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Consideration on the extension of Simulation Caching Framework to Distributed Co-simulation Environment

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1. Introduction

In order to realize real-time steering of interactive scientific simulations on remote large-scale supercomputers, Simulation Caching Framework [1] is developed in our lab for general purpose solution applicable for various applications.

The framework utilizes user side cluster as regional server (RS) to collaborate with remote supercomputers as central server (CS) to hide network delay which is the bottleneck of performance in remote supercomputing and the obstacle for real-time steering.

RS performs a same physical area but in lower resolution simulation than CS. Techniques in framework can restart RS's simulation by receiving information from CS to keep data consistency. However, there is no collaboration between RSs and consistency control is single direction from CS to RS.

This paper considers to realize co-simulation in distributed environment by extending framework. The goal is to refine simulations by exchanging information between RSs.

2. Distributed Multi-scale Co-simulation Scheme

Multiple users served by the framework mean multiple RSs, each RS may be interested in different and limited area but compute higher resolution simulation. In this situation, in order to get accurate result, each RS requires to exchange information with others since the changement of outer space such as boundary condition is critical to simulation's accuracy and may be changed by other RSs.

If they can exchange information, by utilizing the higher resolution simulation result from RSs, a more accurate simulation could be obtained.

Fig.1 illustrates the distributed multi-scale co-simulation scheme: CS computes a wide area simulation, for instance Fukui area in left side of figure, while RS performs higher resolution simulation on an inside small area, like Tojinbo area in Fukui in right side. Furthermore, the collaborations among RSs are via CS, the purpose of this design is to reduce dependences between RSs and avoid the vulnerability caused by complicated situations of RSs' direct exchanging.

Bi-directional cooperation between each RS and CS are implemented via bi-directional consistency control. As a result, local simulation on RS could correctly reflect the influences of boundary conditions' changement happened in outer space indirectly conveyed by CS; on the other hand, the wide area simulation on CS could also be improved since each RS runs a higher resolution simulation.

3. Implementation

Fig.2 shows the implemented co-simulation system with bi-directional consistency control which refers to Downward Quality Control (DQC) from CS to RS and versa Upward Quality Control (UQC) from RS to CS. In extended UQC, data is sent by MPI from RS's UQC processor to CS's, then sent to simulation processor by Sockets.

Multi-scale co-simulation makes exchanging somewhat complicated, the algorithms such as boundary condition's process and data updating have to be considered carefully for data consistency and accuracy. Due to the limitation of one-page paper, bi-directional consistency control including its adjustable parameters couldn't be discussed in details here.

4. Evaluation

A 2D heat diffusion simulation was adopted as a case of user application to evaluate the system. To justify the accuracy of simulation data on RS and CS, we compute a highest resolution wide area simulation as truth standard and choose Root-Mean-Square Relative Error (RMS-RE) and PSNR as measure methods. In RMS-RE, to avoid the excessive values around zero, we amend the simulation data.

Fig.3 shows the RMS-RE result of experiment using one RS and CS, some parameters of experiment is as below: max time step is 1000 steps, DQC is performed per 160 time steps and UQC per 100 time steps.

We can note that bi-directional consistency control will effectively decrease the RMS-RE value on both CS and RS. On the CS curve, UQC per 100 time steps will strongly alleviate errors; on the RS curve, DQC per 160 time steps also effects. Compared to the curves without bi-directional consistency control, the effectiveness of our co-simulation scheme to improve simulation's accuracy is demonstrated.

5. Conclusion

This paper considers a distributed multi-scale co-simulation scheme with bi-directional consistency control as extension to Simulation Caching Framework. The effectiveness of improving simulation accuracy on both local and remote side is evaluated using RMS-RE via a heat diffusion simulation.

References

[1] 山本優，西村祐介，福間慎治，森眞一郎．シミュレーションキャッシングフレームワークの実装．情報処理学会 ACS 論文誌．Vol.57 No.3，pp823-835．2016．3

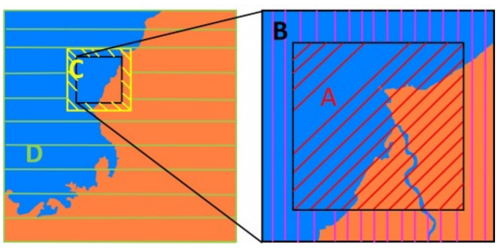

Fig.1 Distributed Multi-scale Co-simulation scheme (left: CS, Fukui area, right: RS, Tojinbo in Fukui)

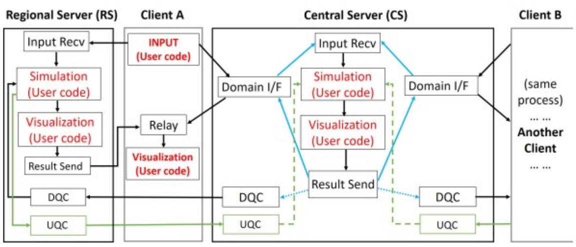

Fig.2 Implemented system with bi-directional consistency control (DQC and UQC)

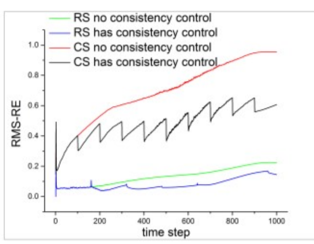

Fig.3 RMS-RE of RS and CS