Scalable Alternative Route Computation with ACE: A C++17 Library for HPC Traffic Simulations

VSB TECHNICAL UNIVERSITY OF OSTRAVA | IT4INNOVATIONS NATIONAL SUPERCOMPUTING CENTER

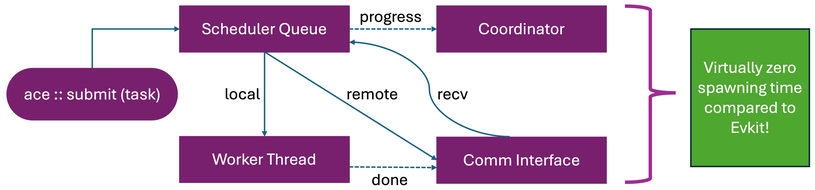
CSC

Paulo Silva, Pavlína Smolková, Kateřina Slaninová, Jan Martinovič, Matej Špeťko, João Barbosa (IT4Innovations, VSB – Technical University of Ostrava), Emanuele Vitali (CSC – IT Center for Science)

ACE: Boosting Large-Scale Traffic Simulation Performance

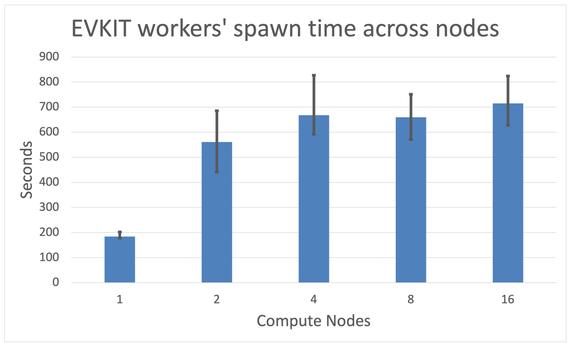
ACE (Asynchronous Communication and Execution) is a C++17 library for scalable, asynchronous task execution on HPC systems. Integrated into RUTH traffic simulator, ACE accelerates alternative route computation by eliminating worker-spawning overhead and dynamically adapting task granularity to workload characteristics.

We evaluate ACE in two scenarios with varying dataset sizes and route complexities. Preliminary results show substantial computation-time reductions and improved scalability compared to a previous Rust-based approach (Evkit), with performance gains ranging from ~1.45× to ~15× depending on route length.



Rethinking Alternative Route Computation: from Evkit to ACE

- Evkit complex to deploy across diverse HPC systems due to hybrid toolchain and non-MPI communication (via ZeroMQ).
- Evkit has fixed batch size, static scheduling, worker spawning overhead (~178 - 824 seconds on 1 to 16 nodes).
- ACE improves performance, portability, and maintainability with native C++17.
- ACE begins execution immediately after MPI job launch.



What Makes ACE Different

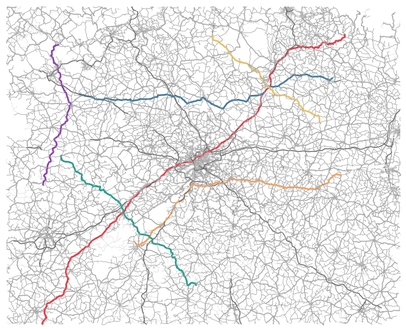
- Native C++17 implementation, self-contained build.
- Asynchronous task model with dynamic load balancing.
- Pluggable comm backends: MPI, TCP.
- Interoperability with OpenMP, TBB, CUDA.
- Dynamic task granularity adaptation.
- Removes worker-spawning overhead.

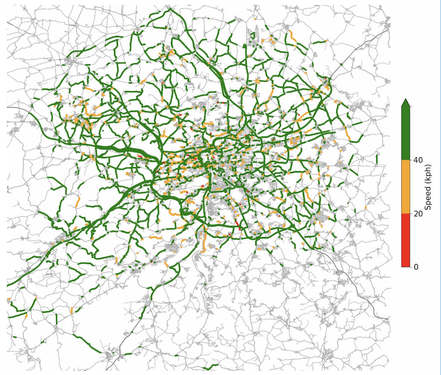
ACE Repository

Feature	Evkit	ACE
Language	Polyglot (Rust, C++, Python)	Pure C++ 17
Backbone	ZeroMQ	MPI / TCP
Architecture	Broker	Distributed Work-Stealing
Asynch Model	Manual Threading	Cooperative Tasking
Load Balancing	Static (Round-robin)	Dynamic (Task Donation)
Termination	Manual / Ad-hoc	Automatic (Coordinator)
Scalability	Limited	Massively Parallel
Collectives	Not Supported	Barriers, Broadcast

Two regions and two workloads

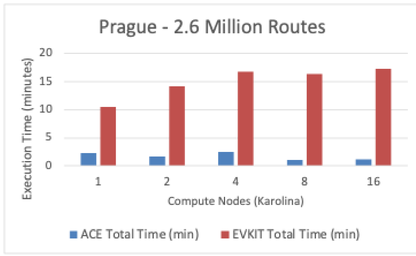
- **Central Bohemia**: large network - longer alternatives, more segments (network and example routes on the left).
- **Prague**: compact network - shorter alternatives, fewer segments (network and simulation example on the right).
- Workload = number vs length of computed alternatives.
- Central Bohemia graph: 194,585 nodes, **478,517 edges.**
- Prague graph: 4,667 nodes, **9,955 edges.**

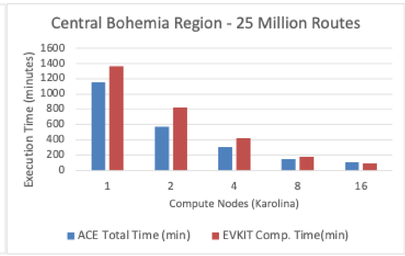




Execution Times and Speed Up

- Scaling efficiency remains high until ~8 nodes.
- Parallel scaling saturation observed from ~16 nodes.
- CPU usage consistently at ~98%.





Prague - 2.6 Million Routes

- ACE delivers a ~15× speedup over Evkit, largely driven by eliminating the multi-minute worker-spawning stage.

Nodes	ACE Total (min)	Evkit Total (min)	Evkit Computation Time (min)	Evkit Spawning Time (min)
1	2.3	10.5	7.6	3.0
2	1.7	14.2	6.9	7.4
4	2.5	16.7	6.9	9.9
8	1.1	16.3	6.8	9.5
16	1.2	17.3	6.8	10.5

Central Bohemia - 25 Million Routes

- ACE still improves runtime (~1.45× speedup).
- Evkit spawning overhead is less dominant.

Nodes	ACE Total (min)	Evkit Total (min)	Evkit Computation Time (min)	Evkit Spawning Time (m)
1	1,151.0	1,369.0	1,365.6	3.4
2	576.7	836.7	825.2	11.4
4	310.4	438.1	424.3	13.8
8	151.9	194.0	181.5	12.5
16	109.4	103.1	90.2	12.9

Ongoing Work and Next Steps

- Further fine-tuning to address the scaling saturation observed from 16 nodes and to improve performance on longer alternative routes.
- Extending evaluation across larger datasets and different regional networks to validate ACE's robustness.

This work was also supported by the EPICURE project under grant agreement No 101139786. The project is supported by the European High-Performance Computing Joint Undertaking and its members (including top-up funding by the Ministry of Education, Youth and Sports of the Czech Republic ID: MC2402).

RUTH Repo

EPICURE Unlocking European-level HPC Support

Video Sample

MINISTRY OF EDUCATION, YOUTH AND SPORTS

This work was supported by the Ministry of Education, Youth and Sports of the Czech Republic through the e-INFRA CZ (ID:90140).