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Scalability and efficiency challenges for the exascale supercomputing system: practice of a parallel supporting environment on the Sunway exascale prototype system

Key words: Parallel computing; Sunway; Ultra-large-scale; Supercomputer

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Motivation

- The growth in the scale of the exascale system will release huge computing power. Taking into account the scalability and efficiency of parallel applications under such a huge parallel scale raises great challenges to the design of the exascale system.

- In addition, with the increasing demand for computing power in artificial intelligence (AI) applications, the fusion of AI and high-performance computing (HPC) applications has become an important breakthrough direction for HPC applications. It is also a challenge to support the high scalability and efficiency of AI applications in the exascale era of HPC.

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1) System and framework

- The Sunway exascale prototype system (SEPS) is a small-scale verification system designed according to the exascale application requirements, and can be scaled up to the exascale level.
- The parallel supporting environment is composed of the parallel operating system, distributed storage system, debugging and tuning system, scientific computing parallel framework, and AI ecosystem.

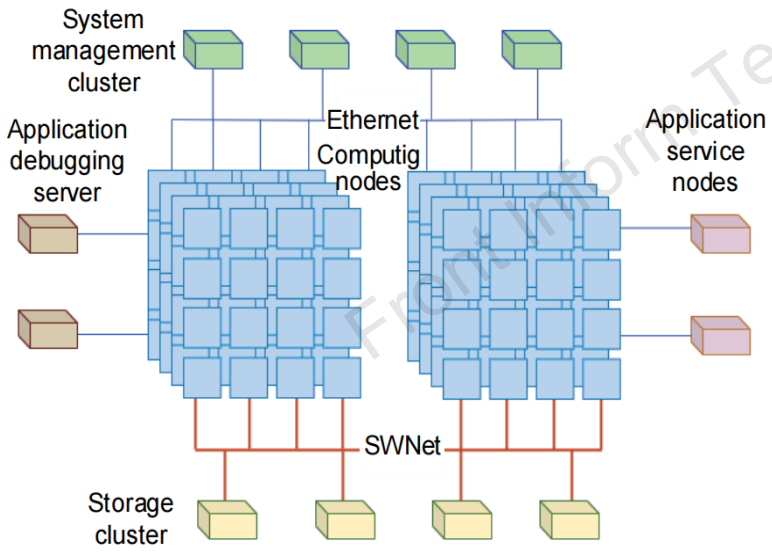


Fig. 1 Architecture of the Sunway exascale prototype system

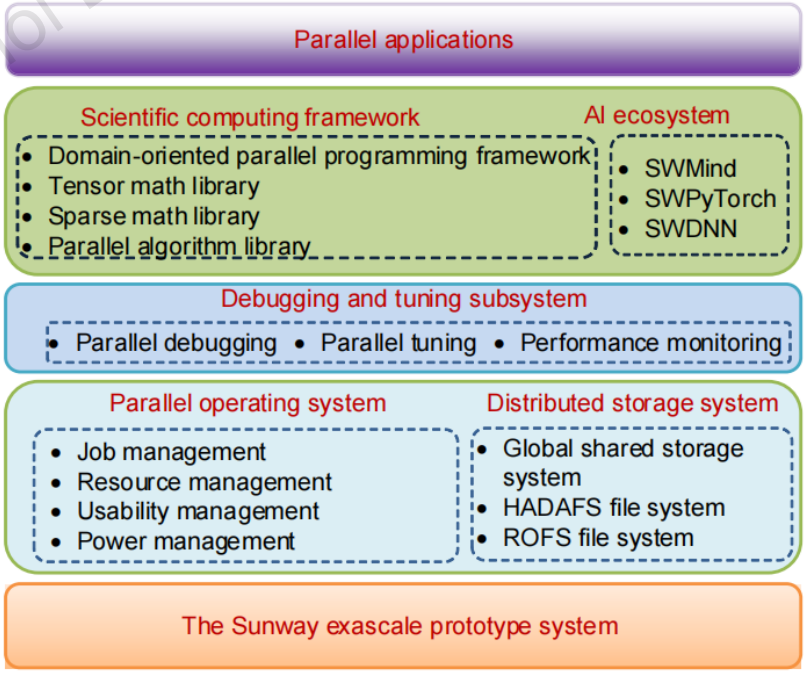


Fig. 2 Components of the parallel supporting environment

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2) Design of the parallel supporting environment

- The resource management for the whole system on SPES enables users to execute their jobs concurrently and achieve the unified management, monitoring, and on-demand allocation for many-core computing nodes.
- SEPS carries a hybrid storage system, consisting of a global file system (GFS), a burst buffer file system (HADAFS), and a read-only file system (ROFS).

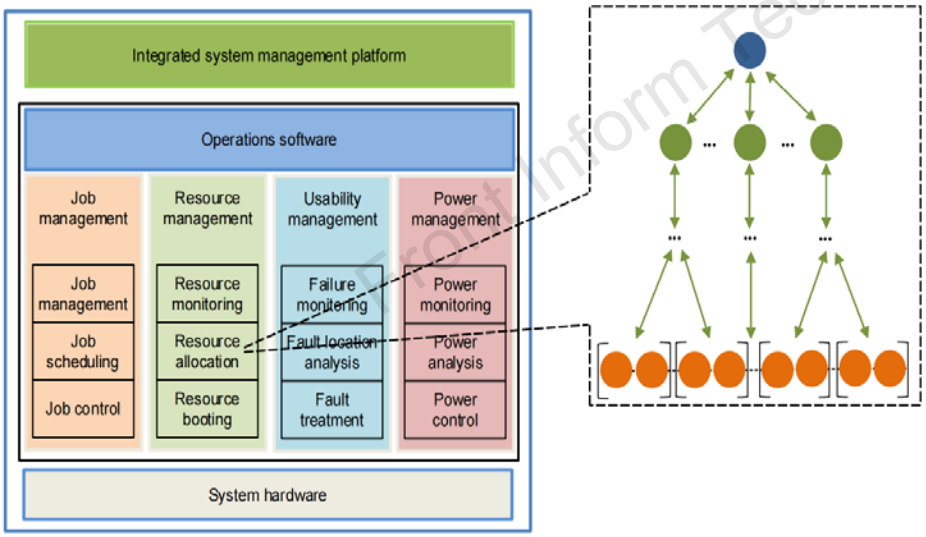


Fig. 3 Parallel operating system structure

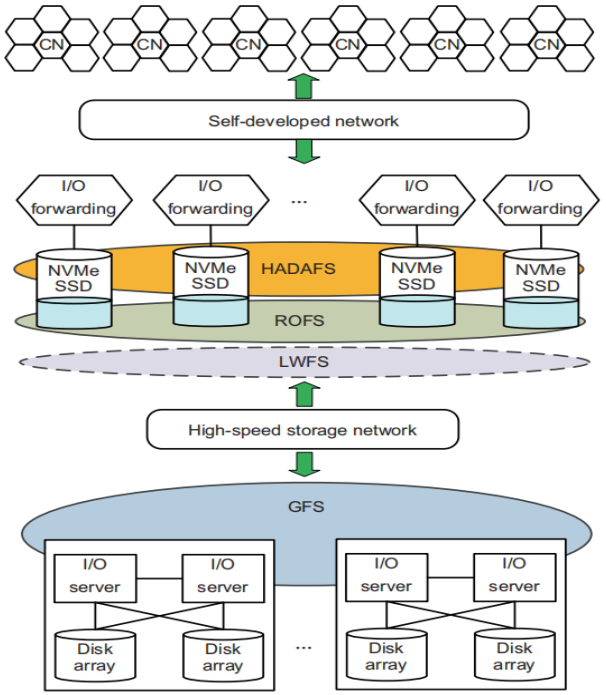


Fig. 4 Sunway storage architecture

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2) Design of the parallel supporting environment

- The debugging and tuning subsystem provides developers with tools to develop a large-scale application in less time. Debugger, parallel debugging tool, and large-scale lightweight debugging tool make up the debugging part. They support single-node applications, medium-scale applications, and large-scale applications, respectively.
- The framework is composed mainly of two parts. One part is a domain-oriented parallel programming framework. The other part is the kernel-level parallel programming framework, including the tensor math library, sparse math library, and parallel algorithm library.

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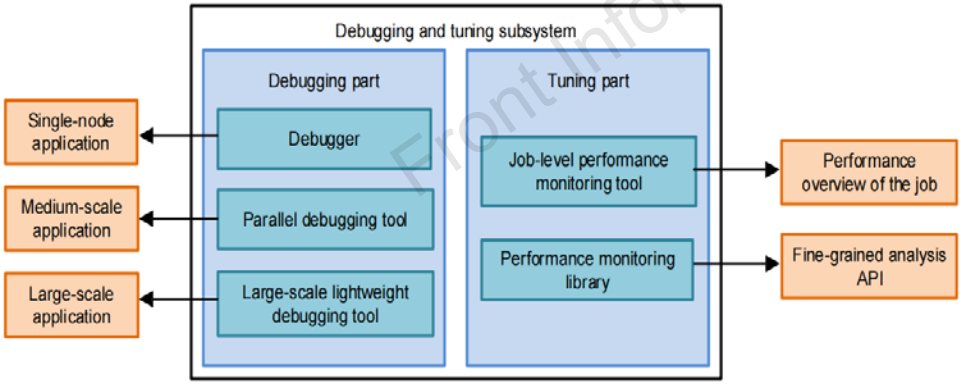


Fig. 5 Debugging and tuning subsystem

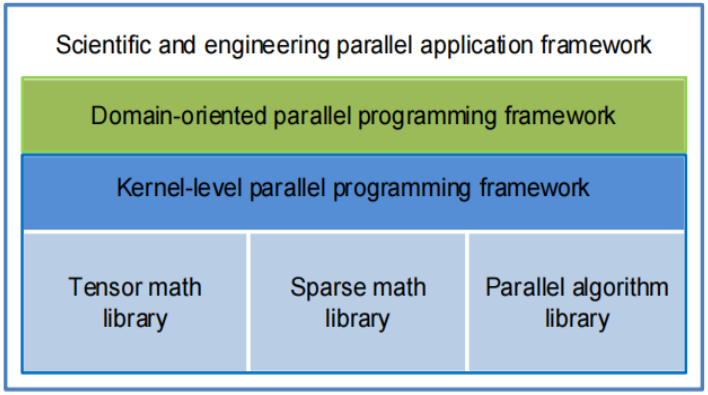


Fig. 6 Scientific computing parallel framework

3) Optimization technologies (I/O optimization)

- LIBIO calls the functions of the LWFS client port in a library manner, including an application request intercepting component and a standard LWFS client port component.
- When LIBIO is used, the user does not need to modify the code; the user needs to just link the LIBIO library in the compilation stage.
- The single-process bandwidth of a computing node is increased by more than twice, and the aggregate bandwidth of a single computing node is increased by more than five times.

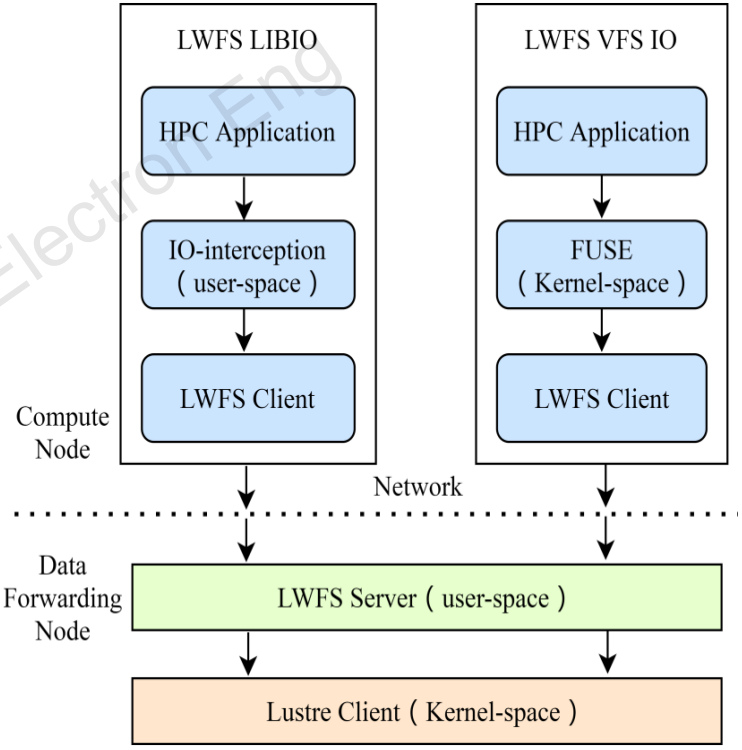


Fig. 7 Software architecture of LWFS LIBIO

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3) Optimization technologies (multi-level parallelization mode)

- At the first level, the computing tasks in the specific application are divided into multiple independent tasks according to physical or geometry characteristics.
- At the second level, i.e., processlevel (MPI) parallelism, the independent task within the subgroup is mapped to each MPI process.
- The third level is thread-level (CPE) parallelism.

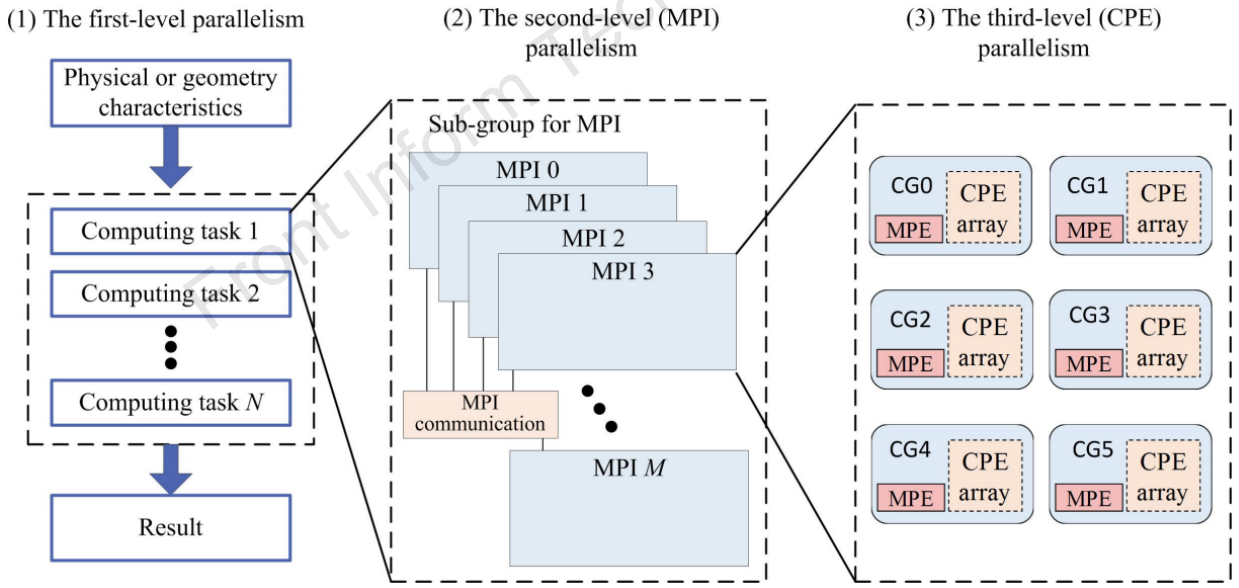


Fig. 8 Multi-level parallelization mode

4) Major results

- These applications show great scalability potential in large-scale systems.
- Among them, the random quantum circuit (RQC) simulation, Raman spectra simulation, and tokamak plasmas simulation have all been shortlisted for the 2021 Gordon Bell Prize due to significant progress in these fields.

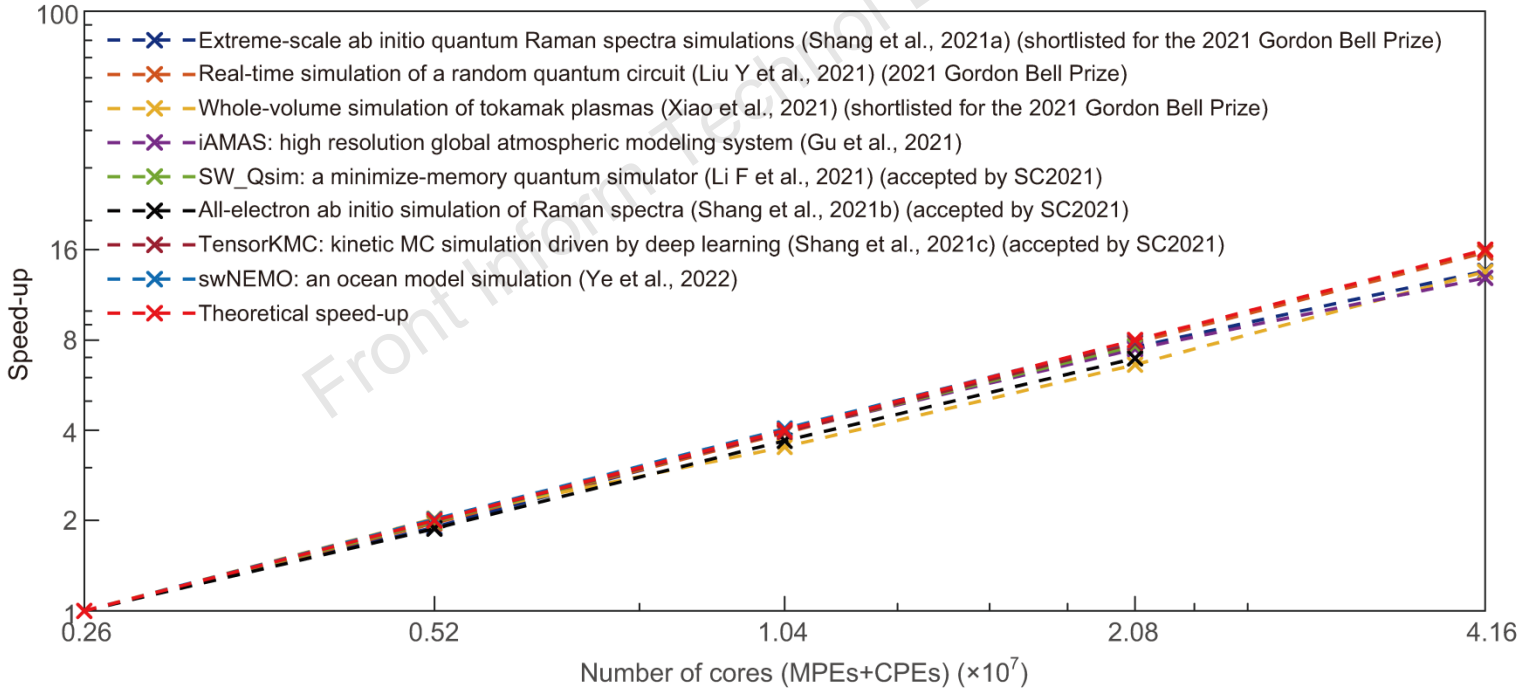
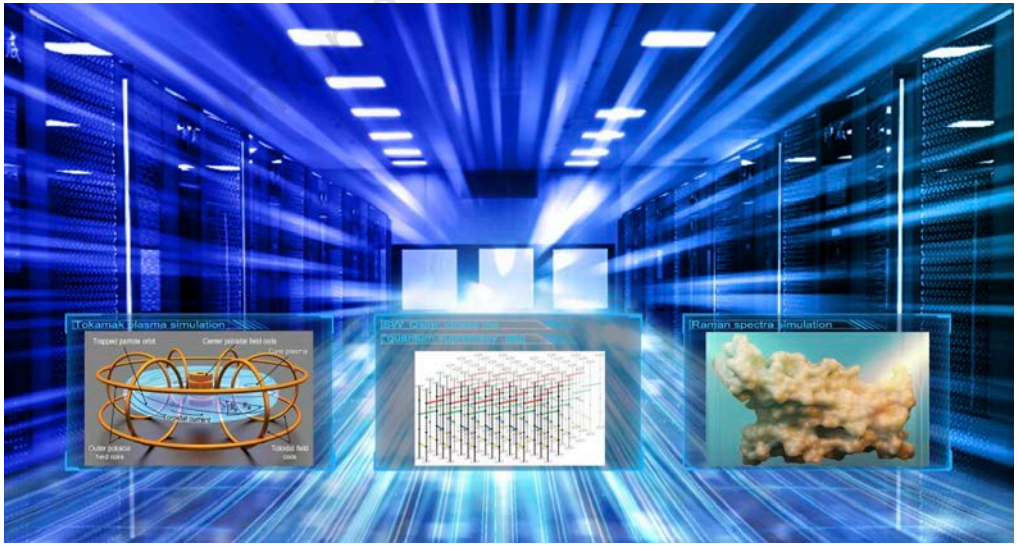
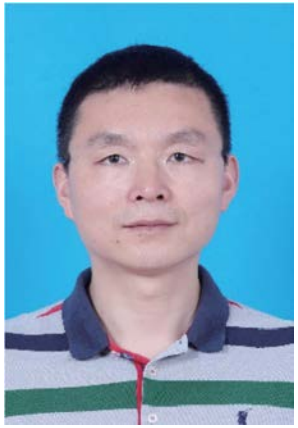


Fig. 9 Expected scalability and efficiency of multiple outstanding applications on SEPS

Conclusions and future outlook

- This paper introduces the design of a parallel application support environment of SEPS and proposes the key technologies of software in guaranteeing the scalability and efficiency of exascale applications.
- Looking to the future, new complex applications reveal novel characteristics, such as computation and data movement varying with time and discreteness and sparseness caused by data non-locality. Given these new features, we will carry out research on novel parallel algorithms and parallel supporting software design and optimization methods.





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