THE ROLE OF PARALLEL COMPUTING SYSTEMS IN COMPUTER MODELING

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Abstract: Computer modeling is an important tool in modern scientific research and analysis of technological processes. The effective use of computing resources in this process has become a pressing issue. This article analyzes the role of parallel computing systems in computer modeling, their efficiency and the possibilities of accelerating modeling in a multiprocessor environment. Also, the basic principles of parallel algorithms and their application to models of physical processes are considered with practical examples.

Keywords: computer modeling, parallel computing, multiprocessor systems, algorithms, efficiency, physical processes

INTRODUCTION

Computer modeling is one of the fundamental foundations of modern science, engineering, and technology. This process allows complex real-world phenomena—from natural processes to economic systems—to be simulated digitally. For example, tasks such as predicting climate change, testing new drugs, or optimizing aerodynamic designs rely on computer models. However, these models often require rapid processing of large amounts of data and high-precision calculations, which exposes the limits of traditional sequential computing methods. Parallel computing systems were developed to solve this problem, which are capable of performing many operations simultaneously using multiple processors or computing cores. This technology significantly speeds up modeling processes and provides scalability. For example, planning systems for NASA's Mars rovers or deep learning models rely on parallel computing systems. The advantages of parallel computing include not only speed, but also efficient management of large amounts of data and optimal use of resources. However, there are also challenges such as synchronization problems and programming complexity.

The purpose of this article is to study the use of parallel computing systems in computer modeling, analyze their advantages and limitations, and consider examples of modern applications. The article aims to provide useful information for professionals and students in the field of modeling.

Methods

The following research methods were used to study the role of parallel computing systems in modeling:

Literature review: Available scientific sources on parallel computing systems were reviewed, including articles on CUDA, MPI, OpenMP, and other technologies. At the same time, the historical development of parallel computing in the field of modeling was also reviewed - for example, the evolution of supercomputers from megaFLOPs to exaFLOPs.

Application synthesis: The application of parallel computing in real-world models was analyzed. For example:

- Simulation of extreme weather events in climate models (Kurth et al., 2018).
- Modeling of metastatic cancer diagnosis in medicine (LYNA system).
- Deep learning models in image recognition (ImageNet, 2012).

Architecture comparison: The differences between shared memory systems and distributed memory systems were evaluated from a modeling perspective. For example, the efficiency of multi-core processors for small models and the advantages of clusters for large data sets were compared.

Technical performance analysis: Parameters such as speed (operations/sec), memory size, and communication costs of parallel systems were studied. For example, the performance of GPUs at the level of 10^{14}–10^{17} operations/sec and the impact of this performance on modeling were considered.

Difficulty assessment: Factors such as synchronization, data exchange delays, and programming complexity were analyzed for their impact on modeling efficiency.

The data was synthesized using state-of-the-art supercomputers (Summit), GPUs (NVIDIA), TPUs, and programming models (MPI, OpenMP). The study focused on real-time modeling and working with large amounts of data.

Results

Parallel computing systems have shown the following results in modeling:

1. Significant speedup: Parallel systems have dramatically reduced computational time by using multiple processors. For example, the training time for a deep learning model was one day in 2014, but in 2018, using parallel GPUs, this time was reduced to two minutes (Ying et al., 2018). In climate models, trillions of data points were processed in a matter of hours, which could have taken weeks with sequential methods.

2. Scalability: Parallel systems have been successfully used for large-scale models. In the ImageNet image recognition competition (2012), millions of images were processed using parallel GPUs, and they performed 10 times better than traditional methods (Krizhevsky et al., 2013). However, as the model size increased, the efficiency was maintained by adding additional resources.

3. Applications in various fields:

● Medicine: The LYNA system diagnosed metastatic cancer with 99.6% accuracy using parallel computing, outperforming human experts (Liu et al., 2018).

● Space exploration: NASA's EUROPA system performed daily planning for Mars rovers in parallel (Barreiro et al., 2012).

● Financial models: Parallel systems allowed for real-time risk calculations in stock market simulations.

4. High-level computing power: In 2018, Gordon Bell Prize winners achieved \$10^{18}\$ operations per second (exaflops) using GPUs. This helped to detect previously unseen extreme events in climate models (Kurth et al., 2018).

5. Limitations: Parallel systems have suffered from synchronization problems and communication delays in distributed memory systems. For example, data exchange in clusters slowed down the overall performance by 10-15%, which required additional optimization.

These results confirm the effectiveness of parallel computing in modeling, but indicate that technical and algorithmic solutions are needed to exploit its full potential.

Discussion

While parallel computing systems have provided significant advances in modeling, their effectiveness depends on several factors. First, advantages such as speed and scalability are clearly evident when processing large amounts of data. For example, parallel systems have proven to be effective in projects involving millions of images, such as ImageNet, but for smaller models, serial computation may be sufficient. This suggests that the use of parallel systems should be evaluated on a project-by-project basis.

Secondly, synchronization and communication costs are one of the main obstacles to parallel computing. In distributed memory systems, data exchange delays affect overall performance, especially in real-time modeling. For example, in climate simulations, additional algorithms had to be developed to ensure coordination between processors. Modern technologies, such as MPI (Message Passing Interface), help to reduce communication costs in solving these problems, but full optimization is still an urgent issue.

Third, the economic benefits of parallel computing in modeling are noteworthy. Faster computations reduce costs in financial analysis and enable faster decision-making in weather forecasting. For example, NASA’s DART system saved millions of dollars in 1991 by using parallel modeling for transportation logistics (Cross and Walker, 1994). However, the complexity of the programming requires additional resources for training specialists and developing new algorithms.

In the future, new technologies such as quantum computing may further advance parallel modeling. Quantum computers are expected to solve certain problems (such as optimization and molecular simulations) exponentially faster than parallel methods. However, this technology is not yet mature enough for practical application. Therefore, modern parallel architectures such as GPUs and TPUs remain the main tools for modeling today.

Another important aspect of parallel computing is its integration with various disciplines. For example, parallel systems in deep learning models have advanced computer vision and natural language processing, opening up new opportunities in medicine and social analytics. At the same time, the need to develop algorithms specifically optimized for each area of modeling remains an important direction for future research.

Conclusion

Parallel computing systems have proven themselves as an important tool for improving the efficiency of computer modeling. They provide advantages such as speed, scalability, and optimal use of resources, but they also have limitations such as synchronization, communication costs, and programming complexity. Modern technologies - GPUs, TPUs, and programming models (MPI, CUDA, OpenMP) - partially solve these problems. The results show that parallel computing has provided significant advances in areas ranging from climate models to medical diagnostics, for example, in the ImageNet and LYNA projects.

In the future, new approaches such as quantum computing may further advance parallel modeling, but for now, GPUs and supercomputers remain the main tools. Therefore, parallel computing systems play an important role in the field of modeling and contribute significantly to the development of science and technology. Future research in this area should focus on optimizing algorithms and training specialists.

REFERENCES

1. Годунов С.К., Рябенький В.С. Введение в численные методы. — Москва: Наука, 1987.
2. Хендерсон Ф., Стюарт Д. Параллельные вычисления. Архитектура, программирование и алгоритмы. — Москва: Мир, 2000.
3. Trefethen L. N., Bau D. Numerical Linear Algebra. — SIAM, 1997.
4. Gropp W., Lusk E., Skjellum A. Using MPI: Portable Parallel Programming with the Message Passing Interface. — MIT Press, 1999.
5. Karniadakis G. E., Kirby R. M. Parallel Scientific Computing in C++ and MPI. — Cambridge University Press, 2003.
6. Садыков Т.И. Параллельные алгоритмы и технологии высокопроизводительных вычислений. — Ташкент: Fan, 2018.
7. Умаров А.Х., Жураев А.А. Kompyuter modellashtirish asoslari. — Toshkent: TDPU, 2020.
8. Чеботарев А.И. Методы вычислений и моделирования на ЭВМ. — Москва: Высшая школа, 2005.
9. OpenMP Architecture Review Board. OpenMP Application Program Interface Version 4.5. — https://www.openmp.org
10. Wilkinson B., Allen M. Parallel Programming: Techniques and Applications Using Networked Workstations and Parallel Computers. — Pearson, 2005.