Resilient applications using MPI-level constructs

2014 Euro/Asia MPI Tutorial

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Declining MTBF

- Despite improvements in per-component reliability, due to large component count, MTBF decreases

Potential System Architecture with a cap of $200M and 20MW

Systems	2011 K computer	2019	Difference Today & 2019
System peak	**10.5 Pflop/s**	**1 Eflop/s**	**O(100)**
Power	**12.7 MW**	**~20 MW**	
System memory	1.6 PB	32 - 64 PB	O(10)
Node performance	128 GF	1,2 or 15TF	O(10) – O(100)
Node memory BW	64 GB/s	2 - 4TB/s	O(100)
Node concurrency	8	O(1k) or 10k	O(100) – O(1000)
Total Node Interconnect BW	20 GB/s	200-400GB/s	O(10)
System size (nodes)	88,124	O(100,000) or O(1M)	O(10) – O(100)
Total concurrency	705,024	O(billion)	O(1,000)
MTTI	days	O(1 day)	- O(10)

Situation Today

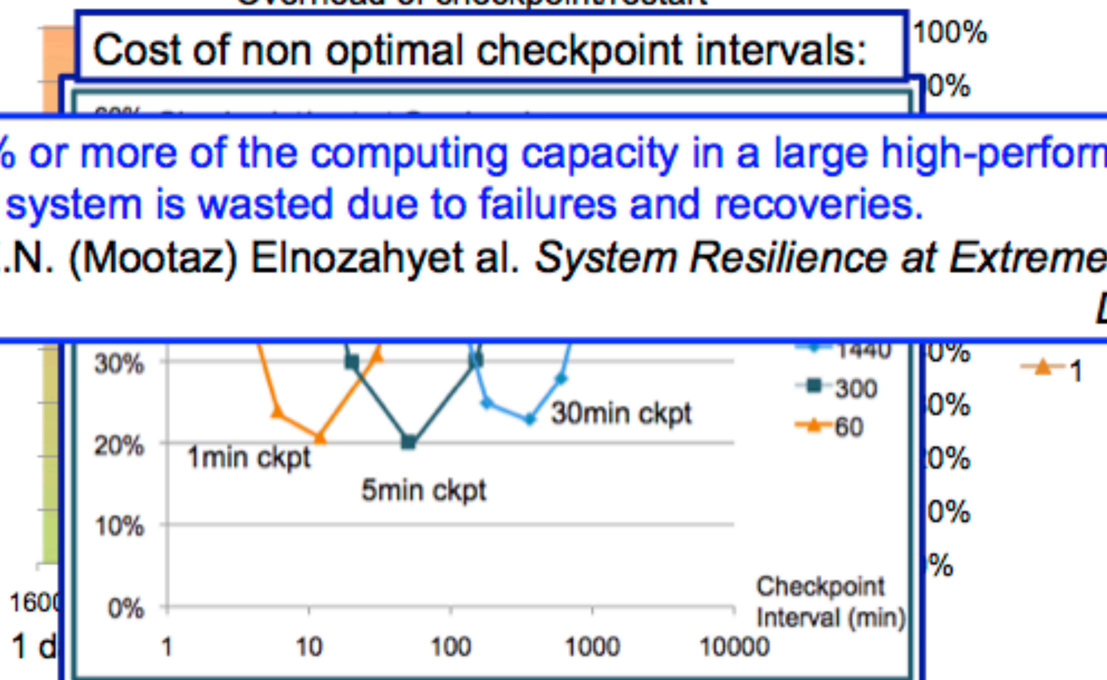
Also an issue at Petascale

Joint Laboratory for Petascale Computation — INRIA — NCSA

Fault tolerance becomes critical at Petascale (MTTI <= 1day)
Poor fault tolerance design may lead to huge overhead

Overhead of checkpoint/restart

Cost of non optimal checkpoint intervals:

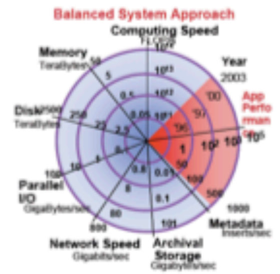


Today, 20% or more of the computing capacity in a large high-performance computing system is wasted due to failures and recoveries.

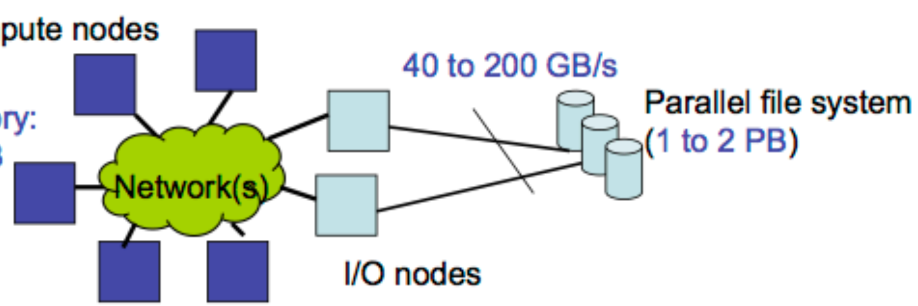
Dr. E.N. (Mootaz) Elnozahyet al. *System Resilience at Extreme Scale, DARPA*

Checkpoint Restart

Classic approach for FT: Checkpoint-Restart

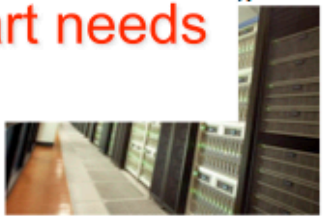


Typical "Balanced Architecture" for PetaScale Computers



RoadRunner

TACC Ranger

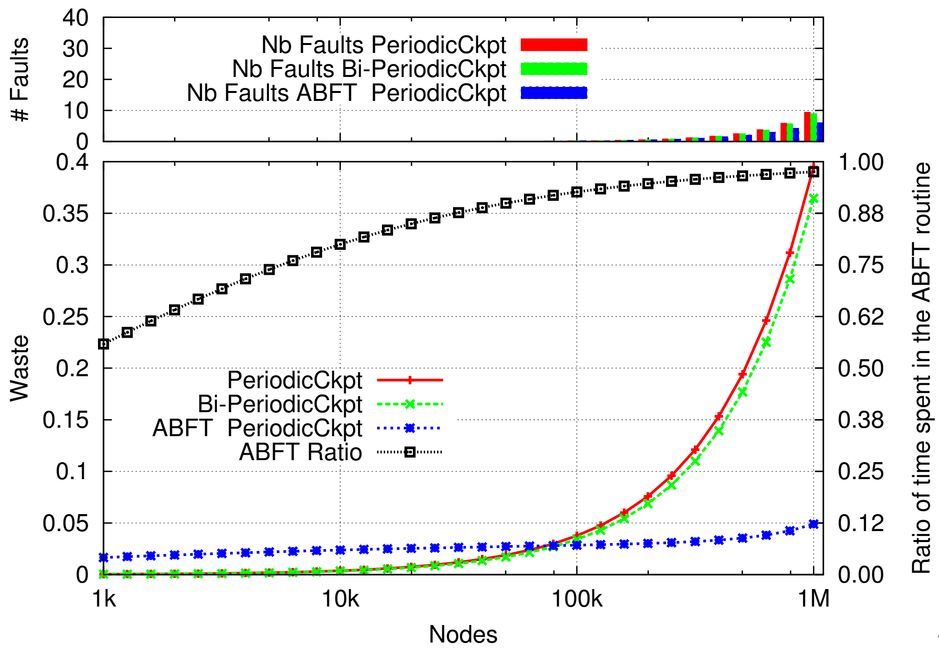


⇨ Without optimization, Checkpoint-Restart needs about 1h! (~30 minutes each)

Systems	Perf.	Ckpt time	Source
RoadRunner	1PF	~20 min.	Panasas
LLNL BG/L	500 TF	>20 min.	LLNL
LLNL Zeus	11TF	26 min.	LLNL
YYY BG/P	100 TF	~30 min.	YYY

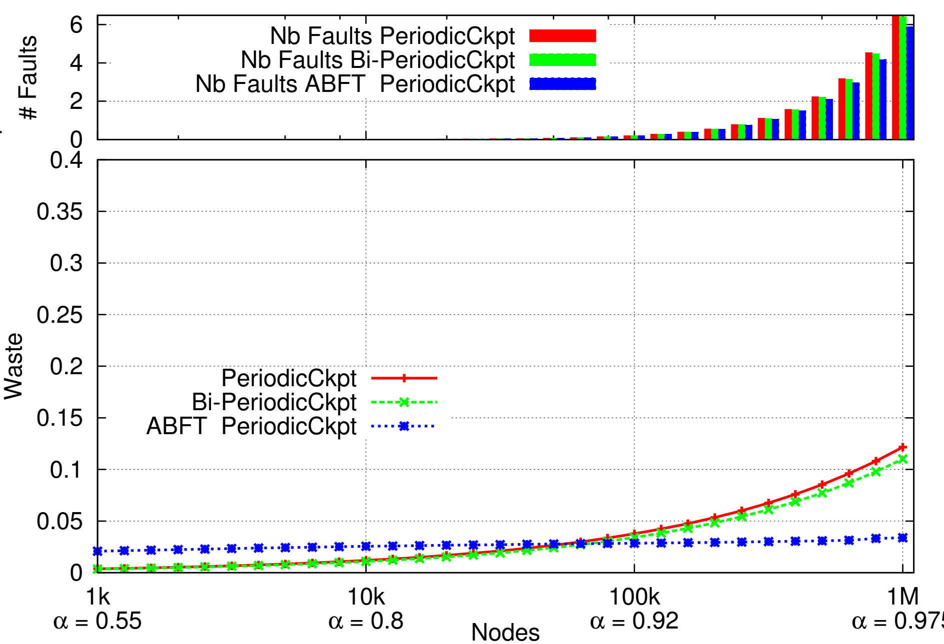
LLNL BG/L

C/R for larger scales



C=R = 1min @ 10^5 nodes (O(n))
MTBF 1 day at 10^5 nodes (O(1/n))
O(n^3) computations for
O(n^2) communications

C=R = 1min @ 10^5 nodes (O(1))
MTBF 1 day at 10^5 nodes (O(1/n))
O(n^3) computations for
O(n^2) communications



Extra hardware (especially NVRAM) might improve the overheads of C/R for an extra cost.
Other hidden costs (energy,…)

Outline

- Diversity in Fault Tolerance
- ULFM functions, rationale, basic use cases
- Hands on:
  - simple examples
  - Master/Worker application
  - SPMD with failed node replacement
  - How to implement transactions
- Concluding remarks

DIVERSITY IN FAULT TOLERANCE

The FT methods landscape

Checkpointing & Restart (C/R)

Diskless Checkpointing

Algorithm Based Fault Tolerance (ABFT)

Overhead

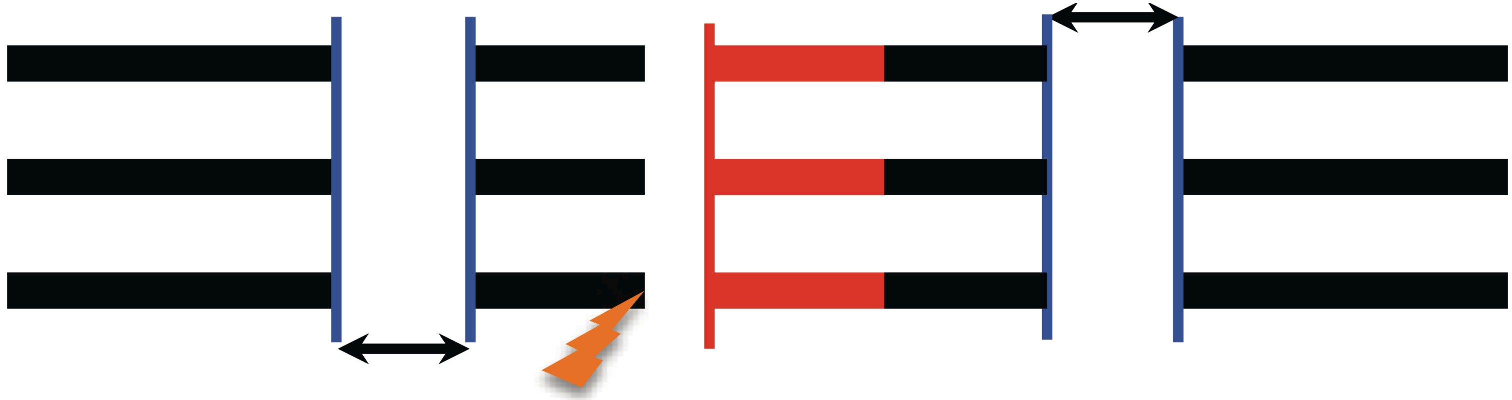
Small

Application Specificity

Small

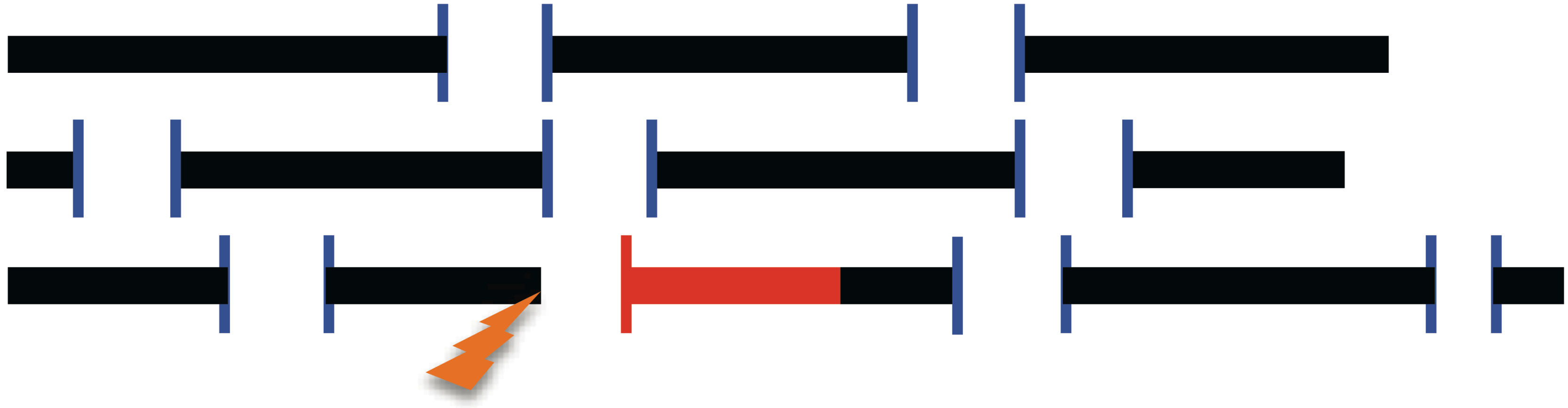
Backward recovery: C/R

Coordinated checkpoint (possibly with incremental checkpoints)



- Coordinated checkpoint is the workhorse of FT today
  - I/O intensive, significant failure free overhead ☹
  - Full rollback (1 fails, all rollback) ☹
  - Can be deployed w/o MPI support ☺
- ULFM enables deployment of in-memory, Buddy-checkpoints, Diskless checkpoint
  - Checkpoints stored on other compute nodes
  - No I/O activity (or greatly reduced), full network bandwidth
  - Potential for a large reduction in failure free overhead, better restart speed

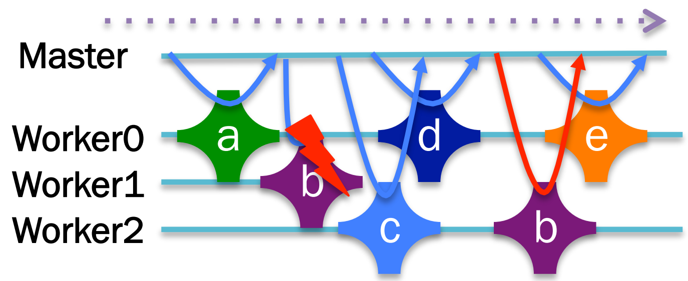
Uncoordinated C/R

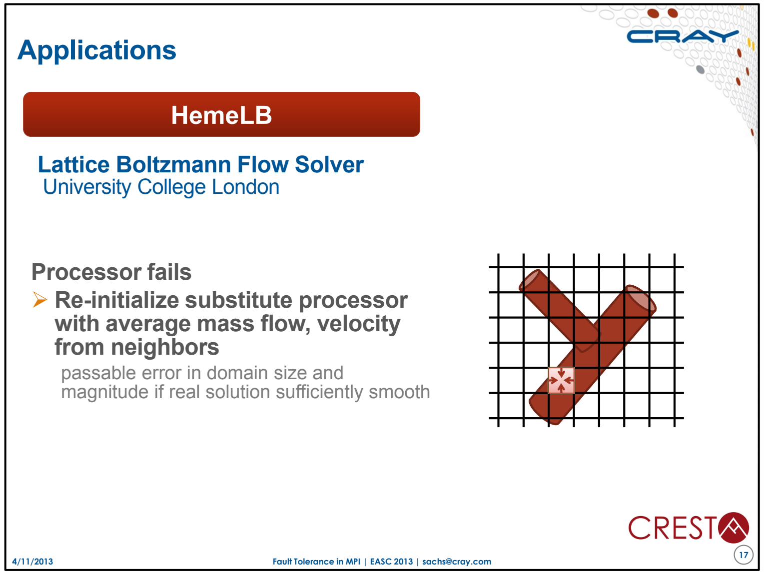


- Checkpoints taken independently
- Based on variants of Message Logging
- 1 fails, 1 rollback
- Can be implemented w/o a standardized user API
- Benefit from ULFM: implementation becomes portable across multiple MPI libraries

Forward Recovery

- Forward Recovery: *Any technique that permit the application to continue without rollback*
  - Master-Worker with simple resubmission
  - Iterative methods, Naturally fault tolerant algorithms
  - Algorithm Based Fault Tolerance
  - Replication *(the only system level Forward Recovery)*
- No checkpoint I/O overhead
- No rollback, no loss of completed work
- May require (sometime expensive, like replicates) protection/recovery operations, *but still generally more scalable than checkpoint* ☺
- Often requires in-depths algorithm rewrite (in contrast to automatic system based C/R) ☹

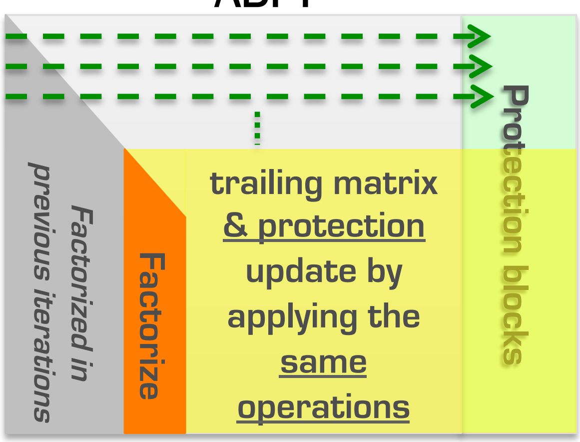


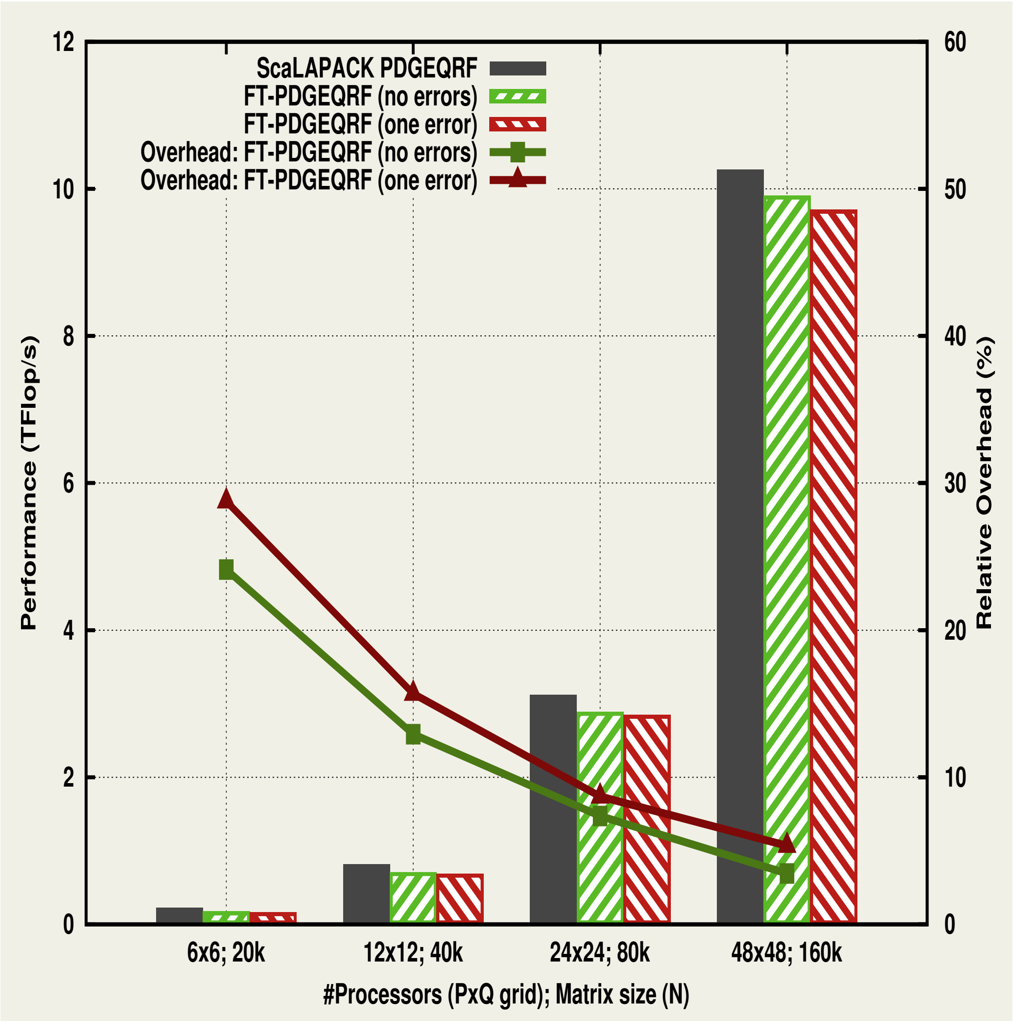


Application specific forward recovery

- Algorithm specific FT methods
  - Not General, but…
  - Very scalable, low overhead ☺
  - *Can't be deployed w/o FT-MPI*

ABFT





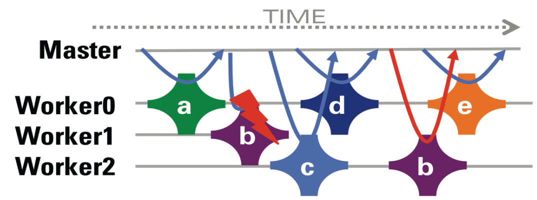
An API for diverse FT approaches

Coordinated Checkpoint/Restart, Automatic, Compiler Assisted, User-driven Checkpointing, etc.

In-place restart (i.e., without disposing of non-failed processes) accelerates recovery, permits in-memory checkpoint

Naturally Fault Tolerant Applications, Master-Worker, Domain Decomposition, etc.

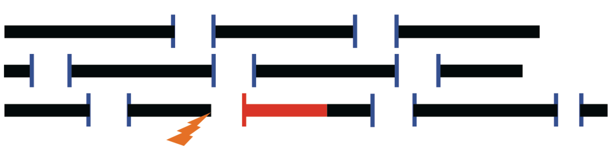
Application continues a simple communication pattern, ignoring failures



ULFM MPI Specification

Uncoordinated Checkpoint/Restart, Transactional FT, Migration, Replication, etc.

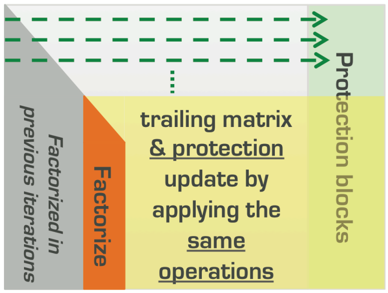
ULFM makes these approaches portable across MPI implementations



Algorithm Fault Tolerance

ULFM allows for the deployment of ultra-scalable, algorithm specific FT techniques.

ABFT

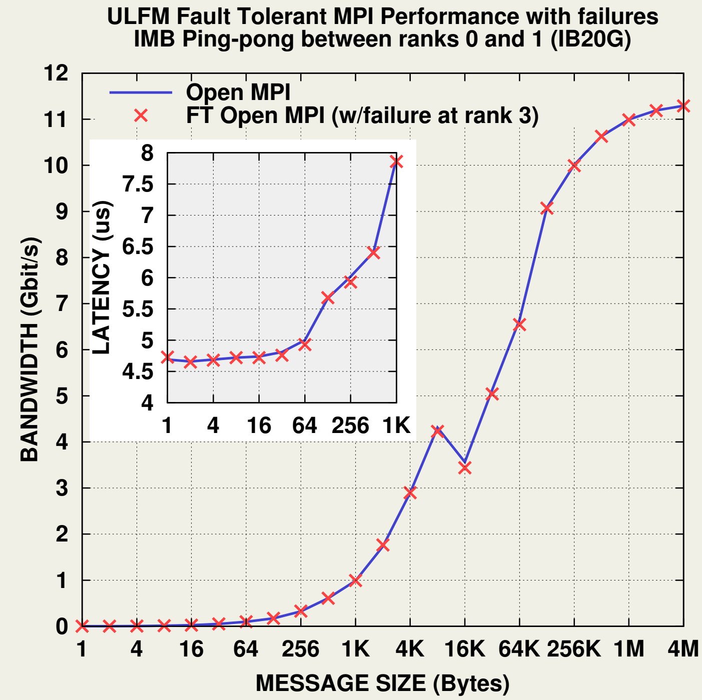


User Level Failure Mitigation: a set of MPI interface extensions to enable MPI programs to restore MPI communication capabilities disabled by failures

ULFM MPI: Software Infrastructure

- Implementation in Open MPI available
  - ANL working on MPICH implementation, close to release
- Very good performance w/o failures
- Optimization and performance improvements of critical recovery routines are close to release
  - New revoke
  - New Agreement

Performance w/failures



The failure of rank 3 is detected and managed by rank 2 during the 512 bytes message test. The connectivity and bandwidth between rank 0 and rank 1 are unaffected by failure handling activities at rank 2.

Applications

HemeLB

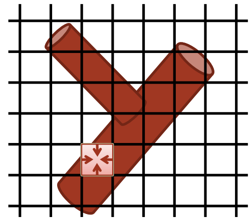
Lattice Boltzmann Flow Solver
University College London

Processor fails

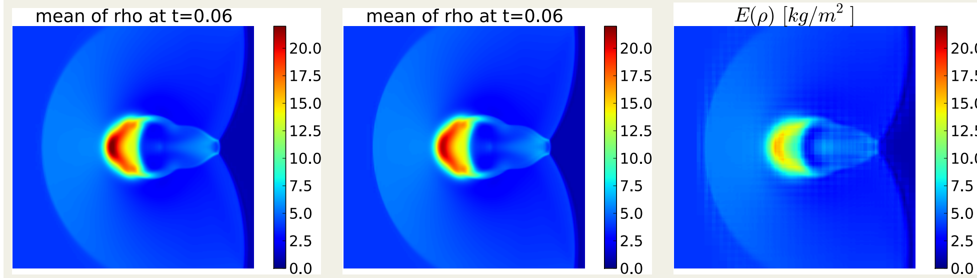
- **Re-initialize substitute processor with average mass flow, velocity from neighbors**
  passable error in domain size and magnitude if real solution sufficiently smooth

Long running computations

- **Small errors can be eliminated by numerical procedure**



Credits: ETH Zurich



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

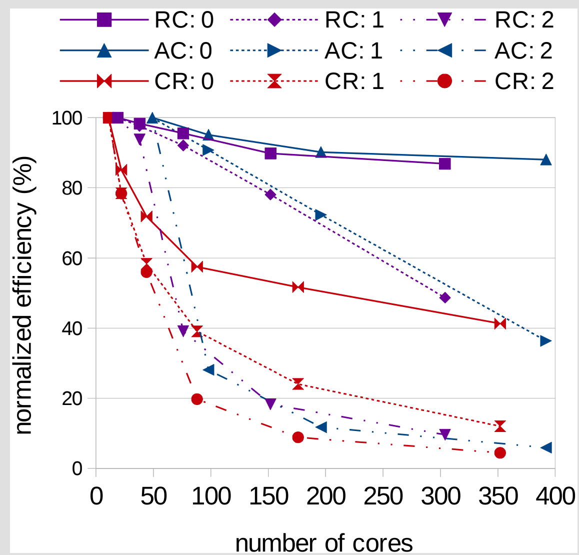
Figure 5. Results of the FT-MLMC implementation for three different failure scenarios.

Users! Users! Users! (S. Balmer style)

- **ORNL:** Molecular Dynamic simulation, C/R in memory with Shrink
- **UAB:** transactional FT programming model
- **Tsukuba:** Phalanx Master-worker framework
- **Georgia University:** Wang Landau Polymer Freezing and Collapse, localized subdomain C/R restart
- **Sandia, INRIA, Cray:** PDE sparse solver
- **Cray:** CREST miniapps, PDE solver Schwartz, PPStee (Mesh, automotive), HemeLB (Lattice Boltzmann)
- **ETH Zurich:** Monte-Carlo, on failure the global communicator (that contains spares) is shrunk, ranks reordered to recreate the same domain decomposition
- ...

All papers at EuroMPI FT session were related to ULFM!

12 Results: Scalability



- results on OPL cluster, max. resolution of 2^{13}
- in terms of absolute time, CR is always more longer (however, uses fewer processes)
- RC and AC also show best scalability
- plots for 2 failures erratic due to high overheads in β version of ULFM MPI

OPL cluster node: 2x6 cores Xeon5670, QDR IB

RC=Replication/resampling
AC=Alternate recombination
CR=Checkpoint/Restart

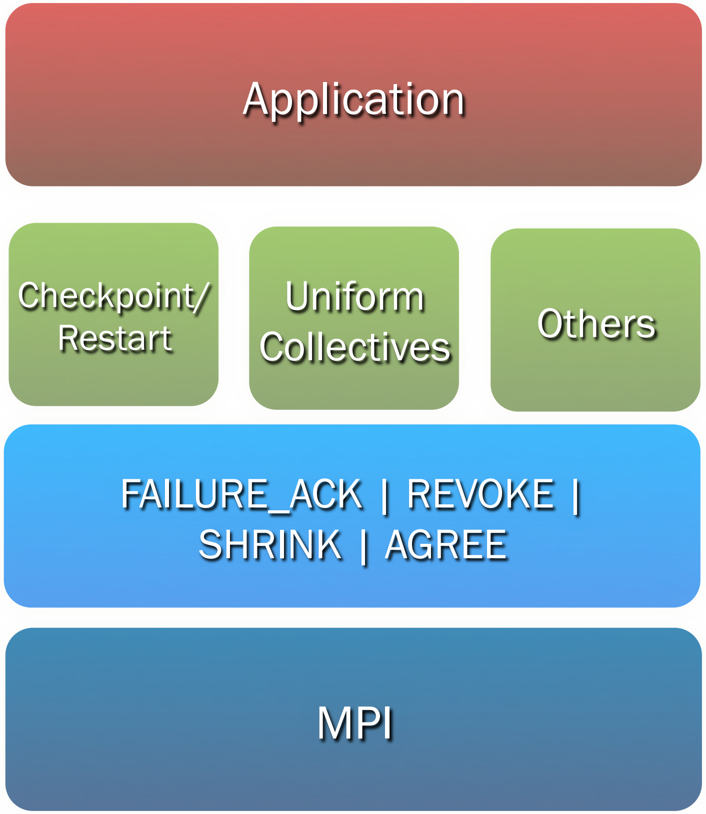
Part rationale, part examples

ULFM MPI API

Minimal Feature Set for FT MPI

- Failure Notification
- Error Propagation
- Error Recovery

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



Integration with existing mechanisms

- 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

Summary of old functions

- MPI_Comm_create_errhandler(errh, errhandler_fct)
  - Declare an error handler with the MPI library
- MPI_Comm_set_errhandler(comm, errh)
  - Attach a declared error handler to a communicator
  - Newly created communicators inherits the error handler that is associated with their parent
  - A global error handler can be specified by associating an error handler to MPI_COMM_WORLD right after MPI_Init
  - Predefined error handlers:
    - MPI_ERRORS_ARE_FATAL (default)
    - MPI_ERRORS_RETURN
- typedef void MPI_Comm_errhandler_function(MPI_Comm *, int *, ...);

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

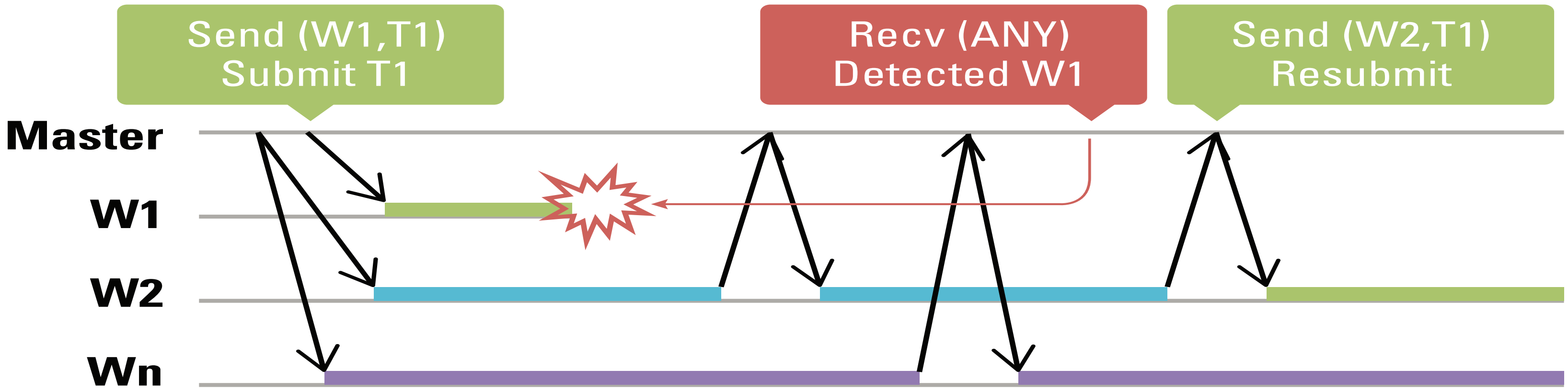
- MPI_Comm_revoke(comm)
  - Non-collective, interrupts all operations on comm (future or active, at all ranks) by raising MPI_ERR_REVOKED

Propagation

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

Recovery

Continuing through errors



- Error notifications do not break MPI
  - App can continue to communicate on the communicator
  - More errors may be raised if the op cannot complete (typically, most collective ops are expected to fail), but p2p between non-failed processes works
- In this Master-Worker example, we can continue w/o recovery!
  - Master sees a worker failed
  - Resubmit the lost work unit onto another worker
  - Quietly continue

Regaining Control

```
legacy_code(void) {
  /* in legacy non FT code, this Recv may deadlock.
   * the runtime is expected to abort the job
   * and do resource cleanup. No opportunity for
   * recovering gracefully. */
  MPI_Recv(buff, count, datatype,
           src, tag, comm,
           MPI_STATUS_IGNORE);
}

ft_code(void) {
  /* MPI_Recv garanteed to return control to the
   * App if src is dead. */
  rc = MPI_Recv(buff, count, datatype,
                src, tag, comm,
                &status);
  /* restartless recovery becomes possible */
  if( MPI_ERR_PROC_FAILED == rc ) recover();
}
```

- If the sender of a receive fails
  - The receive cannot complete properly anymore
  - If we want to handle the failure, that recv must be interrupted
  - All **MPI operations** must complete (possibly in error) when a failure prevents their normal completion
  - Recv from non failed processes complete normally

Regaining Control: ANY_SOURCE

```
ft_code_any(void) {
  int NBR, nfailed=0;
  MPI_Group_size( sendergrp, &NBR );
  for(nbrecv = 0; (nbrecv+nfailed)<NBR; nbrecv++) {
    rc = MPI_Recv(buff, count, datatype,
                  MPI_ANY_SOURCE, tag, comm,
                  &statusany);
    if( MPI_ERR_PROC_FAILED == rc )
      nfailed = nbsendersfailed( sendergrp );
  }
}
nbsendersfailed(MPI_Group sendergrp) {
/* Count how many of the ANY_SOURCE recv we
 * should repost */
  int nfailed;
  MPI_Group failedgrp, igrp;
  MPI_Comm_failure_ack(comm);
  MPI_Comm_failure_get_acked(comm, &failedgrp);
  MPI_Group_intersection( failedgrp, sendergrp,
                          &igrp );
  MPI_Group_size( igrp, &nfailed );
  MPI_Group_free( &igrp );
  MPI_Group_free( &failedgrp );
  return nfailed;
}
```

- If the recv uses ANY_SOURCE:
  - Any failure in the comm is potentially a failure of the matching sender!
  - To avoid deadlocking, the recv must be interrupted in any case
  - Application uses new interfaces to inspect the list of failed processes, determine if the ANY_SOURCE receive needs to be reissued

Failure Discovery

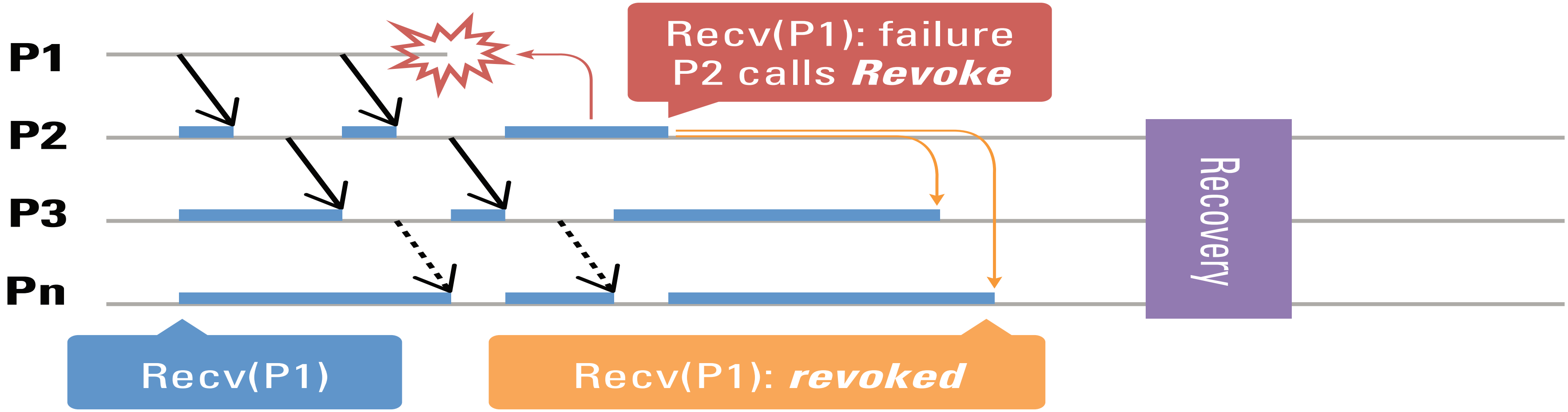
- Discovery of failures is *local* (different processes may know of different failures)
- MPI_COMM_FAILURE_ACK(comm)
  - This local operation gives the users a way to acknowledge all locally notified failures on comm. After the call, unmatched MPI_ANY_SOURCE receive operations proceed without further raising MPI_ERR_PROC_FAILED_PENDING due to those acknowledged failures.
- MPI_COMM_FAILURE_GET_ACKED(comm, &grp)
  - This local operation returns the group *grp* of processes, from the communicator comm, that have been locally acknowledged as failed by preceding calls to MPI_COMM_FAILURE_ACK.
- Employing the combination ack/get_acked, a process can obtain the list of all failed ranks (as seen from its local perspective)

ANY_SOURCE and matching

```
ft_code_any(void) {
  for(i=0; i<nbrecv; i++) {
    MPI_Irecv(buff, count, datatype,
              MPI_ANY_SOURCE, tag, comm, &reqs[i]);
  }
  MPI_Irecv(buff, count, datatype,
            1, tag, comm, &req);
  do {
    rc = MPI_Waitall(nbrecv, reqs, statuses);
    if( MPI_SUCCESS != rc ) {
      int nfailed = nbsendersfailed(sendergrp);
           i=nbrecv;
      while(nfailed) {
        i--;
        if( statuses[i].MPI_ERROR ==
              MPI_ERR_PROC_FAILED ) {
          nfailed--;
        }
        if( statuses[i].MPI_ERROR ==
              MPI_ERR_PROC_FAILED_PENDING ) {
          MPI_Cancel(reqs[i]);
          MPI_Request_free(reqs[i]);
          nfailed--;
        }
             }
  } while( MPI_SUCCESS != rc )
```

- Non-blocking operations
  - Interrupting non-blocking ANY_SOURCE could change matching order, uh oh…
  - New error code: the operation is interrupted by a process failure, but is still *pending*
  - Can be completed again, if the application knows its safe, matching order respected

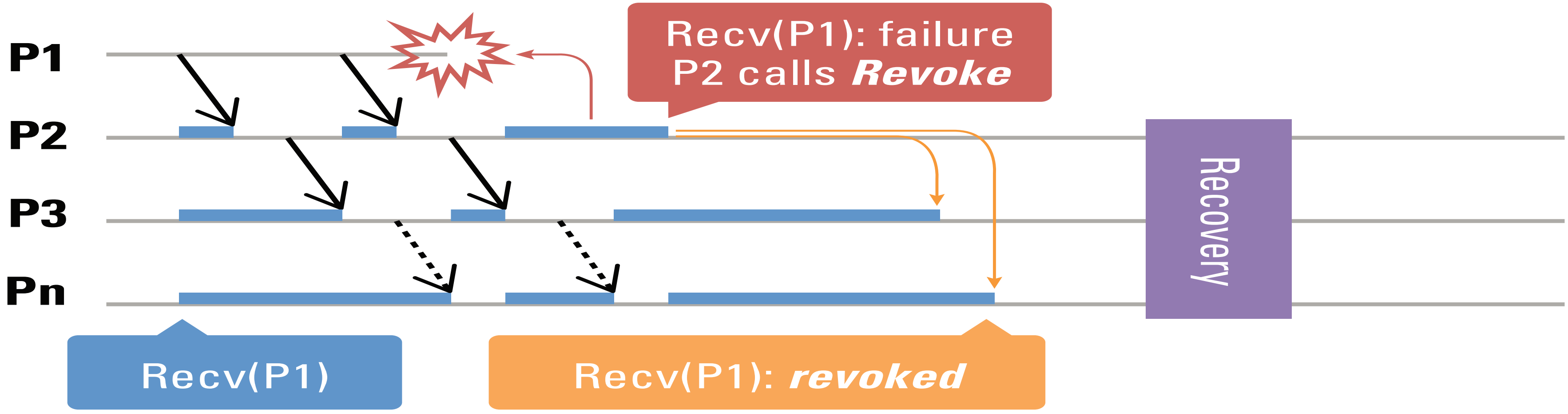
Resolving transitive dependencies




```
proc_failed_err_handler(MPI_Comm comm, int err) {
  if(err == MPI_ERR_PROC_FAILED) recovery(comm);
}
deadlocking_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

Resolving transitive dependencies




```
proc_failed_err_handler(MPI_Comm comm, int err) {
  if(err == MPI_ERR_PROC_FAILED ||
     err == MPI_ERR_REVOKED ) {
    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);
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- but P3..Pn are stuck in their posted recv
- P2 can unlock them with **Revoke** ☺
- P3..Pn join P2 in the recovery

Errors and Collective Operations

```
proc_failed_err_handler(MPI_Comm comm, int err) {
  if(err == MPI_ERR_PROC_FAILED) recovery(comm);
}

deadlocking_collectives(void) {
  for(i=0; i<nbrecv; i++) {
     MPI_Bcast(buff, count, datatype, 0, comm);
  }
}
```

- Exceptions are raised only at ranks where the Bcast couldn’t succeed (lax consistency)
  - In a tree-based Bcast, only the subtree under the failed process sees the failure
  - Other ranks succeed and proceed to the next Bcast
  - Ranks that couldn’t complete enter “recovery”, do not match the Bcast posted at other ranks => deadlock ☹

Errors and Collective Operations

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  }
}
```
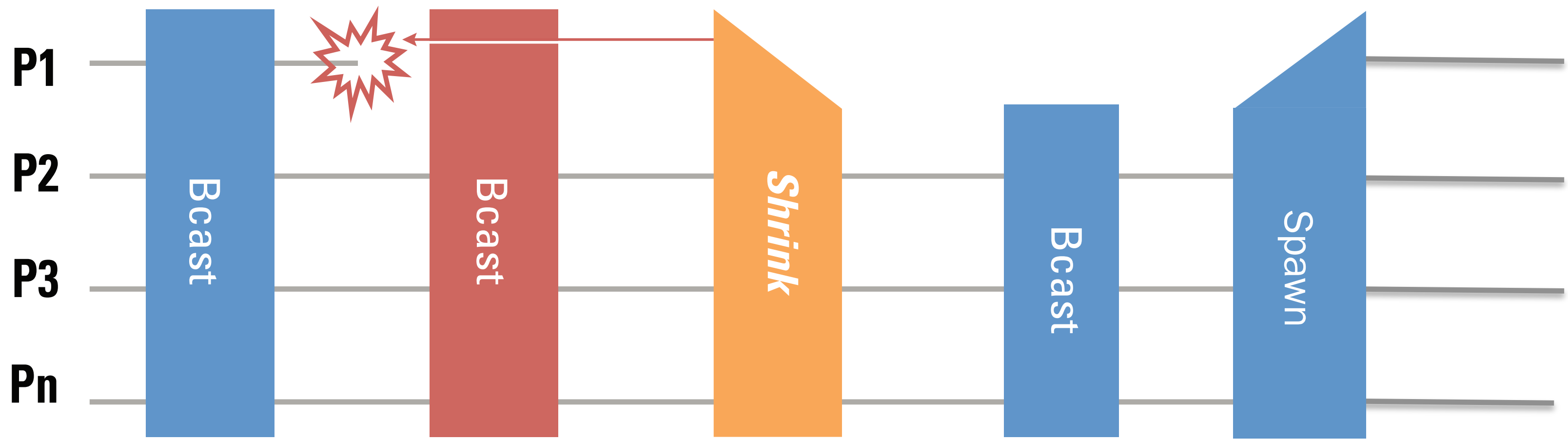

- Exceptions are raised only at ranks where the Bcast couldn't succeed (lax consistency)
  - In a tree-based Bcast, only the subtree under the failed process sees the failure
  - Other ranks succeed and proceed to the next Bcast
  - Ranks that couldn't complete enter "recovery", do not match the Bcast posted at other ranks => MPI_Comm_revoke(comm) interrupts unmatched Bcast and forces an exception (and triggers recovery) at all ranks

ICL UT

Full Recovery



- Restores full communication capability (all collective ops, etc).
- MPI_COMM_SHRINK(comm, newcomm)
  - Creates a new communicator excluding failed processes
  - New failures are absorbed during the operation
  - The communicator can be restored to full size with MPI_COMM_SPAWN

A cookbook of the most useful techniques

HANDS ON

Your first resilient application

```
int main( int argc, char* argv[] )
{
    int rank, size;

    MPI_Init(NULL, NULL);

    MPI_Comm_rank(MPI_COMM_WORLD, &rank);
    MPI_Comm_size(MPI_COMM_WORLD, &size);
    if( rank == (size-1) ) raise(SIGKILL);

    MPI_Barrier(MPI_COMM_WORLD);
    printf("Rank %d / %d\n", rank, size);

    MPI_Finalize();
}
```

- What do we obtain upon failure of the single process?
- What are we missing in order to get the expected output?

Slightly more complex

```
int main( int argc, char* argv[] )
{
    int rank, size, rc, len;
    char errstr[MPI_MAX_ERROR_STRING];

    MPI_Init(NULL, NULL);
    MPI_Comm_set_errhandler(MPI_COMM_WORLD,
                MPI_ERRORS_RETURN);

    MPI_Comm_rank(MPI_COMM_WORLD, &rank);
    MPI_Comm_size(MPI_COMM_WORLD, &size);
    if( rank == (size-1) ) raise(SIGKILL);

    rc = MPI_Barrier(MPI_COMM_WORLD);
    MPI_Error_string( rc, errstr, &len );
    printf("Rank %d / %d (error %s)\n",
           rank, size, errstr);

    MPI_Finalize();
}
```

- Will this code deadlock?
  - It is guaranteed by the standard that the fail process error will eventually propagate
  - Some processes will detect the failure themselves (if the barrier algorithm create communications between them and the dead process)
  - Others will be informed wither by the runtime (OOB) or by revoking the internal communicator used for the collectives.

Who is the dead process?

```
/* usual initialization */
if( rank == (size-1) ) raise(SIGKILL);

rc = MPI_Barrier(MPI_COMM_WORLD);
MPI_Error_string( rc, errstr, &len );
if( MPI_ERR_PROC_FAILED == rc ) {
   OMPI_Comm_failure_ack(MPI_COMM_WORLD);
   OMPI_Comm_failure_get_acked(MPI_COMM_WORLD,
                               &group);
   MPI_Comm_group(MPI_COMM_WORLD, &cgroup);
   MPI_Group_size(group, &g_size);
   ranks1 = (int*)malloc(g_size * sizeof(int));
   ranks2 = (int*)malloc(g_size * sizeof(int));
   for(i = 0; i < g_size; ranks1[i] = i, i++ );
   MPI_Group_translate_ranks(group, g_size, ranks1,
                                cgroup, ranks2);
   printf("Rank %d / %d (error %s) [%d dead: ",
          rank, size, errstr, g_size);
   for(i = 0; i < g_size; ranks1[i] = i, i++ )
       printf("%d ", ranks2[i]);
   printf("]\n");
} else
    printf("Rank %d / %d (error NONE)\n", rank, size);
```

- Upon failure one can use OMPI_Comm_failure_ack to acknowledge the known dead processes
- The group of dead processes is then retrieved using OMPI_Comm_failure_get_acked
- A lot of code is needed to print the failed rank
- Can the same code handle multiple failures?

Who are the dead processes?

```
/* usual initialization */
if( rank > (size/2) ) raise(SIGKILL);

rc = MPI_Barrier(MPI_COMM_WORLD);
MPI_Error_string( rc, errstr, &len );
if( MPI_ERR_PROC_FAILED == rc ) {
   OMPI_Comm_failure_ack(MPI_COMM_WORLD);
   OMPI_Comm_failure_get_acked(MPI_COMM_WORLD,
                               &group);
   MPI_Comm_group(MPI_COMM_WORLD, &cgroup);
   MPI_Group_size(group, &g_size);
   ranks1 = (int*)malloc(g_size * sizeof(int));
   ranks2 = (int*)malloc(g_size * sizeof(int));
   for(i = 0; i < g_size; ranks1[i] = i, i++ );
   MPI_Group_translate_ranks(group, g_size, ranks1,
                                cgroup, ranks2);
   printf("Rank %d / %d (error %s) [%d dead: ",
          rank, size, errstr, g_size);
   for(i = 0; i < g_size; ranks1[i] = i, i++ )
       printf("%d ", ranks2[i]);
   printf("]\n");
} else
    printf("Rank %d / %d (error NONE)\n", rank, size);
```

- It is a distributed system!
  - A single dead process is enough to force a process out of the barrier
  - Thus it is possible that different processes return from the barrier for different reasons
- The group of failed processes returned by OMPI_Comm_failure_ack is not consistent!

Detecting errors (consistently)

- Can you devise a quick way to obtain a globally consistent group of failed processes?

```
void MPIX_Comm_failures_allget(MPI_Comm comm, MPI_Group * grp) {
  ???
}
```

Detecting errors (consistently)

- Can you devise a quick way to obtain a globally consistent group of failed processes?

```
void MPIX_Comm_failures_allget(MPI_Comm comm, MPI_Group * grp) {
        MPI_Comm s; MPI_Group c_grp, s_grp;
        MPI_Comm_shrink( comm, &s);
        MPI_Comm_group( c, &c_grp ); MPI_Comm_group( s, &s_grp );
        MPI_Group_diff( c_grp, s_grp, grp );
        MPI_Group_free( &c_grp ); MPI_Group_free( &s_grp );
        MPI_Comm_free( &s );
}
```

Creating Communicators, safely

```
int MPIX_Comm_split_safe(MPI_Comm comm, int color, int key, MPI_Comm *newcomm) {
        int rc;
        int flag;

        rc = MPI_Comm_split(comm, color, key, newcomm);
        flag = (MPI_SUCCESS==rc);
???
        return rc;
}
```

- Communicator creation functions are collective
- Like all other collective, they may succeed or raise ERR_PROC_FAILED differently at different ranks
- Therefore, caution is needed before using the new communicator: is the context valid at the peer?
- How can you create a wrapper that looks like normal MPI (except for communication cost!), and ensures a safe communicator creation?

Creating Communicators, safely

```
int MPIX_Comm_split_safe(MPI_Comm comm, int color, int key, MPI_Comm *newcomm) {
  int rc;
  int flag;

  rc = MPI_Comm_split(comm, color, key, newcomm);
  flag = (MPI_SUCCESS==rc);
  MPI_Comm_agree( comm, &flag);
  if( !flag ) {
    if( rc == MPI_Success ) {
      MPI_Comm_free( newcomm );
      rc = MPI_ERR_PROC_FAILED;
    }
  }
  return rc;
}
```

- Communicator creation functions are collective
- Like all other collective, they may succeed or raise ERR_PROC_FAILED differently at different ranks
- Therefore, caution is needed before using the new communicator: is the context valid at the peer?
- Can be embedded into wrapper routines that look like normal MPI (except for communication cost!)

Creating Communicators, safely

```
int APP_Create_grid2d_comms(grid2d_t* grid2d,
MPI_Comm comm, MPI_Comm *rowcomm,
MPI_Comm *colcomm) {
        int rc, rcr, rcc;
        int flag;
        int rank;
        MPI_Comm_rank(comm, &rank);
        int myrow = rank%grid2d->nprows;
        int mycol = rank%grid2d->npcols;

        rcr = MPI_Comm_split(comm, myrow, rank,
rowcomm);
        rcc = MPI_Comm_split(comm, mycol,
 rank, colcomm);

flag = (MPI_SUCCESS==rcr)
                                && (MPI_SUCCESS==rcc);
MPI_Comm_agree( comm, &flag );
if( !flag ) {
      if( MPI_Success == rcr ) {
MPI_Comm_free( rowcomm );
                  }
                  if( MPI_Success == rcc ) {
MPI_Comm_free( colcomm );
                  }
                  return MPI_ERR_PROC_FAILED;
}
return MPI_SUCCESS;
}
```

- The cost of one MPI_Comm_agree is amortized when it renders consistent multiple operations at once
- Amortization cannot be achieved in “transparent” wrappers, the application has to control when agree is used to benefit from reduced cost

Recreating the world, no spawn

```
int MPIX_Comm_replace(MPI_Comm worldwspares, MPI_Comm comm, MPI_Comm *newcomm) {
  MPI_Comm shrinked; MPI_Group cgrp, sgrp, dgrp;
  int rc, flag, i, nc, ns, nd, crank, srank, drank;

redo:
  MPI_Comm_shrink(worldwspares, &shrinked);
  MPI_Comm_size(shrinked, &ns); MPI_Comm_rank(comm, &srank);
  if(MPI_COMM_NULL != comm) {
    MPI_Comm_size(comm, &nc); if( nc > ns ) MPI_Abort(comm, MPI_ERR_INTERN);
    MPI_Comm_rank(comm, &crank);
        MPI_Comm_group(comm, &cgrp); MPI_Comm_group(shrinked, &sgrp);
        MPI_Group_difference(cgrp, sgrp, &dgrp); MPI_Group_size(dgrp, &nd);
    if(0 == srank) for(i=0; i<ns-nc-nd; i++) {
      if( i < nd ) MPI_Group_translate_ranks(dgrp, 1, &i, cgrp, &drank);
      else drank=-1;
      MPI_Send(&drank, 1, MPI_INT, i+nc-nd, 1, shrinked);
    } // some group free clutter missing
  } else {
    MPI_Recv(&crank, 1, MPI_INT, 0, 1, shrinked, MPI_STATUS_IGNORE);
  }
  rc = MPI_Comm_split(shrinked, crank<0?MPI_UNDEFINED:1, crank, newcomm);
  flag = (MPI_SUCCESS==rc);
  MPI_Comm_agree(shrinked, &flag); MPI_Comm_free(&shrinked);
  if( !flag ) goto redo; //some newcomm free clutter missing
  return MPI_SUCCESS;
}
```

Recreating the world

```
int MPIX_Comm_replace(MPI_Comm comm, MPI_Comm *newcomm) {
        MPI_Comm shrinked, spawned, merged;
        int rc, flag, flagr, nc, ns;

        redo:
                MPI_Comm_shrink(comm, &shrinked);
                MPI_Comm_size(comm, &nc); MPI_Comm_size(shrinked, &ns);
                rc = MPI_Comm_spawn(…, nc-ns, …, 0, shrinked, &spawned, …);
                flag = MPI_SUCCESS==rc;
                MPI_Comm_agree(shrinked, &flag);
                if( !flag ) {
                        if(MPI_SUCCESS == rc) MPI_Comm_free(&spawned);
                        MPI_Comm_free(&shrinked);
                        goto redo;
                }
        rc = MPI_Intercomm_merge(spawned, 0, &merged);
                flag = MPI_SUCCESS==rc;
                MPI_Comm_agree(shrinked, &flag);
                flagr = flag;
                MPI_Comm_agree(spawned, &flagr);
                if( !flag || !flagr ) {
                        if(MPI_SUCCESS == rc) MPI_Comm_free(&merged);
                        MPI_Comm_free(&spawned);
                        MPI_Comm_free(&shrinked);
                        goto redo;
                }
```

Recreating the world (cont.)

```
int MPIX_Comm_replace(MPI_Comm comm, MPI_Comm *newcomm) {
        …
/* merged contains a replacement for comm, ranks are not ordered properly */
        int c_rank, s_rank;
        MPI_Comm_rank(comm, &c_rank);
        MPI_Comm_rank(shrinked, &s_rank);
        if( 0 == s_rank ) {
                MPI_Comm_grp c_grp, s_grp, f_grp; int nf;
                MPI_Comm_group(comm, &c_grp); MPI_Comm_group(shrinked, s_grp);
                MPI_Group_difference(c_grp, s_grp, &f_grp);
                MPI_Group_size(f_grp, &nf);
                for(int r_rank=0; r_rank<nf; r_rank++) {
                        int f_rank;
                        MPI_Group_translate_ranks(f_grp, 1, &r_rank, c_grp, &f_rank);
                        MPI_Send(&f_rank, 1, MPI_INT, r_rank, 0, spawned);
                }
        }
        rc = MPI_Comm_split(merged, 0, c_rank, newcomm);
        flag = (MPI_SUCCESS==rc);
        MPI_Comm_agree(merged, &flag);
        if( !flag ) { goto redo; } // (removed the Free clutter here)
```

Example: in-memory C/R

```
int checkpoint_restart(MPI_Comm *comm) {
            int rc, flag;
      checkpoint_in_memory(); // store a local copy of my checkpoint
      rc = checkpoint_to(*comm, (myrank+1)%np); //store a copy on myrank+1
      flag = (MPI_SUCCESS==rc); MPI_Comm_agree(*comm, &flag);
      if( !flag ) { // if checkpoint fails, we need restart!
                  MPI_Comm newcomm; int f_rank; int nf;
                        MPI_Group c_grp, n_grp, f_grp;
redo:
                  MPIX_Comm_replace(*comm, &newcomm);
                  MPI_Comm_group(*comm, &c_grp); MPI_Comm_group(newgroup, &n_grp);
                  MPI_Group_difference(c_grp, n_grp, &f_grp);
                  MPI_Group_size(f_grp, &nf);
                        for(int i=0; i<nf; i++) {
                              MPI_Group_translate_ranks(f_grp, 1, &i, c_grp, &f_rank);
                              if( (myrank+np-1)%np == f_rank ) {
                                          serve_checkpoint_to(newcomm, f_rank);
                              }
                  }
                        MPI_Group_free(&n_grp); MPI_Group_free(&c_grp); MPI_Group_free(&f_grp);
                  rc = MPI_Barrier(newcomm);
                  flag=(MPI_SUCCESS==rc); MPI_Comm_agree(*comm, &flag);
                  if( !flag ) goto redo; // again, all free clutter not shown
                  restart_from_memory(); // rollback from local memory
                  MPI_Comm_free(comm);
                  *comm = newcomm;
      }
```

Iterative Algorithm – with shrink

```
while( gnorm > epsilon ) {
    iterate();
    compute_norm(&lnorm);

    rc = MPI_Allreduce( &lnorm, &gnorm, 1,
                        MPI_DOUBLE, MPI_MAX, comm);

    if( (MPI_ERR_PROC_FAILED == rc) ||
        (MPI_ERR_COMM_REVOKED == rc) ||
        (gnorm <= epsilon) ) {
      if( MPI_ERR_PROC_FAILED == rc )
          MPI_Comm_revoke(comm);

      allsuceeded = (rc == MPI_SUCCESS);
      MPI_Comm_agree(comm, &allsuceeded);
      if( !allsucceeded ) {
         MPI_Comm_revoke(comm);
         MPI_Comm_shrink(comm, &comm2);
         MPI_Comm_free(comm);
         comm = comm2;
         gnorm = epsilon + 1.0;
      }
    }
}
```

- The compute_norm function can help to detect the failure earlier
- As MPI_Allreduce can complete on some processes and not others, there will be instances where the processors will be out of sync (working at different iterations)
- The agreement has two roles:
  - Agree in the case of a failure
  - Completion consensus to make sure that every process leave the algorithm in same time

Transaction-like approaches

```
/* save data to be used in the code below */

do {
  /* if not original instance restore the data */

  /* do some extremely useful work */

  /* validate that no errors happened */

} while  (!errors)
```

- Let's not focus on the data save and restore
- Use the agreement to decide when a work unit is valid
- If the agreement succeed the work is correctly completed and we can move forward
- If the agreement fails restore and data and redo the computations
- Use REVOKE to propagate specific exception every time it is necessary (even in the work part)
- Exceptions must be bits to be able to work with the agreement

Transaction-like approaches

```
#define TRY_BLOCK(COMM, EXCEPTION) \
do { \
  int __flag = 0xffffffff; \
  __stack_pos++; \
  EXCEPTION = setjmp(&stack_jmp_buf[__stack_pos]);\
  __flag &= ~EXCEPTION; \
  if( 0 == EXCEPTION ) {

#define CATCH_BLOCK(COMM)  \
    __stack_pos--; \
    __stack_in_agree = 1;  /* prevent longjmp */ \
    OMPI_Comm_agree(COMM, &__flag); \
    __stack_in_agree = 0; /* enable longjmp */ \
  } \
  if( 0xffffffff != __flag ) {

#define END_BLOCK() \
  } } while (0);

#define RAISE(COMM, EXCEPTION) \
  OMPI_Comm_revoke(COMM); \
  assert(0 != (EXCEPTION)); \
  if(!__stack_in_agree ) \
    longjmp( stack_jmp_buf[__stack_pos],
               (EXCEPTION) ); /* escape */
```

- TRY_BLOCK setup the transaction, by setting a setjmp point and the main if
- CATCH_BLOCK complete the if from the TRY_BLOCK and implement the agreement about the success of the work completion
- END_BLOCK close the code block started by the TRY_BLOCK
- RAISE revoke the communicator and if necessary (if not raised from the agreement) longjmp at the beginning of the TRY_BLOCK catching the if

Transaction-like approaches

```
/* save data1 to be used in the code below */
transaction1:
TRY_BLOCK(MPI_COMM_WORLD, exception) {

    /* do some extremely useful work */

    /* save data2 to be used in the code below */
transaction2:
    TRY_BLOCK(newcomm, exception) {

        /* do more extremely useful work */

    } CATCH_BLOCK(newcomm) {
        /* restore data2 for transaction 2 */
        goto transaction2;
    } END_BLOCK()

} CATCH_BLOCK(MPI_COMM_WORLD) {
    /* restore data1 for transaction 1 */
    goto transaction1;
} END_BLOCK()
```

Transaction 2

Transaction 1

- Skeleton for a 2 level transaction with checkpoint approach
  - Local checkpoint can be used to handle soft errors
  - Other types of checkpoint can be used to handle hard errors
  - No need for global checkpoint, only save what will be modified during the transaction
- Generic scheme that can work at any depth

Transaction-like approaches

```
MPI_Comm_rank(MPI_COMM_WORLD, &rank);
MPI_Comm_size(MPI_COMM_WORLD, &size);

TRY_BLOCK(MPI_COMM_WORLD, exception) {

    int rank, size;

    MPI_Comm_dup(MPI_COMM_WORLD,
&newcomm);
    MPI_Comm_rank(newcomm, &rank);
    MPI_Comm_size(newcomm, &size);

    TRY_BLOCK(newcomm, exception) {

        if( rank == (size-1) ) exit(0);
        rc = MPI_Barrier(newcomm);

    } CATCH_BLOCK(newcomm) {
    } END_BLOCK()

} CATCH_BLOCK(MPI_COMM_WORLD) {
} END_BLOCK()
```

Transaction 1

Transaction 2

- A small example doing a simple barrier
- We manually kill a process by brutally calling exit
- What is the correct or the expected output?

Thank you

More info, examples and resources available

http://fault-tolerance.org

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