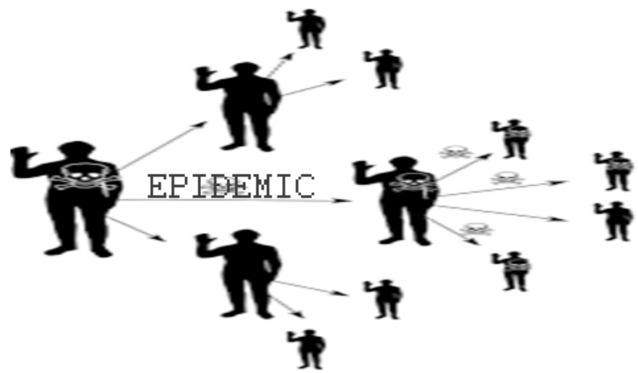
EuroMPI'15, Bordeaux, France, September 21-23, 2015

Scalable and Fault Tolerant Failure Detection and Consensus



Amogh Katti, Giuseppe Di Fatta,

University of Reading, UK

Thomas Naughton, Christian Engelmann

Oak Ridge National Laboratory, USA

Funded By: Felix Scholarship and US Department of Energy, Advanced Scientific Computing Research

Outline

- Motivation
- Overview of related work
- Proposed approach
- Experimental Results
- Conclusion
- Future work

Motivation

- The need for resilience in High Performance Computing (HPC)
- Algorithm Based Fault Tolerance (ABFT) can help
- ABFT needs a fault tolerant MPI
- User Level Failure Mitigation (ULFM) is being proposed
- MPI_Comm_shrink and MPI_Comm_agree need a failure detection and consensus protocol

The need for resilience in HPC

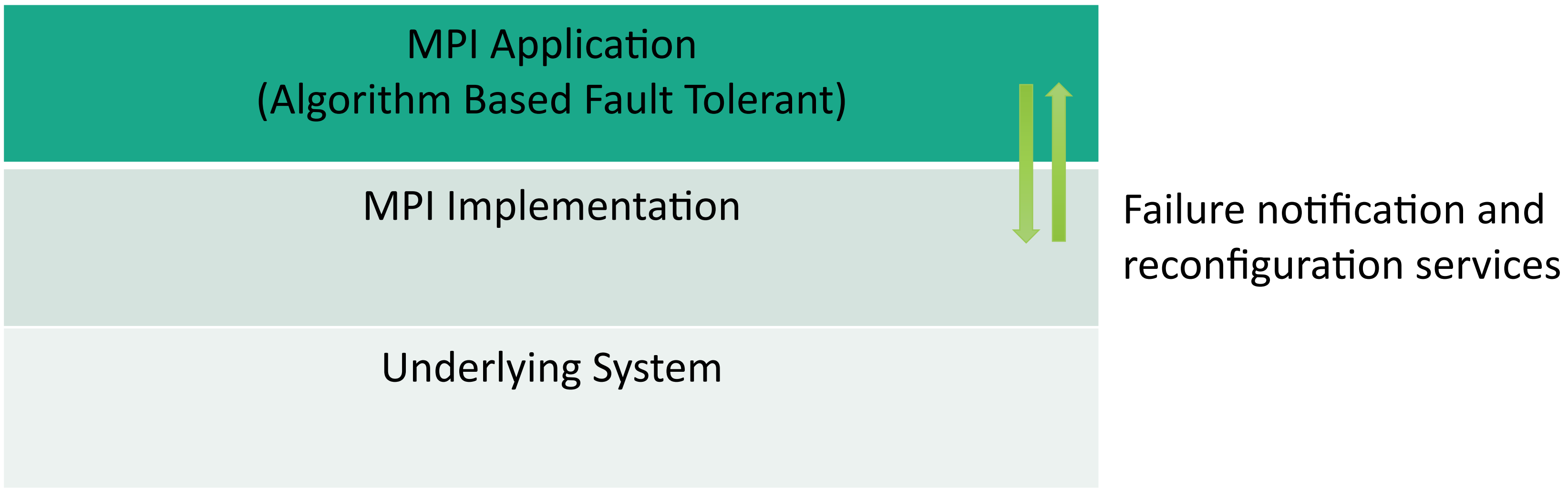
- Resilience is a critical challenge
  - Increasing component count, decreasing component reliability and increasing software complexity
  - Parallel application correctness and efficiency are essential for success of extreme-scale systems
- Cost effective, hardware and software cooperative resilience approach necessary
- Global checkpoint-restart, the dominant resilience strategy, will be less efficient at scale

ABFT can help

- Application-specific techniques, like Algorithm Based Fault Tolerance (ABFT), can be more effective
- Loss of application state can be dealt with through reconfiguration and adaptation
- ABFT applications incorporate the needed fault tolerance logic
- Some ABFT techniques that can be used:
  - Error correction using data redundancy or encoding
  - Re-execution using local checkpoints

ABFT needs a fault tolerant MPI

- Failure detection and notification
- Reconfiguration without global restart based on consensus on detected failures



User Level Failure Mitigation

- MPI's Fault Tolerance Working Group (FTWG) has proposed User Level Failure Mitigation (ULFM)
- Specifies semantics/interfaces for an MPI implementation's behaviour in the presence of process failures
  - Fail-stop: Failed processes stop communicating
- In a conformant MPI implementation:
  - No operation hangs in the presence of failures but completes by returning an error
  - Global knowledge of failures can be achieved whenever necessary
- Local failure detection left to the implementations

ULFM requires a failure detection and consensus protocol

- MPI_Comm_shrink
  - Creates a new communicator by excluding the failed processes in the old communicator
  - An agreement is reached on the failed processes
- MPI_Comm_agree
  - Agrees on a value among the non-failed processes
- Both operations need to be supported by a fault-tolerant failure detection and consensus algorithm

Related work in failure detection and consensus protocols

- Coordinator based protocols
  - Assume failures to be pre-detected at each process
  - Use consensus algorithm to achieve consistent failure detection
  - Typically good log-based scaling
  - Not completely fault tolerant (failures occurring during the failure detection are not detected)
- Completely distributed Gossip-based protocols
  - Consistent failure detection in phases:
    - Failure suspicion, failure detection and consensus
  - Very poor scalability
  - Completely fault tolerant

Approach

- Gossip-based failure detection and consensus
- Assumptions
- Algorithm 1: Consensus using global knowledge
- Algorithm 2: Efficient heuristic consensus

Gossip-based failure detection and consensus

- Gossiping is a randomized communication scheme
- Gossip-based protocols are intrinsically fault tolerant and extremely scalable
- Two Gossip-based failure detection and consensus algorithms are proposed
  - Maintaining global knowledge
  - Efficient heuristic consensus
- Based on a combined method for detecting failures locally and quickly disseminating detections to achieve consensus using Gossip

A. Katti, G. Di Fatta, T. Naughton, and C. Engelmann. Scalable and Fault Tolerant Failure Detection and Consensus. EuroMPI'15.

Assumptions

- Detects fail-stop failures
- Reliable communication medium
- Failures are permanent
- Synchronous system with bounded message delay
- Failures during the algorithm will stop at some point to allow the algorithm to complete with successful consensus detection
- A process once detected as failed is detected to have failed by all the processes eventually

Algorithm 1: Consensus using global knowledge

- At each process p *F*p*[n, n], where n is system size,* is maintained
  - *Fp[r, c]* is the view at process *p* of the status of process *c* as detected by process *r.* 0 if alive; 1 otherwise
- Algorithm executed at each process
  - Initialization – assume all processes are alive
  - At each Gossip cycle
    - Direct failure detection using stochastic pinging
      - Send PING gossip message with Fp to a random process and post a timeout event for receiving REPLY gossip message
      - Timeout event and no reply received - direct failure detection of the PINGed process
      - Update Fp to reflect the failure detection
    - Gossip reception event – Merge Fault Matrices (Indirect local failure detection and propagation)
    - Consensus detection – When all fault-free processes detect the failed process

Algorithm 2: Efficient heuristic consensus

- At each process p Fault list Lp = {< r, ccnt >*,…}* is maintained.
  - An entry in this list is a 2-tuple < r, ccnt >, where r is the rank of the failed process and ccnt is the consensus count associated with it
- Algorithm executed at each process
  - Initialization – assume all processes are alive
  - At each Gossip cycle
    - Direct failure detection using stochastic pinging
      - Send PING gossip message with Lp to a random process and post a timeout event for receiving REPLY gossip message
      - Timeout event and no REPLY received - direct failure detection of the PINGed process
      - Add the pinged process to Lp with ccnt set to 0
    - Gossip reception event – Merge Fault Lists (Indirect failure detection and propagation)
    - Consensus detection – Wait for log(n) number of cycles
      - When ccnt for an entry <r,ccnt> reaches MIN_CCNT, which indicates with a high probability that the failed process r is recognized by all the processes, consensus on failure of r is reached

A. Katti, G. Di Fatta, T. Naughton, and C. Engelmann. Scalable and Fault Tolerant Failure Detection and Consensus. EuroMPI'15.

Results

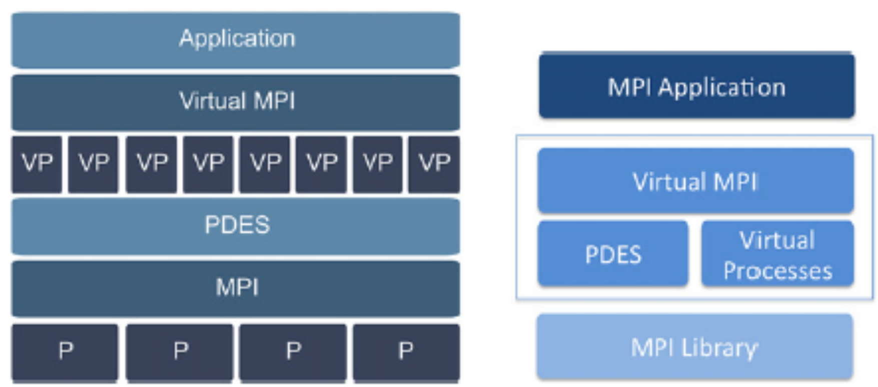
- Overview of implementations
- Overview of the use of xSim
- Overview of the hardware environment
- Overview of the simulative environment
- Results for Algorithm 1
- Results for Algorithm 2
- Comparison (Algorithm 1 and Algorithm 2)

Overview of implementations

- Algorithms have been implemented as MPI applications using point-to-point operations
- Fault Matrix in algorithm 1 implemented as integer matrix
- Failed process id in algorithm 2 implemented as an integer
- Failures were simulated by restraining a process from participating in communications

Overview of the use of xSim

- To evaluate the algorithms at significantly larger scale than the available physical system
- Extreme-scale Simulator (xSim) is an application performance and resilience investigation toolkit



(a) Architecture (© 2010 IEEE [14]). (b) Design (© 2010 IEEE [14]).

Fig. 1. xSim's implementation architecture and design.

Overview of the hardware environment

- Experiments on the Linux cluster computer:
  - One head node and 16 compute nodes
  - Head node has two AMD Opteron 4386 3.1 GHz processors with eight cores/processor and 64 GB RAM
  - Compute nodes have one Intel Xeon E3-1220 3.1GHz processor with four cores/processor and 16 GB RAM
  - Nodes are connected by Gigabit Ethernet
  - System is running the Ubuntu 12.04 LTS operating system and Open MPI 1.6.5

Overview of the simulation environment

- Simulations using the Extreme-scale Simulator (xSim) atop the Linux cluster
  - One simulator MPI process per physical processor core
  - Multiple simulated MPI processes per simulator MPI process (oversubsciption)
  - Processor model is set with a 1-to-1 performance match to the physical AMD processor core
  - Network interconnect model with a basic star topology, 1 us link latency, and infinite bandwidth
  - Processor and network models are set to evaluate the algorithms, and not the system the algorithm runs on

Results for Algorithm 1: Consensus using global knowledge

Consensus on single failure with 2^4-2^11 MPI ranks

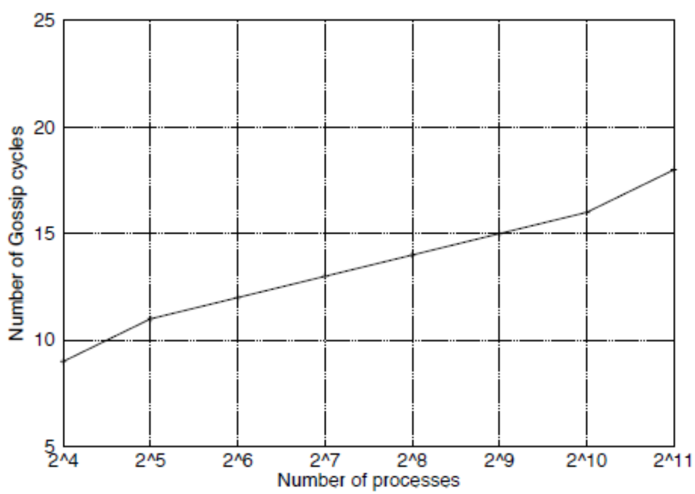


Figure 4: Number of cycles to achieve global consensus after a single failure injection (algorithm 1)

Consensus on four failures with 2^4-2^11 MPI ranks

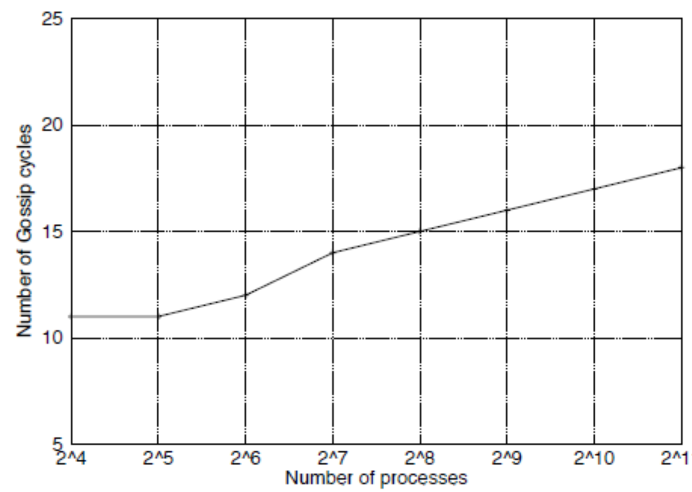


Figure 7: Number of cycles to achieve global consensus after multiple (4) failures, which were injected before algorithm execution (algorithm 1)

Results for Algorithm 1: Consensus using global knowledge

Exponential consensus propagation

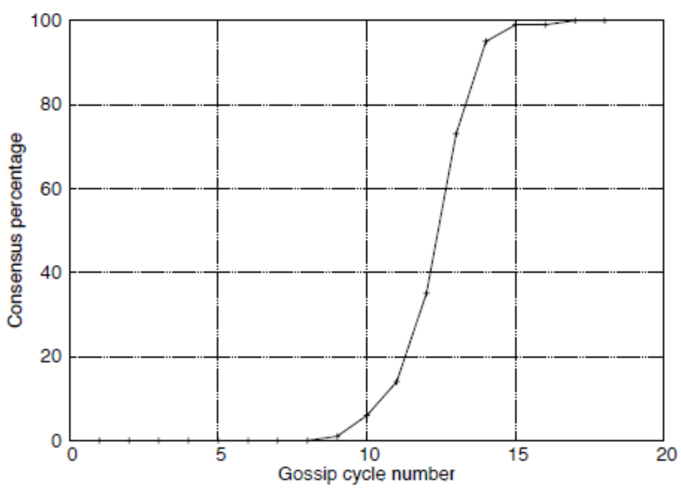


Figure 5: Local consensus progress at a process after a single failure injection for system size of 2048 (algorithm 1)

Asyncronous consensus detection

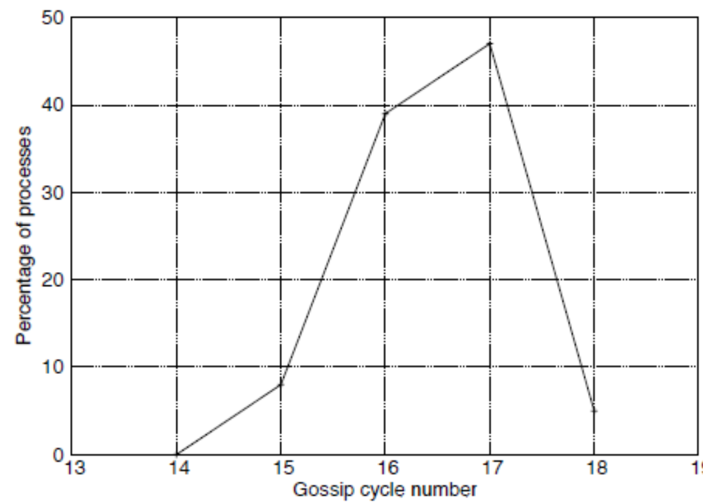


Figure 6: Consensus detection spread for a system size of 2048 (algorithm 1)

A. Katti, G. Di Fatta, T. Naughton, and C. Engelmann. Scalable and Fault Tolerant Failure Detection and Consensus. EuroMPI'15.

Results for Algorithm 1: Consensus using global knowledge

Fault tolerant consensus propagation and detection

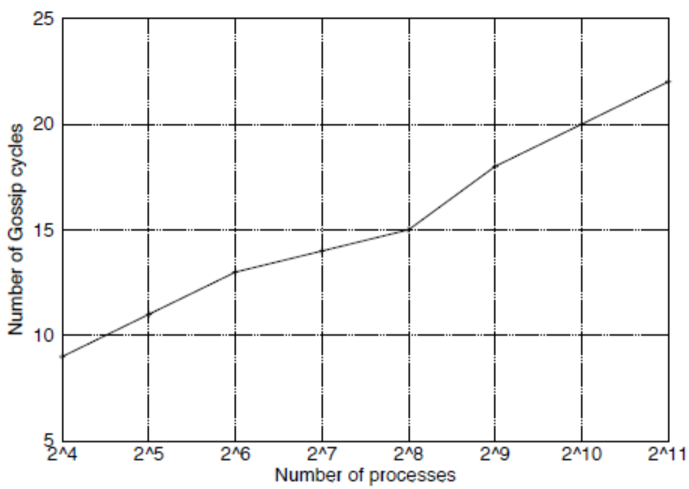


Figure 8: Number of cycles to achieve global consensus with multiple (4) failures, which were injected during algorithm execution (algorithm 1)

Results for Algorithm 2: Efficient heuristic consensus

Consensus on single failure with 2^4-2^20 MPI ranks

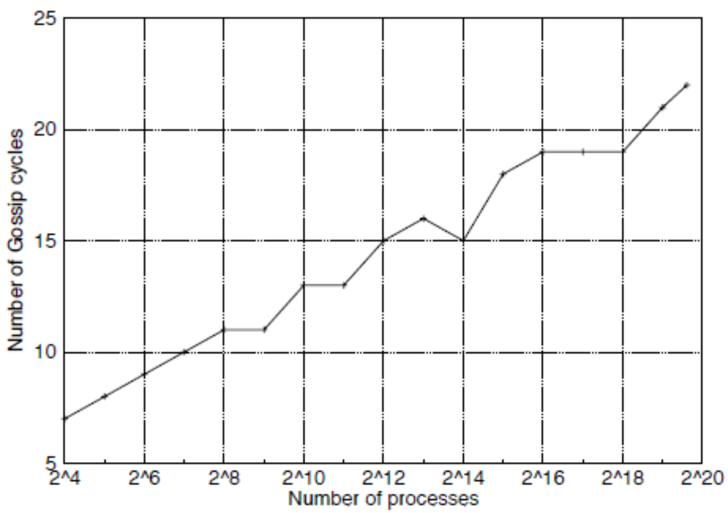


Figure 9: Number of cycles to achieve global consensus after a single failure injection (algorithm 2)

Comparison of Algorithm 1 vs. Algorithm 2

Consensus on single failure with 2^2-2^20 MPI ranks

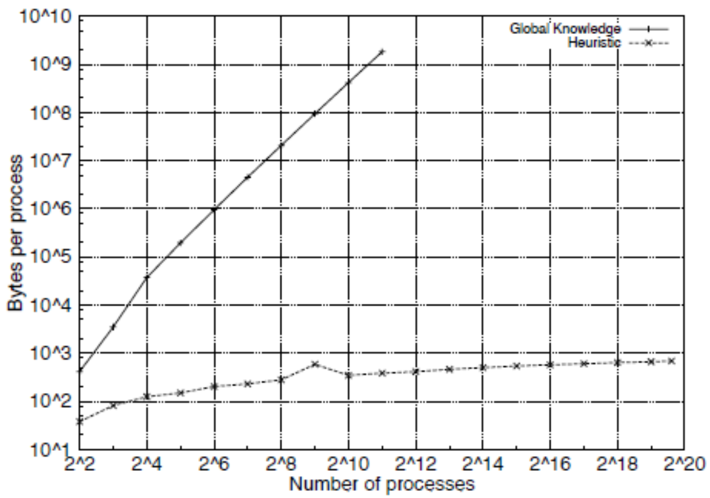


Figure 10: Total bandwidth utilization of the consensus algorithms with a single failure injection

Conclusion

- Failure detection and consensus for a fault-tolerant MPI enable HPC applications to adopt ABFT
- Two novel Gossip-based failure detection and consensus algorithms were presented
    1. Global knowledge at each process
    2. Efficient heuristic consensus
- Results confirm their scalability and fault tolerance
- The second algorithm uses significantly lower memory and bandwidth and achieves a perfect consensus synchronization

Future work

- Better method to efficiently detect consensus
- Mechanisms to avoid false positives
- Further experimental analysis and comparison with other methods

Questions?