An efficient GPU implementation for large scale individual-based simulation of collective behavior

ABSTRACT

In this work we describe a GPU implementation for an individual-based model for fish schooling. In this model each fish aligns its position and orientation with an appropriate average of its neighbors positions and orientations. This carries a very high computational cost in the so-called nearest neighbors search. By leveraging the GPU processing power and programming models such as **OpenCL** and **OpenGL** we implement an efficient framework which permits to simulate the collective motion of high-density individual groups. In particular we present as a case study a simulation of motion of millions of fishes. We describe our implementation and present extensive experiments which demonstrate the effectiveness of our GPU implementation.

MOTIVATION

As a gaming enthusiast, I always wondered how do developers incorporate laws of physics into simulation for the purpose of making effects appear more real to the observer. For example games such as FIFA 14 require correct projectile physics for objects such as the football. This project has given me the opportunity to explore the world of graphics to find out the answers to my questions.

OBJECTIVE

The objective of our project is to demonstrate a GPU-based method for running high performance individual-based simulations based on OpenCL and OpenGL. We adopt an approach based on defining field of view for every fish in order to perform neighbors search by using the parallel architecture of the GPU.

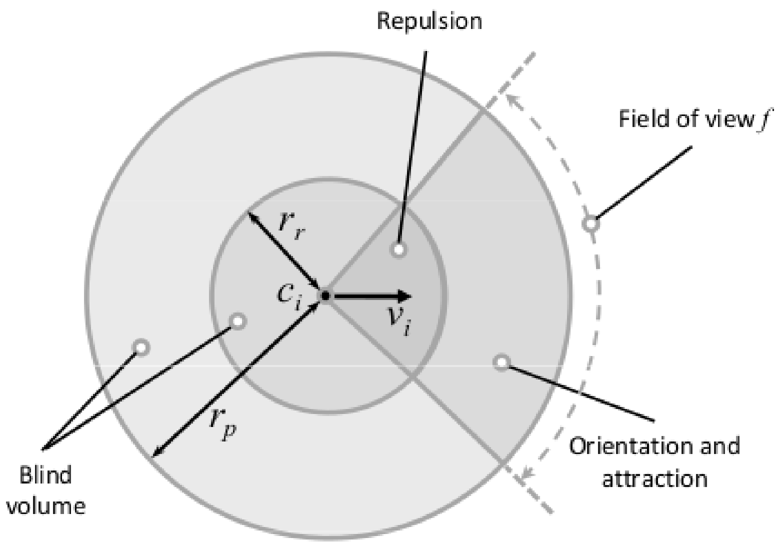
INTRODUCTION

Individual-based simulation is a common way to implement autonomous characters or individuals to create crowds and other flock-like coordinated group motion. In this simulation an individual has a local behavior model and it moves by coordinating with the motion of each other individual. The number of individuals involved in such collective motion can be huge, from several hundred birds to millions of individuals. Biologists consider the collective motion from a mathematical point of view by modeling each organism individually. Others models can incorporate experimental observations of the behaviors of the organisms, predicting that individuals typically interact with a fixed, relatively small, number of near neighbors. In all of these models, the simulation of local perception is a key aspect for an interactive results. Each individual must take decisions according only with its neighbors and so it must be able to identify efficiently these individuals among all others in the world. This problem from computational point has solution $O(n^2)$ by using a brute force approach which is a bottleneck for a massive simulation. In recent years, graphics processing units (GPUs) outperform CPUs in both floating-point performance and memory bandwith. Furthermore, general purpose computation on the GPU (aka GPGPU) is becoming easier thanks to the new programing model OpenCL that allows to exploit the GPU processing power by using a C-like programming language.

In this work, we present a GPU-based method for massive simulation of fish schooling model by using OpenCL and OpenGL framework. We adopt the GPU processing power for implementing a uniform data grid to support local perception.

METHODOLOGY

Many animal groups such as fish schools and bird flocks clearly display structural order, with the behaviour of the organisms so integrated that even though they may change shape and direction, they appear to move as a single coherent entity. Many of the collective behaviours exhibited by such groups can only be understood by considering the very large number of interactions among group members. Individual- based computer



simulations are a very useful analytical tool to study such groups, and using this technique, it has been possible to demonstrate that group leadership, hierarchical control, and global information are not necessary for collective behaviour.

In the collective behaviors model two rules play a crucial part in the simulations. In the first rule, individuals attempt to maintain a minimum distance between themselves and others at all times. This rule has the highest priority and corresponds to a frequently observed behaviour of animals in nature. In the second rule, if individuals are not performing an avoidance manoeuvre to maintain a minimum distance they tend to be attracted towards other individuals (to avoid being isolated) and to align themselves with neighbours. These behavioural tendencies are simulated using local perception and simple response behaviours.

Each individual has a strictly local perception of the space it occupies. None of the creatures being part of group has a full knowledge of the entire group. Hence, the decision must be taken by every individual taking into account only local neighbors that are perceived from its fields of view f.

Groups are composed of n individuals. At time t, each individual i has a position $c_i(t)$, a direction $v_i(t)$, a speed s_i (See Figure). Individuals simultaneously determine a new desired direction of travel d_i by considering neighbors within two behavioral zones. The first zone, called zone of repulsion, has a local interaction range r_r . Each individual attempts to avoid collision between itself and others individual j in this zone by turning away

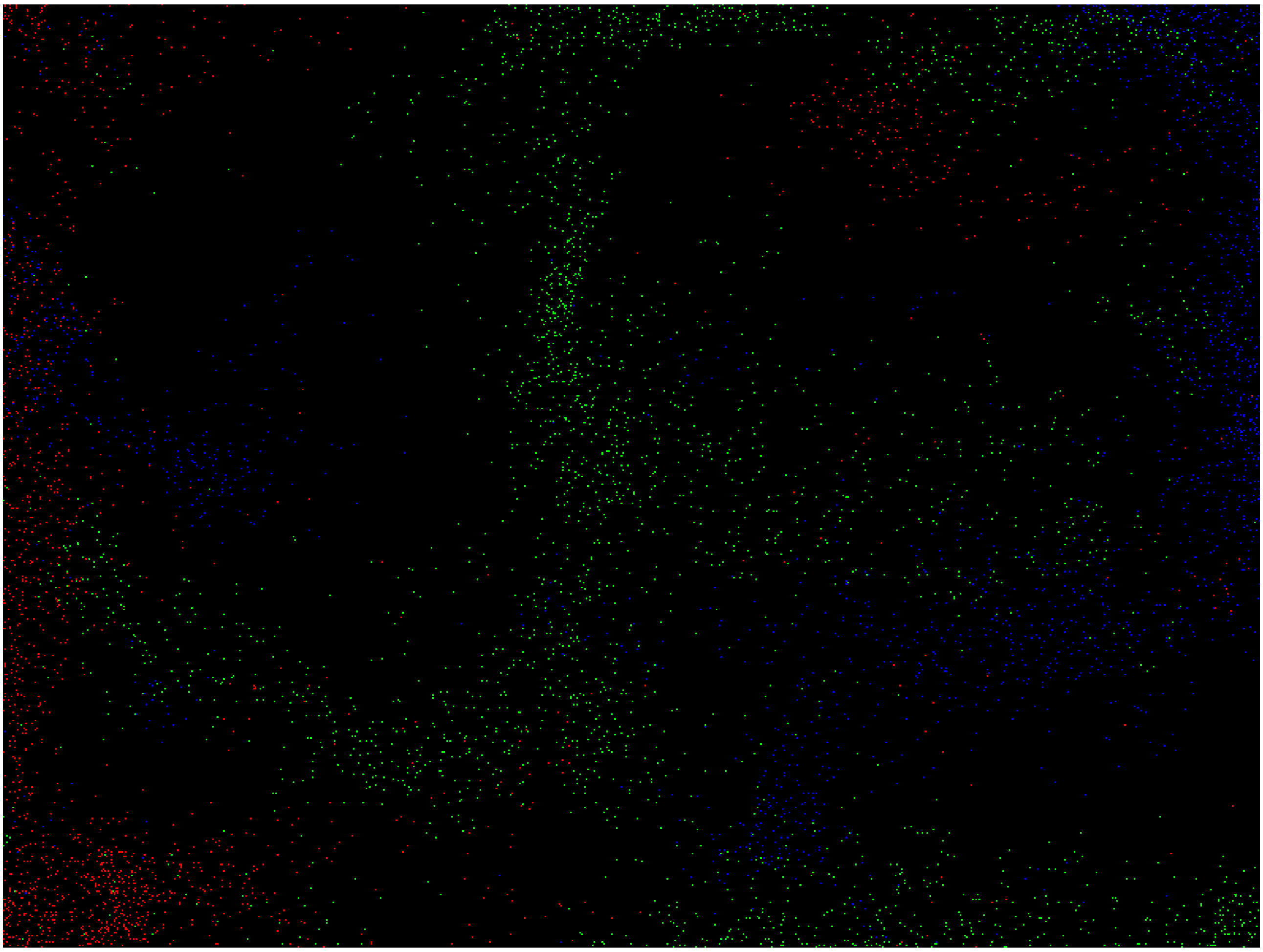
$$\boldsymbol{d}_i(t + \Delta t) = -\sum_{j \neq i} \frac{\boldsymbol{c}_j(t) - \boldsymbol{c}_i(t)}{|\boldsymbol{c}_j(t) - \boldsymbol{c}_i(t)|}$$

This behavior has always the highest priority. If neighbors are not detected in the zone of repulsion then the individual i tend to align with j neighbors in the second zone called zone of orientation. This zone is a annulus of inner radius r_r and outer radius r_p around the individual. The desired direction of travel in this case is:

$$\boldsymbol{d}_i(t + \Delta t) = \sum_{j=1} \frac{\boldsymbol{v}_j(t)}{|\boldsymbol{v}_j(t)|}$$

The model illustrated above requires to identify neighbors out of whole world and in particular determines all individuals that fall inside the zone of repulsion and zone of orientation and attraction. A brute force approach requires $O(n^2)$ steps for a proximity screening i.e., compares each individual to all others and gathers all individuals within the range r_r and r_p. This approach is sufficient for a hundred individuals but it is clear that is computationally inefficient for the simulation of thousands individuals in real-time.
In our implementation, we are controlling the behavior of each individual through a separtate kernel thereby achieving better complexity than $O(n^2)$.

RESULTS



A rendering of the implemented model. In this case, GPU performs simulation and visualization by using OpenGL. Here n=12000. The different colors represent different species of fishes.

Comparision with real life fish swarming

LIMITATIONS AND POSSIBLE IMPROVEMENTS

Using Intel Haswell-ULT Integrated Graphics Controller as our GPU, we observed smooth simulation of our model for n = 6000. By using more powerful GPUs, we could have achieved it for higher values of n.

In our model, we have represent each fish as a point object. Our model would have resembled more with a real life fish swarm if we had used a three dimensional coordinate system.

By exploiting the GPU processing power, we expect that it will be possible to simulate more complex models or to integrate features like collective motion during escape and pursuit response. Our approach extends beyond the study of fish schools and animal groups. With appropriate modifications of the interaction terms it could be modified to simulate very effectively a large number of systems in which local interactions among mobile elements scale to collective behavior, from cell aggregates, including tumors and bacterial biofilms, to aggregates of vertebrates such as migrating wildebeest, and even human crowds. In addition, our capacity to include variation among individuals could have enormous potential for the study of the evolution of collective behavior.

CONCLUSION

This project has described a GPU-based method for running high performance individual-based simulations based on OpenCL and OpenGL. We adopt an approach based on defining field of view for every fish in order to perform neighbors search by using the parallel architecture of the GPU. Our results show that this approach can be very effective for such simulations.

REFERENCES

[1] http://icouzin.princeton.edu/wp-content/uploads/file/PDFs/Erra%20et%20al,%202009.pdf

[2] http://open.gl/drawing

[3] http://khronos.org/opencl