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A Distributed Lattice Boltzmann-based Flow Simulator

The use of Lattice Boltzmann (LB) methods is interesting to describe flows through complex geometries encountered in Chemical Engineering (porous media, packed beds, multi phase flows). However, flow simulations based on LB methods can require big amounts of memory. It is not always possible to run a simulation on a single machine. Distributed computing is a solution to this problem and also accelerates the execution of the flow simulation.

In the context of dynamic heterogeneous clusters, the available machines can have different computational powers. The computational power of each machine can vary during a flow simulation (because of background load). Also, the number of available machines can change. These characteristics impose the use of special technics. Dynamic Load Balancing allows the optimal use of available machines. A fault occurs when one or several machines interrupt the execution of the distributed software component they were executing. Checkpointing makes the system fault tolerant.

In order to obtain a scalable software and to suppress single points of failure, a special effort is made to decentralize as much as possible the software components of the simulator.

Currently, fluid flows of 400^3 points (more than 9 GBytes of data) are simulated using an heterogeneous cluster of 54 machines.

Key words

Distributed Computing, Fault Tolerance, Load Balancing

Academic career

Since October 2005 : PhD Student
 Algorithmics Lab, ULg, Liège

September 2004 - September 2005 : DEA in Computer Science
 Computer Vision Lab, ULg, Liège

September 2000 - June 2004 : Master in Computer Science
 ULg, Liège

Research

The objective of the thesis is to develop an LB flow simulator that can be run on dynamic heterogeneous clusters. The main addressed topics are Distributed Systems and Software Engineering.

Distributed Systems:

The flow simulator is a complex distributed system that uses advanced techniques to cope with the difficult environment of dynamic heterogeneous clusters.

The dynamic load balancing problem is solved using an original distributed algorithm. This algorithm applies to Iterative Stencil Applications (ISA). An ISA is composed of periodically recomputed interdependent computational tasks needing frequent communications between subsets of them.

Fault tolerance is another important problem that must be solved. Indeed, in the context of the distributed execution of an LB flow simulation (and more generally, of an ISA), if a distributed agent (the software run on each machine) is interrupted on one or several machines (there is one distributed agent (DA) per machine), all the simulation is lost because the simulation data present on a machine cannot be recalculated from the data available on other machines.

Checkpointing is used to be able to recover from these interruptions. Each DA saves its "state" (in our context, simulation data) on a regular time basis. In case of interruption, all DAs go back to their last saved state and the lost states are loaded by remaining or new DAs. In order to avoid a single point of failure and a central bottleneck, a distributed checkpointing mechanism is used : the state of each DA is saved on several machines running other DAs.

Software Engineering:

The complexity of the developed distributed software is mastered by the use of asynchronous agents. These agents handle messages arriving in a queue. The execution of such systems consists of asynchronous exchanges of messages. This paradigm eases the development of highly parallel softwares.

The simulation code, even if embedded in a complex distributed software, must remain flexible and easy to modify and enhance. Simulations are described in XML configuration files that can be modified to match new simulation scenarios.

Results:

The current version of the simulation software allows the simulation of flows in complex geometries (like porous media, see left picture below) encountered in Chemical Engineering. A flow can be described by its speed field (see right picture below).