ULFM Process Fault Tolerance reading

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FT WG

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Chicago, IL

Info, resources, participate

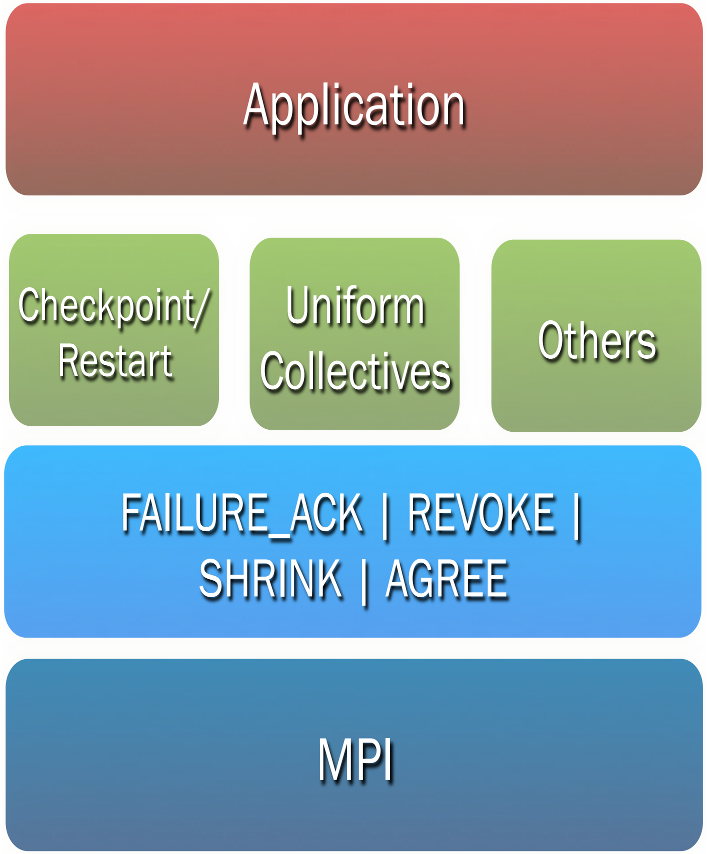
- Issue Ticket (w/ links to PRs)
  - https://github.com/mpi-forum/mpi-issues/issues/20

- Implementation available
  - Version 1.1 based on Open MPI 1.6 released early November 2015
    https://bitbucket.org/icldistcomp/ulfm
  - Full communicator-based (point-to-point and all flavors of collectives) support
  - Network support IB, uGNI, TCP, SM
  - Runs with ALPS, PBS, etc...
  - RMA, I/O in progress

http://fault-tolerance.org/

Minimal Feature Set for a Resilient MPI

1. Failure Notification
2. Error Propagation
3. Error Recovery

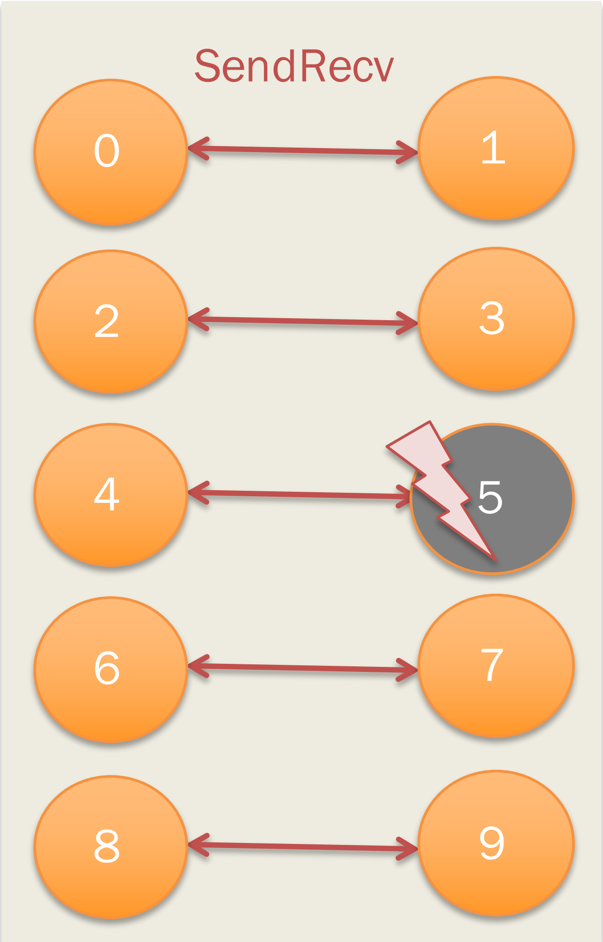


Not all recovery strategies require all of these features, that's why the interface splits notification, propagation and recovery.

ULFM is not a recovery strategy, but a minimalistic set of building blocks for more complex recovery strategies.

Errors are visible only for operations that can't complete

- New error codes to deal with failures
  - MPI_ERROR_PROC_FAILED: report that the operation discovered a newly dead process. Returned from all blocking function, and all completion functions.
  - MPI_ERROR_PROC_FAILED_PENDING: report that a non-blocking MPI_ANY_SOURCE potential sender has been discovered dead.
  - MPI_ERROR_REVOKED: a communicator has been declared improper for further communications. All future communications on this communicator will raise the same error code, with the exception of a handful of recovery functions
- Operations that can't complete return ERR_PROC_FAILED
  - State of MPI objects unchanged (communicators, etc)
  - Repeating the same operation has the same outcome
- Operations that can be completed return MPI_SUCCESS
  - Pt-2-pt operations between non failed ranks can continue
- Leverage on existing error handler infrastructure
  - MPI_COMM_SET_ERRHANDLER
  - conveniently capture and manage the new survivable error codes



Example: only rank4 should report the failure of rank 5

Summary of new functions

- MPI_Comm_failure_ack(comm)
  - Resumes matching for MPI_ANY_SOURCE
- MPI_Comm_failure_get_acked(comm, &group)
  - Returns to the user the group of processes acknowledged to have failed

Notification

- MPI_Comm_revoke(comm)
  - Non-collective, interrupts all operations on comm (future or active, at all ranks) by raising MPI_ERR_REVOKED

Propagation

- MPI_Comm_shrink(comm, &newcomm)
  - Collective, creates a new communicator without failed processes (identical at all ranks)
- MPI_Comm_agree(comm, &mask)
  - Collective, agrees on the AND value on binary mask, ignoring failed processes (reliable AllReduce), and the return code

Recovery

Bibliography of users' activity

These works use ULFM

FRAMEWORKS USING ULFM

LFLR, FENIX, FTLA, Falanx, X10

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- ZOUNMEVO, Judicael A., KIMPE, Dries, ROSS, Robert, *et al.* Extreme-scale computing services over MPI: Experiences, observations and features proposal for next-generation message passing interface. *International Journal of High Performance Computing Applications*, 2014, vol. 28, no 4, p. 435-449.
- NAUGHTON, Thomas, BÖHM, Swen, ENGELMANN, Christian, *et al.* Using Performance Tools to Support Experiments in HPC Resilience. In : *Euro-Par 2013: Parallel Processing Workshops*. Springer Berlin Heidelberg, 2014. p. 727-736.
- ENGELMANN, Christian et NAUGHTON, Thomas. A NETWORK CONTENTION MODEL FOR THE EXTREME-SCALE SIMULATOR.
- GAMELL, Marc, KATZ, Daniel S., KOLLA, Hemanth, *et al.* Exploring automatic, online failure recovery for scientific applications at extreme scales. In : *Proceedings of the International Conference for High Performance Computing, Networking, Storage and Analysis*. IEEE Press, 2014. p. 895-906.
- XIAOGUANG, Ren, XINHAI, Xu, YUHUA, Tang, *et al.* An Application-Level Synchronous Checkpoint-Recover Method for Parallel CFD Simulation. In : *Computational Science and Engineering (C*
- Judicael A. Zounmevo, Dries Kimpe, Robert Ross, and Ahmad Afsahi. 2013. Using MPI in high-performance computing services. In *Proceedings of the 20th European MPI Users' Group Meeting* (EuroMPI '13). ACM, New York, NY, USA, 43-48.*SE), 2013 IEEE 16th International Conference on*. IEEE, 2013. p. 58-65.
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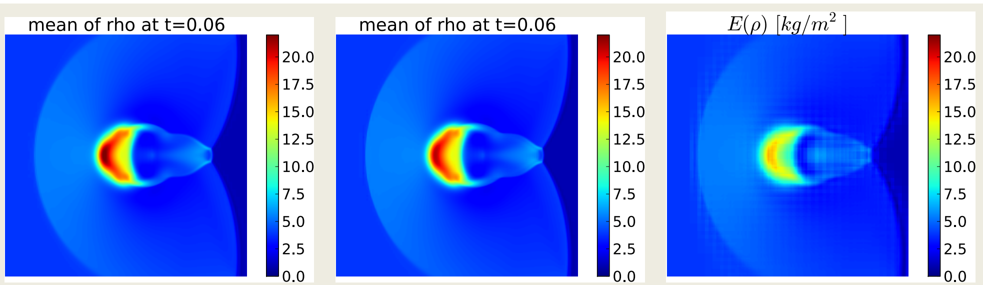
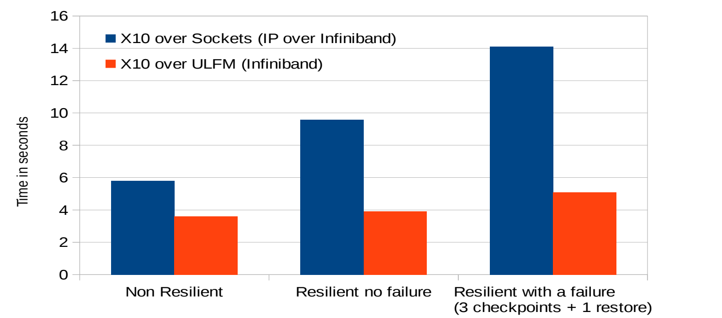


(a) failure-free (b) few failures (c) many failures

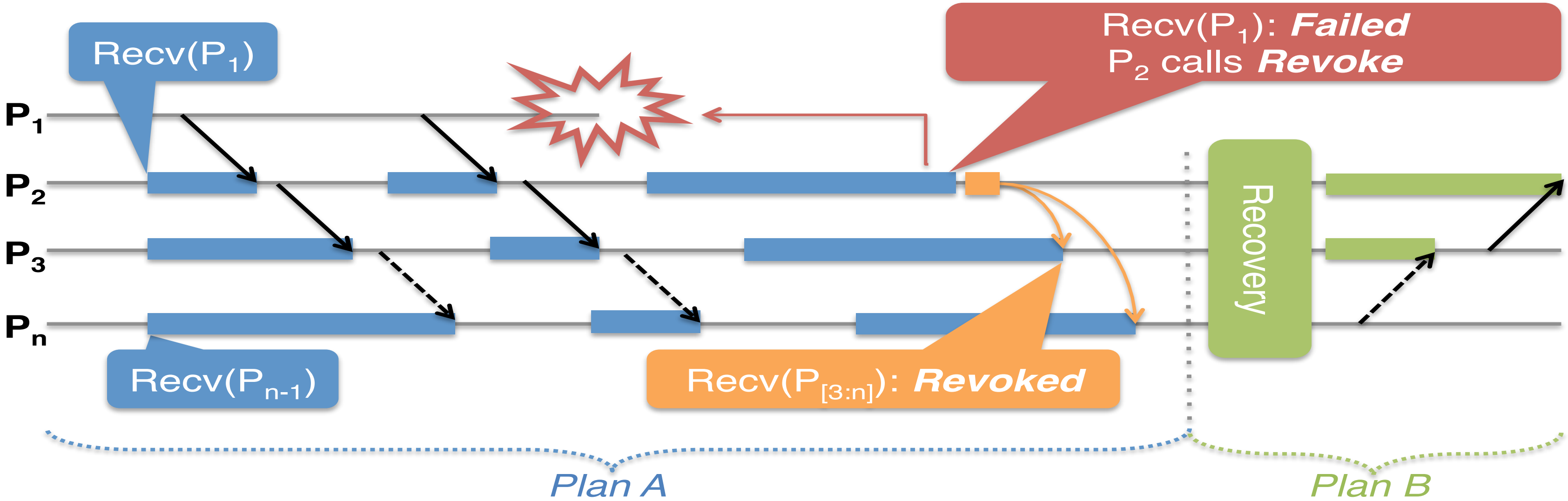
Credits: ETH Zurich

Figure 5. Results of the FT-MLMC implementation for three different failure scenarios.



The performance improvement due to using ULFM v1.0 for running the LULESH proxy application [3] (a shock hydrodynamics stencil based simulation) running on 64 processes on 16 nodes with

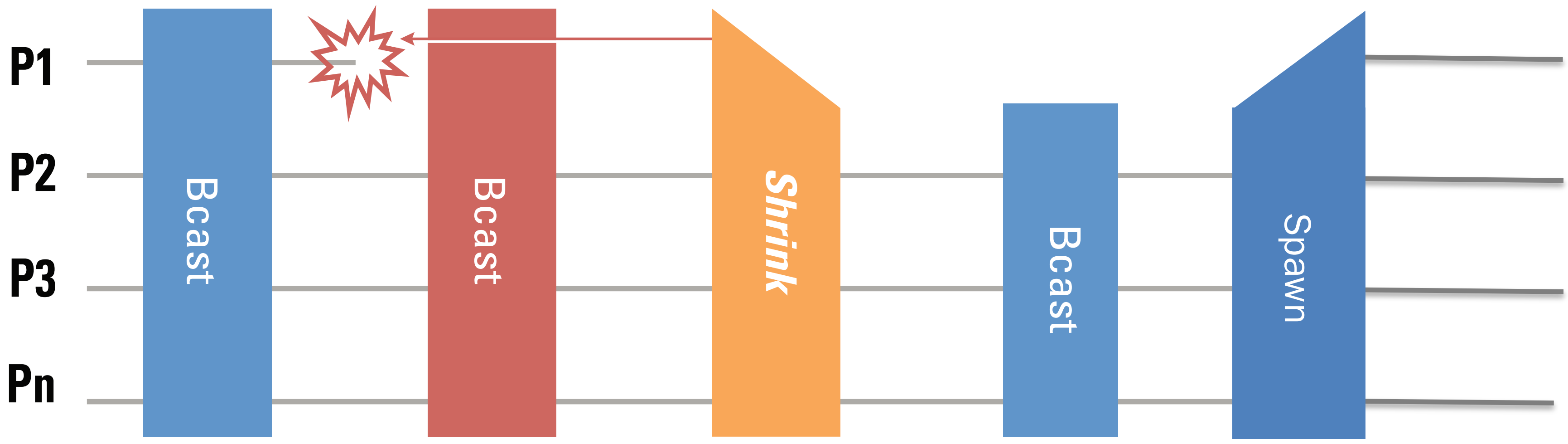
Resolving transitive dependencies




```
proc_failed_err_handler(MPI_Comm comm, int err, ...) {
   if(err == MPI_ERR_PROC_FAILED ||
      err == MPI_ERR_REVOKED ) {
     if(err == MPI_ERR_PROC_FAILED) MPI_Comm_revoke(comm);
     recovery(comm);
   }
}
ft_transitive_deps(void) {
   for(i=0; i<nbrecv; i++) {
      if(myrank>0) MPI_Irecv(buff, count, datatype,
                            myrank-1, tag, comm, &req);
      if(myrank<n) MPI_Send(buff2, count, datatype,
                            myrank+1, tag, comm, &req); }
}
```

- P1 fails
  - P2 raises an error and wants to change comm pattern to do application recovery
  - but P3..Pn are stuck in their posted recv
  - P2 can unlock them with Revoke
  - P3..Pn join P2 in the recovery

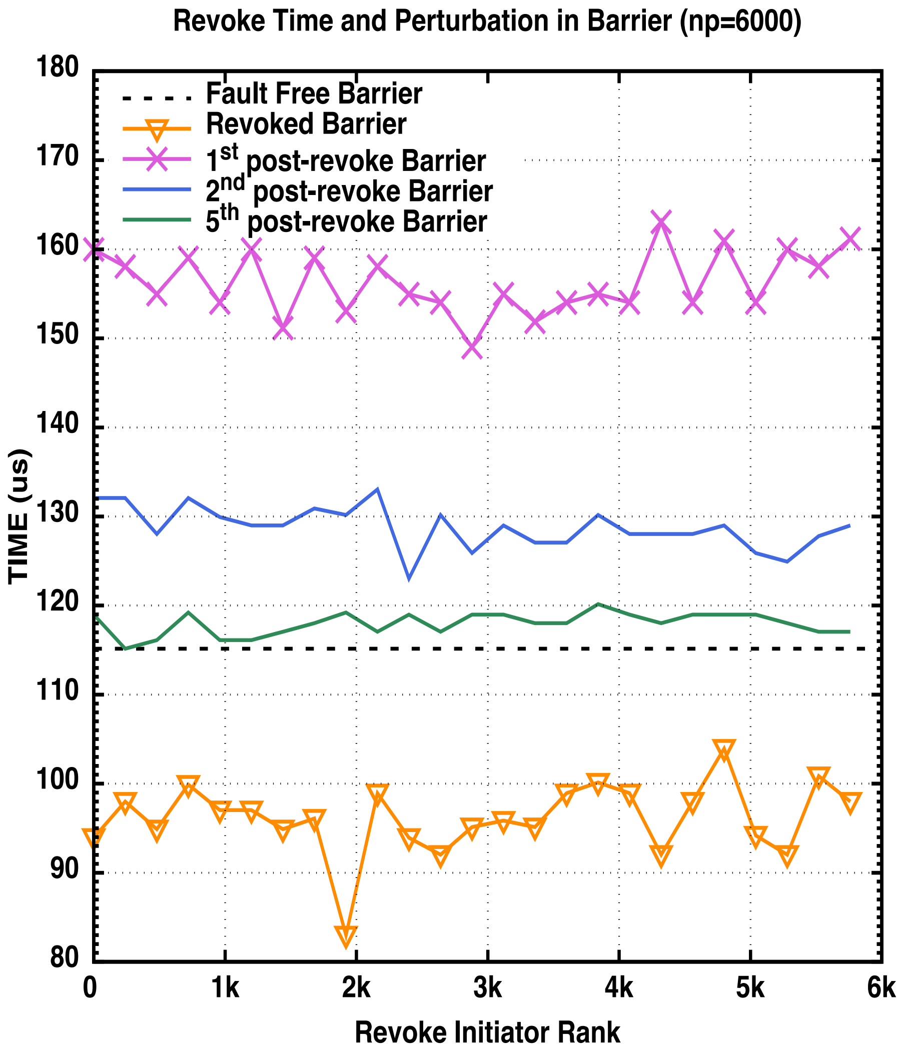
Full Capabilities Recovery



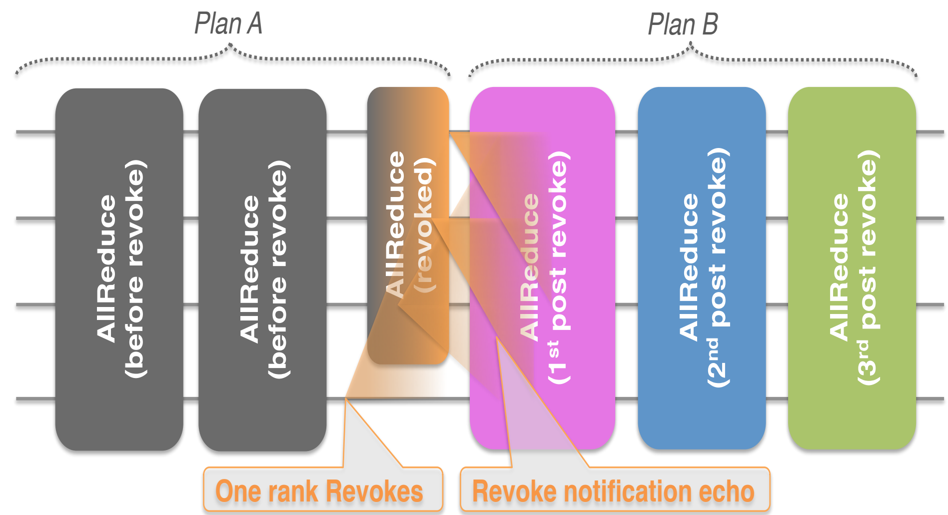
- Some applications are moldable
  - Shrink creates a new communicator on which collectives work
- Some applications are not moldable
  - Spawn can recreate a "same size" communicator
  - It is easy to reorder the ranks according to the original ordering

Scalable Resilient Constructs: Revoke

Darter, ugni network, 6000 processes

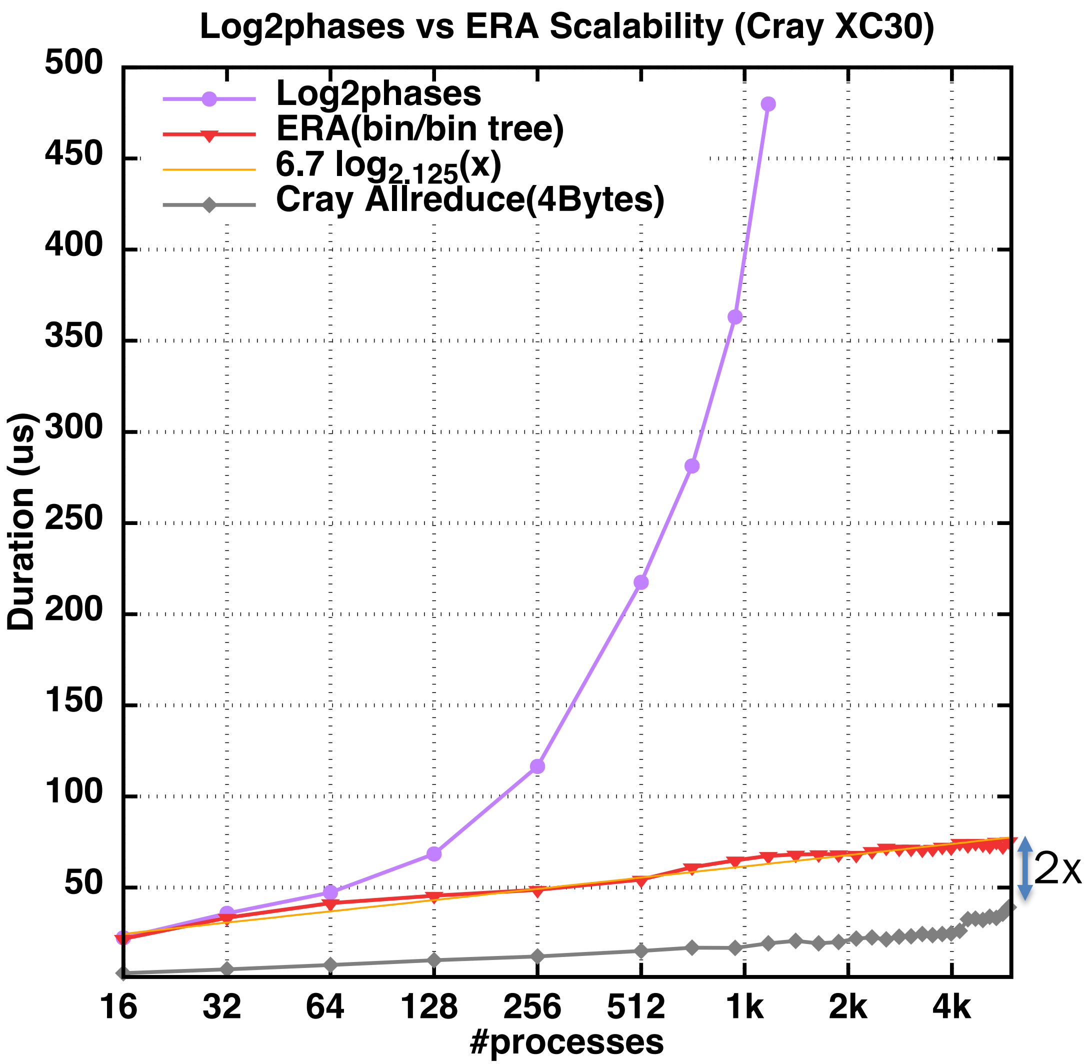


- BMG* Revoke propagation in less than 100μs
- First post-Revoke collective operation sustains some performance degradation resulting from the network jitter associated with the circulation of revoke tokens
- After the fifth Barrier (approximately 700μs), the Revoke reliable broadcast has completely terminated, therefore leaving the application free from observable jitter.



* Bouteiller, A., Bosilca, G., Dongarra, J.J. “Plan B: Interruption of Ongoing MPI Operations to Support Failure Recovery,” In *Proceedings of the 22nd European MPI Users' Group Meeting* (EuroMPI '15). ACM

Scalable Resilient Agreement



- Novel Early Returning Agreement algorithm*
- Logarithmic topology & logarithmic computation: scalable
- 2x the Cray AllReduce latency at 6k processors!

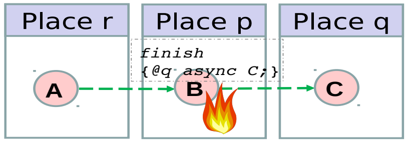
* Herault, T., Bouteiller, A., Bosilca, G., Gamell, M., Teranishi, K., Parashar, M., Dongarra, J. "Practical Scalable Consensus for Pseudo-Synchronous Distributed Systems," SuperComputing, Austin, TX, November, 2015

User projects: Resilient X10

- X10 is a PGAS programming language
  - Legacy resilient X10 TCP based

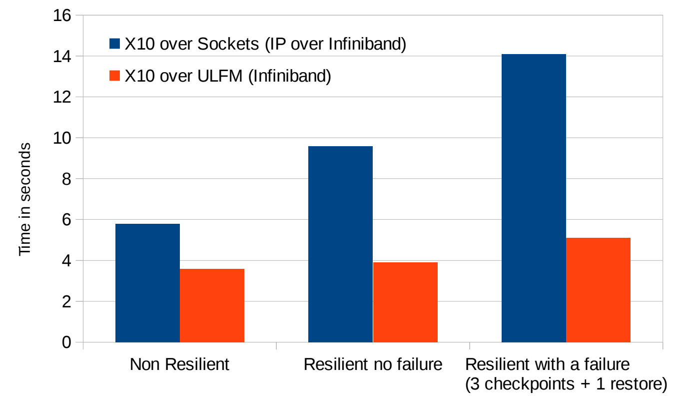
Happens Before Invariance Principle (HBI):
Failure of a place should not alter the happens before relationship between statements at the remaining places.

```
try{ /*Task A*/
 at (p) { /*Task B*/
  finish { at (q) async { /*Task C*/ } }
 }
} catch(dpe:DeadPlaceException){ /*recovery steps*/}
D;
```



By applying the HBI principle, Resilient X10 will ensure that statement D executes after Task C finishes, despite the loss of the synchronization construct (finish) at place p

- MPI operations in resilient X10 runtime
  - Progress loop does MPI_Iprobe, post needed recv according to probes
  - Asynchronous background collective operations (on multiple different comms to form 2d grids, etc).
- Recovery
  - Upon failure, all communicators recreated (from shrinking a large communicator with spares, or using MPI_COMM_SPAWN to get new ones)
  - Ranks reassigned identically to rebuild the same X10 "teams"
- Injection of FT layer
  - Unnecessary, x10 has a runtime that hides all MPI from the application and handles failures internally



The performance improvement due to using ULFM v1.0 for running the LULESH proxy application [3] (a shock hydrodynamics stencil based simulation) running on 64 processes on 16 nodes with

Source: Sara Hamouda, Benjamin Herta, Josh Milthorpe, David Grove, Olivier Tardieu. *Resilient X10 over Fault Tolerant MPI.* In : poster session SC'15, Austin, TX, 2015.

User projects: Fenix+S3D

- Fenix is a framework to provide scoped user level checkpoint/restart
  - Provides some of the same services provided by the "MPI_Reinit" idea floated around by T. Gamblin
  - Recover failed processes with revoke-shrink-spawn-reoder sequence
  - Revovered and surviving processes jump back to the start (longjump in Fenix_init)
  - Fenix has helpers to perform user directed "in-memory" or "buddy" checkpointing (and reload)
  - Injection of FT layer: PMPI based
- **Fenix_Checkpoint_Allocate** mark a memory segment (baseptr,size) as part of the checkpoint.
- **Fenix_Init** Initialize Fenix, and restart point after a recovery, status contains info about the restart mode
- **Fenix_Comm_Add** can be used to notify Fenix about the creation of user communicators
- **Fenix_Checkpoint** performs a checkpoint of marked segments

```
allocate(yspc(nx,ny,nz,nslvs))
allocate(other_arrays)
call MPI_Init()
[...] ! Initialize non-conflicting modules
call Fenix_Checkpoint_Allocate(C_LOC(yspc),
     sizeof(yspc),ckpt_yspc)
call Fenix_Init(Fenix_Neighbors,PEER_NODE_SIZE,
     Fenix_resume_to_init, status, C_LOC(world))

if(status.eq.Fenix_st_survivor) then
      [...] ! Finalize conflicting modules
endif
[...] ! Initialize conflicting modules
if(status.eq.Fenix_st_new)
      call initialize_yspc()
endif

do ! Main loop
      [...]   ! Iterate and update yspc array
      if(mod(step-1,CHECKPOINT_PERIOD).eq.0) then
            call Fenix_Checkpoint(ckpt_yspc);
      endif
enddo

call Fenix_Finalize()
call MPI_Finalize()
```

GAMELL, Marc, KATZ, Daniel S., KOLLA, Hemanth, *et al.* Exploring automatic, online failure recovery for scientific applications at extreme scales. In : *Proceedings of the International Conference for High Performance Computing, Networking, Storage and Analysis*. IEEE Press, 2014. p. 895-906.

User projects: Fenix+S3D

- S3D is a production, highly parallel method-of-lines solver for PDEs
  - used to perform first-principles-based direct numerical simulations of turbulent combustion
- S3D rendered fault tolerant using Fenix/ULFM
- 35 lines of code modified in S3D in total!
- Order of magnitude performance improvement in failure scenarios
  - thanks to online recovery and in-memory checkpoint advantage over I/O based checkpointing
- Injection of FT layer: addition of a couple of Fenix calls

```
call MPI_Comm_split(gcomm, py+1000*pz, r, xcomm)
call MPI_Comm_split(gcomm, px+1000*pz, r, ycomm)
call MPI_Comm_split(gcomm, px+1000*py, r, zcomm)
call Fenix_Comm_Add(xcomm);
call Fenix_Comm_Add(ycomm);
call Fenix_Comm_Add(zcomm);
[...]
call MPI_Comm_split(gcomm, xid, r, yz_comm)
call MPI_Comm_split(gcomm, yid, r, xz_comm)
call MPI_Comm_split(gcomm, zid, r, xy_comm)
call Fenix_Comm_Add(yz_comm);
call Fenix_Comm_Add(xz_comm);
call Fenix_Comm_Add(xy_comm);
```

S3D Code snippet to declare to Fenix the communicators to recover

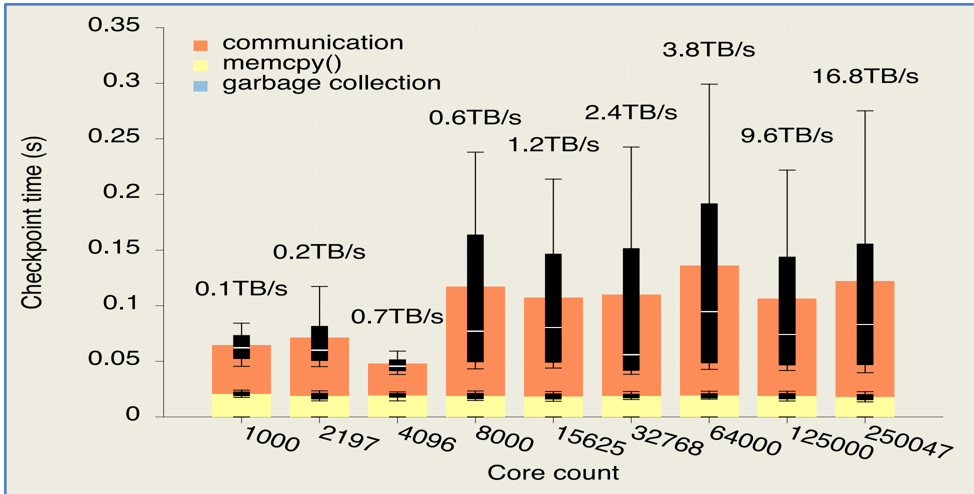


Fig. 3. Checkpoint time for different core counts (8.6 MB/core). The numbers above each test show the aggregated bandwidth (the total checkpoint size over the average checkpoint time).

Pictures and examples from M. Gamel&al SC14' paper