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High performance distributed cluster-based individual-oriented fish school simulation

Roberto Solar, Remo Suppi, Emilio Luque

Department of Computer Architecture & Operating Systems
Universitat Autnoma de Barcelona
Bellaterra, 08193, Barcelona, Spain

Abstract

Individual-oriented simulation allows us to represent the global behavior of a system through local interaction in discrete time steps. As we face up close-to-reality models and large-scale workloads, we focus on turning from traditional approaches towards distributed simulation in order to obtain more accurate results in less time. One of the main problems in distributed simulation is how to distribute individuals efficiently through distributed architecture. Individual-oriented systems can be implemented in a distributed fashion by using either a *grid-based* or *cluster-based* approach. On one hand, grid-based approaches consist of assigning to each node a simulation space portion, together with the set of individuals currently residing in that area. On the other hand, cluster-based approaches consist of assigning to each node a fixed set of individuals. In this work we present a cluster-based method based on *Voronoi* diagrams and covering radius criterion in order to avoid unnecessary interaction between individuals. We can show experimentally that our proposal reduces the communication and computing times significantly increasing simulation efficiency.

Keywords: High performance simulation, individual-oriented models, distributed simulation, data clustering, nearest-neighbor.

1. Introduction

Collective behavior in groups of autonomous individuals is a common phenomenon observed in different scales and levels of complexity. Individual members act on the basis of some limited local information coming from interaction with other individuals and/or the environment. This local information flows through the system producing collective patterns. Collective behaviors can be seen in many research areas such as: ecology and biology [1, 2, 3, 4, 5], military strategies [6], sociology [7, 8, 9], physics [10, 11], health care [12], vehicular traffic [13], fire suppression strategies [14], etc.

Individual-oriented models have been created to solve limitations imposed by population-oriented models, in

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Email addresses: roberto.solar@caos.uab.es (Roberto Solar), remo.suppi@uab.es (Remo Suppi), emilio.luque@uab.es (Emilio Luque)

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which the system variables evolve according continuous functions in time (eg *Lotka-Volterra* equations, also known as *prey-predator* equations). An individual-oriented approach allows us obtaining a global vision of how system variables evolve from interaction between individuals and their environment. Nevertheless, it is very difficult to solve an individual-oriented model analytically whereby it is necessary using simulation tools in order to observe system variables through time. During the last few years, the great disadvantages of individual-oriented simulation have been: on one hand, the workload assigned to a single computing element and, on the other hand, the high complexity level of the models. But due the advent of distributed/parallel architectures and high performance computing these disadvantages have become a challenge for parallel/distributed simulation.

One of important problem in distributed simulation is how to distribute individuals through the architecture in order to get the best performance of applications (scalability, efficiency, minimum communication times, etc). Individual-oriented systems can be implemented in a distributed fashion by making each node responsible for a fixed portion of the problem domain. This fixed portion can be assigned using either a *grid-based* or a *cluster based* approach.

The *grid-based* approach consist of assigning to each node a simulation space portion together with the set of individuals currently residing in that area. Grid-based partitioning methods can be classified into two groups: *static decomposition* - eg: strip, rectangular, recursive and scatter, and *dynamic decomposition* - strip, rectangular, recursive and quadrilateral [15]. The *cluster-based* approach consist of assigning to each node a fixed set of individuals. Each set is determined from individuals grouping into clusters of similar/near members. Similarity is determined according to a distance measure.

In this work we present a distributed fish school simulator which implements a cluster-based approach based on an hybrid *voronoi diagrams*/*covering radius* construction criterion. Furthermore, a high-level metric data structure called *list of clusters* is used in order to store and manipulate individuals as the simulation progresses. In subsection 1.1 we present an overview of some previous works about partitioning algorithms in distributed individual-oriented simulations. In section 2 we show the biological behavior model that describes the motion of a fish school. In section 3 we present our partitioning algorithm, the data structure to store and manipulate individuals, its construction and the sequential cluster-based simulation algorithm. In section 4 we present out model distribution and the distributed simulation. The experimental results, comparing a grid-based partitioning method (dynamic strip decomposition) and our cluster-based implementation are presented in section 5. Finally, in section 6 the conclusions and future work are proposed.

1.1. Related Work

In this section we focus at previous works about partitioning approaches in distributed individual-oriented simulation. Partitioning methods can be classified into two approaches: grid-based and cluster-based (also can be hybrid). Next, we will take a look at the most important works in this area.

Grid-based methods

In [10] is proposed two partitioning methods based on *Voronoi cells* (body-centered-cubic and face-centered-cubic lattices), used in simulations of the sillium model for amorphous silicon. In [16] a micro-cells based method is used. In this method, the problem domain is decomposed to small cubes, called *micro-cells*, and they are grouped into sub-domains (groups of adjacent micro-cells), and each sub-domain is assigned to a distinct processing element. In [5] is presented a column wise block-striped decomposition to partition the simulated space in bird flocking simulation. In [4, 3] is used a *grid-based approach*, named *strip decomposition*. The simulation space is divided evenly into *n* strips, each strip is assigned to a processing node together with the individuals residing currently in that area. Every processing node executes the simulation with local data, making data exchange using two types of messages: neighbors exchange [17] and migration. In this work a simulation study of large-scale of fish schools is carried out.

Cluster-based methods

In [11] is proposed a new approach for parallel domain decomposition of vortex particles, based on *k-means* clustering of the particle coordinates. The paper investigates hierarchical evaluation of vortical velocities in a vortex simulation of a transverse jet at high Reynolds number. In [8] is presented a method of partitioning individuals through the distributed architecture using an adapted k-means clustering algorithm. The paper shows the application of cluster partitioning algorithms for large-scale agent-based crowd simulation. In [7] is proposed a partitioning method based