all cases a quite homogeneous behaviour, independent of the resolution level selected. The use of a multiresolution scheme involves the fact that the propagation of the deformation is performed very quickly, improving the behaviour of both global and local deformations. In all the experiments, the animation engine has produced an answer granting a realist interaction with the other objects present in the scene.

Acknowledgments

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