Adding Fault Tolerance to NPB Benchmarks Using ULFM

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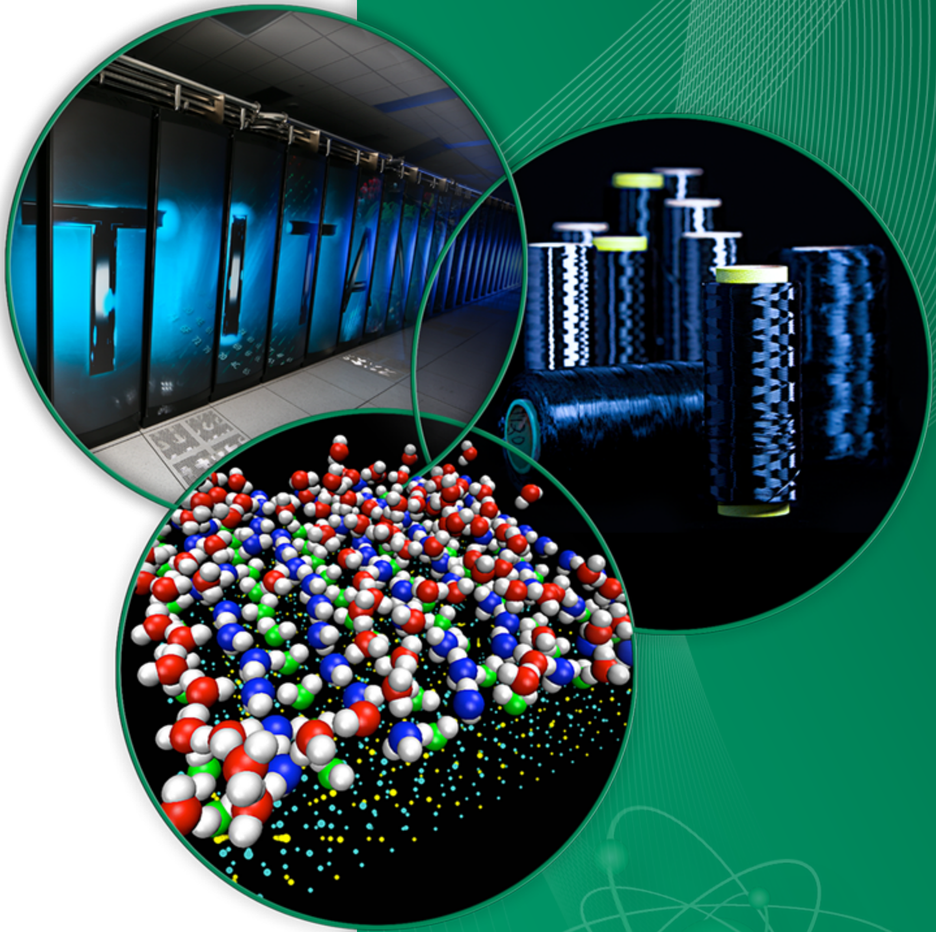


Motivation

- Fault tolerance (FT) and application resilience is becoming a primary concern for HPC
- Research community has been very active over the past decade
  - Checkpoint/restart
  - Redundancy
  - Application Based Fault Tolerance
- Standards start to consider FT extensions

The MPI forum fault tolerance working group is proposing the User-Level Failure Mitigation (ULFM)

Goals & Contributions

- This study does NOT aim at evaluating the performance of an ULFM implementation
- This study aims at
  - Investigating application-level strategies that leverage ULFM
  - Providing benchmarks that can illustrate the use of ULFM
- Other contributions
  - In-memory checkpoint/restart mechanism
    - Direct integration into the benchmarks to minimize dependencies
    - Avoids the cost of going through the file system layers
  - Fault injection tool based on the ULFM model

ULFM Overview

- Target failure model: Process failure
  - Explicitly handle fail-stop failures
  - Transient failures are masked as fail-stop
  - Failures are detected only in the context of MPI operations
  - NO support for silent and byzantine errors
- Target capabilities
  - Failure detection
  - Failure notification
  - Recovery of the MPI layer only

ULFM API - Overview

- Detection
  - Assumes perfect fault detectors
  - Via return codes of MPI communication functions
- Recovery of the MPI layer
  - MPI_Comm_shrink()
  - Creates a new communicator that includes only the surviving ranks
- Agreement
  - MPI_Comm_agree() and MPI_Comm_iagree()
  - All surviving ranks perform a collective consensus to agree on a value

In-memory Application Checkpointer

- Avoid the cost of going through the file system
- Implemented using MPI send/receive primitives
  - Simple
  - Potentially enables more opportunities to detect failures with ULFM
  - Checkpointed data is sent to one or more “neighbors”
- 2 strategies implemented
  - SINGLE_REDUNDANCY: the data is saved in a single neighbor’s memory
  - FULL_REDUNDANCY: the data is saved in all MPI ranks’ memory
  - Tradeoff between cost (extra communications and memory) vs. number of tolerated failures

Failure Injection Tool

- Based on ULFM model
  - Detection only in the context of MPI operations
  - Failures can be injected right before or after an MPI operation, other locations will not change the behavior
- Annotations of the application code
- Rely on a configuration file
  - Help reproducing experiments
  - Many injection points can be "activated"
  - When an activated injection point is reached, the MPI rank is terminated

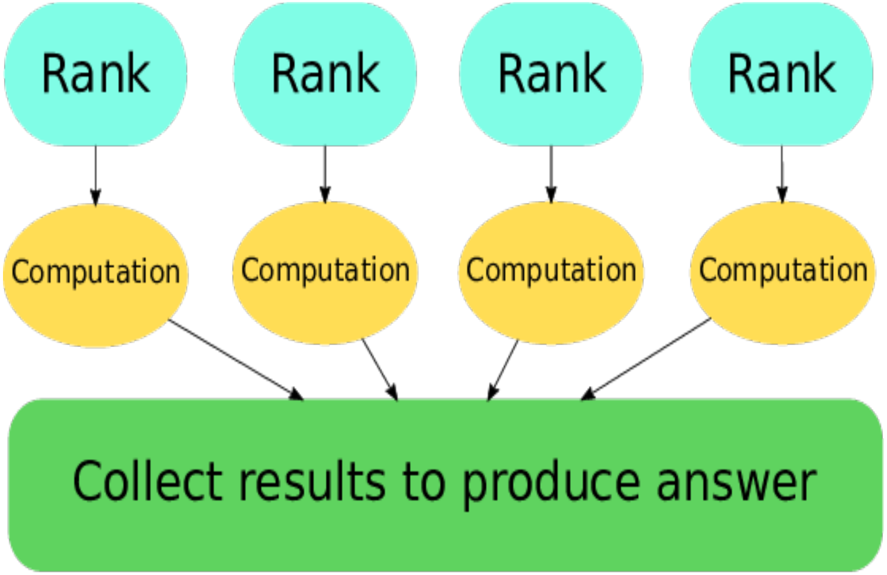
NPB Modified for ULFM Support

- 3 benchmarks have been extended
  - Embarrassingly Parallel – EP
  - Data Transfer – DT
  - Integer Sort – IS
- EP, DT and IS benchmarks have been modified
  - Only DT and EP are presented
  - Based on SINGLE_REDUNDANCY

Experimental Setup

- Up to 32 ranks, 1 rank per node to highlight the cost of in-memory checkpoint/restart via the network
- Nodes have two 12-core AMD Opteron 6164 HE, 64 GB RAM and bonded dual non-blocking 1 Gbps Ethernet
- Comparison of
  - No FT mechanism enabled
  - 0 failures: highlight the checkpoint/restart cost
  - 1 and 2 failures: highlight the overhead and behavior of the FT strategy
- Performed 10 runs per experiment

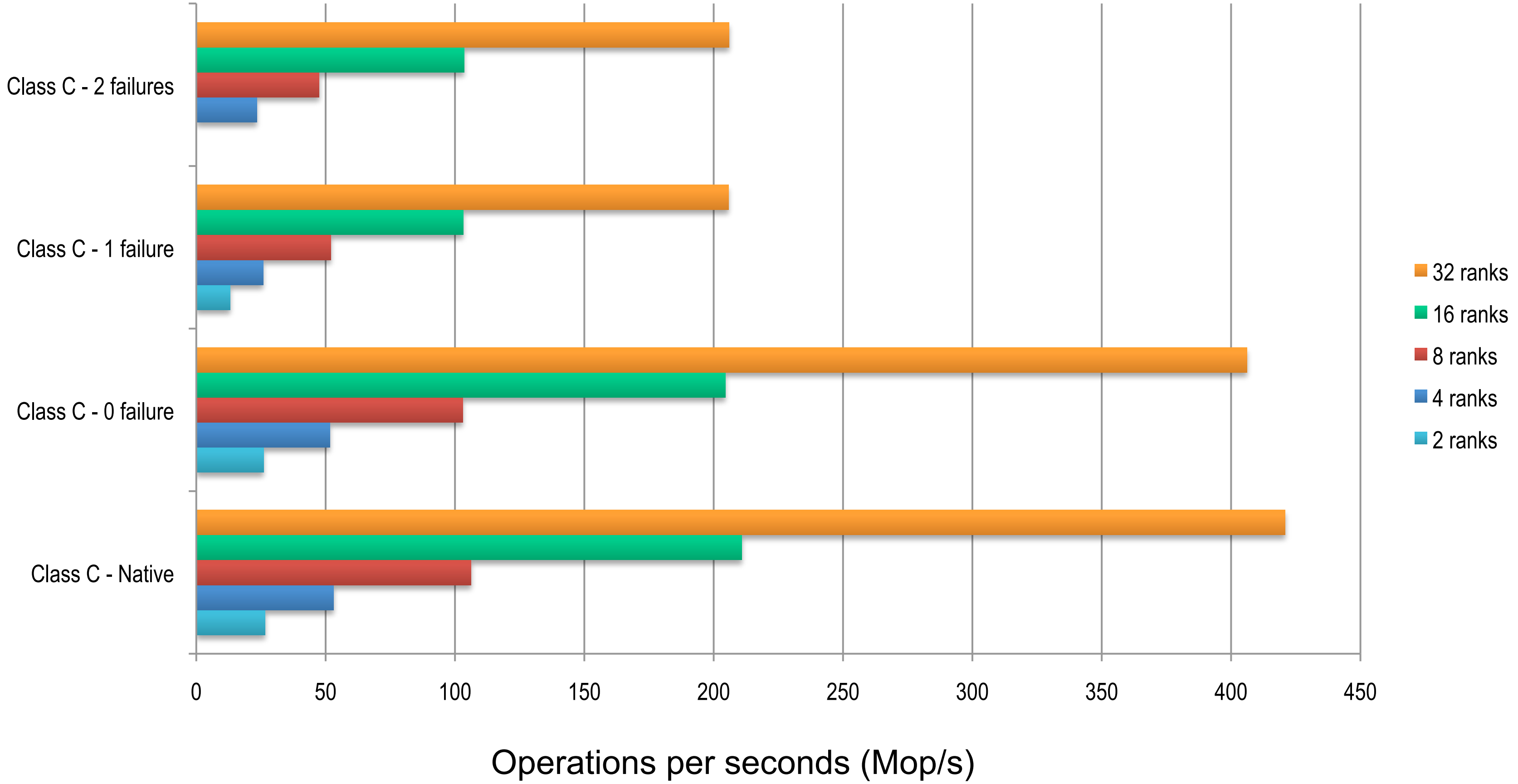
Extension of the EP Benchmark



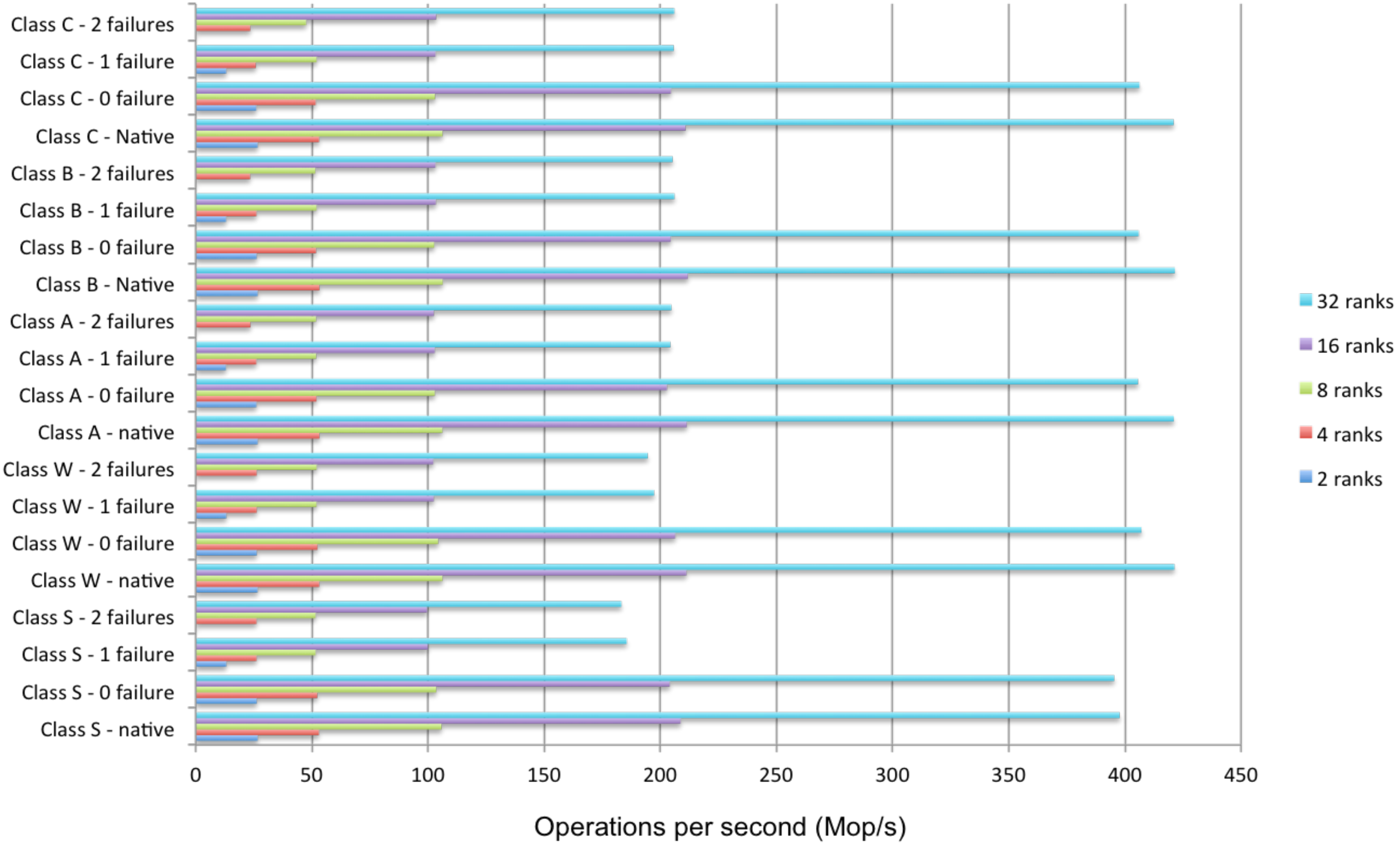
- Communication pattern
  - Barrier during initialization
  - Allreduce to collect the results
- FT Modifications
  - Detect failure during the allreduce communication phase
  - Redistribute the work that was lost because of the failure, after surviving ranks complete their work
- Experiments
  - Inject failures before executing the allreduce operation

EP – Results (1)

- Results for Class C



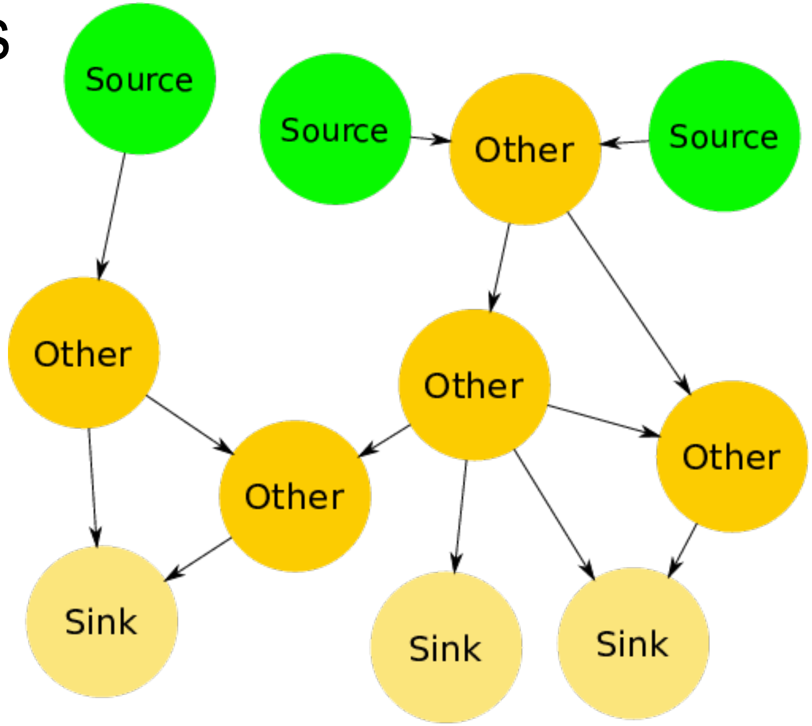
EP – Results (2)



Class C - 2 failures
Class C - 1 failure
Class C - 0 failure
Class C - Native
Class B - 2 failures
Class B - 1 failure
Class B - 0 failure
Class B - Native
Class A - 2 failures
Class A - 1 failure
Class A - 0 failure
Class A - native
Class W - 2 failures
Class W - 1 failure
Class W - 0 failure
Class W - native
Class S - 2 failures
Class S - 1 failure
Class S - 0 failure
Class S - native
0
50
100
150
200
250
300
350
400
450
Operations per second (Mop/s)
32 ranks
16 ranks
8 ranks
4 ranks
2 ranks

Extension of the DT Benchmark

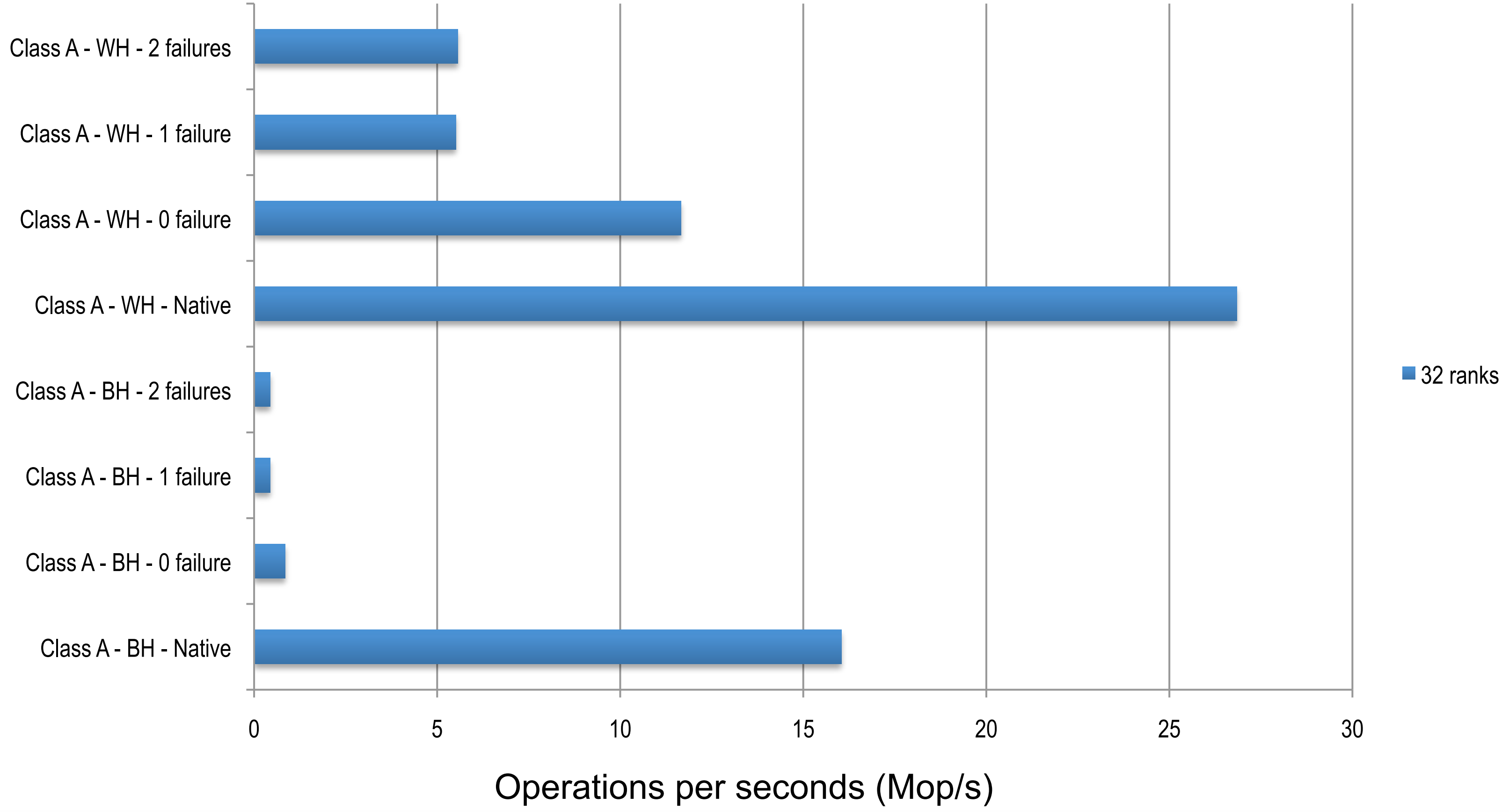
- Communication/computation patterns
  - Irregular communications
  - One-to-one mapping task/rank
  - All ranks have the same vision of the initial graph
  - At the end, rank0 collects all the results



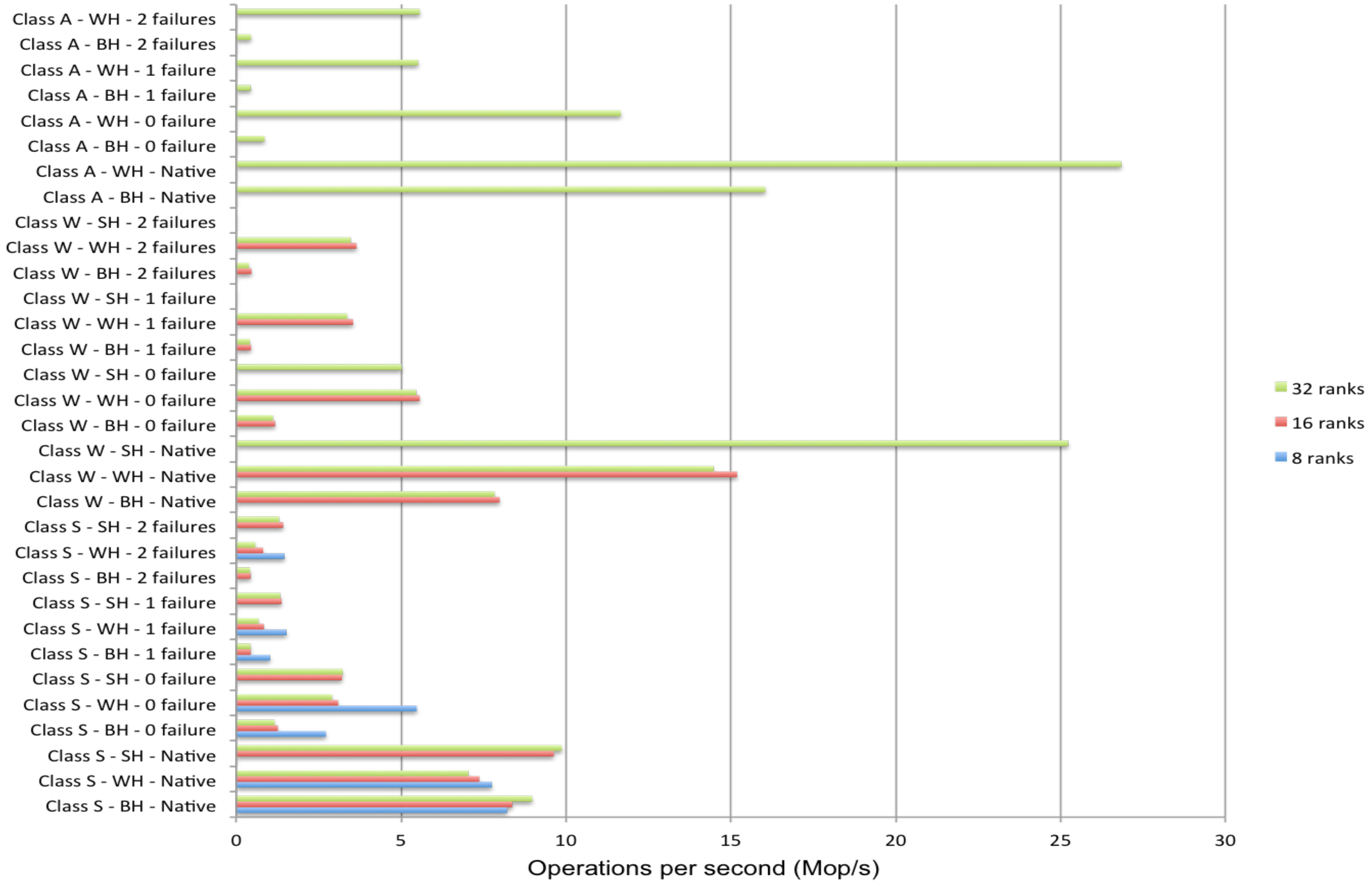
- FT Modifications
  - Serialize the graph for checkpointing
  - If a rank fails, a spare rank is "activated" and executes the task
- Experiments
  - Inject a failure before the result can be retrieved by rank0

DT – Results (1)

- Results for Class A (both BH and WH graphs)



DT – Results (2)



Class A - WH - 2 failures
Class A - BH - 2 failures
Class A - WH - 1 failure
Class A - BH - 1 failure
Class A - WH - 0 failure
Class A - BH - 0 failure
Class A - WH - Native
Class A - BH - Native
Class W - SH - 2 failures
Class W - WH - 2 failures
Class W - BH - 2 failures
Class W - SH - 1 failure
Class W - WH - 1 failure
Class W - BH - 1 failure
Class W - SH - 0 failure
Class W - WH - 0 failure
Class W - BH - 0 failure
Class W - SH - Native
Class W - WH - Native
Class W - BH - Native
Class S - SH - 2 failures
Class S - WH - 2 failures
Class S - BH - 2 failures
Class S - SH - 1 failure
Class S - WH - 1 failure
Class S - BH - 1 failure
Class S - SH - 0 failure
Class S - WH - 0 failure
Class S - BH - 0 failure
Class S - SH - Native
Class S - WH - Native
Class S - BH - Native
0
5
10
15
20
25
30
Operations per second (Mop/s)
32 ranks
16 ranks
8 ranks

Conclusion

- No one-size-fits-all solution
  - ULFM only provides basic primitives and capabilities: detection, notification and MPI runtime recovery
  - Best strategy really depends on the application (communication patterns and checkpoint size)
  - Understanding the various overheads is difficult
  - Witnessed behavior basically matches what we expected (based on work redistribution)
- Good illustration of the ULFM potential
- Work in progress
  - Detailed profiling
  - Provide additional strategies, including re-init
  - Integration of SCR