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Adaptive Algorithms for Intelligent Geometric Computing

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INTRODUCTION

This chapter spans topics from such important areas as Artificial Intelligence, Computational Geometry and Biometric Technologies. The primary focus is on the proposed ***Adaptive Computation Paradigm*** and its applications to surface modeling and biometric processing.

Availability of much more affordable storage and high resolution image capturing devices have contributed significantly over the past few years to accumulating very large datasets of collected data (such as GIS maps, biometric samples, videos etc.). On the other hand, it also created significant challenges driven by the higher than ever volumes and the complexity of the data, that can no longer be resolved through acquisition of more memory, faster processors or optimization of existing algorithms. These developments justified the need for radically new concepts for massive data storage, processing and visualization. To address this need, the current chapter presents the original methodology based on the paradigm of the ***Adaptive Geometric Computing***. The methodology enables storing complex data in a compact form, providing efficient access to it, preserving high level of details and visualizing dynamic changes in a smooth and continuous manner.

The first part of the chapter discusses adaptive algorithms in real-time visualization, specifically in GIS (Geographic Information Systems) applications. Data structures such as Real-time Optimally Adaptive Mesh (ROAM) and Progressive Mesh (PM) are briefly surveyed. The adaptive method ***Adaptive Spatial Memory (ASM)***, developed by R. Apu and M. Gavrilova, is then introduced. This method allows fast and efficient visualization of complex data sets representing terrains, landscapes and Digital Elevation Models (DEM). Its advantages are briefly discussed.

The second part of the chapter presents application of adaptive computation paradigm and evolutionary computing to missile simulation. As a result, patterns of complex behavior can be developed and analyzed. The final part of the chapter marries a concept of ***adaptive computation*** and ***topology-based techniques*** and discusses their application to challenging area of ***biometric computing.***

BACKGROUND

For a long time, researchers were pressed with questions on how to model real-world objects (such as terrain, facial structure or particle system) realistically, while at the same time preserving rendering efficiency and space. As a solution, grid, mesh, TIN, Delaunay triangulation-based and other methods for model representation were developed over the last two decades. Most of these are static methods, not suitable for rendering dynamic scenes or preserving higher level of details.

In 1997, first methods for dynamic model representation: Real-time Optimally Adapting Mesh *(ROAM)* (Duchaineauy et. al., 1997, Lindstrom and Koller, 1996) and Progressive Mesh (PM) (Hoppe, 1997) were developed. Various methods have been proposed to reduce a fine mesh into an optimized representation so that the optimized mesh contains less primitives and yields maximum detail. However, this approach had two major limitations. Firstly, the cost of optimization is very expensive (several minutes to optimize one medium sized mesh). Secondly, the generated non-uniform mesh is still static. As a result, it yields poor quality when only a small part of the mesh is being observed. Thus, even with the further improvements, these methods were not capable of dealing with large amount of complex data or significantly varied level of details. They have soon were replaced by a different computational model for rendering geometric meshes (Li Sheng et. al. 2003, Shafae and Pajarola, 2003). The model employs a continuous refinement criteria based on an error metric to optimally adapt to a more accurate representation. Therefore, given a mesh representation and a small change in the viewpoint, the optimized mesh for the next viewpoint can be computed by refining the existing mesh.

ADAPTIVE GEOMETRIC COMPUTING

This chapter presents ***Adaptive Multi-Resolution Technique*** for real-time terrain visualization utilizing a clever way of optimizing mesh dynamically for smooth and continuous visualization with a very high efficiency (frame rate) (Apu and Gavrilova (2005) (2007)). Our method is characterized by the efficient representation of massive underlying terrain, utilizes efficient transition between detail levels, and achieves frame rate constancy ensuring visual continuity. At the core of the method is *adaptive processing*: a formalized hierarchical representation that exploits the *subsequent refinement* principal. This allows us a full control over the complexity of the feature space. An error metric is assigned by a higher level process where objects (or features) are initially classified into different labels. Thus, this adaptive method is highly useful for feature space representation. In 2006, Gavrilova and Apu showed that such methods can act as a powerful tool not only for terrain rendering, but also for motion planning and adaptive simulations (Apu and Gavrilova, 2006). They introduced ***Adaptive Spatial Memory (ASM)*** model that utilizes adaptive approach for real-time online algorithm for multi-agent collaborative motion planning. They have demonstrate that the powerful notion of adaptive computation can be applied to perception and understanding of space. Extension of this method for 3D motion planning as part of collaborative research with Prof. I. Kolingerova group has been reported to be significantly more efficient than conventional methods (Broz et.al., 2007).

We first move to discuss ***evolutionary computing***. We demonstrate the power of adaptive computation by developing and applying adaptive computational model to missile simulation (Apu and Gavrilova, 2006). The developed adaptive algorithms described above have a property that spatial memory units can form, refine and collapse to simulate learning, adapting and responding to stimuli. The result is a complex multi-agent learning algorithm that clearly demonstrates organic behaviors such as sense of territory, trails, tracks etc. observed in flocks/herds of wild animals and insects. This gives a motivation to explore the mechanism in application to swarm behavior modeling.

Swarm Intelligence (SI) is the property of a system whereby the collective behaviors of unsophisticated agents interacting locally with their environment cause coherent functional global patterns to emerge (Bonabeau, 1999). Swarm intelligence provides a basis for exploration of a collective (distributed) behavior of a group of agents without centralized control or the provision of a global model. Agents in such system have limited perception (or intelligence) and cannot individually carry out the complex tasks. According to Bonebeau, by regulating the behavior of the agents in the swarm, one can demonstrate emergent behavior and intelligence as a collective phenomenon. Although the swarming phenomenon is largely observed in biological organisms such as an ant colony or a flock of birds, it is recently being used to simulate complex dynamic systems focused towards accomplishing a well-defined objective (Kennedy, 2001, Raupp ans Thalmann, 2001).

Figure 1. Split and merge operations in ASM model