PERFORMANCE ANALYSIS IN PARALLEL PROGRAMMING EDUCATION:

A Comparative Usability Study

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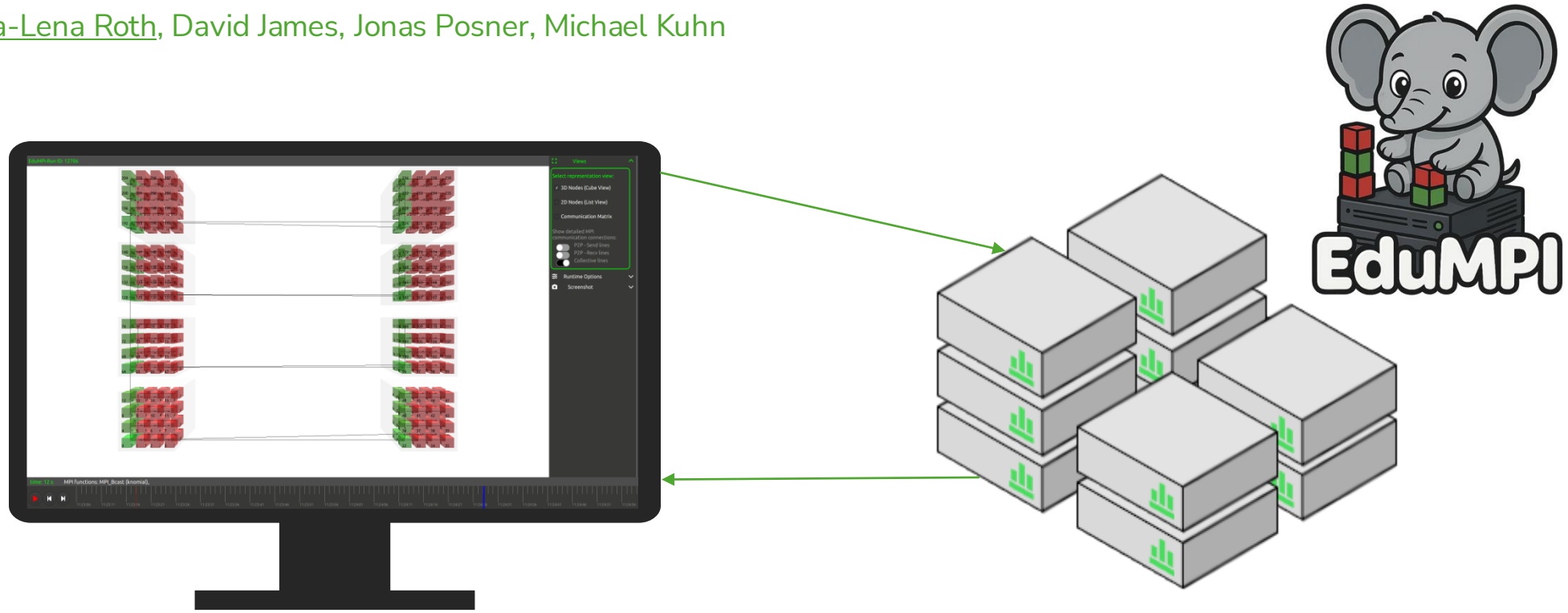


PARS Workshop 2025, Hagen, Germany
Session 2: MPI Correctness and Education

MOTIVATION

- Students in parallel programming courses face two challenges:
  - Learning MPI and cluster computing basics
  - Understanding performance issues like load imbalance or bottlenecks

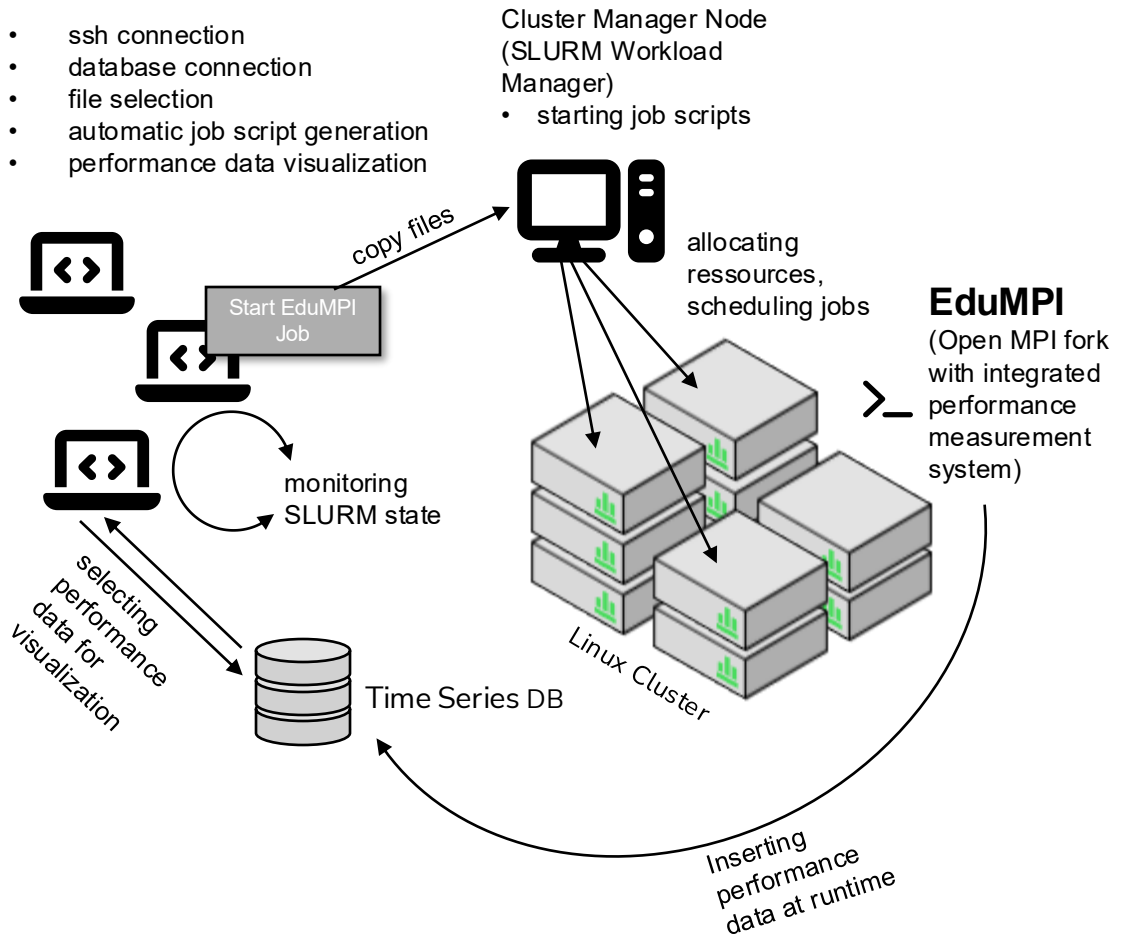
- Professional tools (Score-P, TAU, CUBE, Vampir) are powerful but
  - Complex to install and use
  - Require deep prior knowledge
  - Often overwhelming for beginners

- Performance analysis is crucial in HPC education… BUT in practice…
  - Courses remain theory-heavy
  - Access to real HPC environments is limited
  - Performance analysis is often reduced to simple runtime comparisons

OVERVIEW

Three essential components of EduMPI:

- EduMPI - Measurement and data collection within an Open MPI fork
- Time-series database
  - PostgreSQL
  - Timescale DB
- EduMPI GUI



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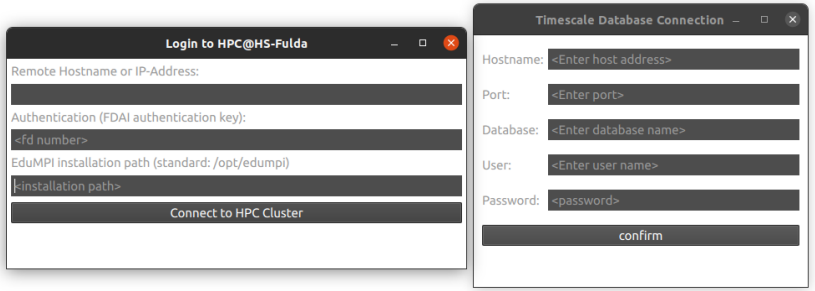
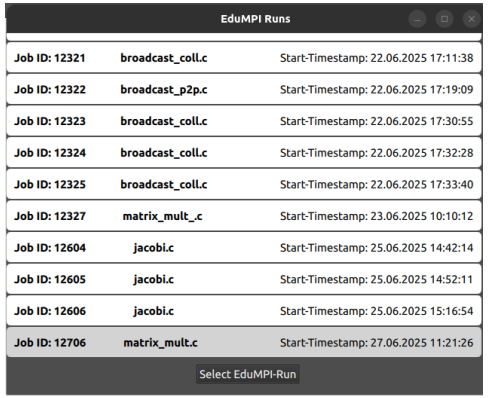
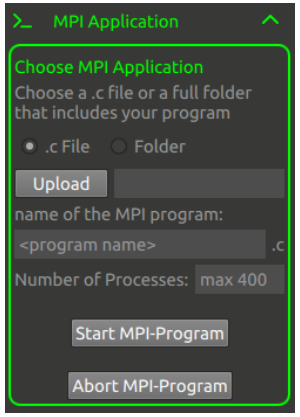


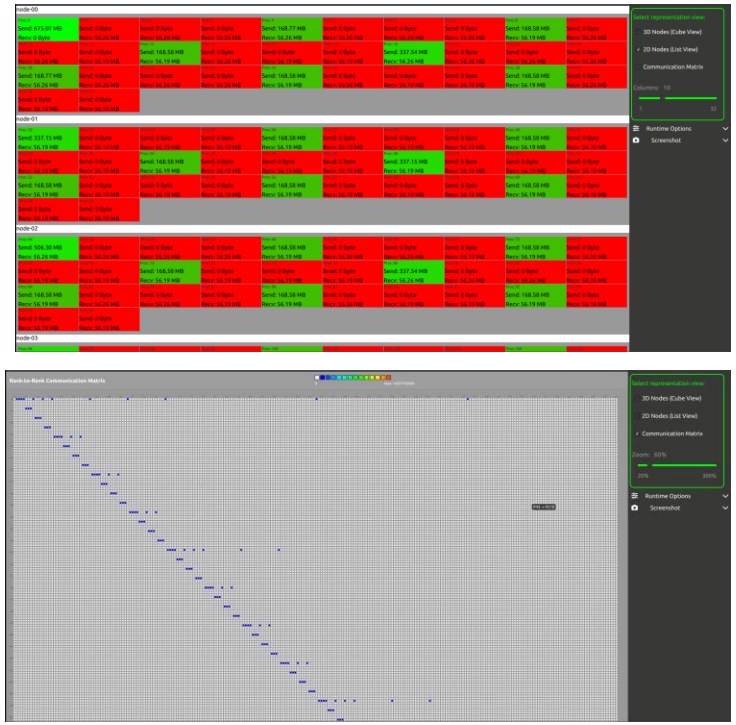
Connection to Cluster, Database



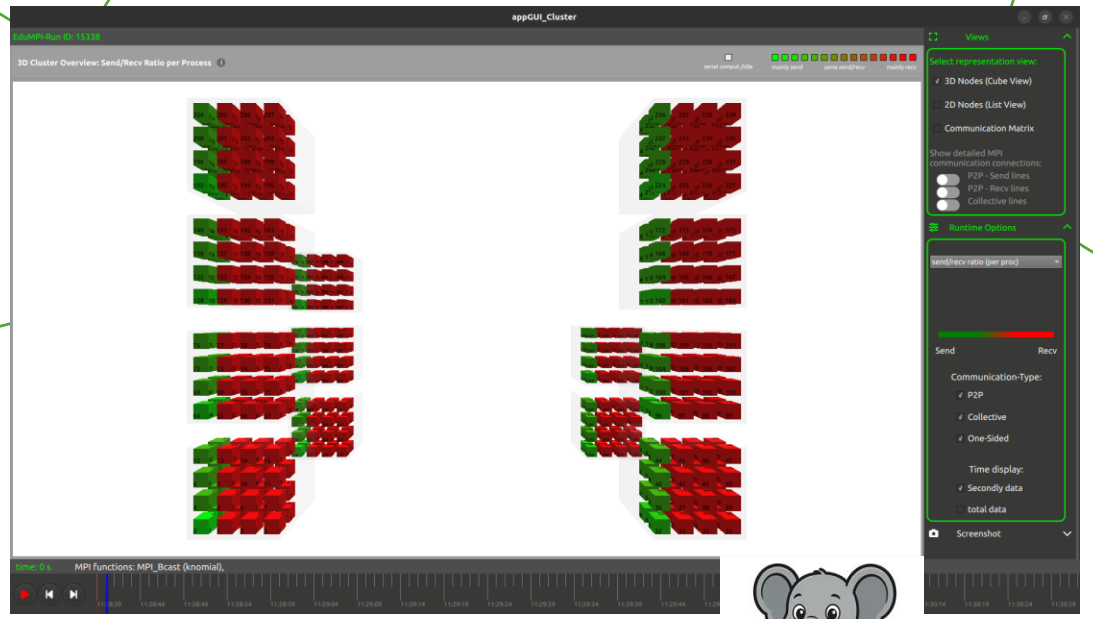
Load earlier runs from DB

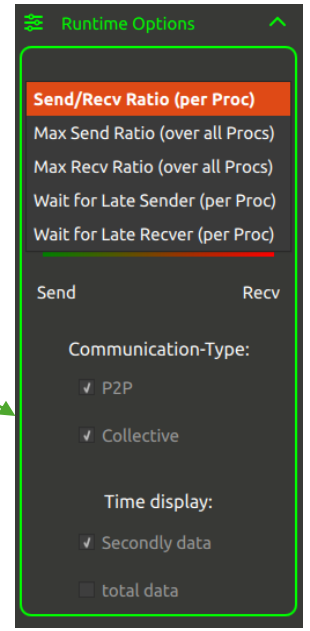


Start EduMPI Program



Views – 3D / 2D / Communication Matrix





Options

EduMPI GUI

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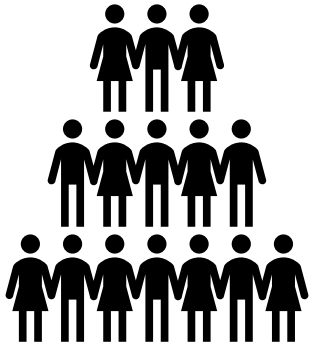
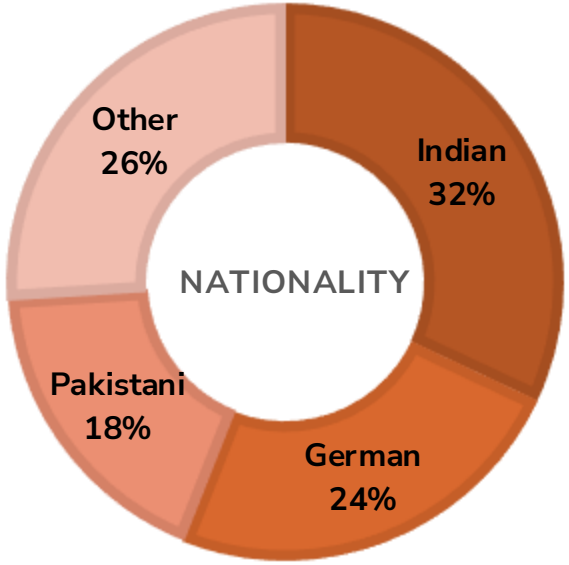
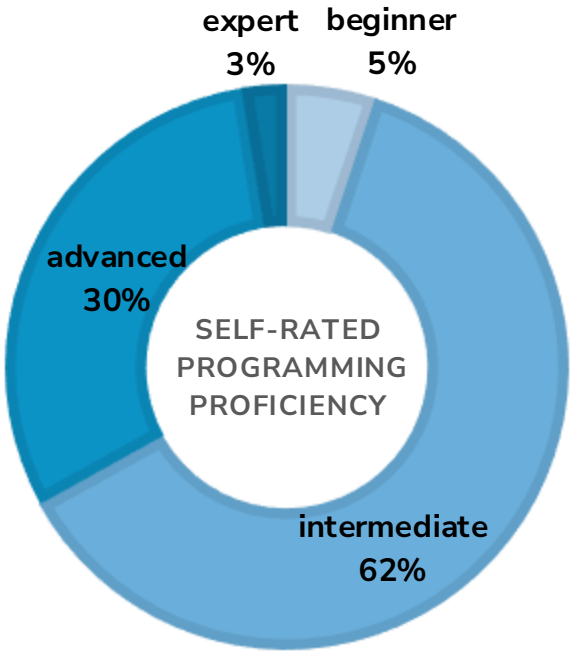
Performance Analysis in Parallel Programming Education

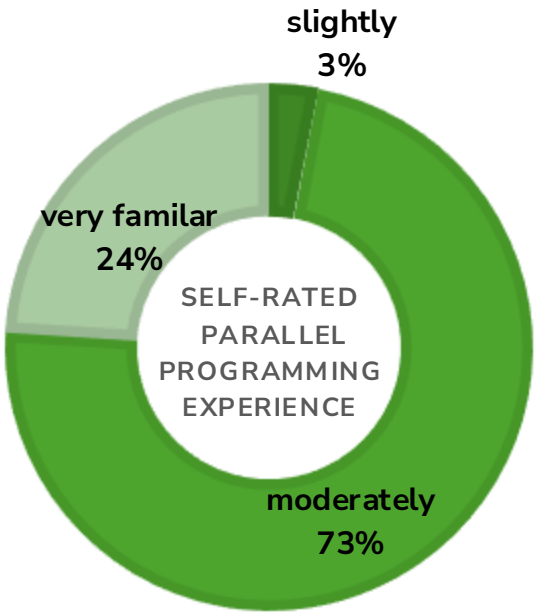
EDUCATIONAL EVALUATION – USER TEST



33 participants – 12 Groups







- Participation in the Parallel Programming course, summer semester 2025
- Sessions fully moderated, recorded, and followed a standardized protocol.

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PROGRAM AND SETUP

- Examined program: parallel row-wise **matrix multiplication** (master–worker pattern)
  - Master generates matrices A and B
  - Entire B sent to all processes
  - A distributed row by row → workers compute partial C
  - Master collects results

- Program discussed in class (focus not on runtime behavior, but on source code)
  - 73% of participants had attended the lecture

- Usability study setup:
  - 256 processes
  - Two workflows (groups):
    A. EduMPI → CUBE/TAU
    B. CUBE/TAU → EduMPI
  - EduMPI offered automated Score-P profiling
  - Evaluation criteria: correctness, insight generation, efficiency, satisfaction

Usability Tasks (T1 – T7)

T1 **Process distribution:** How and across how many nodes?

T2 **Color coding**: Meaning of visual encodings in tools?

T3 **Matrix B distribution**: Duration & MPI function used?

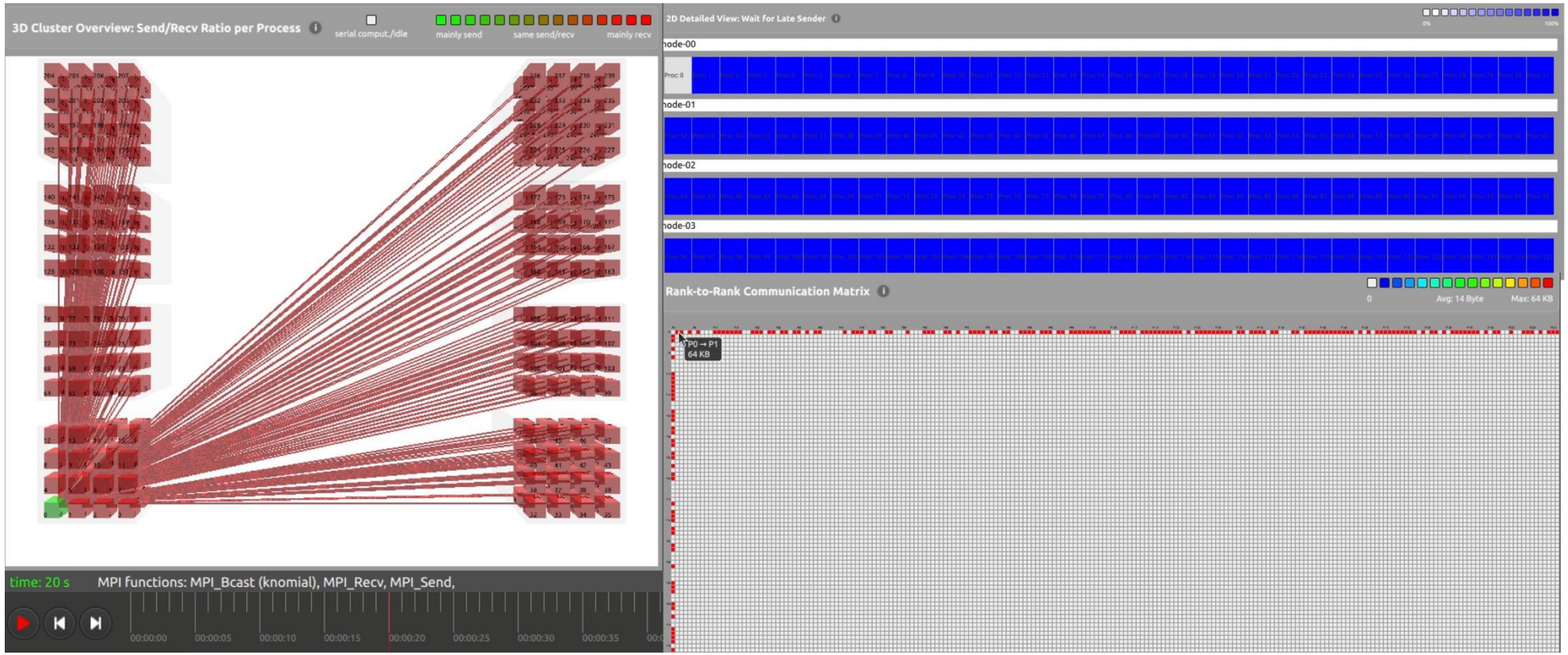
T4 **First phase (broadcast):** Bottlenecks & causes?

T5 **Second phase (row-wise A distribution):** Problems & reasons?

T6 **Centralized vs. distributed communication**: Efficiency & scalability?

T7 **Dominant MPI communication**: Which function consumes most time & data?

USABILITY STUDY – EduMPI



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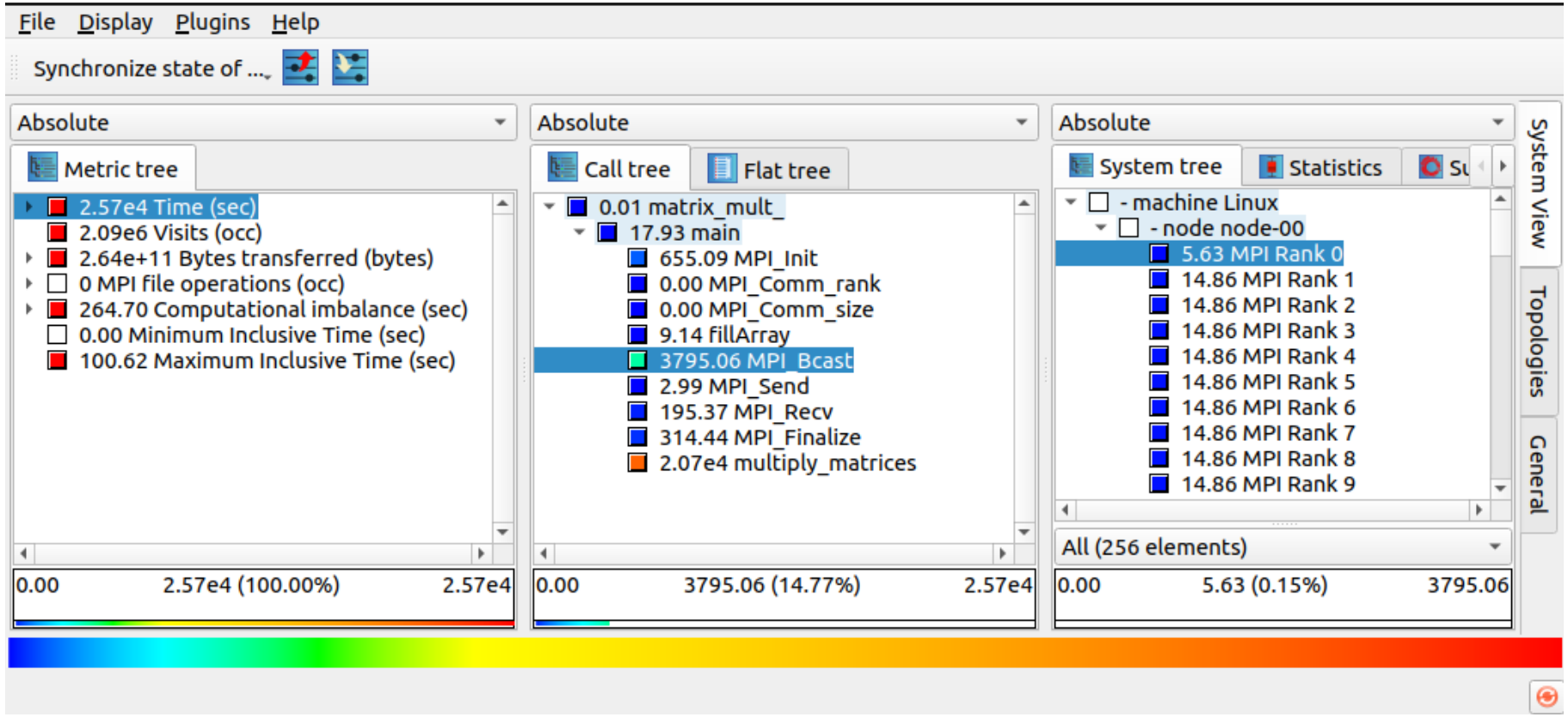
USABILITY STUDY – Scalasca/Cube



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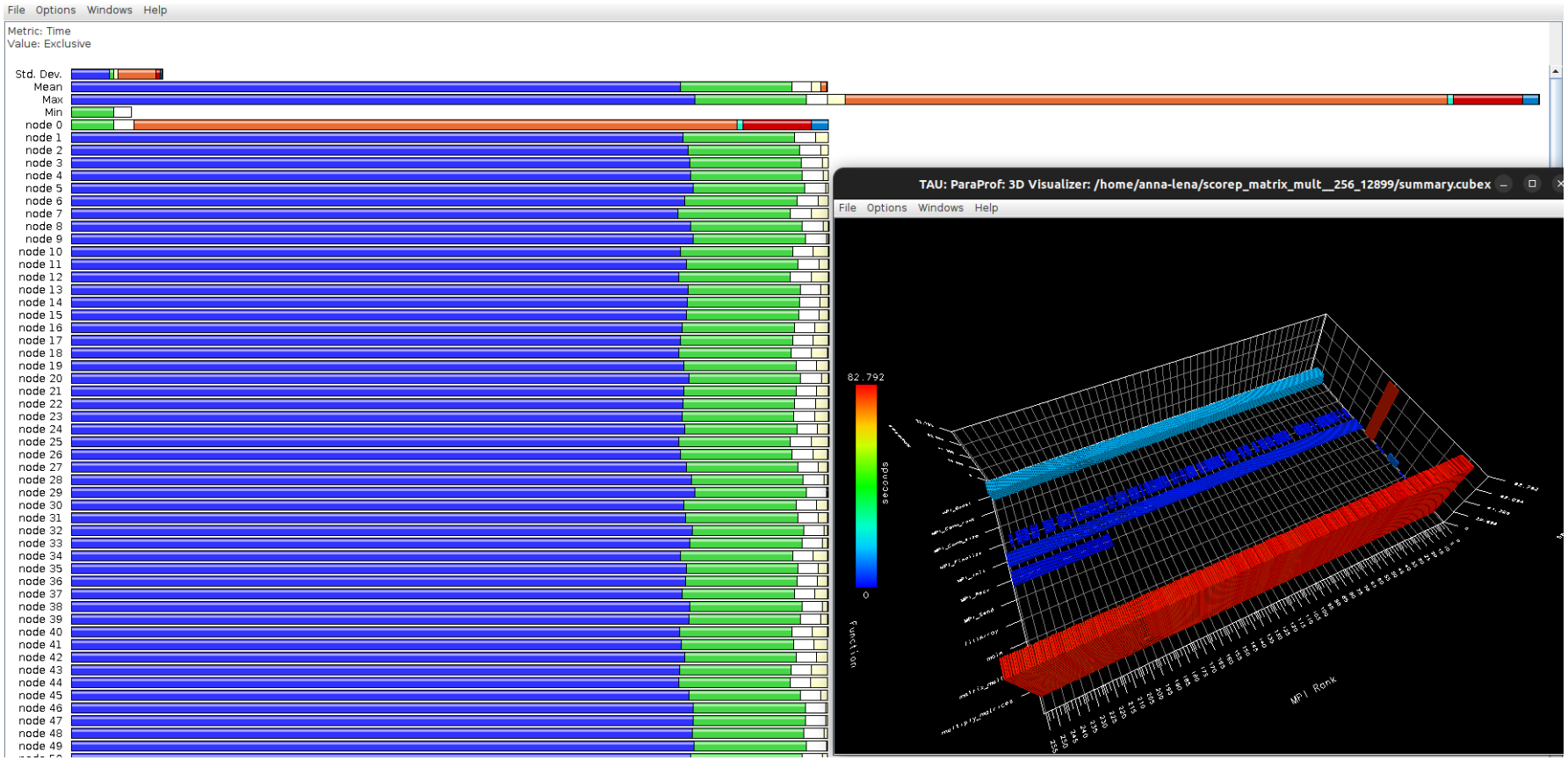
USABILITY STUDY – TAU/Paraprof



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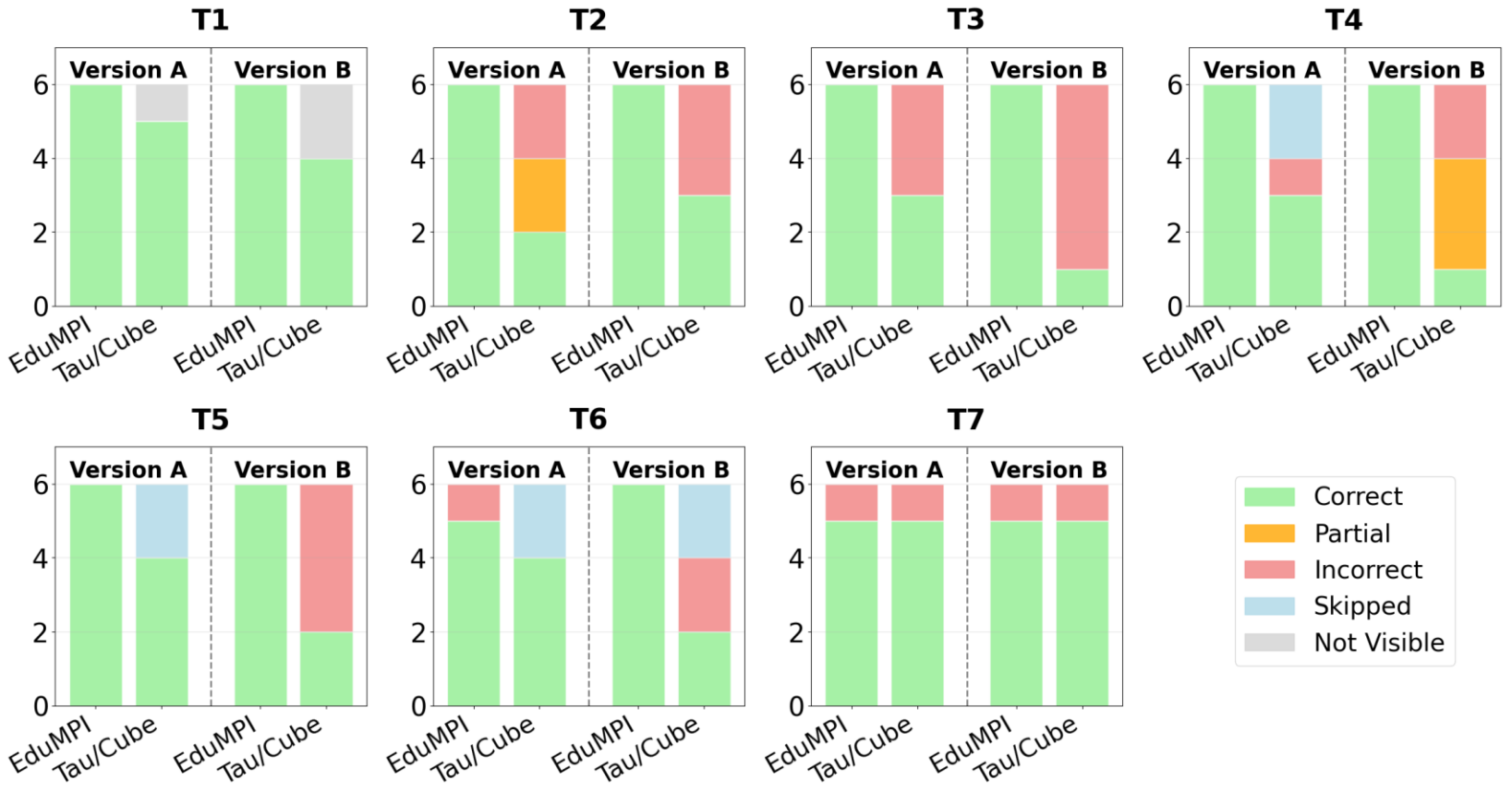
USABILITY STUDY – RESULTS - EFFECTIVENESS



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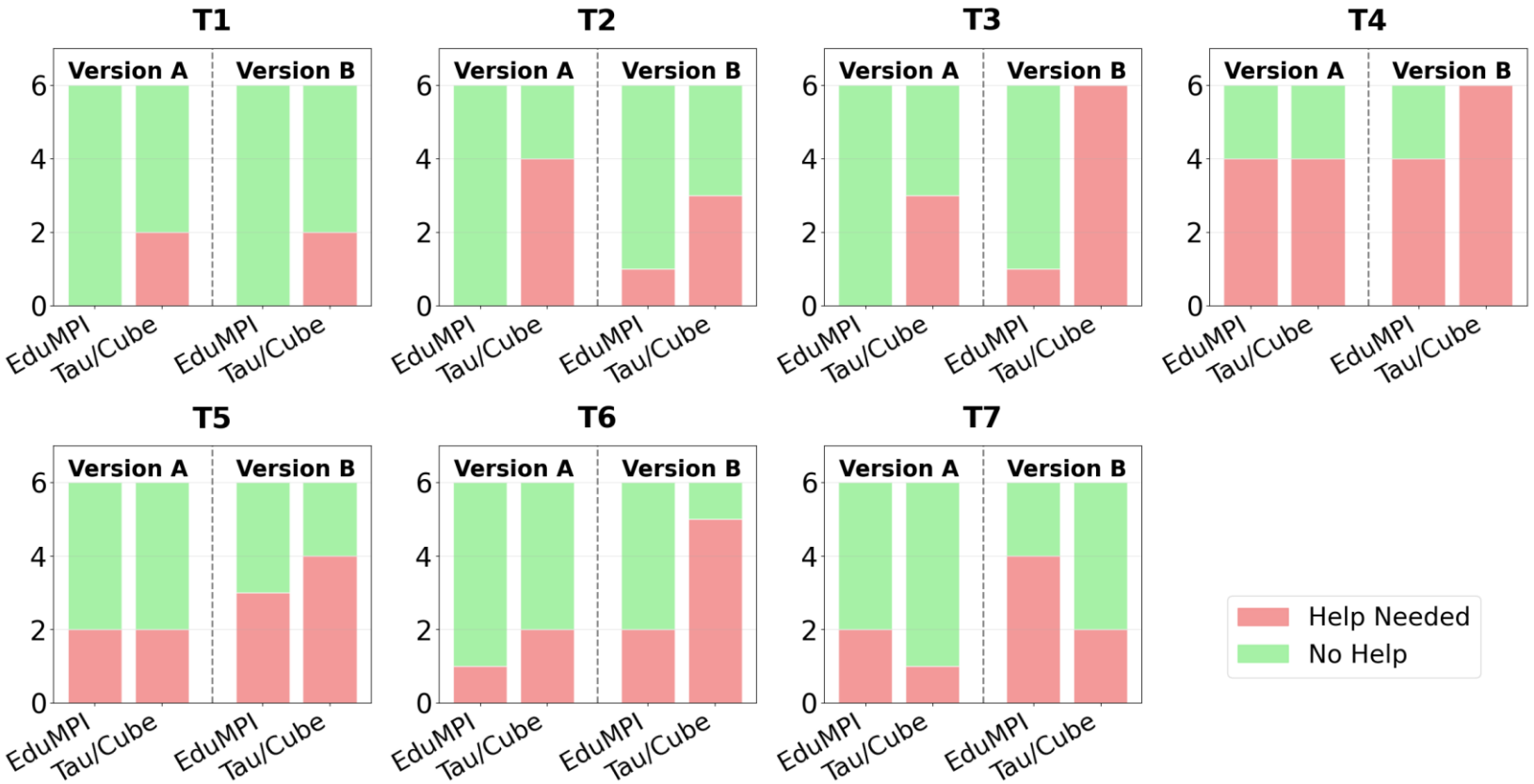
USABILITY STUDY – RESULTS - EFFECTIVENESS



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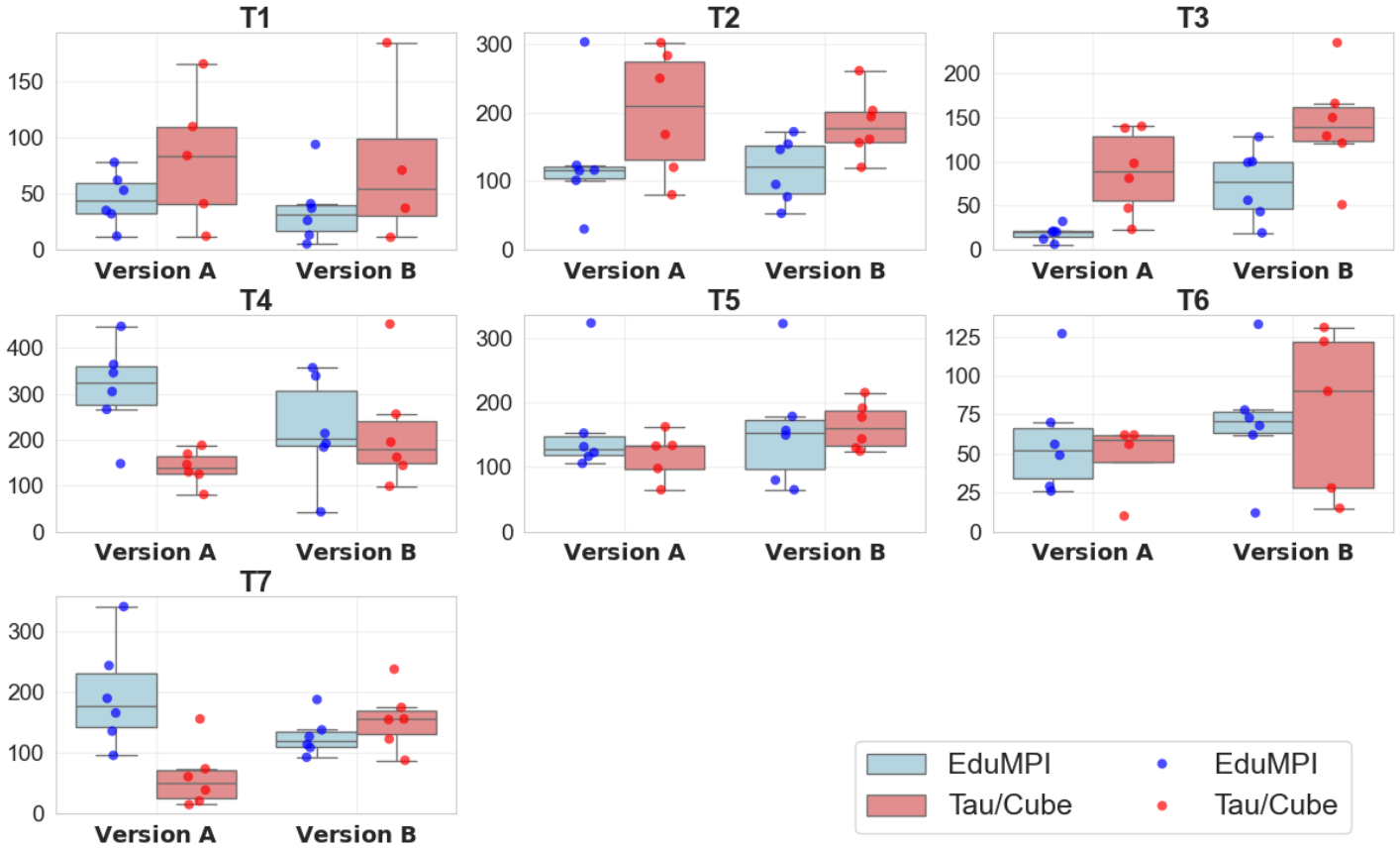
USABILITY STUDY – RESULTS - EFFICIENCY



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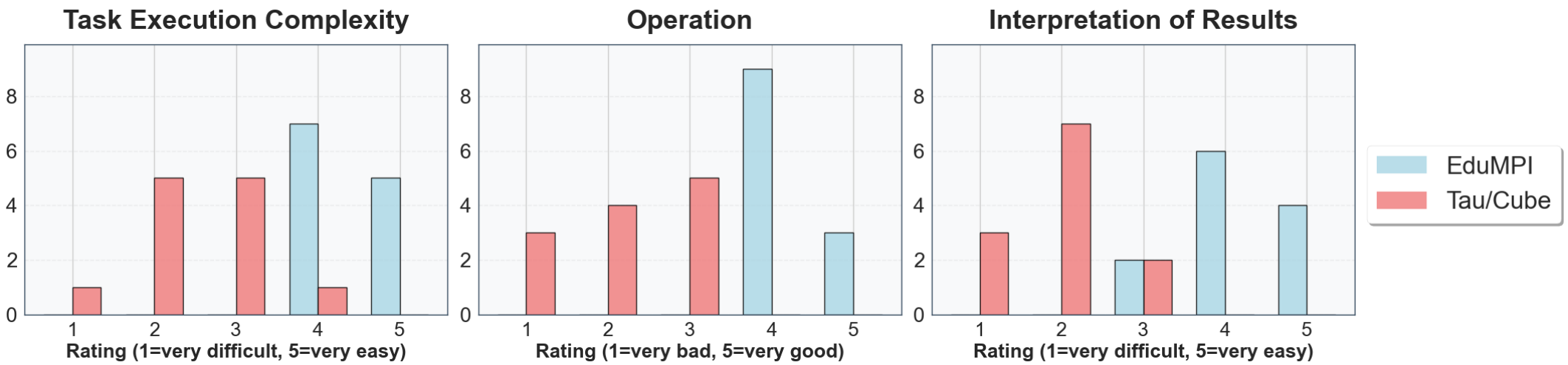
USABILITY STUDY – RESULTS - SATISFACTION



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DISCUSSION

- **EduMPI vs. TAU/CUBE**
  - EduMPI significantly improved analysis of program behavior
  - Students preferred **visualizations in EduMPI**:
    - More intuitive, accessible, and engaging
    - Less metric overload, easier exploration

- **Effectiveness**
  - Students solved **96% of tasks** correctly with EduMPI
  - With TAU/CUBE: only **60% correct**
  - EduMPI supported clearer identification of performance problems
  - Served as a **bridge**: students who used EduMPI first performed better with TAU/CUBE

DISCUSSION

- **Efficiency**
  - Students required **fewer interventions** with EduMPI
  - Analysis process more transparent and exploratory
  - Less time needed to identify most performance issues

- **Satisfaction**
  - EduMPI rated as **more intuitive, accessible, and engaging**
  - All 33 participants recommended EduMPI for teaching
  - Only 15 (14 with improvements) recommended TAU/CUBE
  - Increased student initiative, earlier cluster use, stronger focus on communication efficiency

CONCLUSION

- **Conclusion**
  - EduMPI: effective & accessible tool for parallel programming education
  - Lowers barriers to performance analysis
  - Shifts focus from “code runs” → to **efficiency & communication improvement**
  - Supports transition toward professional tools (bridge role)

- **Future Work**
  - Improve **aggregation of performance data** (whole runtime view)
  - Extend usability evaluation with **tracing-based tools**
  - Refine interface for clearer interpretation of global metrics

Thank you for your attention! - Questions?

Publications

- Roth, Anna-Lena; Süß, Tim (2023): **Performance Analysis Tools for MPI Applications and their Use in Programming Education.** In Companion of the 2023 ACM/SPEC International Conference on Performance Engineering (ICPE '23 Companion). Association for Computing Machinery, New York, NY, USA, 361–368. https://doi.org/10.1145/3578245.3584358

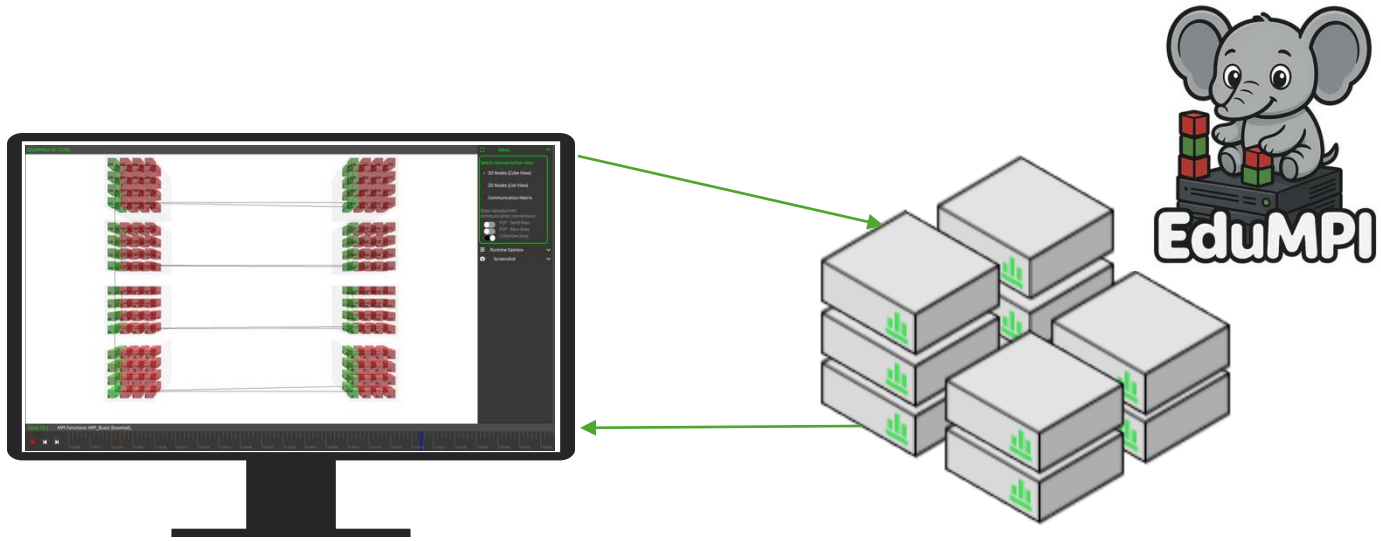
- Roth, Anna-Lena; James, David; Kuhn, Michael; Konert, Johannes (2024): **Enhancing Parallel Programming Education with High-Performance Clusters Utilizing Performance Analysis.** Proceedings of DELFI 2024. DOI: 10.18420/delfi2024_42. Gesellschaft für Informatik e.V. https://doi.org/10.18420/delfi2024_42

- 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

- Roth, Anna-Lena; James, David; Kuhn, Michael; Frisch, Dustin (2025): **Making MPI Collective Operations Visible: Understanding Their Utility and Algorithmic insights.** In: Nagel, W.E., Goehringer, D., Diniz, P.C. (eds) Euro-Par 2025: Parallel Processing. Euro-Par 2025. Lecture Notes in Computer Science, vol 15900. Springer, Cham. https://doi.org/10.1007/978-3-031-99854-6_5

GitHub:

- https://github.com/AnnaLena77/EduMPI_GUI.git
- https://github.com/AnnaLena77/EduMPI.git



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