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Multimodal Virtual Reality System for Large Scale Simulations

Natural Exploration of Virtual Environments.

Introduction

The common focus in the development of VR-systems lies mostly on the visual immersion of the user. By providing stereoscopic visualisation, the user is relocated in a virtual environment and obtains a spatial impression of the simulated scenery. But the emphasis on the visual perception is for some applications insufficient as the user is limited in his interactions within the virtual reality. This is mainly related to the incomplete sensorical feedback, which is normally provided when the user interacts with his environment. Despite the fact that our sense of touch is the fundamental element in our motor control, VR-systems usally give no feedback in the haptic modality. In consequence, the motor controlled actions of the user do not correspond to the intended manipulation. Due to this defect, users need tedious training, learning to control their operations in absence of the haptic feedback to their actions.

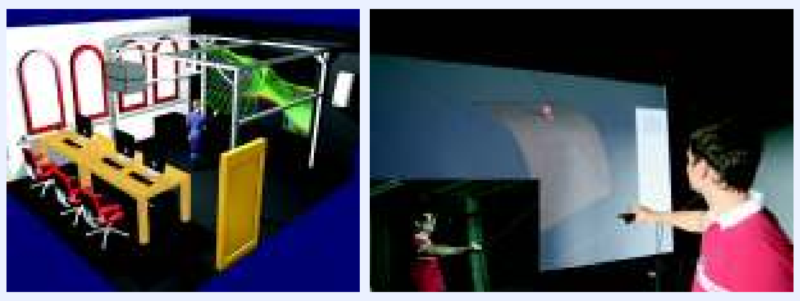

Figure 1: (left) Schematic drawing of the VR-Room (right) using the VR-system

We therefore present a VR-system that features not only visual immersion but also haptic feedback in a large workspace. Thus system is capable of creating all information neccessary to control interactions in the virtual environment. Furthermore, supported by a massive parallel computing system it allows to simulate complex physical phaenomena in visual and haptic realtime.

System Architecture

As in Figure 2 illustrated, the system is structured into four component types. The main component of the architecture is the computing element. This component is responsible for the processing of the data coming from the input devices. It also coordinates the information transfer to the other components. The requirement of simulating highly complex scenarios in visual as well as in haptic interactive rates necessitates the distribution of the high computational load. Therefore, the computing element is splitted into three subcomponents executing different tasks of the physical simulation. The central unit is the high performance workstation controlling the overall dataflow. The two other components, a HPC- and a GPU-cluster, support the workstation in handling the high computational load for the simulation.

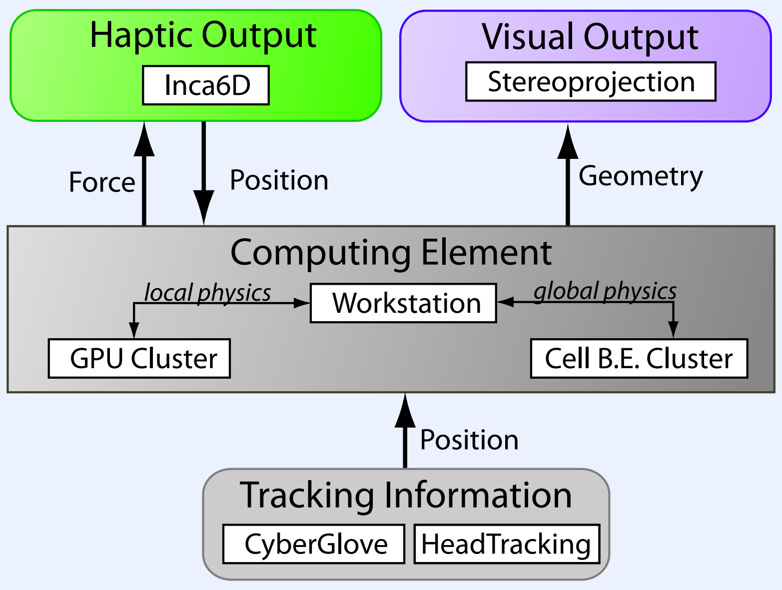

Figure 2: different components of the VR-System

In providing the information for the visual and haptic sense, different requirements for the distribution of the load arise. For our visual sense an update rate of up to 25 frames per second is sufficient to produce the illusion of a continous animation, the haptic sense requires a significant higher update rate of 1kHz in force feedback to get an acceptable illusion of touch perception. Thus, in order to achieve these update rates for the haptic sense, it is needed to have low latency in the communication and high bandwidth between the components.

Computing Hardware

The GPU-cluster (NVidia Tesla S1070) internally consists of four graphic cards. Each of them employs a massively parallel architecture with 240 stream processors, that can reach a peak performance of 933GFlop/s in single, or 78GFlop/s in double precision. The additional HPC-cluster, connected by high speed infiniband technology provides the data for visual real time rendering. Its latencies doesn't reach that of the GPU-System being directly attached to the workstations' data bus, but with a transferrate of 1,5 GB/s and latencies of $1\mu s$ it allows considerable scaling of the simulation size. Especially noteworthy is the fact, that the HPC-cluster has complete processors, as opposed to the GPU. Calculations with a higher need of synchronization can profit from that, a fact that we plan to exploit in the aforementioned global physics simulation. The HPC-cluster is made up of 12 blade units, each of them are equipped with 2 Cell B.E. Processors each. Both processors can access a total of 8GB DDR2 RAM, provided by a NUMA architecture.

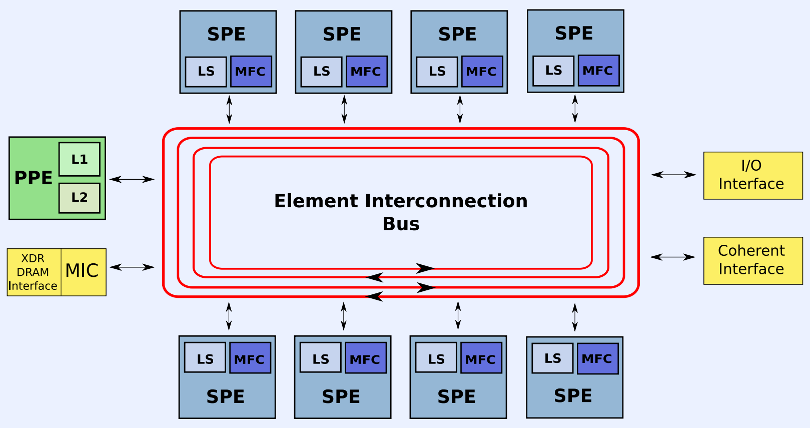

Figure 3: Cell B.E. Processor Architecture

Internally, a processor consists of a PowerPC Processor Element (PPE) and eight vector units (SPE). The SPEs are optimized for floating point calculations by achieving a theoretical peak performance in single precision of up to 25.4 GFlop/ and 12,8 GFlop/s in double precision respectively. Thus the complete cluster is able to achieve a total theoretical performance of up to 5,5 TFlop. The PPEs and SPEs are connected by a quadruple ring bus (EIB) with a maximum rate of 204GB/s, making the communication extremely efficient and optimal for stream processing.

Haptic Device

For our purpose we use the commercially available Inca6D, which is a 6DoF-haptic device especially created for large workspace VR environments. The transmission of forces and torques to the user is done by a so-called endeffector. This device is attached to a pulley system by steel cables and can be exchanged against other endeffectors based on the needs of the simulation. The cables originating from the endeffector are held by motors in the eight corners of the supportive frame. In our current setup, we use an endeffector that was constructed by Haption specifically adapted for our needs. The endeffector features an additional degree of freedom, that for example allows the grasping of virtual objects. Another possible setup is depicted in figure 4 (left). Using the endeffector as a wristband, the system can be combined with a dataglove (*Cyberglove*) Fig. 4 (right) allowing a full grasp. In that case, the INCA would exert force feedback on the wrist, and a complete contact model of the hand would be realised in combination with the dataglove.

Figure 4: (left) wristband endeffector (right) CyberGlove

A system based on thin cables is ideal to keep the impairment of the projection to a minimum. This is of special importance when, like in our case, a back projection (used for the visualisation) is not possible due to spatial limitations. In our current setup an average sized user (up to 180cm) can work virtually without occlusion (seen fig. 1 (right)).

Exploiting Parallelism

In order to be able to accelerate the numerical computations by using the two cluster components, it is needed to split the simulation into independent processes. We therefore distinguish between local and global physics. Hereby, the haptic information will be provided by the local physics simulating the contact area between a small refined portion of the physical model and the user at high update rates. For precise treatment of the contact, we will use the signorini contact model as presented in [2] to run on the GPU cluster. The global physics provide the information for the visual sense and computes the dynamics of the entire physical model at visual rates. The workstation creates the link between both physical representations by energy transfers, which we have already modeled for the haptic rendering of virtual textiles [1] as to make use of multicore systems. Due to the separation it is possible to concurrently simulate the object at different rates and levels of accuracy.

First Results

We embedded our textile simulation in a modular simulation framework and ported the underlying algorithms to the cell processor architecture. For doing this, we had to split the computations into parallel counterparts to fully utilise the processor power. In our early results, we achieved with a single blade consisting of 2 cell processors and thus 16 SPEs a speedup of factor 10 compared to a high end Intel Nehalem 3.2GHz processor (single core).

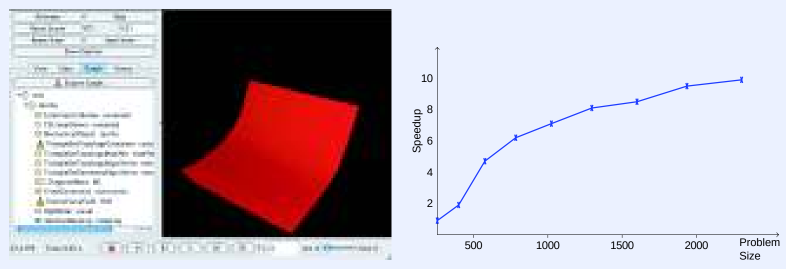

Figure 5: (left) textile simulation (right) speedup at different refinement levels

We expect to significantly increase the speedup even in the current configuration with using only one blade as the system is far from being optimally configured. Additionally, we found out that the communication libraries advertised by IBM do not natively support Infiniband communications, which drastically reduces the net bandwidth and occupies the cpu for data transfers.

References

[1] G. Böttcher, D. Allerkamp, D. Glöckner, and F.E. Wolter. Haptic two-finger contact with textiles. *The Visual Computer*, 24(10):911–922, 2008.

[2] G. Böttcher, R. Buchmann, M. Klein, and F.E. Wolter. Aufbau eines VR-Systems zur multimodalen Interaktion mit komplexen physikalischen Modellen. In *6. GI-Workshop „Virtuelle und Erweiterte Realität"*, 2009.

[3] C. Duriez, F. Dubois, A. Kheddar, and C. Andriot. Realistic haptic rendering of interacting deformable objects in virtual environments. *IEEE Transactions on Visualization and Computer Graphics*, 12(1):36–47, 2006.

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