REINIT: A Simple and Efficient Fault-Tolerance Model for MPI Applications

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Fault-Tolerance Solutions for HPC Applications

Our focus

Application

Examples: MPI FT programming models, ABFT, C/R
+ better view of what needs to be protected/recovered
– can be hard to integrate in large codes

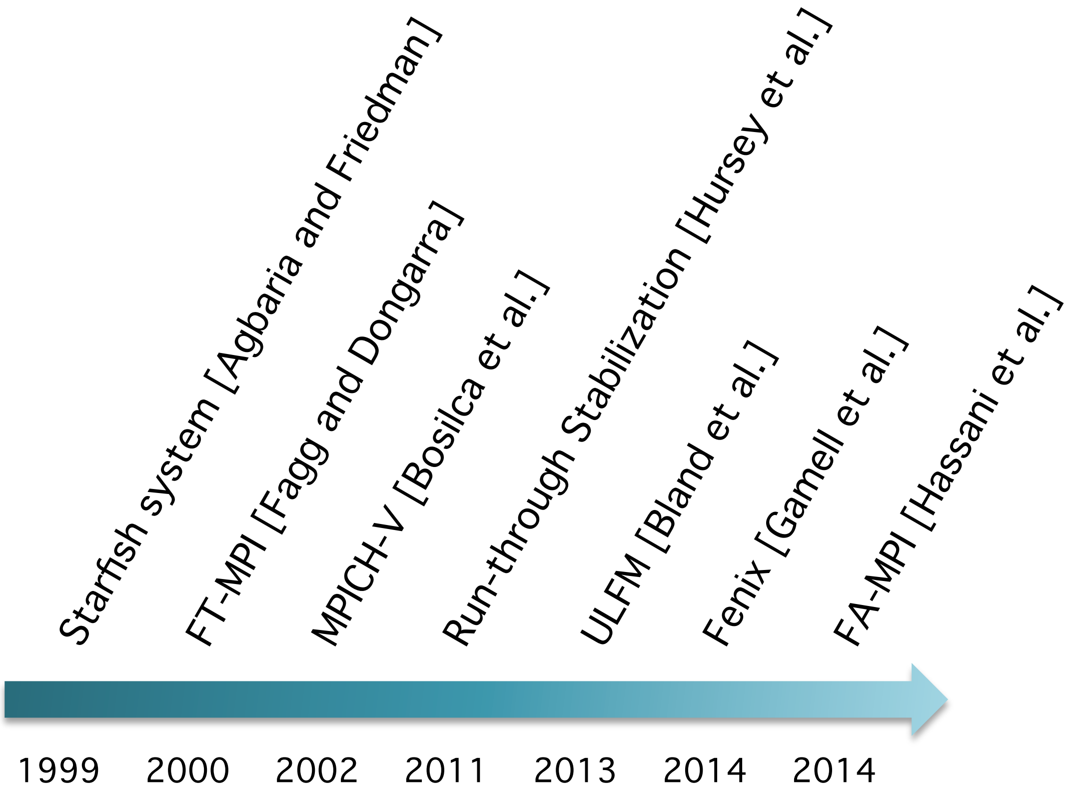
System

Examples: System-level checkpoints, message logging
+ don't require code changes, application agnostic
– overhead can be high, know little about applications

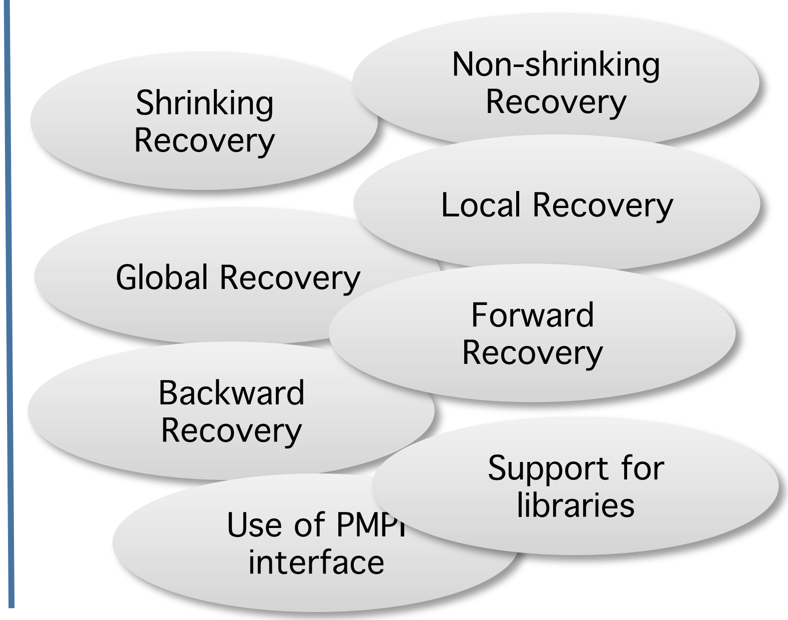
Hardware

Examples: Hardware replication, parity, ECC
+ don't require code changes, system/app agnostic
– can be very expensive (power, performance)

Several FT Programming Models for MPI have been Proposed…



There are many paradigms & features



How do we group or classify them all?

Classification of Existing FT Programming Models

Fine — **Medium** — **Coarse**

Granularity of control / detection →

Error Code Checking

```
err = MPI_Operation1();
if (err) {
  recovery();
}
```

A

Try Blocks

```
TRY {
  MPI_Operation1();
  MPI_Operation2();
}
TRY {
  MPI_Operation3();
  MPI_Operation4();
}
```

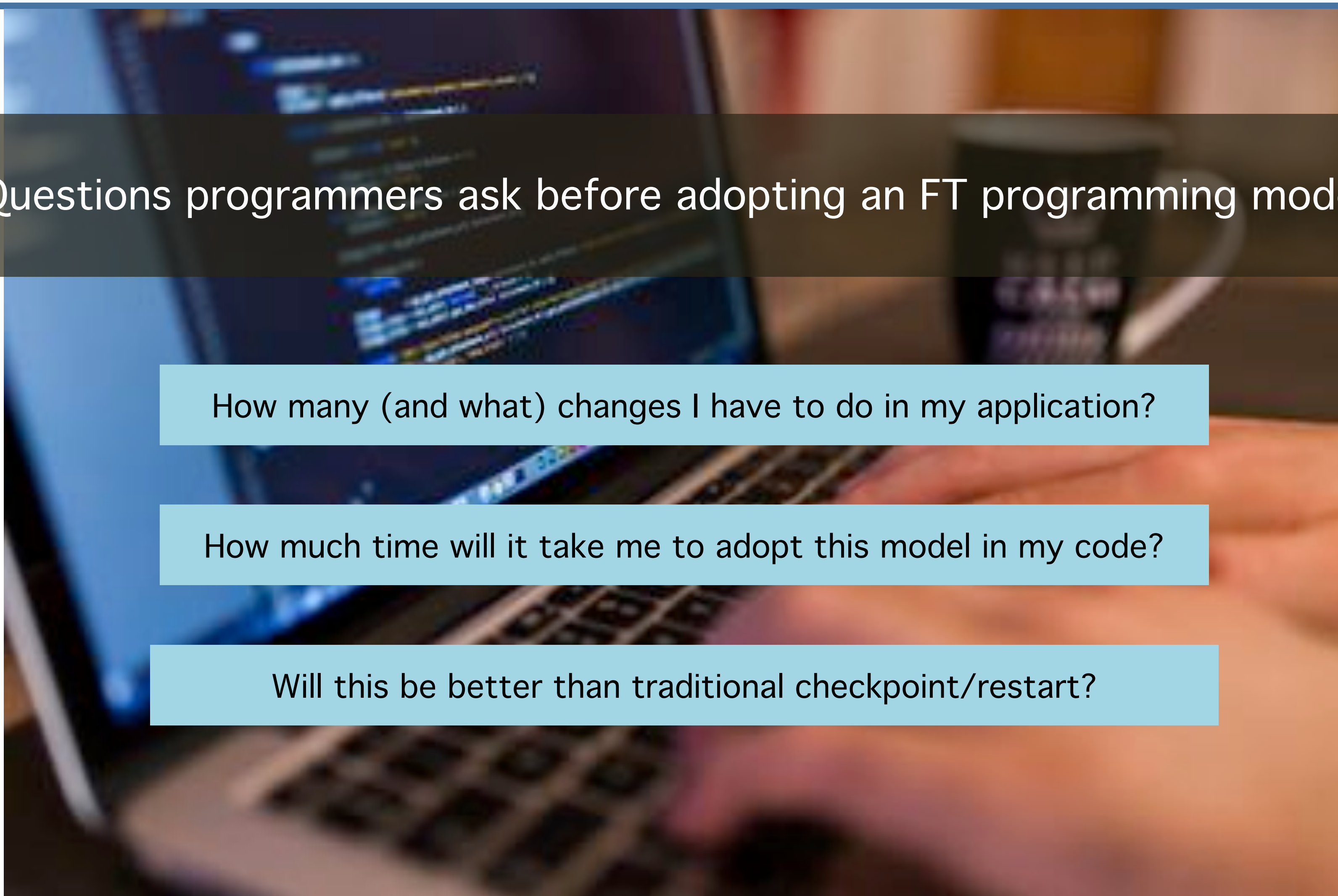
B

Full Restart

```
main () {
  restart_from_here();

  MPI_Operation1();

  MPI_Operation2();

  MPI_Operation3();

  MPI_Operation4();
  return 0;
}
```

C

Programmability and Usability can be Major Concerns



Questions programmers ask before adopting an FT programming model

How many (and what) changes I have to do in my application?

How much time will it take me to adopt this model in my code?

Will this be better than traditional checkpoint/restart?

But....How to Measure Programmability or Usability?

- Lines of code
- Number of files modified (or functions, ...)
- Time spent modifying the code
- ...
- ...
- ...
- Cyclomatic complexity
  - McCabe '76, '89, Gill et al. '91, Lanning et al. '94, Kozlov et al. '08

Cyclomatic Complexity in Software Engineering

- Programs with high complexity have higher rates of bugs
- Programs with high complexity are more difficult to maintain and test
  - Lanning et al., Computer (1994)
  - Kozlov et al., Journal of Software Maintenance and Evolution (2008)
- CC is adopted by the NIST Structured Testing Methodology
  - A. H. Watson, T. J. McCabe, and D. R. Wallace. *Structured testing: A testing methodology using the cyclomatic complexity metric* (1996).

Cyclomatic Complexity Metric

Which code is easier to understand and easier to test?

Code with 10 assignments

```
a = …
b = …
c = …
…
…
…
…
…
…
j = …
```

One execution path

$$CC = 0 + 1 = 1$$

Code with 10 **`if`** conditions

```
if (cond1) {
    if (cond2) {
        if (cond3) {
            …
            …
            …
            …
            …
            …
            if (cond10) {
```

More than 1,000 execution paths!

$$CC = 10 + 1 = 11$$

Cyclomatic complexity (CC) measures number of decisions in a program

$$CC = decisions + 1$$

The recommended value for CC in software engineering and industry is 10

Example:
Cyclomatic Complexity with the Error Code Checking Model

Refinement original loop

```
while(error > threshold) {
  /* perform computation */
  MPI_Allreduce(..., comm);
}
```

Cyclomatic Complexity = 2

Fault-tolerant loop using return error code checking*

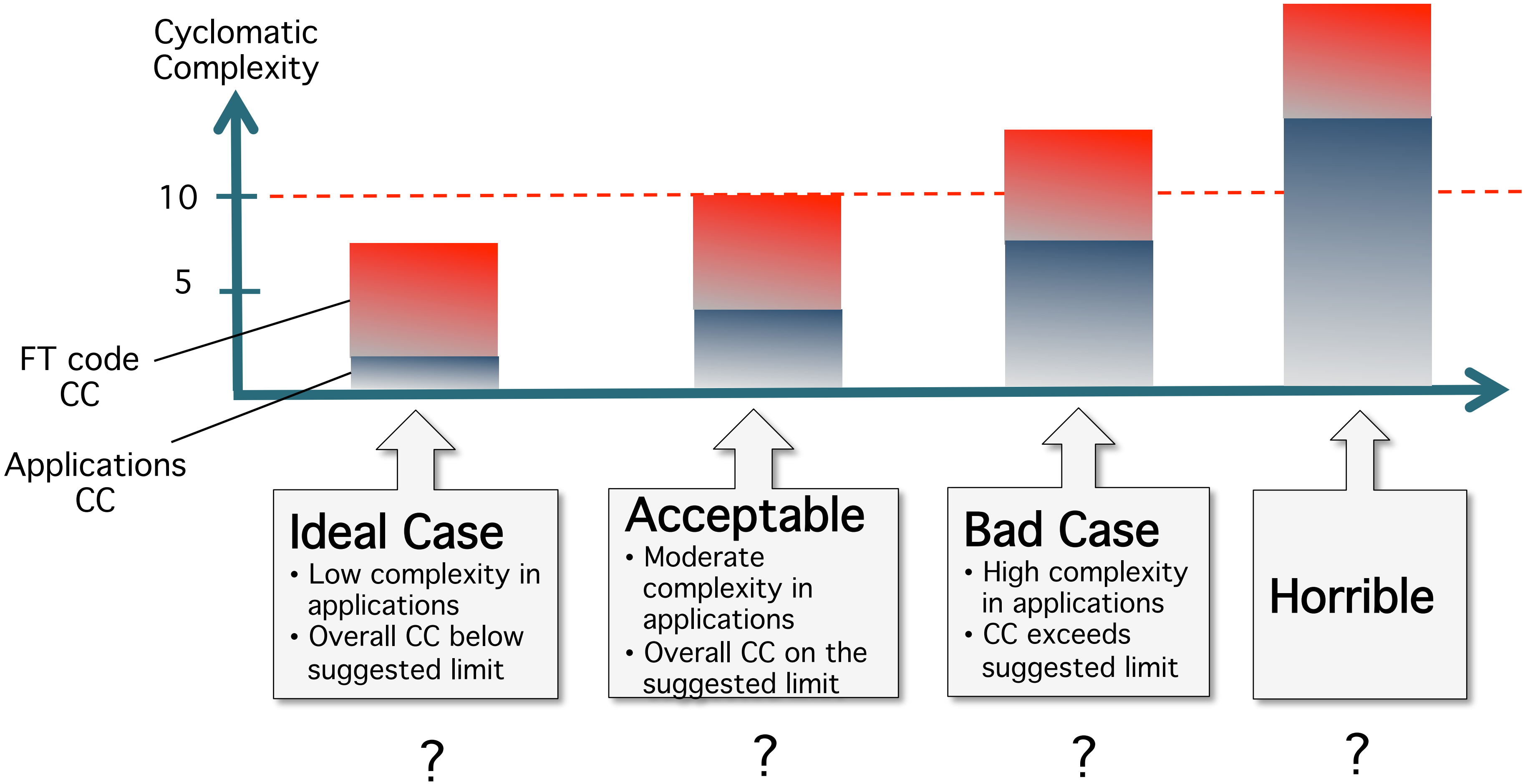
```
while(error > threshold) {
  rc = MPI_Allreduce(..., comm);
  if( (FAILED_PROCESS == rc) ||
      (FAILED_COMMUNICATOR == rc) ||
      (error <= threshold) ) {

    if(FAILED_PROCESS == rc )
      MPI_Comm_revoke(comm);

    allgood = (rc == MPI_SUCCESS);
    rc = MPI_Comm_agree(comm, &allgood);
    if( rc == FAILED_PROCESS ||
        !allsucceeded ) {
      /* repair communicator */
    }
  }
}
```

6 additional conditions

*ULFM example (taken from ULFM documentation)

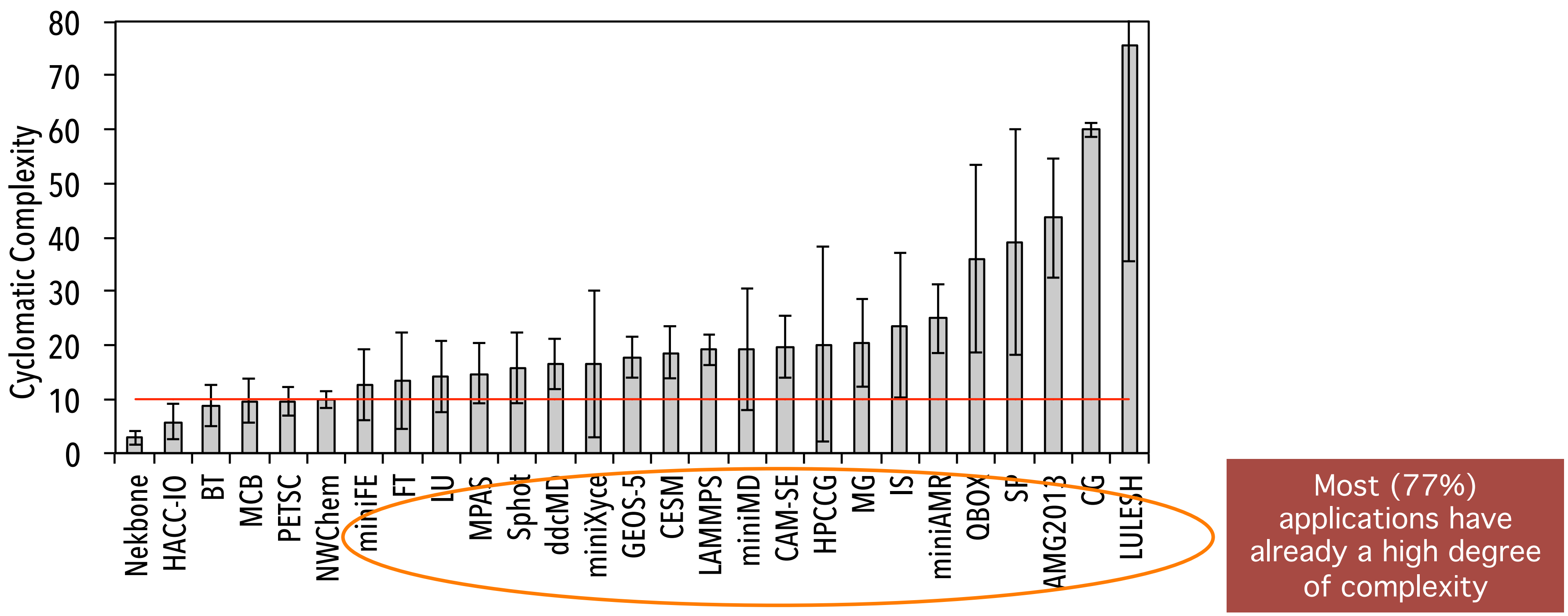
Cyclomatic Complexity = 8

What is the Complexity of MPI Applications?

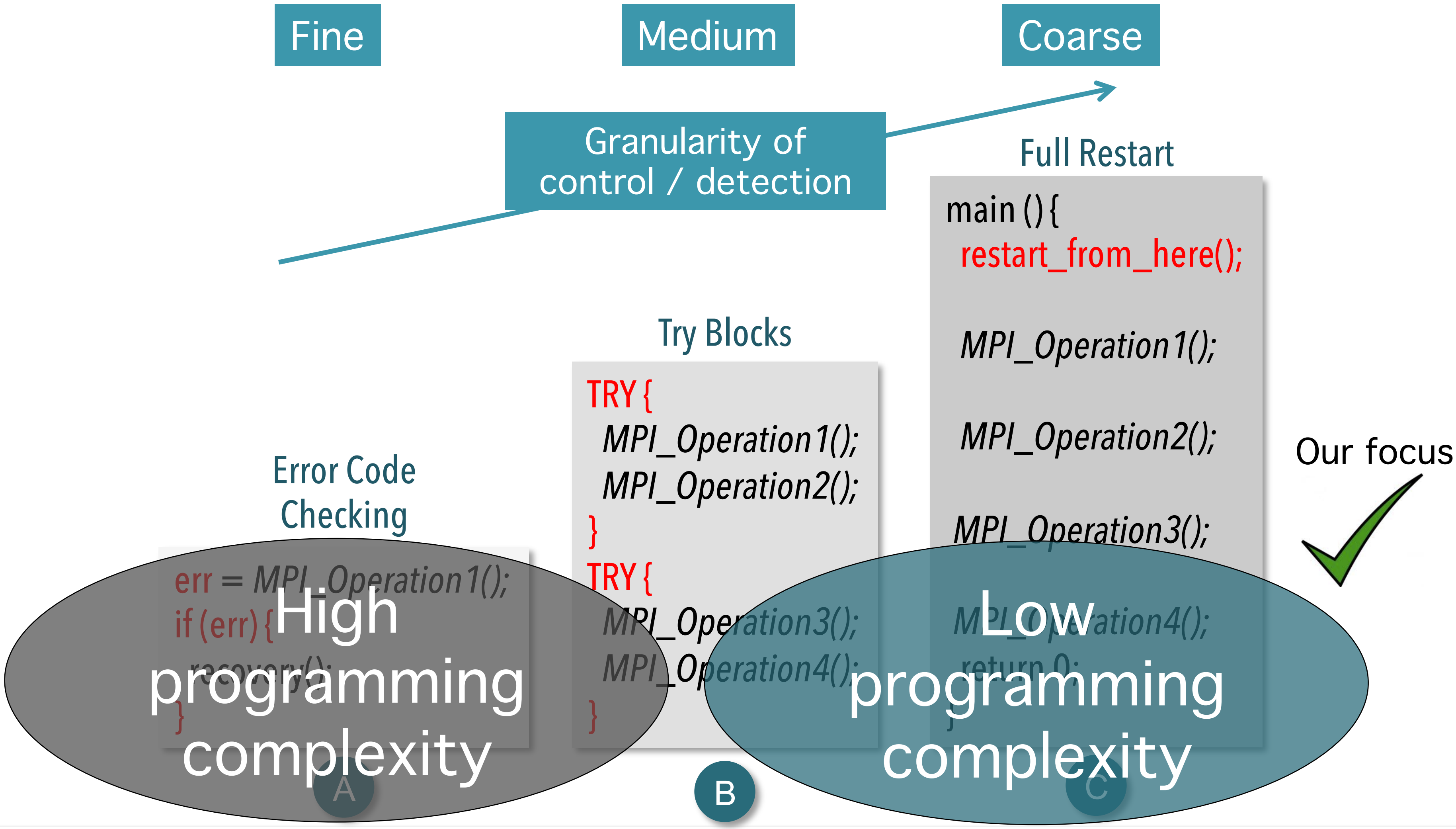


Study of Cyclomatic Complexity of MPI Applications

- Conducted analysis on a large number of MPI applications
- Measured CC of functions that use MPI communication routines
  - Analyzed over 2,300 functions



Our Solution Space: *Low Programming Complexity*



Design Goals of the Reinit Interface

1. Simple to program interface
- Support current fault-tolerance programming practices
- Checkpoint/Restart

2. MPI library cleans up its state (not the application)
- Provide state similar to MPI_Init
- All communicators are gone (except MPI_COMM_WORLD)

3. Close interaction between MPI & resource manager
- More efficient reparation of failed resources
- Faster recovery time

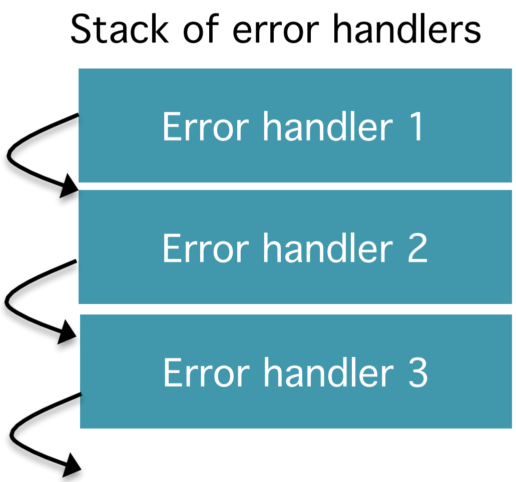
4. Mechanism to clean up libraries
- FIFO stack of error handlers
- Libraries and applications provide their own handlers

Description of the Reinit Interface

```c
/* Initialization routines */
typedef enum {
    MPI_START_NEW,          // Fresh process
    MPI_START_RESTARTED,    // Restarted after fault
    MPI_START_ADDED         // Replaced process
} MPI_Start_state;

/* Application entry point */
typedef void (*MPI_Restart_point)
    (int argc, char **argv, MPI_Start_state state);

int MPI_Reinit
    (int argc, char **argv, MPI_Restart_point point);
```

Cleanup Stack Mechanisms

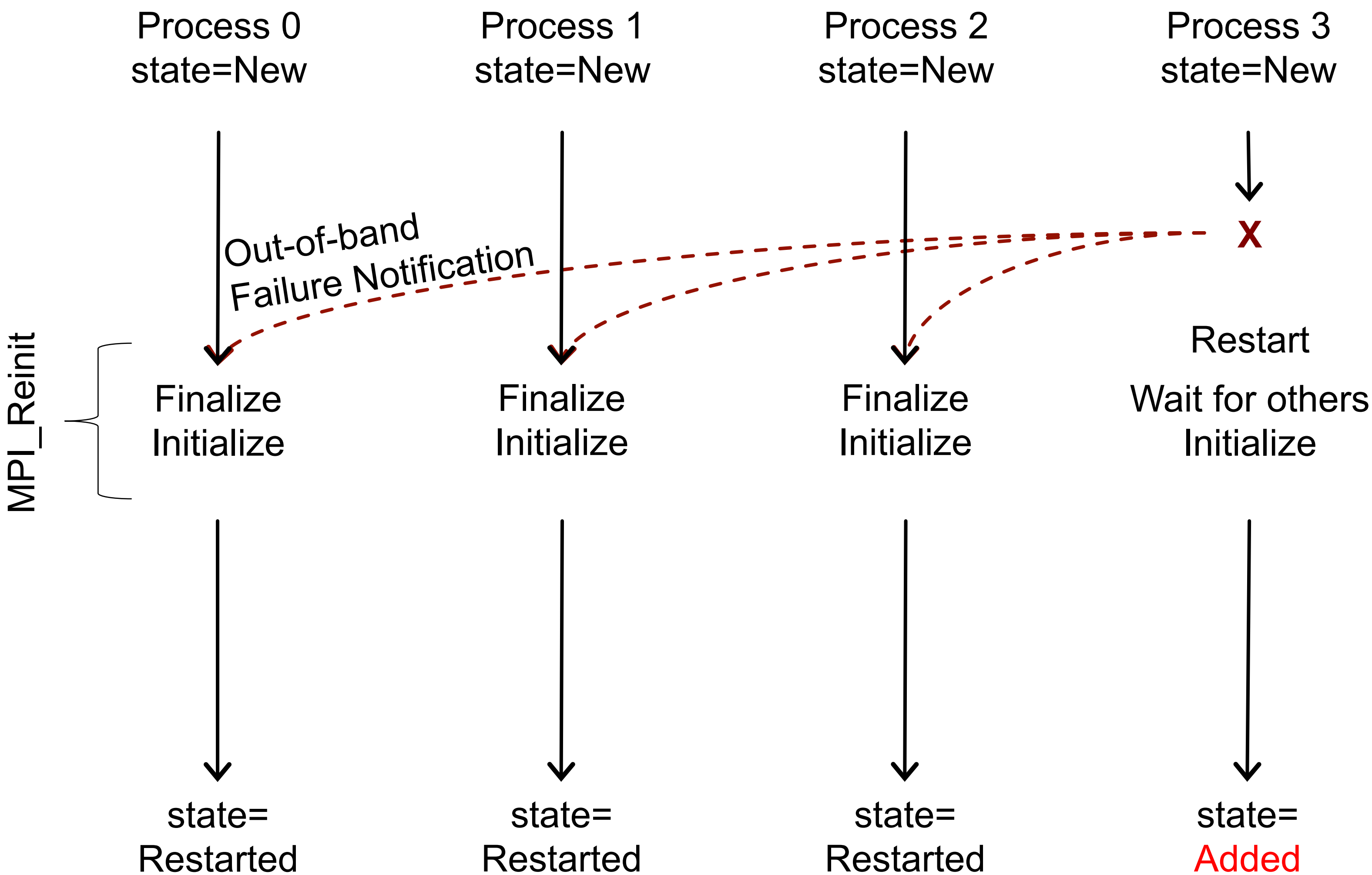
```
/* Cleanup routines */
typedef int (*MPI_Cleanup_handler) (
  MPI_Start_state start,
  void *state);

int MPI_Cleanup_handler_push (
  MPI_Cleanup_handler handler,
  void *state);

int MPI_Cleanup_handler_pop (
  MPI_Cleanup_handler *handler,
  void **state);
```



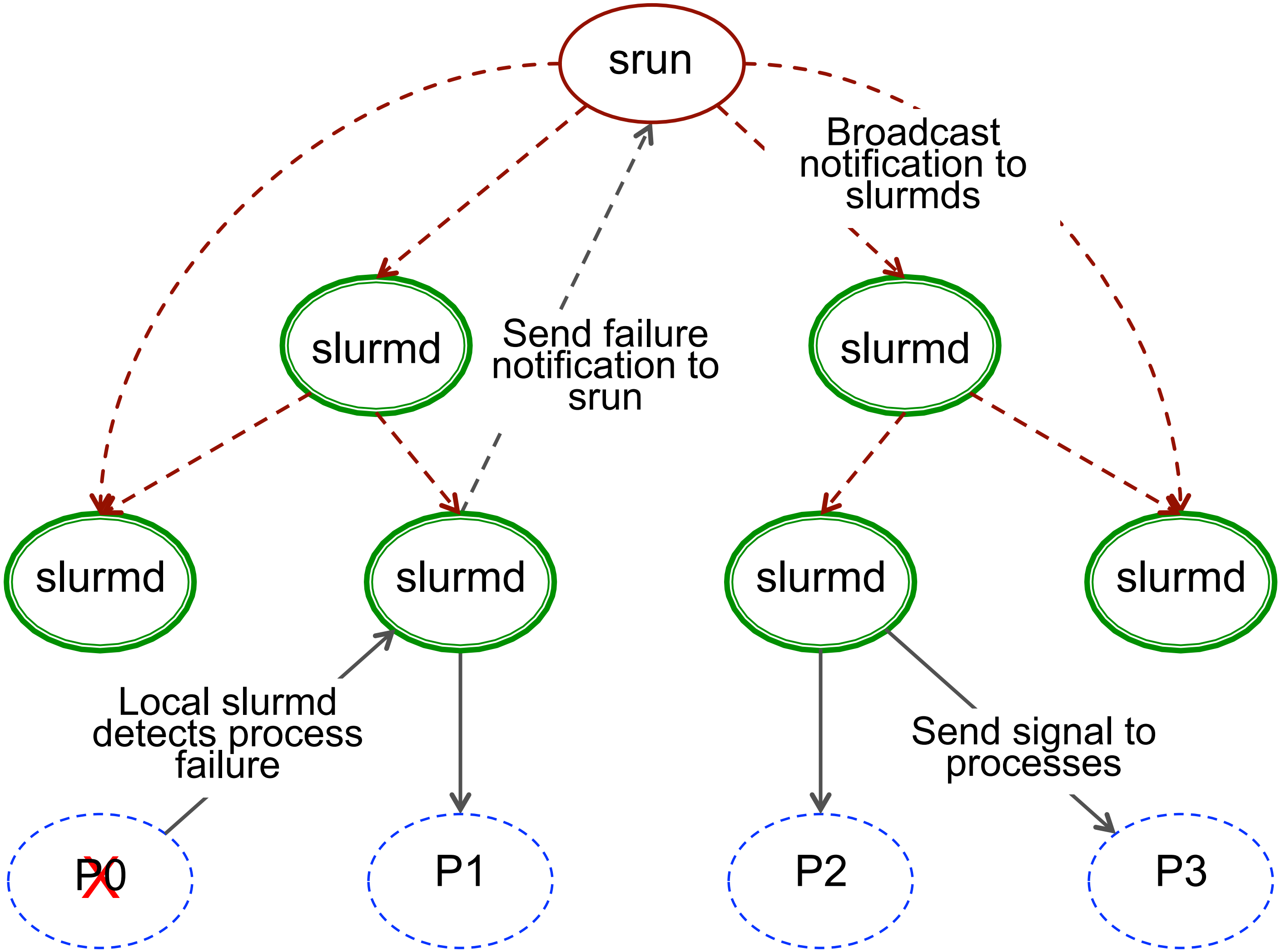
Example Program

```c
int cleanup_handler (MPI_Start_state, void *);

int resilient_main (int argc, char **argv,
     MPI_Start_state start_state)
{
  /* Recover using checkpoint */
  /* Do computation */
  /* Store checkpoint */
}

int main(int argc, char **argv)
{
  MPI_Init(&argc, &argv);

  MPI_Cleanup_handler_push(cleanup_handler);  // Register application cleanup handler

  MPI_Reinit(&argc, &argv, resilient_main);   // Entry point for resilient MPI program

  MPI_Finalize();
}
```

Execution Flow of Reinit



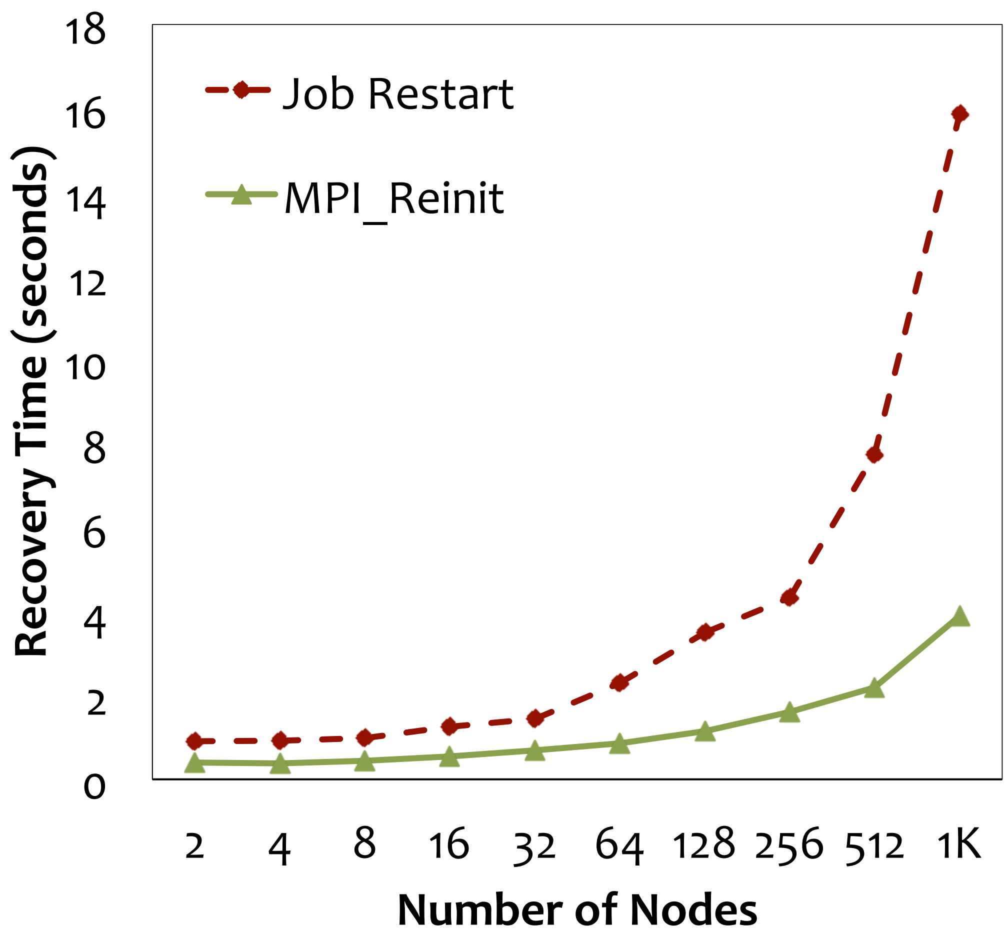
Failure Detection and Notification in SLURM



Experimental Evaluation

- Implementation of Reinit in SLURM-2.6.5 + MVAPICH2-2.1
- Experimental system
  - Sierra cluster @ LLNL
  - Intel Xeon 6-core EP X5660
  - 12 Cores per Node
- Single process failure scenario

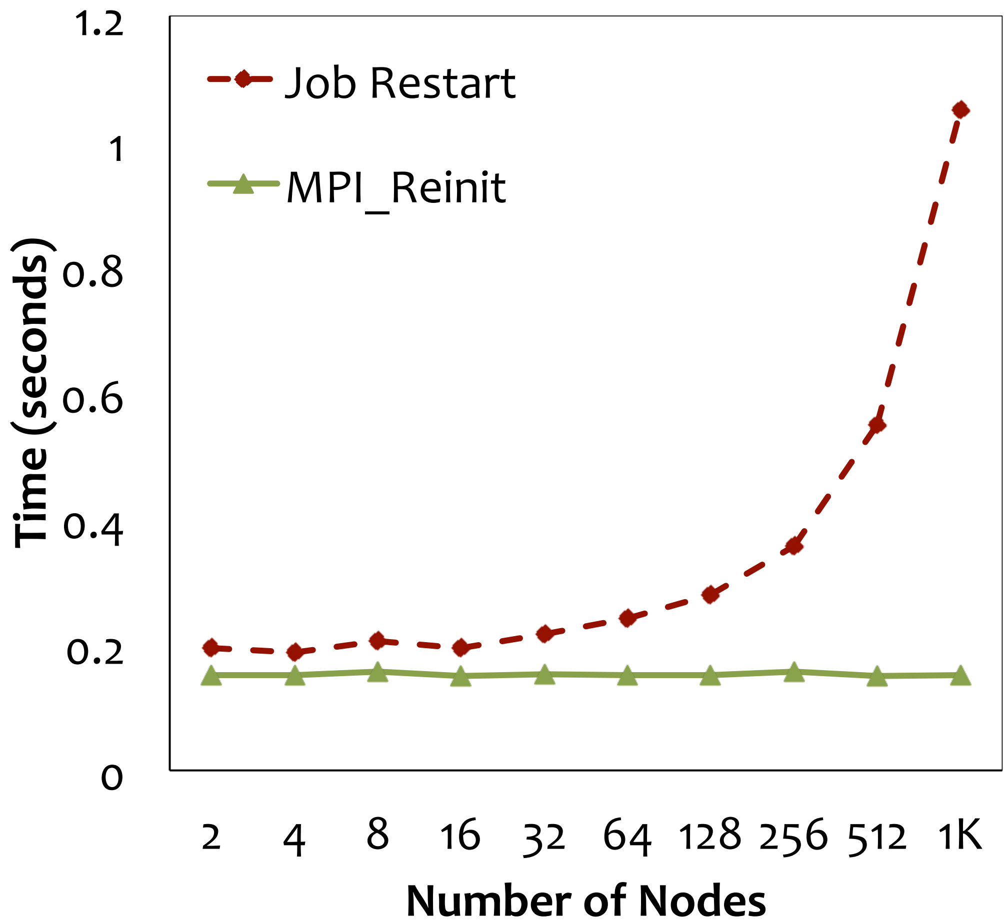
Recovery Time with MPI_Reinit Function



Less than 4 seconds to recover with 1K nodes, 12K processes

Recovery with REINIT is 4 times faster than Job restart

Time to Restore a 100 MB Checkpoint



Job restart forces each process to load checkpoints from persistent storage

Only the failed processes need to reload for REINIT

REINIT is 7 times faster than Job restart with 1K nodes, 12K processes

Summary

- Programming complexity can be a major impediment in adopting FT programing models for MPI applications
- We propose Reinit for low programing complexity and high scalability
  - Supports current FT programing practices (checkpoint/restart)
  - Close integration with resource manager (faster recovery)
  - Simple library and application cleanup
- Current implementation in MVAPICH + SLURM
- Future Work:
  - Support for node failures
  - Code release

Thanks to the Team Members!

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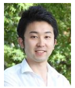 Kento Sato

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