Near-real-time Performance Visualization of MPI Applications:

Integrating Performance Analysis into HPC Education

Anna-Lena Roth, Jonas Posner {anna-lena.roth, jonas.posner}@cs.hs-fulda.de

HOCHSCHULE FULDA
UNIVERSITY OF APPLIED SCIENCES

Fulda HPC

Motivation

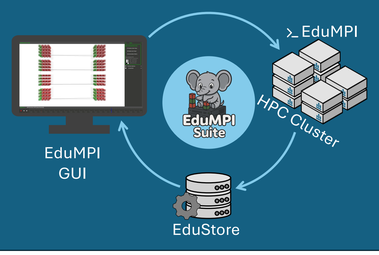
- **Learning MPI is challenging:** beginners must understand parallel programming concepts while also learning cluster operation.
- **Real cluster environments matter:** MPI programs should be executed under realistic conditions, not only locally.
- **Cluster usage adds complexity**: SSH, Linux commands, file transfer, SLURM scripts, and job management create additional barriers.
- **Performance is essential**: students need to understand not only whether an MPI program works, but how processes communicate and perform.
- **Professional tools are complex**: tools such as Score-P, CUBE, TAU, and Vampir require instrumentation, measurement runs, and interpretation of complex performance data.
- **Traditional analysis is delayed**: communication behavior is usually inspected post-mortem, after the program has finished.
- **Educational resources are limited**: small clusters, shared partitions, and queue times slow down experimentation and feedback.

Research Focus

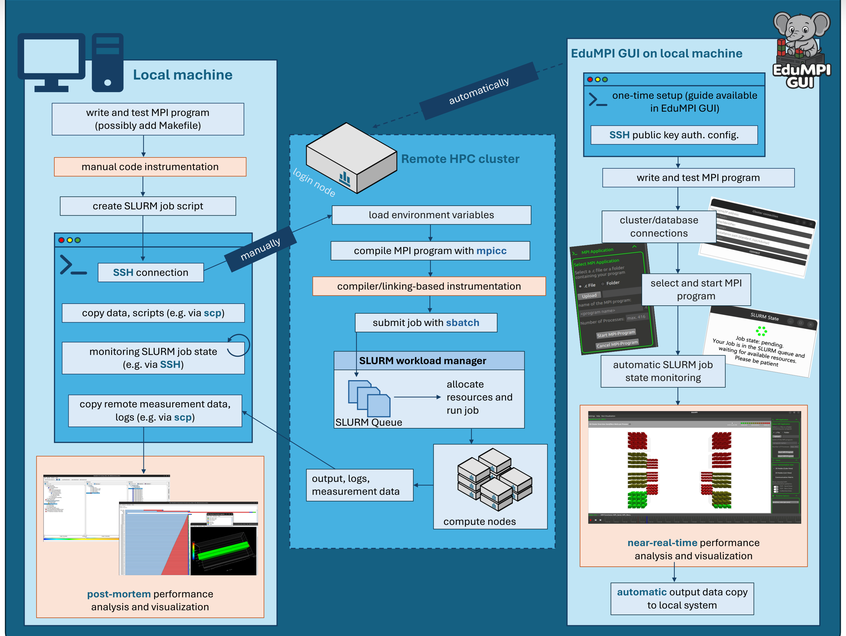
- How can program execution and performance analysis be automated for educational use?
- How can visualizations help learners understand MPI communication, including the internal algorithms of collective operations?
- How does EduMPI Suite support usability and students' ability to identify performance issues compared with established tools?

EduMPI Suite Components

- **EduMPI**: Open MPI Fork with automatic measurement functionality for MPI events, installed on cluster nodes
- **EduStore**: Time-series database (based on TimescaleDB) for continuous data aggregation
- **EduMPI GUI**: Graphical user interface for near-real-time visualizations



Running and Analyzing MPI Programs on a Cluster: Conventional vs. EduMPI GUI

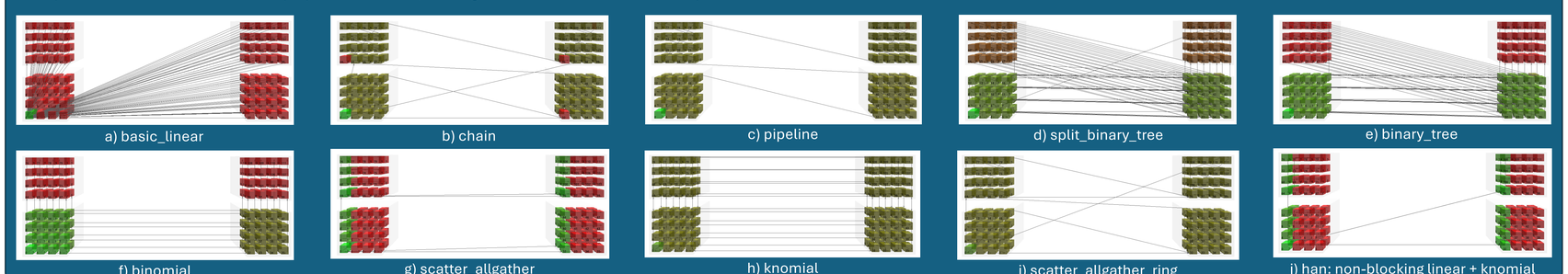


Near-real-time Analysis

- EduMPI records timestamps, bytes, communication types, process mapping, wait states, and details from collective algorithms inside Open MPI.
- Each process writes events into a ring buffer
- A dedicated thread streams them to EduStore via optimized binary ingestion.
- EduStore based on TimescaleDB uses hypertables, indexing, and continuous aggregates for responsive GUI queries.
- Benchmarks show **<3.8% overhead** and **<0.09 s query latency**

Special Feature: Visualizing MPI Internals of Collective Communication

- EduMPI Suite visualizes the internal point-to-point operations behind collective communication, making the underlying MPI algorithms easier to understand.
- The example demonstrates MPI_Bcast and shows possible broadcast algorithms used internally by Open MPI.
- EduMPI GUI represents compute nodes as large outer cubes and MPI processes as smaller inner cubes. Communication behavior is visualized through color coding: green indicates more sending, red indicates more receiving, and mixed behavior is shown based on the send/receive ratio.
- Explicit communication flow is displayed with arrows, making data movement between MPI processes visible.



Educational Evaluation

- EduMPI Suite was evaluated over 3 semesters through usability tests and questionnaire-based studies with master's students. Findings informed continuous improvements.
- Repeated comparisons with professional tools included Score-P, CUBE, and TAU.
- **Comparative usability study – summer 2025:**
  33 master's students in 12 groups completed 7 analysis tasks on a matrix multiplication with 256 MPI processes. Each group used EduMPI Suite and either CUBE or TAU; tool order was counterbalanced.

Outcome	EduMPI Suite	CUBE/TAU
Tasks completed correctly (including moderator-assisted solutions)	96%	60%
Tasks requiring moderator assistance	29%	55%
Unreserved recommendation for future courses	32/33	1/33

Conclusions

- EduMPI Suite makes MPI behavior visible early, including deadlocks, bottlenecks, and late senders/receivers.
- Near-real-time analysis provides faster visual feedback, helping learners identify problems quickly and release resources sooner.
- EduMPI Suite makes MPI internals visible, such as the point-to-point operations underlying collective communication.
- EduMPI GUI lowers the entry barriers of performance analysis while still exposing the underlying MPI communication behavior.
- EduMPI acts as a conceptual bridge toward professional performance analysis tools.
- Performance analysis becomes practical from the first MPI exercises.
- **Key results: < 3.8% runtime overhead · < 0.09 s query latency · 96% vs. 60% task success**
- EduMPI Suite is not a replacement for expert tools, but a bridge for their effective use.

References

1. Roth, Anna-Lena; Süß, Tim (2023): **Performance Analysis Tools for MPI Applications and their Use in Programming Education.** In Companion of the International Conference on Performance Engineering (ICPE '23 Companion). ACM, New York, NY, USA, 361–368. *https://doi.org/10.1145/3578245.3584358*
2. Roth, Anna-Lena; James, David; Kuhn, Michael; Konert, Johannes (2024): **Enhancing Parallel Programming Education with High-Performance Clusters Utilizing Performance Analysis**. Proceedings of DELFI 2024. Gesellschaft für Informatik e.V. *https://doi.org/10.18420/delfi2024_42*
3. Roth, Anna-Lena; James, David; Kuhn, Michael (2025): **EduMPI – Simplifying the Use of High-Performance Clusters and Focusing Performance Analysis in Parallel Programming Education.** PARS-Mitteilungen: Vol. 37. Gesellschaft für Informatik e.V., Fachgruppe PARS. ISSN: 0177-0454. *https://dl.gi.de/handle/20.500.12116/46131*
4. Roth, Anna-Lena; James, David; Kuhn, Michael; Frisch, Dustin (2025): **Making MPI Collective Operations Visible: Understanding Their Utility and Algorithmic Insights.** Euro-Par 2025. LNCS, vol 15900. Springer, Cham. *https://doi.org/10.1007/978-3-031-99854-6_5*
5. Roth, Anna-Lena; James, David; Posner, Jonas; Kuhn, Michael (2026): **Performance Analysis in Parallel Programming Education: A Comparative Usability Study**. PARS-Mitteilungen: Vol. 38. Gesellschaft für Informatik e.V., Fachgruppe PARS. ISSN: 0177-0454. *https://dl.gi.de/handle/20.500.12116/48841*
6. Roth, Anna-Lena; Posner, Jonas; Kuhn, Michael (2026): **Enabling Interactive Visualization for Near-Real-Time Performance Analysis of MPI Applications**. In Companion of the International Conference on Performance Engineering (ICPE '26 Companion). ACM, New York, NY, USA, 120 – 129. *https://doi.org/10.1145/3777911.3800642*
7. Roth, Anna-Lena; Posner, Jonas (2026): **An Empirical Analysis of High-Performance Computing Education in Germany**. In Computational Science (ICCS) Workshops (WTCS). LNCS, vol 16789. Springer, Cham. *https://doi.org/10.1007/978-3-032-29918-5_32*

EduMPI + EduStore | EduMPI GUI | Demo Video