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HOLONIC MODELING OF PARTICLE INTERACTION FOR COMPUTATIONAL FLUID DYNAMICS

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ABSTRACT

This paper presents a holonic modeling approach to simulate the behavior of fluid–particle interaction for computational fluid dynamics. Holonic modeling is employed to model the dynamics of a fluid. A software proof-of-concept application is presented to simulate the fluid flow. The particle–fluid interaction is modeled by means of holons, intelligent software entities that handle every particle behavior in the simulation considering local information, such as forces, drag force, and gravitation. The new approach proposes a model that requires low computational resources compared to analytical solutions and might provide solutions in specific scenarios with complex boundary conditions.

KEYWORDS: holonic modeling, particle interaction, fluid dynamics

1. INTRODUCTION

Solving fluid dynamic simulation by means of CFD (Computer Fluid Dynamics) models involves three steps: pre-processing, solving and post-processing [1], [5], [6]. The first step, pre-processing, allows the user to specify the computational problem by assigning all the necessary information, such as the geometry of the computational domain, the properties of the computational grid, and the initial and boundary conditions.

The second step, solving, allows the user to start computing a numerical result. Most of the commercial CFD codes relate to finite volume method. The model uses integration of Gauss and Leibnitz theorems on a control-volume basis [7], [8]. Also used are Navier–Stokes equations named after Claude-Louis Navier and George Gabriel Stokes, which describe the motion of viscous fluid substances.

The third step, post-processing, means that the user needs to analyze the simulation results. This is done by generating diagrams and using different graphics tools.

In the traditional mesh-based approach to CFD simulation [2], [3], [4], the reliability of results depends on the quality of the mesh. Also, there are specific cases when the automatic mesh of the computational domain fails and manual mesh needs to be done by the user. That means for certain cases that engineers spend a lot of time working on the manual discretization. This also translates as companies spending millions of euros on manual meshing.

The proposed modeling uses Lattice Boltzmann model. Furthermore, there are severe difficulties in dealing with the changes in the presence of objects with complex geometry and fluid-structure interaction.

A Holon (from Greek, *holos* meaning "whole") is something that is simultaneously a part and also a whole. The word was used by philosopher Arthur Koestler in his book *The Ghost in the Machine*. Koestler proposed the term "Holon" in order to explain some social behaviour.

The main idea is that an entity acts as a part, meaning a Holon aims to reach individual goals, but also as a part of a group (a whole) aiming to reach group goals [13], [14], [15]. Agent technology is a software paradigm that allows implementation of complex problems. This paper describes a practical example of a new generic model represented by holonic modeling designed, defining a new type of holon entities to meet CFD needs for development application based on particle interaction. To this end, it is important that the basic principles of multi-agent systems are applied to the development of software applications that allow holonic modelling.

A software proof-of-concept application is presented to simulate the fluid flow in a 2D space. The particle–fluid interaction is modeled by means of holons, intelligent software entities that handle every particle behavior in the simulation considering local information, such as forces, drag force, and gravitation. The new approach promise low computational resources model compared to analytical solutions and might provide solutions in specific scenarios with complex boundary conditions.

2. EXPERIMENTAL PROCEDURE

Further on we define some concepts used in this approach. Definitions: - A Holon is a computer system entity within a software application and with an autonomous behavior made for achieving some peculiar objectives.
Development of such virtual environments where entities has own knowledge and rules to operate different actions as defined by the user. The goal is to make intelligent system to allow modelling of complex multi-variable problems. Holonic modelling approach begins to emerge as a viable solution for large-scale multi-variable complex problems.
Practically, a Holon is an operating system process with specific characteristics that communicates with other processes as defined bellow; - A Holon system is a system that contains a set of Holons that interact and are able to achieve a common objective by interacting within certain rules. Different holons have different interactions with other holons, in the sense that they influence neighbour holons. The author previously defined some specific operations to the holon entities, for different applications, that is modeling the kinematics of reconfigurable manufacturing systems, and also to a computer vision application concerning scene recognition [9], [10], [11]. Similarly, we define operations that are performed by holons and instinct law (a set of law governing each holon behaviour).

Several operations are defined as described below:

1) The operation of unification - is the operation whereby two or more holons are grouped in a holarchy, forming a new Holon. It should be noted that the concept of Holon loses its meaning when there is at least one other partner in solving a given task.

2) The operation of insolation - is one Holon action in which it leaves a holarchy to be a part of another holarchy and will have no longer any relation with “former colleagues” of the former holarchy.

3) Creation - is the act of creating a new Holon (at a software level one process will create one or more processes).

4) Destruction - is the destroying of a Holon at its own initiative. On a software level the process ends its own instance. This operation occurs when a Holon notices that it can move with no dependence to other holons, so the reason for his existence disappears.

5) Change in holarchy - is when a Holon chooses to pass to another holarchy.

6) Proposal - is the action of a Holon to inform another Holon on a proposal.

7) Accept - is the action of holons to accept a proposal.

8) Employment – the Holon is changing its position in sollution space, given by search function as defined by user with a specific language.

Instinct laws are those laws applied universally, regardless of the form of the search function. Below are defined the following laws instinct for the issue of particle interaction.

1) Any unoccupied space needs to be occupied.

2) If the search function notices inactivity of a Holon this will activate self-destruction, calling the destruction operation. This is the case when a particle continues moving in space but does not interact with other particles or objects.

3) Operations are performed only between neighbors in the search space.

Knowledge acquired. The knowledge acquired is those functions that are provided by the user. This knowledge defines the function that informs the user on the task of finding the search space.

Based on the specific architecture, a modeling algorithm is defined. A Holon aims to be universal in solving various problems or finding solutions.

The Holonic modeling algorithm takes into account the following steps.

- the objective of a Holon is to occupy space and mark positions as part of “a Holon’s own territory”.

- Furthermore, each Holon has its own assigned mass, speed;

- The interaction with other holons is described by a law.

The behaviour of each holon that controls a particle in the developed software is modelled as a sequence of transitions in time considering consecutive state of particles. The sequence of state transitions for each particle associated with each agent is time-driven. In this way this model is a basically a continous transition of holon states. A comparative analysis of the two computing techniques, namely CFD using Navier–Stokes equation and particle interaction based on holonic modeling, cannot be done at the moment as the present research is in early development stages.

In Fig. 1 are shown several stages of the interaction between particles: Fig. 1 a) – the initial state, where all particles have initial speed and gravitation g is present. Fig.1 b) – the phase when the particles encounter the wall, and Fig.1 c) – interaction results. The ever-growing use of holon systems in practical applications such as CFD modelling poses the problem of taking into account physics law which must be implemented as part of holon properties, which might prove a very difficult task. The idea is to use specific physics in order to model an system and further asses about the suitability of holons in solving specific problems.

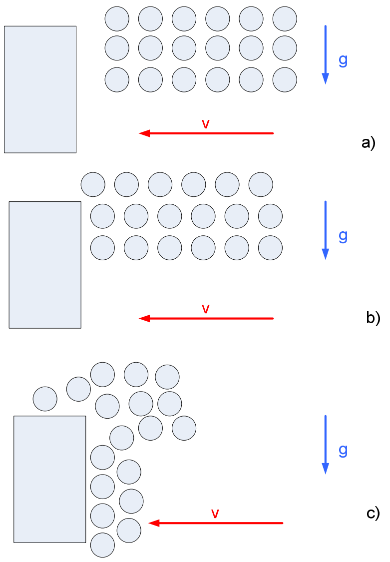

Fig. 1. *Particle interaction phases*

Fig. 2 shows how Holons interact and form new Holarchyes. Holonic Group 2 has no interactions with Holonic group 1. Holon no. 6 is interacting with Holon nr. 7, while in Holonic group 1, Holon no. 1 has only contact with 2. Holon no. 2 is interacting with Holons no. 4, 5, 1, and 3, respectivelly. As can be noticed, the relations between holons are dictated by their position relative to other holons and they form a holarchy. The software developed used a 100x100 mm wall and, from a source at a distance of 250 mm, 2000 particles with mass corresponding to water, were dispersed with a 5m/s speed. The source is a 5mm line shape. It will correspond to a circle in a 3D space. Each particle is considered incompressible. As stated above, each particle was assigned a process able to interact with neighbouring particles and with the wall defined. The simulation run on an i3 processor needs low computational resources. The simulation completed in 2 minutes and 30 seconds. Holons, as operating system processes sharing the same processor resources invariably compete for available resources. In case of our developed application the need for resources was not low. In case of 3d space and complex situation the processor resources will impact global performance of a holonic modelling application. In this paper a model for control of resources for multi-process applications haven't been considered, which might allow such applications to to access resources taking into account predictable resource availability information. No relative comparison to classical CFD simulation was performed at this stage of development. Also, there is no accurate comparison with real cases or other established software for simulation. There is an increasing need to ensure that the systems being developed are robust, reliable and fit for purpose. Simulations of important amount is the interaction between holons which will require important computational resources - but will have the capability to simulate complex scenarios such as simulating free surface CFD simulation, multiple fluid interactions and foremost advanced scientific visualization. The trajectory estimation problem is to determine where each holon is modifying its own trajectory taking into account specific physics. Trajectory algorithms are important to describe CFD robustness. Estimation of trajectory requires significant part of the computation time for many holonic modelling. Moreover CFD simulation should also take into account highly dynamic environments where each holons has specific properties concerning the thermal transfer specification or specific mass of each particle associated with a holon.

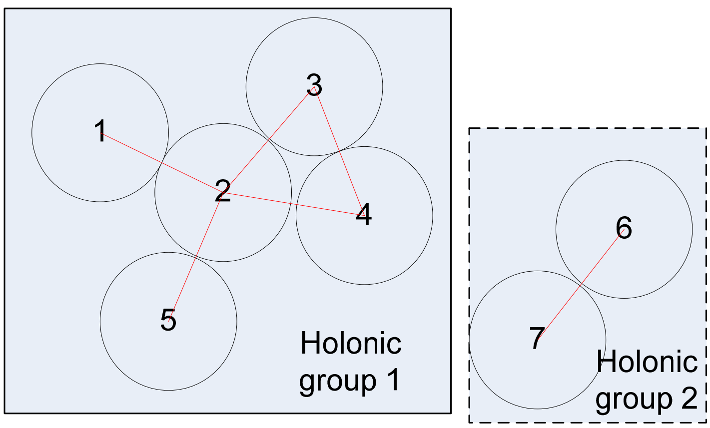

Fig. 2. *Holarchy*

Groups of autonomous holons will play an important role in the simulation of fluid dynamics. Efficient coordination of the holons within cooperative holarchic organisation composed of another holons will allow complex fluid dynamics simulation. Behaviour of the holons based on specific rules is an important characteristic of any system utilizing holonic concept. In a fluid model, we consider the phase as continuum. Approaches in defining fluid(s) interactions will be based on on each agent's laws and roles imposed by the user. The lack of a universal algorithm usually results in ad hoc algorithm and setup for holonic design. In this paper we have developed specific holonic architecture based on holon behavior descriped by law instinct and operations as we previously defined. The user tasks must be converted in operations and law instaing in order to model a specific fluid dynamics simulation. The individual holon interaction with other holons is then based on the knowledge defined in such a manner. The turbulance model is described using k-ε turbulence model. In the gas-solid flow simulation, particle motion of fluid is described by the collision interactions of the particles.

3. CONCLUSIONS

With respect to holonic modelling the effort to define new special class of holons depending of the specific problem to solve should continue. New classes must employ all features represented by holon instinct law that will facilitate holon and the hololny to model complex systems. The computation between holons must be enhanced so that it can offer robustness in case of complex problems. There are some obvious advantages in case of holonic modelling using goal oriented holons. The future development might include better interaction modelling concerning heat transfer. Good emulation of different particle type is another goal of any CFD simulation. This is highly desirable in several industy fields where fluid simulation requires a high level of resolution such in case of processes involving gas behaviour in cylinder of automobiles. There is also room for further enhancing the way the user (the programmer) forward information to holons, and a specific scripting language will allow a faster programming of such holonic systems. The holonic modeling proposed in this paper might be suitable for low computational CFD application. Further development needs to be done concerning 3D modeling. Improved modeling of physics governing the process needs to be done. This in an ongoing research and more work is neccesary, which aim is to provide concepts, algorithms, to be integrated in software that will allow modelling of CFD systems. Currently we are working on refining the concepts that define holons and rules of interactions for a better modelling of complex systems.

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