Fault Tolerance Interface (FTI)

State-of-the-art multi-level checkpointing library

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Why FTI

- Supercomputers grow exponentially
- Failures grow with the number of components
- Mean Time Between Failures (MTBF) decreasing
- Parallel File Systems (PFS) grow linearly
- Time to checkpoint increasing

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- Checkpoint 1000 nodes (100GB/node)
- PFS about 100GB/s => 1000 seconds (~17 minutes)
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We need multi-level checkpointing!!!

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https://github.com/leobago/fti

How to use FTI

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

    MPI_Init(&argc, &argv);

    MPI_Comm comm = MPI_COMM_WORLD;




    for(step=0; step<NB_STEPS; step++) {

        accu = doWork(grid, ghost, comm);
        if (accu < TARGET_ACCU) break;
    }


    MPI_Finalize();
    return 0;
}
```

How to use FTI

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

    MPI_Init(&argc, &argv);
    FTI_Init("conf.fti", MPI_COMM_WORLD);
    MPI_Comm comm = MPI_COMM_WORLD;




    for(step=0; step<NB_STEPS; step++) {

        accu = doWork(grid, ghost, comm);
        if (accu < TARGET_ACCU) break;
    }

    FTI_Finalize();
    MPI_Finalize();
    return 0;
}
```

How to use FTI

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

    MPI_Init(&argc, &argv);
    FTI_Init("conf.fti", MPI_COMM_WORLD);
    MPI_Comm comm = MPI_COMM_WORLD;

    FTI_Protect(0, &step, 1,   FTI_INTG);
    FTI_Protect(1, grid,  M*N, FTI_DBLE);
    FTI_Protect(2, ghost, G,   FTI_DBLE);

    for(step=0; step<NB_STEPS; step++) {

        accu = doWork(grid, ghost, comm);
        if (accu < TARGET_ACCU) break;
    }

    FTI_Finalize();
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```

How to use FTI

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    FTI_Protect(2, ghost, G,   FTI_DBLE);

    for(step=0; step<NB_STEPS; step++) {
        FTI_Snapshot();
        accu = doWork(grid, ghost, comm);
        if (accu < TARGET_ACCU) break;
    }

    FTI_Finalize();
    MPI_Finalize();
    return 0;
}
```

How to use FTI

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

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    for(step=0; step<NB_STEPS; step++) {
        FTI_Snapshot();
        accu = doWork(grid, ghost, comm);
        if (accu < TARGET_ACCU) break;
    }

    FTI_Finalize();
    MPI_Finalize();
    return 0;
}
```

```
Node_size = 4

Ckpt_dir = /scratch/
Glbl_dir = /gpfs/myProject
Meta_dir = /home/user/.fti

Ckpt_L1 = 0
Ckpt_L2 = 0
Ckpt_L3 = 0
Ckpt_L4 = 120 #minutes
```

How to use FTI

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

    MPI_Init(&argc, &argv);
    FTI_Init("conf.fti", MPI_COMM_WORLD);
    MPI_Comm comm = MPI_COMM_WORLD;

    FTI_Protect(0, &step, 1,   FTI_INTG);
    FTI_Protect(1, grid,  M*N, FTI_DBLE);
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    for(step=0; step<NB_STEPS; step++) {
        FTI_Snapshot();
        accu = doWork(grid, ghost, comm);
        if (accu < TARGET_ACCU) break;
    }

    FTI_Finalize();
    MPI_Finalize();
    return 0;
}
```

```
Node_size = 4

Ckpt_dir = /scratch/
Glbl_dir = /gpfs/myProject
Meta_dir = /home/user/.fti

Ckpt_L1 = 30
Ckpt_L2 = 0
Ckpt_L3 = 0
Ckpt_L4 = 360
```

How to use FTI

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

    MPI_Init(&argc, &argv);
    FTI_Init(argv[2], MPI_COMM_WORLD);
    MPI_Comm comm = MPI_COMM_WORLD;

    FTI_Protect(0, &step, 1,   FTI_INTG);
    FTI_Protect(1, grid,  M*N, FTI_DBLE);
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    for(step=0; step<NB_STEPS; step++) {
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        accu = doWork(grid, ghost, comm);
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    FTI_Finalize();
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```

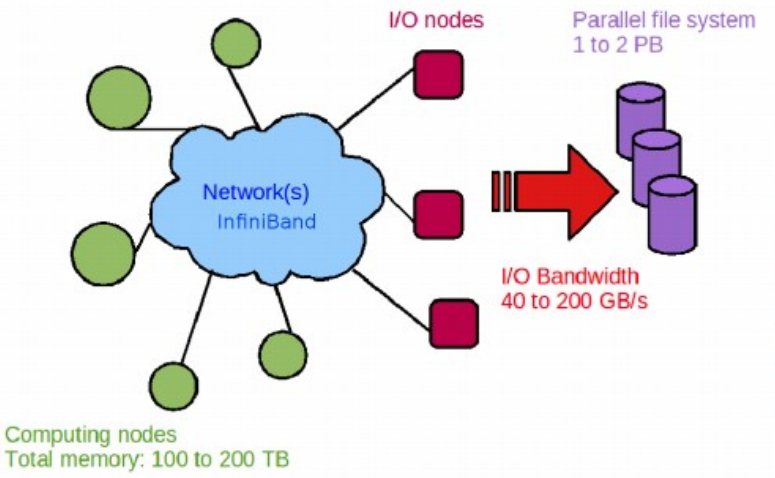
```
Node_size = 4

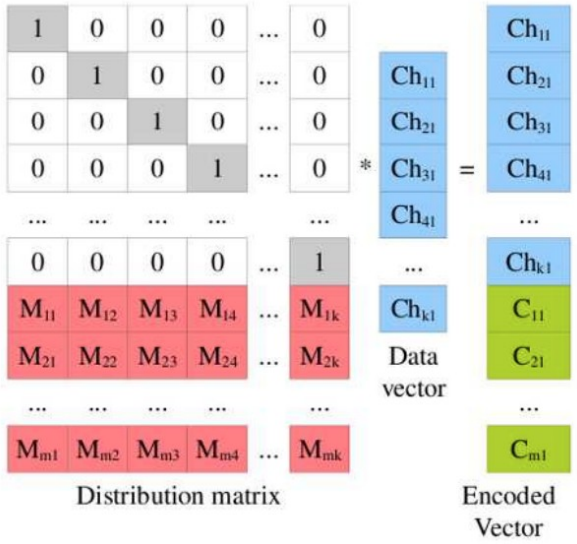
Ckpt_dir = /scratch/
Glbl_dir = /gpfs/myProject
Meta_dir = /home/user/.fti

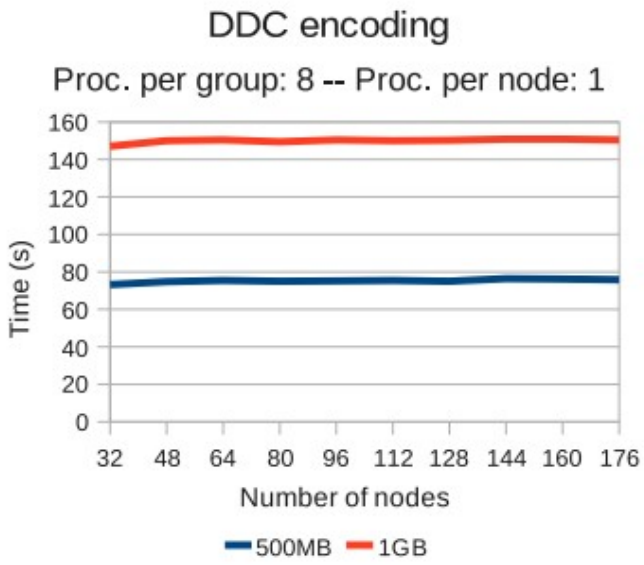
Ckpt_L1 = 30
Ckpt_L2 = 60
Ckpt_L3 = 0
Ckpt_L4 = 600
```

Reed-Solomon Encoding

- Data replication is not space efficient
- Erasure codes to recover data lost upon failures
- Same space as replication but much higher resilience
- Scalable Reed-Solomon implementation by groups
- Evaluation on hundreds of nodes







* *"Distributed diskless checkpoint for large scale systems"* - Leonardo Bautista-Gomez, Naoya Maruyama, Franck Cappello, Satoshi Matsuoka - 2010 10th IEEE/ACM International Conference on Cluster, Cloud and Grid Computing (**CCGrid'10**)

Reed-Solomon Encoding

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

    MPI_Init(&argc, &argv);
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Node_size = 4

Ckpt_dir = /scratch/
Glbl_dir = /gpfs/myProject
Meta_dir = /home/user/.fti

Ckpt_L1 = 30
Ckpt_L2 = 60
Ckpt_L3 = 90
Ckpt_L4 = 0
```

Fine Tuning Time to Checkpoint

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

    MPI_Init(&argc, &argv);
    FTI_Init(argv[2], MPI_COMM_WORLD);
    MPI_Comm comm = MPI_COMM_WORLD;

    FTI_Protect(0, &step, 1,   FTI_INTG);
    FTI_Protect(1, grid,  M*N, FTI_DBLE);
    FTI_Protect(2, ghost, G,   FTI_DBLE);
    state = FTI_Status();
    if (state == RESTART || state == KEEP) {
            result = FTI_Recover();
    }
    for(step=1; step=<NB_STEPS; step++) {
        if (step % 100 == 0) {
            FTI_Checkpoint(step, FTI_L3);
        }
        accu = doWork(grid, ghost, comm);
        if (accu < TARGET_ACCU) break;
    }

    FTI_Finalize();
    MPI_Finalize();
    return 0;
}
```

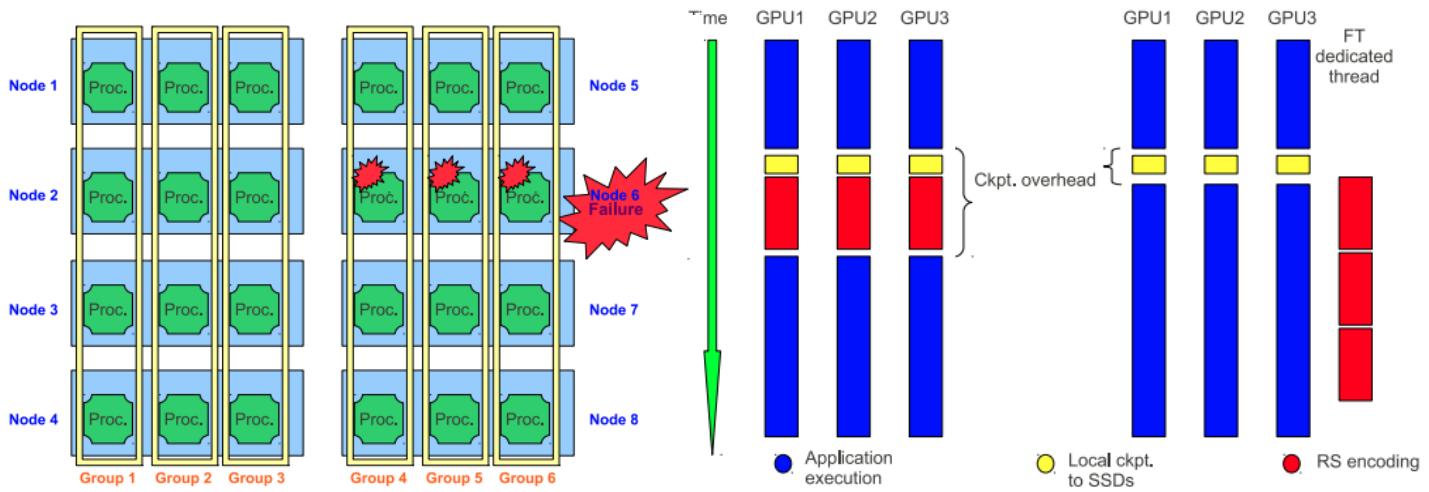
```
Node_size = 4

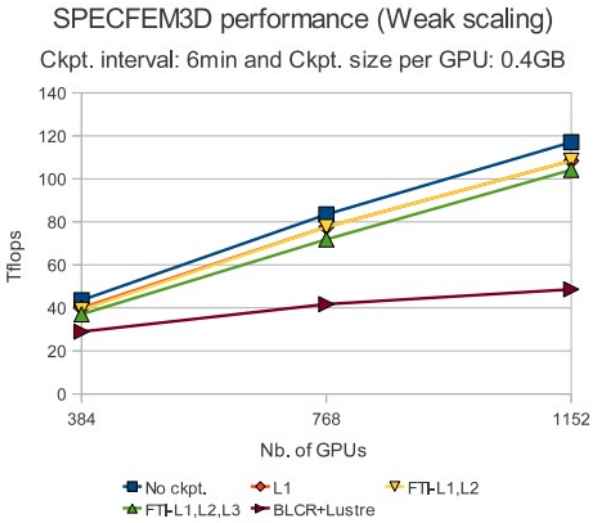
Ckpt_dir = /scratch/
Glbl_dir = /gpfs/myProject
Meta_dir = /home/user/.fti

Ckpt_L1 = 0
Ckpt_L2 = 0
Ckpt_L3 = 0
Ckpt_L4 = 0
```

Asynchronous Checkpointing

- Virtual ring domain decomposition for RS-encoding
- Dedicated threads for asynchronous checkpointing
- Multilevel ckpt: 4 levels of resilience and performance
- Under 10% overhead while executing over 1K GPUs
- Available: https://github.com/leobago/fti





* *"FTI: high performance fault tolerance interface for hybrid systems"* - Leonardo Bautista-Gomez, Seiji Tsuboi, Dimitri Komatitsch, Franck Cappello, Naoya Maruyama, Satoshi Matsuoka - 2011 international conference for high performance computing, networking, storage and analysis (**SC'11**)

Asynchronous Checkpointing

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

    MPI_Init(&argc, &argv);
    FTI_Init(argv[2], MPI_COMM_WORLD);
    MPI_Comm comm = MPI_COMM_WORLD;

    FTI_Protect(0, &step, 1,   FTI_INTG);
    FTI_Protect(1, grid,  M*N, FTI_DBLE);
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    for(step=0; step<NB_STEPS; step++) {
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        accu = doWork(grid, ghost, comm);
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    }

    FTI_Finalize();
    MPI_Finalize();
    return 0;
}
```

```
Node_size = 4
Head = 0

Ckpt_dir = /scratch/
Glbl_dir = /gpfs/myProject
Meta_dir = /home/user/.fti

Ckpt_L1 = 30
Ckpt_L2 = 60
Ckpt_L3 = 0
Ckpt_L4 = 600
```

Asynchronous Checkpointing

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int main(int argc, char *argv[]) {

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    }

    FTI_Finalize();
    MPI_Finalize();
    return 0;
}
```
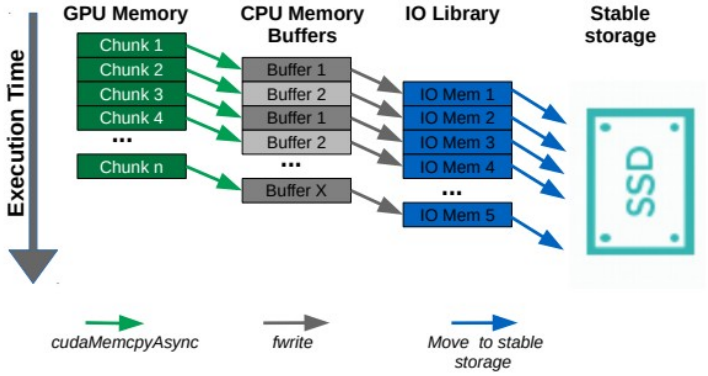
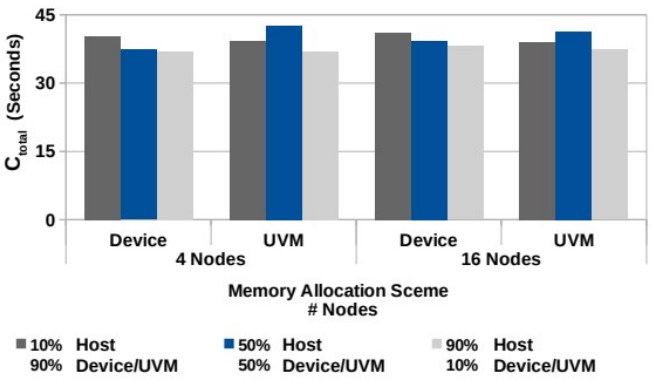

```
Node_size = 5
Head = 1

Ckpt_dir = /scratch/
Glbl_dir = /gpfs/myProject
Meta_dir = /home/user/.fti

Ckpt_L1 = 30
Ckpt_L2 = 60
Ckpt_L3 = 90
Ckpt_L4 = 0
```

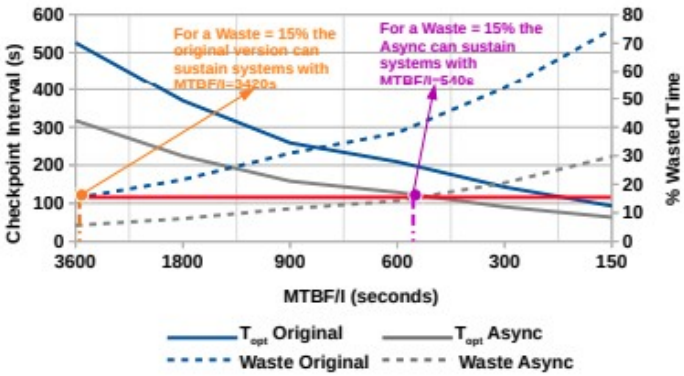

* *"Optimization of a multilevel checkpoint model with uncertain execution scales"* - Sheng Di, Leonardo Bautista-Gomez, Franck Cappello - 2014 international conference for high performance computing, networking, storage and analysis (**SC'14**)

C/P support for Heterogeneous HPC

- Out of the top 10 supercomputers, 8 use GPUs
- Heterogeneity in memory as well (host, device, UVM)
- Streams and pipelines to optimize data movements
- Automatic and transparent data handling
- GPU-Accelerated MD5 computation
- Reduction of 15.23X/5.21X on checkpointing/recovery







* "*Checkpoint Restart Support for Heterogeneous HPC Applications*" - Konstantinos Parasyris, Kai Keller, Leonardo Bautista-Gomez, Osman Unsal - 2020 20th IEEE/ACM International Symposium on Cluster, Cloud and Internet Computing (**CCGRID'20**)

C/P support for Heterogeneous HPC

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

    MPI_Init(&argc, &argv);
    FTI_Init(argv[2], MPI_COMM_WORLD);
    MPI_Comm comm = FTI_COMM_WORLD;
    grid=(*double)malloc(M*N * sizeof(double));
    ghost=(*double)malloc(G *  sizeof(double));

    FTI_Protect(0, &step, 1,   FTI_INTG);
    FTI_Protect(1, grid,  M*N, FTI_DBLE);
    FTI_Protect(2, ghost, G,   FTI_DBLE);

    for(step=0; step<NB_STEPS; step++) {
        FTI_Snapshot();
        accu = doWork(grid, ghost, comm);
        if (accu < TARGET_ACCU) break;
    }

    FTI_Finalize();
    MPI_Finalize();
    return 0;
}
```

```
Node_size = 5
Head = 1

Ckpt_dir = /scratch/
Glbl_dir = /gpfs/myProject
Meta_dir = /home/user/.fti

Ckpt_L1 = 0
Ckpt_L2 = 6
Ckpt_L3 = 60
Ckpt_L4 = 600
```

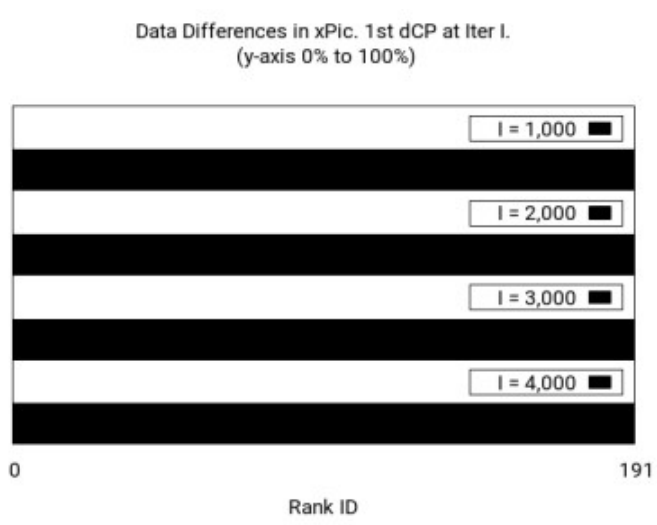
C/P support for Heterogeneous HPC

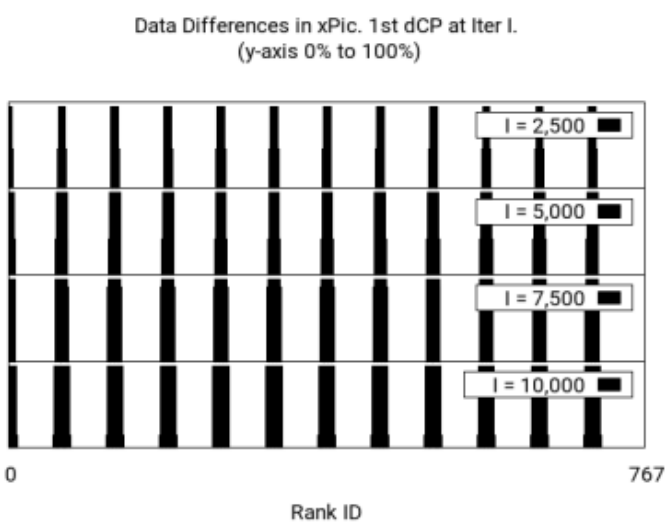
```
int main(int argc, char *argv[]) {

    MPI_Init(&argc, &argv);
    FTI_Init(argv[2], MPI_COMM_WORLD);
    MPI_Comm comm = FTI_COMM_WORLD;
    cudaMalloc(&grid, M*N * sizeof(double);
    cudamalloc(&ghost, G *  sizeof(double);

    FTI_Protect(0, &step, 1,   FTI_INTG);
    FTI_Protect(1, grid,  M*N, FTI_DBLE);
    FTI_Protect(2, ghost, G,   FTI_DBLE);

    for(step=0; step<NB_STEPS; step++) {
        FTI_Snapshot();
        accu = cudaWork(grid, ghost, comm);
        if (accu < TARGET_ACCU) break;
    }

    FTI_Finalize();
    MPI_Finalize();
    return 0;
}
```

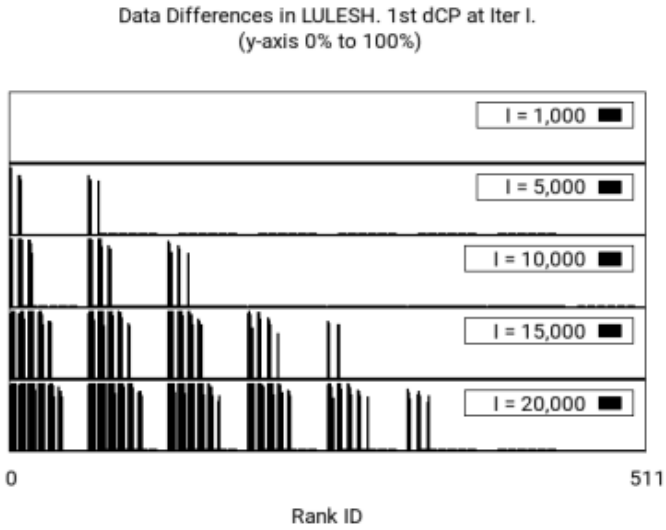
```
Node_size = 5
Head = 1

Ckpt_dir = /scratch/
Glbl_dir = /gpfs/myProject
Meta_dir = /home/user/.fti

Ckpt_L1 = 0
Ckpt_L2 = 6
Ckpt_L3 = 60
Ckpt_L4 = 600
```

Differential Checkpointing

- Checkpoint only the diff between last ckpt and this one
- Dirty page technology is not enough to detect changes
- Checksum based diff calculations (MD5)
- Dynamics Dataset sizes increases complexity
- Application data evolves differently: Xpic, Heat, Lulesh







* *"Application-Level Differential Checkpointing for HPC Applications with Dynamic Datasets"* - Kai Keller and Leonardo Bautista-Gomez - 2019 19th IEEE/ACM International Symposium on Cluster, Cloud and Grid Computing (**CCGRID'19**)

Differential Checkpointing

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

    MPI_Init(&argc, &argv);
    FTI_Init(argv[2], MPI_COMM_WORLD);
    MPI_Comm comm = FTI_COMM_WORLD;



    FTI_Protect(0, &step, 1,   FTI_INTG);
    FTI_Protect(1, grid,  M*N, FTI_DBLE);
    FTI_Protect(2, ghost, G,   FTI_DBLE);

    for(step=0; step<NB_STEPS; step++) {
        FTI_Snapshot();
        accu = doWork(grid, ghost, comm);
        if (accu < TARGET_ACCU) break;
    }

    FTI_Finalize();
    MPI_Finalize();
    return 0;
}
```

```
Node_size = 5
Head = 1

Ckpt_dir = /scratch/
Glbl_dir = /gpfs/myProject
Meta_dir = /home/user/.fti

Ckpt_L1 = 30
Ckpt_L2 = 0
Ckpt_L3 = 0
Dcp_L4  = 0
Ckpt_L4 = 60

Enable_dcp = 0
Dcp_mode = 0
Dcp_block_size = 16384
```

Differential Checkpointing

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

    MPI_Init(&argc, &argv);
    FTI_Init(argv[2], MPI_COMM_WORLD);
    MPI_Comm comm = FTI_COMM_WORLD;



    FTI_Protect(0, &step, 1,   FTI_INTG);
    FTI_Protect(1, grid,  M*N, FTI_DBLE);
    FTI_Protect(2, ghost, G,   FTI_DBLE);

    for(step=0; step<NB_STEPS; step++) {
        FTI_Snapshot();
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        if (accu < TARGET_ACCU) break;
    }

    FTI_Finalize();
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    return 0;
}
```

```
Node_size = 5
Head = 1

Ckpt_dir = /scratch/
Glbl_dir = /gpfs/myProject
Meta_dir = /home/user/.fti

Ckpt_L1 = 30
Ckpt_L2 = 0
Ckpt_L3 = 0
Dcp_L4  = 60
Ckpt_L4 = 240

Enable_dcp = 1
Dcp_mode = 1
Dcp_block_size = 16384
```

I/O Features

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

    MPI_Init(&argc, &argv);
    FTI_Init(argv[2], MPI_COMM_WORLD);
    MPI_Comm comm = FTI_COMM_WORLD;
    cudaMalloc(&grid, M*N * sizeof(double);
    cudamalloc(&ghost, G *  sizeof(double);

    FTI_Protect(0, &step, 1,   FTI_INTG);
    FTI_Protect(1, grid,  M*N, FTI_DBLE);
    FTI_Protect(2, ghost, G,   FTI_DBLE);

    for(step=0; step<NB_STEPS; step++) {
        FTI_Snapshot();
        accu = cudaWork(grid, ghost, comm);
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```

```
Node_size = 5
Head = 1

Ckpt_dir = /scratch/
Glbl_dir = /gpfs/myProject
Meta_dir = /home/user/.fti

Ckpt_L1 = 0
Ckpt_L2 = 6
Ckpt_L3 = 60
Ckpt_L4 = 600

Ckpt_IO = 1 #POSIX
```

I/O Features

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

    MPI_Init(&argc, &argv);
    FTI_Init(argv[2], MPI_COMM_WORLD);
    MPI_Comm comm = FTI_COMM_WORLD;
    cudaMalloc(&grid, M*N * sizeof(double);
    cudamalloc(&ghost, G *  sizeof(double);

    FTI_Protect(0, &step, 1,   FTI_INTG);
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    for(step=0; step<NB_STEPS; step++) {
        FTI_Snapshot();
        accu = cudaWork(grid, ghost, comm);
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    }

    FTI_Finalize();
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}
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Node_size = 5
Head = 1

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Meta_dir = /home/user/.fti

Ckpt_L1 = 0
Ckpt_L2 = 6
Ckpt_L3 = 60
Ckpt_L4 = 600

Ckpt_IO = 2 #MPI-IO
```

I/O Features

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

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    FTI_Init(argv[2], MPI_COMM_WORLD);
    MPI_Comm comm = FTI_COMM_WORLD;
    cudaMalloc(&grid, M*N * sizeof(double);
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    FTI_Protect(0, &step, 1,   FTI_INTG);
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Ckpt_dir = /scratch/
Glbl_dir = /gpfs/myProject
Meta_dir = /home/user/.fti

Ckpt_L1 = 0
Ckpt_L2 = 6
Ckpt_L3 = 60
Ckpt_L4 = 600

Ckpt_IO = 3 #FFF
```

I/O Features

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

    MPI_Init(&argc, &argv);
    FTI_Init(argv[2], MPI_COMM_WORLD);
    MPI_Comm comm = FTI_COMM_WORLD;
    cudaMalloc(&grid, M*N * sizeof(double);
    cudamalloc(&ghost, G *  sizeof(double);

    FTI_Protect(0, &step, 1,   FTI_INTG);
    FTI_Protect(1, grid,  M*N, FTI_DBLE);
    FTI_Protect(2, ghost, G,   FTI_DBLE);

    for(step=0; step<NB_STEPS; step++) {
        FTI_Snapshot();
        accu = cudaWork(grid, ghost, comm);
        if (accu < TARGET_ACCU) break;
    }

    FTI_Finalize();
    MPI_Finalize();
    return 0;
}
```

```
Node_size = 5
Head = 1

Ckpt_dir = /scratch/
Glbl_dir = /gpfs/myProject
Meta_dir = /home/user/.fti

Ckpt_L1 = 0
Ckpt_L2 = 6
Ckpt_L3 = 60
Ckpt_L4 = 600

Ckpt_IO = 4 #SIONlib
```

I/O Features

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

    MPI_Init(&argc, &argv);
    FTI_Init(argv[2], MPI_COMM_WORLD);
    MPI_Comm comm = FTI_COMM_WORLD;
    cudaMalloc(&grid, M*N * sizeof(double);
    cudamalloc(&ghost, G *  sizeof(double);

    FTI_Protect(0, &step, 1,   FTI_INTG);
    FTI_Protect(1, grid,  M*N, FTI_DBLE);
    FTI_Protect(2, ghost, G,   FTI_DBLE);

    for(step=0; step<NB_STEPS; step++) {
        FTI_Snapshot();
        accu = cudaWork(grid, ghost, comm);
        if (accu < TARGET_ACCU) break;
    }

    FTI_Finalize();
    MPI_Finalize();
    return 0;
}
```

```
Node_size = 5
Head = 1

Ckpt_dir = /scratch/
Glbl_dir = /gpfs/myProject
Meta_dir = /home/user/.fti

Ckpt_L1 = 0
Ckpt_L2 = 6
Ckpt_L3 = 60
Ckpt_L4 = 600

Ckpt_IO = 5 #HDF5
```

I/O Features

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

    MPI_Init(&argc, &argv);
    FTI_Init(argv[2], MPI_COMM_WORLD);
    MPI_Comm comm = FTI_COMM_WORLD;
    cudaMalloc(&grid, M*N * sizeof(double);
    cudamalloc(&ghost, G *  sizeof(double);

    FTI_Protect(0, &step, 1,   FTI_INTG);
    FTI_Protect(1, grid,  M*N, FTI_DBLE);
    FTI_Protect(2, ghost, G,   FTI_DBLE);

    for(step=0; step<NB_STEPS; step++) {
        FTI_Snapshot();
        accu = cudaWork(grid, ghost, comm);
        if (accu < TARGET_ACCU) break;
    }

    FTI_Finalize();
    MPI_Finalize();
    return 0;
}
```

```
Node_size = 5
Head = 1

Ckpt_dir = /scratch/
Glbl_dir = /gpfs/myProject
Meta_dir = /home/user/.fti

Ckpt_L1 = 0
Ckpt_L2 = 6
Ckpt_L3 = 60
Ckpt_L4 = 600

Ckpt_IO = 6 #IME native
```

I/O Features

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

    MPI_Init(&argc, &argv);
    FTI_Init(argv[2], MPI_COMM_WORLD);
    MPI_Comm comm = FTI_COMM_WORLD;
    cudaMalloc(&grid, M*N * sizeof(double);
    cudamalloc(&ghost, G *  sizeof(double);

    FTI_Protect(0, &step, 1,   FTI_INTG);
    FTI_Protect(1, grid,  M*N, FTI_DBLE);
    FTI_Protect(2, ghost, G,   FTI_DBLE);

    for(step=0; step<NB_STEPS; step++) {
        FTI_Snapshot();
        accu = cudaWork(grid, ghost, comm);
        if (accu < TARGET_ACCU) break;
    }

    FTI_Finalize();
    MPI_Finalize();
    return 0;
}
```

```
Node_size = 5
Head = 1

Ckpt_dir = /scratch/
Glbl_dir = /gpfs/myProject
Meta_dir = /home/user/.fti

Ckpt_L1 = 0
Ckpt_L2 = 6
Ckpt_L3 = 60
Ckpt_L4 = 600

Ckpt_IO = 5 #HDF5
Keep_Last_ckpt = 1
```

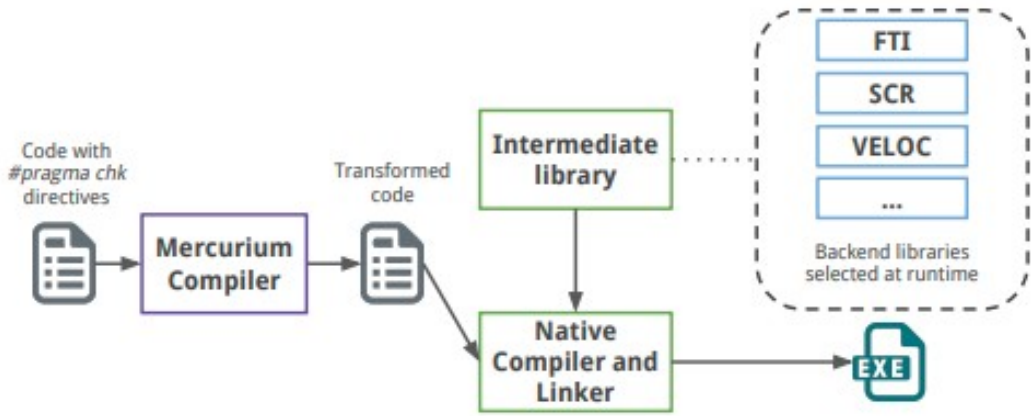
I/O Features

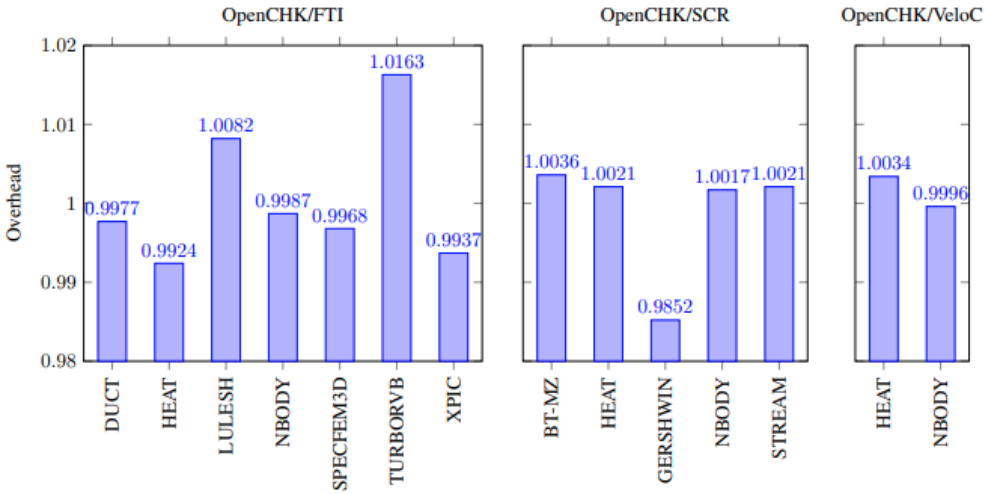
```
int main(int argc, char *argv[]) {

    MPI_Init(&argc, &argv);
    FTI_Init(argv[2], MPI_COMM_WORLD);
    MPI_Comm comm = FTI_COMM_WORLD;
    cudaMalloc(&grid, M*N * sizeof(double);
    cudamalloc(&ghost, G *  sizeof(double);

    FTI_Protect(0, &step, 1,   FTI_INTG);
    FTI_Protect(1, grid,  M*N, FTI_DBLE);
    FTI_Protect(2, ghost, G,   FTI_DBLE);

    for(step=0; step<NB_STEPS; step++) {
        FTI_Snapshot();
        accu = cudaWork(grid, ghost, comm);
        if (accu < TARGET_ACCU) break;
    }

    FTI_Finalize();
    MPI_Finalize();
    return 0;
}
```

```
Node_size = 5
Head = 1

Ckpt_dir = /scratch/
Glbl_dir = /gpfs/myProject
Meta_dir = /home/user/.fti

Ckpt_L1 = 0
Ckpt_L2 = 6
Ckpt_L3 = 60
Ckpt_L4 = 600

Ckpt_IO = 5 #HDF5
Keep_L4_ckpt = 1
```

OpenCHK: pragma interface

- Multilevel checkpointing libraries (FTI, SCR, VeloC)
- Similar tasks, different interfaces (file vs data)
- Pragma interface linked with checkpoint runtime
- #pragma chk (init, load, store, shutdown)
- Reduced LoC by 71% FTI, 94% SCR and 64% VeloC
- No overhead





* "*Extending the OpenCHK Model with advanced checkpoint features*" - Marcos Maroñas, Sergi Mateo, Kai Keller, Leonardo Bautista-Gomez, Eduard Ayguadé, Vicenç Beltran - **2020 Journal Future Generation Computer Systems**

OpenCHK: pragma interface

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

    MPI_Init(&argc, &argv);
    FTI_Init(argv[2], MPI_COMM_WORLD);
    MPI_Comm comm = FTI_COMM_WORLD;

    FTI_Protect(0, &step, 1,   FTI_INTG);
    FTI_Protect(1, grid,  M*N, FTI_DBLE);
    FTI_Protect(2, ghost, G,   FTI_DBLE);

    for(step=0; step<NB_STEPS; step++) {

        FTI_Snapshot();

        accu = doWork(grid, ghost, comm);
        if (accu < TARGET_ACCU) break;
    }

    FTI_Finalize();
    MPI_Finalize();
    return 0;
}
```

```
Node_size = 4
Head = 0

Ckpt_dir = /scratch/
Glbl_dir = /gpfs/myProject
Meta_dir = /home/user/.fti

Ckpt_L1 = 30
Ckpt_L2 = 0
Ckpt_L3 = 0
Ckpt_L4 = 180
```

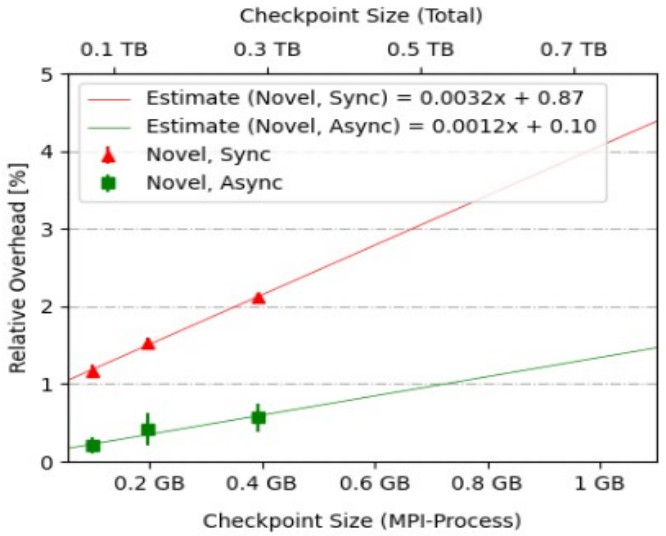
OpenCHK: pragma interface

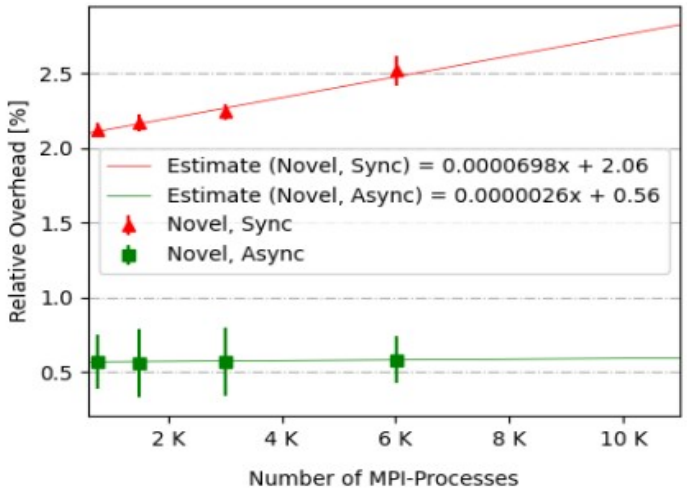
```
int main(int argc, char *argv[]) {

    MPI_Init(&argc, &argv);
    #pragma chk init comm(MPI_COMM_WORLD);
    MPI_Comm comm = FTI_COMM_WORLD;

    #pragma chk load(step, grid[M*N], ghost[G])



    for(step=0; step<NB_STEPS; step++) {
        #pragma chk store(step, grid[M*N], ghost[G],
                          id(id), level(level))

        accu = doWork(grid, ghost, comm);
        if (accu < TARGET_ACCU) break;
    }

    #pragma chk shutdown;
    MPI_Finalize();
    return 0;
}
```

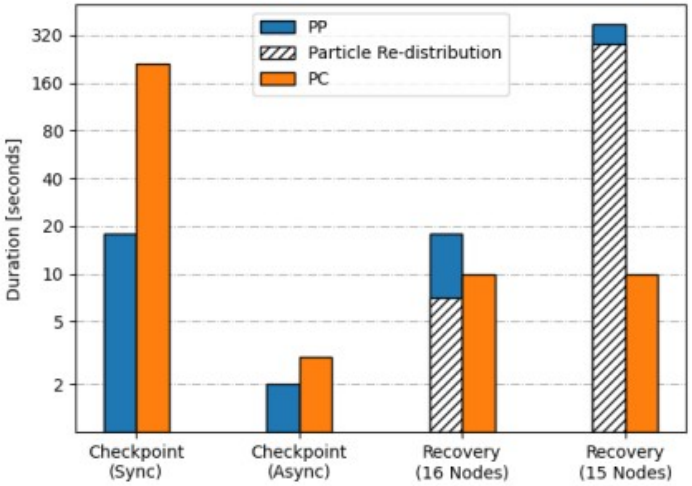
```
Node_size = 4
Head = 0

Ckpt_dir = /scratch/
Glbl_dir = /gpfs/myProject
Meta_dir = /home/user/.fti

Ckpt_L1 = 30
Ckpt_L2 = 0
Ckpt_L3 = 0
Ckpt_L4 = 180
```

Elastic Recovery in HPC Applications

- Restart with a different number of processes
- Use HDF5 format with a N-1 ckpt. (instead of N-N)
- Two stages: First local N-N, then asynchronous N-1
- Over 5X speedup in comparison to ADIOS
- Tested on regular(heat) and irregular (xPic) applications







** "Design and Study of Elastic Recovery in HPC Applications"* - Kai Keller, Konstantinos Parasyris, Leonardo Bautista Gomez - 2020 International Conference on High Performance Computing (**HiPC'20**)

Elastic Recovery in HPC Applications

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

    MPI_Init(&argc, &argv);
    FTI_Init(argv[2], MPI_COMM_WORLD);
    MPI_Comm comm = FTI_COMM_WORLD;


    FTI_Protect(0, &step, 1,   FTI_INTG);
    FTI_Protect(1, grid,  M*N, FTI_DBLE);
    FTI_Protect(2, ghost, G,   FTI_DBLE);


    for(step=0; step<NB_STEPS; step++) {

        FTI_Snapshot();

        accu = doWork(grid, ghost, comm);
        if (accu < TARGET_ACCU) break;
    }

    FTI_Finalize();
    MPI_Finalize();
    return 0;
}
```

```
Node_size = 4
Head = 0

Ckpt_dir = /scratch/
Glbl_dir = /gpfs/myProject
Meta_dir = /home/user/.fti

Ckpt_L1 = 30
Ckpt_L2 = 0
Ckpt_L3 = 0
Ckpt_L4 = 180
```

Elastic Recovery in HPC Applications

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

    MPI_Init(&argc, &argv);
    FTI_Init(argv[2], MPI_COMM_WORLD);
    MPI_Comm comm = FTI_COMM_WORLD;
    FTI_DefineGlobalDataset(GRID_DATASET_ID, 2,
    {Mglobal,Nglobal}, "GRID", NULL, FTI_DBLE)
    FTI_Protect(0, &step, 1,   FTI_INTG);
    FTI_Protect(1, grid,  M*N, FTI_DBLE);
    FTI_Protect(2, ghost, G,   FTI_DBLE);
    FTI_AddSubset(1 (GRID_VARIABLE_ID), 2, {nrank*M,
    0}, {M, N}, GRID_DATASET_ID)
    for(step=0; step<NB_STEPS; step++) {

        FTI_Snapshot();

        accu = doWork(grid, ghost, comm);
        if (accu < TARGET_ACCU) break;
    }

    FTI_Finalize();
    MPI_Finalize();
    return 0;
}
```

```
Node_size = 4
Head = 0

Ckpt_dir = /scratch/
Glbl_dir = /gpfs/myProject
Meta_dir = /home/user/.fti

Ckpt_L1 = 30
Ckpt_L2 = 0
Ckpt_L3 = 0
Ckpt_L4 = 180
```

Impact

- European projects: MontBlanc2, MontBlanc2020, Deepest, Legato, EoCoE, EoCoE2, eProcessor.
- ATOS integrates FTI as part of its software stack
- ASTRON integrated FTI for its Image Domain Gridding
- ALYA code ported with FTI at BSC
- Huawei testing FTI on its new hardware
- VeloC library from DoE uses same interface as FTI
- Integration with MPI_Re-Init (Collaboration with LLNL)

* “Co-Designing Multi-Level Checkpoint Restart for MPI Applications” - Konstantinos Parasyris, Giorgis Georgakoudis, Leonardo Bautista-Gomez, Ignacio Laguna - 2021 21th IEEE/ACM International Symposium on Cluster, Cloud and Internet Computing (**CCGRID’21**) (To appear)

Summary

- Multi-level checkpointing, for reliability and performance
- Asynchronous checkpointing with dedicated processes
- Transparent GPU checkpointing for heterogeneous system
- Multiple I/O output formats supported
- Checkpointing for other than fault tolerance
- Differential checkpointing to reduce storage
- Fine tuning checkpoint frequency
- Elastic recovery for malleable applications

References

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- *Optimization of multi-level checkpoint model for large scale HPC applications* - Sheng Di, Mohamed Slim Bouguerra, Leonardo Bautista-Gomez, Franck Cappello - 2014 IEEE 28th International Parallel and Distributed Processing Symposium (**IPDPS'14**)
- *Analysis of the tradeoffs between energy and run time for multilevel checkpointing* - Prasanna Balaprakash, Leonardo Bautista Gomez, Mohamed-Slim Bouguerra, Stefan M Wild, Franck Cappello, Paul D Hovland - 2015 International Workshop on Performance Modeling, Benchmarking and Simulation of High Performance Computer Systems (**PMBS'15**)
- *Reducing waste in extreme scale systems through introspective analysis* - Leonardo Bautista-Gomez, Ana Gainaru, Swann Perarnau, Devesh Tiwari, Saurabh Gupta, Christian Engelmann, Franck Cappello, Marc Snir - 2016 IEEE International Parallel and Distributed Processing Symposium (**IPDPS'16**)
- *Performance study of non-volatile memories on a high-end supercomputer* - Leonardo Bautista Gomez, Kai Keller, Osman Unsal - 2018 International Conference on High Performance Computing (**WOPSS'18**)
- *Towards Ad Hoc Recovery for Soft Errors* - Nuria Losada, Leonardo Bautista-Gomez, Kai Keller, Osman Unsal - 2018 IEEE/ACM 8th Workshop on Fault Tolerance for HPC at eXtreme Scale (**FTXS'18**)
- *Checkpoint/restart approaches for a thread-based MPI runtime* - Julien Adam, Maxime Kermarquer, Jean-Baptiste Besnard, Leonardo Bautista-Gomez, Marc Pérache, Patrick Carribault, Julien Jaeger, Allen D Malony, Sameer Shende - (**2019 Journal Parallel Computing**)
- *Application-Level Differential Checkpointing for HPC Applications with Dynamic Datasets* - Kai Keller and Leonardo Bautista-Gomez - 2019 19th IEEE/ACM International Symposium on Cluster, Cloud and Grid Computing (**CCGRID'19**)
- *Checkpointing Kernel Executions of MPI+ CUDA Applications* - Max Baird, Sven-Bodo Scholz, Artjoms Šinkarovs, Leonardo Bautista-Gomez - 2019 European Conference on Parallel Processing (**EuroPar'19**)
- *Checkpoint Restart Support for Heterogeneous HPC Applications* - Konstantinos Parasyris, Kai Keller, Leonardo Bautista-Gomez, Osman Unsal - 2020 20th IEEE/ACM International Symposium on Cluster, Cloud and Internet Computing (**CCGRID'20**)
- *Extending the OpenCHK Model with advanced checkpoint features* - Marcos Maroñas, Sergi Mateo, Kai Keller, Leonardo Bautista-Gomez, Eduard Ayguadé, Vicenç Beltran - (**2020 Journal Future Generation Computer Systems**)
- *Design and Study of Elastic Recovery in HPC Applications* - Kai Keller, Konstantinos Parasyris, Leonardo Bautista Gomez - 2020 International Conference on High Performance Computing (**HiPC'20**)
- * "Co-Designing Multi-Level Checkpoint Restart for MPI Applications" - Konstantinos Parasyris, Giorgis Georgakoudis, Leonardo Bautista-Gomez, Ignacio Laguna - 2021 21th IEEE/ACM International Symposium on Cluster, Cloud and Internet Computing (**CCGRID'21**) (To appear)

Questions?

Thank you!

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https://github.com/leobago/fti

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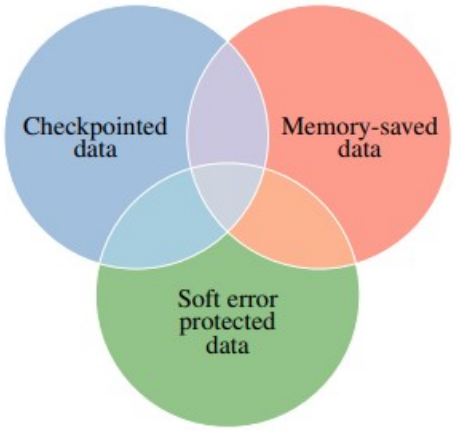
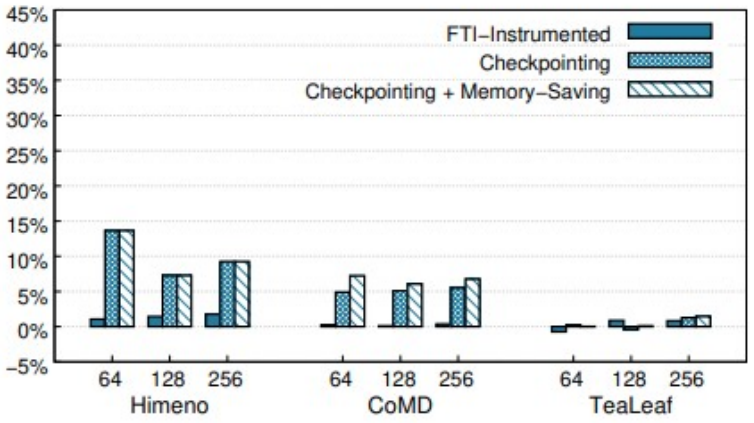
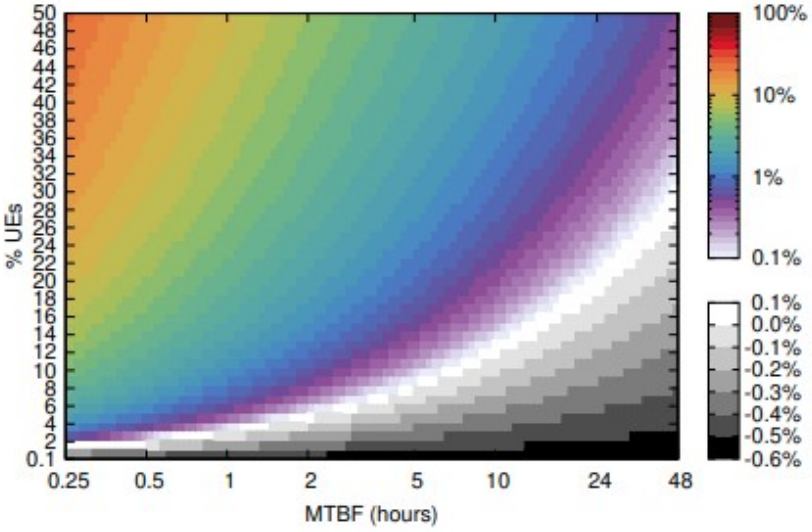
Ad Hoc Recovery for Soft Errors

- Detected Uncorrected Errors (DUEs) are common
- Silent Data Corruption (SDC) can occur in new devices
- Handling soft errors differs from handling hard errors
- Several extensions added to FTI to handle soft errors
- MemSave, MemLoad, RecoverLocalVars
- Evaluated with 3 applications







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