ERLANGEN REGIONAL
COMPUTING CENTER

Application driven fault tolerance and asynchronous checkpointing

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HPC-Software für skalierbare Parallelrechner
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FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

Challenge

- Nowadays, the increasing computational capacity is mainly due to extreme level of hardware parallelism.
- The reliability of hardware components does not increase with the similar rate.
- With future machines, the Mean time to failure is expected to be in minutes and hours.
- Absence of fault tolerant environment will put precious data at risk.

Checkpoint/Restart optimizations

1. Application level checkpointing
   - Minimal checkpoint data

2. **Asynchronous checkpointing**

3. **Multi-level checkpointing (PFS/remote node/localFS)**

Hide / avoid costs of computational costs of checkpoints

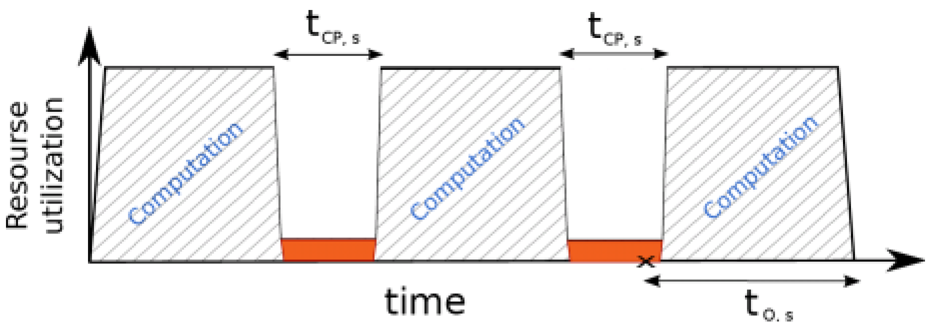
4. Checkpoint compression

5. …

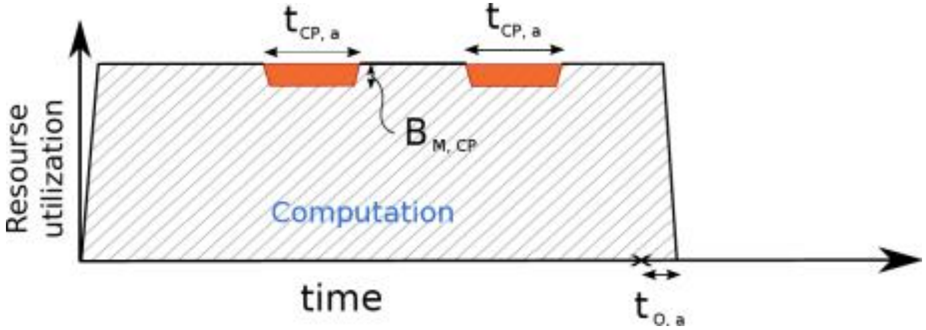
ASYNCHRONOUS CHECKPOINTING

Synchronous vs. asynchronous checkpointing

- Synchronous checkpointing:
  - Computation halts for I/O time
  - High execution time overhead



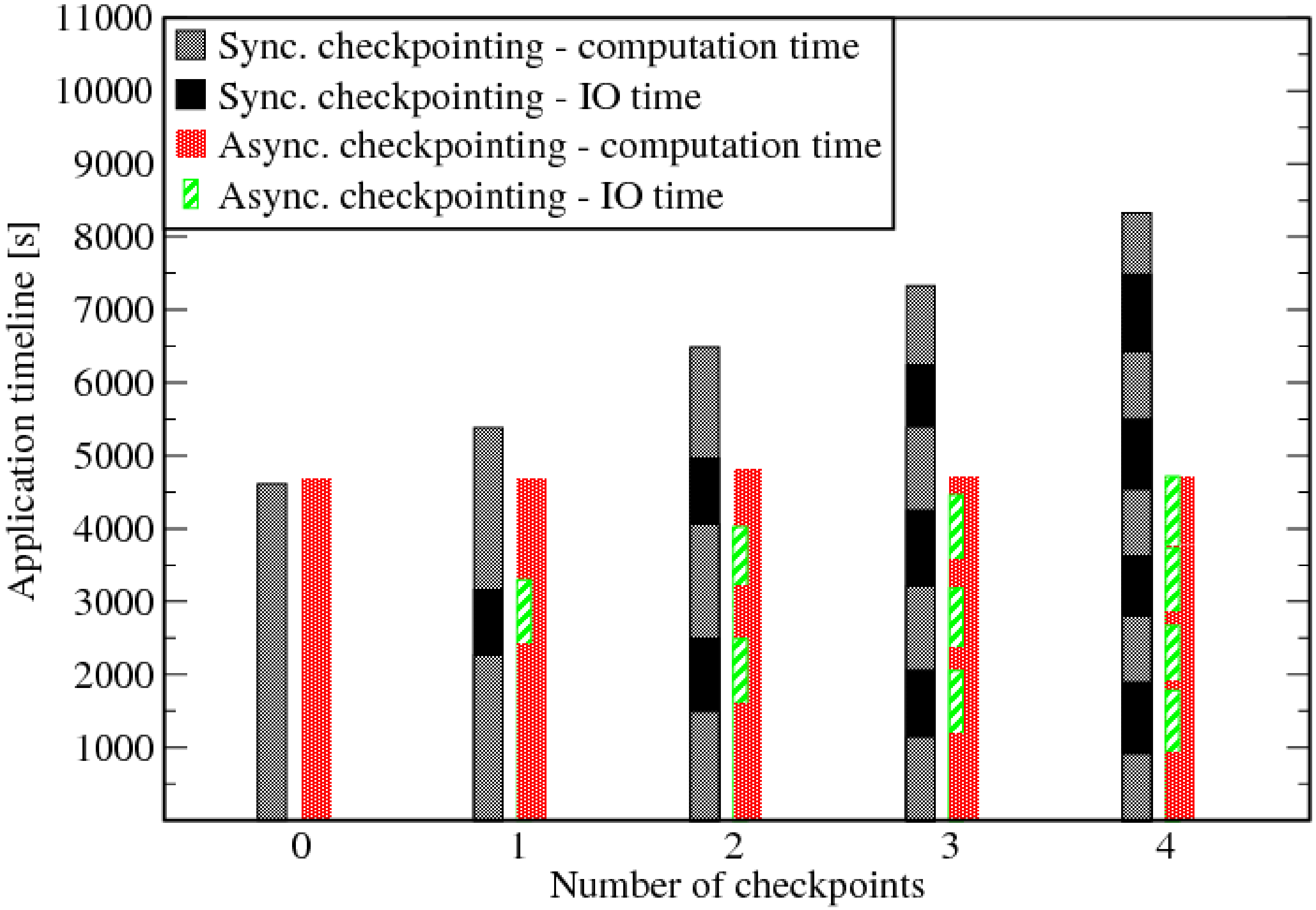
- Asynchronous checkpointing:
  - Using dedicated threads for performing asynchronous I/O
  - Low execution time overhead
  - An in-memory copy of checkpoint is required.



Asynchronous vs. Synchronous Checkpointing

- Benchmark (LiMa)

Num. of nodes = 128, np = 1536, PFS = LXFS, Aggregated CP size = 800GB/CP

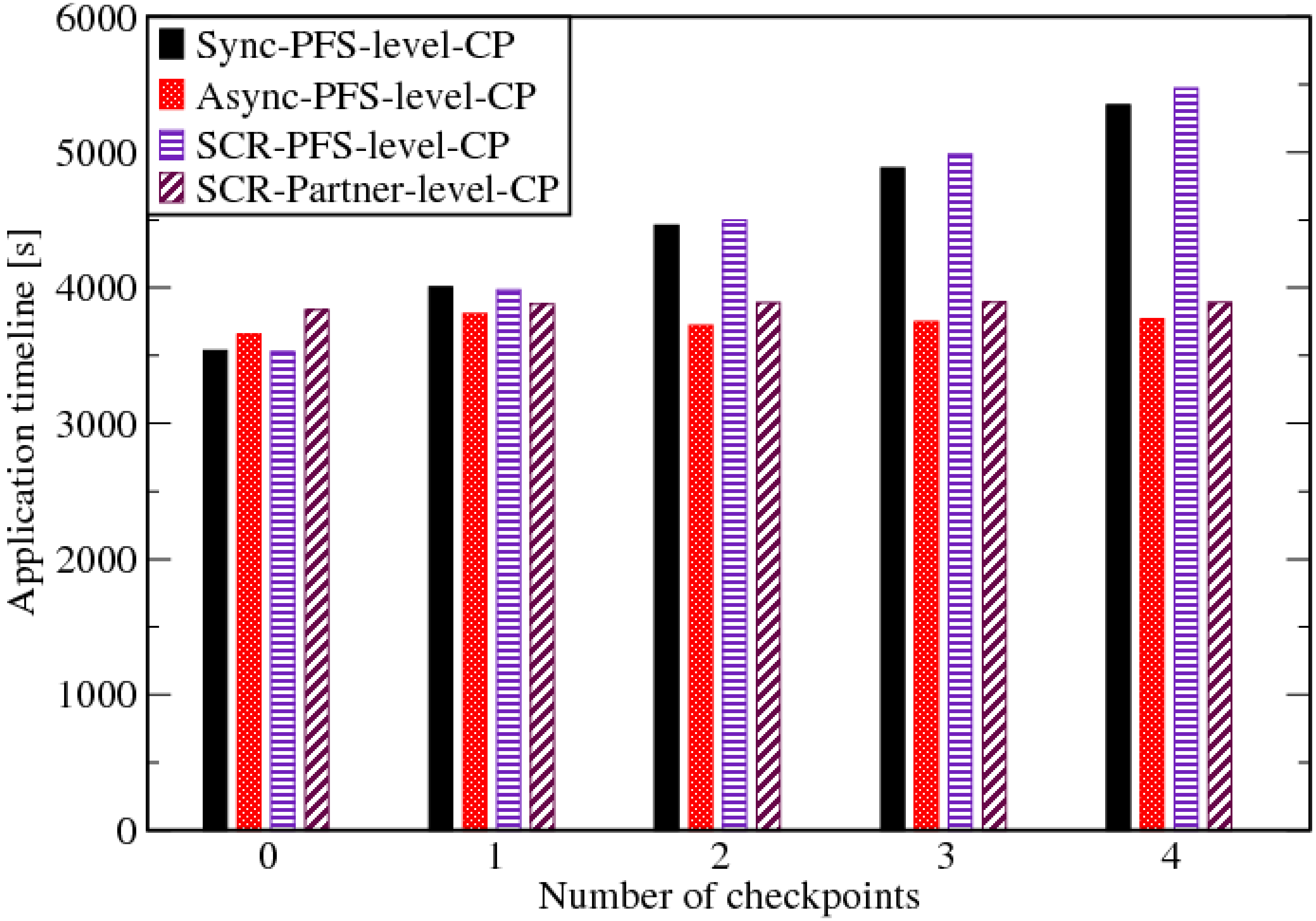


% overhead

- **1 Sync. CP = 20 %**
- **1 Async. CP = 0.4 %**

Async. vs. Sync. vs. SCR Checkpointing

- Benchmark (LiMa)



Num. of nodes = 128, PFS = LXFS,

CP size = 510 GB /CP

- **<u>% overhead:</u>**
- **1 Sync. CP = 13 %**
- **1 Async. CP = 1.3 %**
- **1 Partner. CP = 1 %**

SCR: A. Moody, G. Bronevetsky, K. Mohror, and B. R. d. Supinski, “Design, Modeling, and Evaluation of a Scalable Multilevel Checkpointing System,” in Proceedings of the 2010 ACM/IEEE International Conference for HPC, Networking, Storage and Analysis, Washington,DC, USA

Remarks: Asynchronous checkpointing

- Effective implementation of C/R and effective resource utilization can reduce overhead to minimum level.
- The overhead due to I/O bottlenecks can be reduced with asynchronous checkpointing approach.

- Critical parameter → checkpoint frequency
  - System parameters, checkpoint latency, restart time ,…
  - Upper limit on the number of checkpoints

- Limitations
  - In-memory copy of the checkpoint data costs
    1. Extra memory space (in worst case, can be up to 50%)
    2. Time (can be avoided)

AUTOMATIC FAULT TOLERANCE APPLICATION (AFT) WITH GPI

Automatic Fault Tolerance Application (AFT)

- **Automatic fault tolerance application (AFT)**
  - In the absence of failed processes, the algorithm itself is able to detect and correct the incorrectly produced results
- **Fault Tolerant - MPI ?**
- **GPI (Global address space Programming Interface)**
  - Fault tolerance → In case of single node failure, rest of the nodes stay up and running

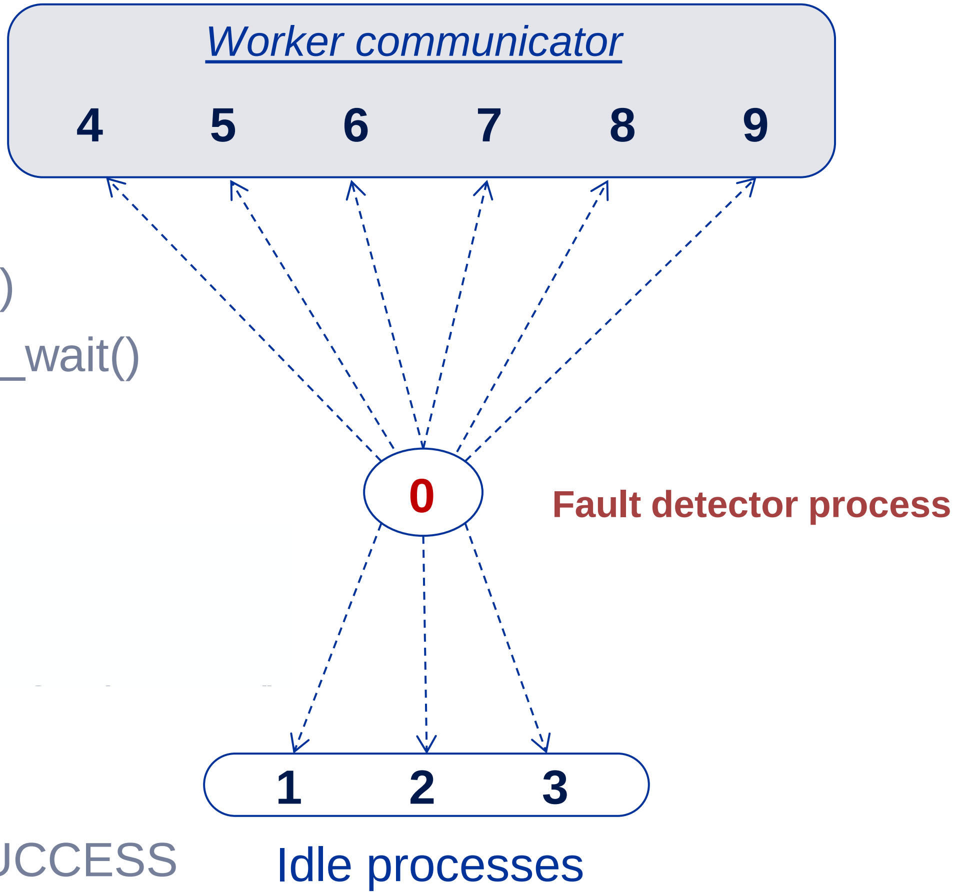
AFT: GPI Introduction

- Developed by Fraunhofer IWTM
- Based on PGAS programming model
- Two memory parts
  - Local: only local to the GPI process (and its threads)
  - Global: Available to other processes for reading and writing.
- Enables fault tolerance
  - Provides TIMEOUT for every communication call.
  - Each process maintains a health vector with the communicating partners.

Failure detector:

gaspi_write()

return_val = gaspi_wait()



return_val:

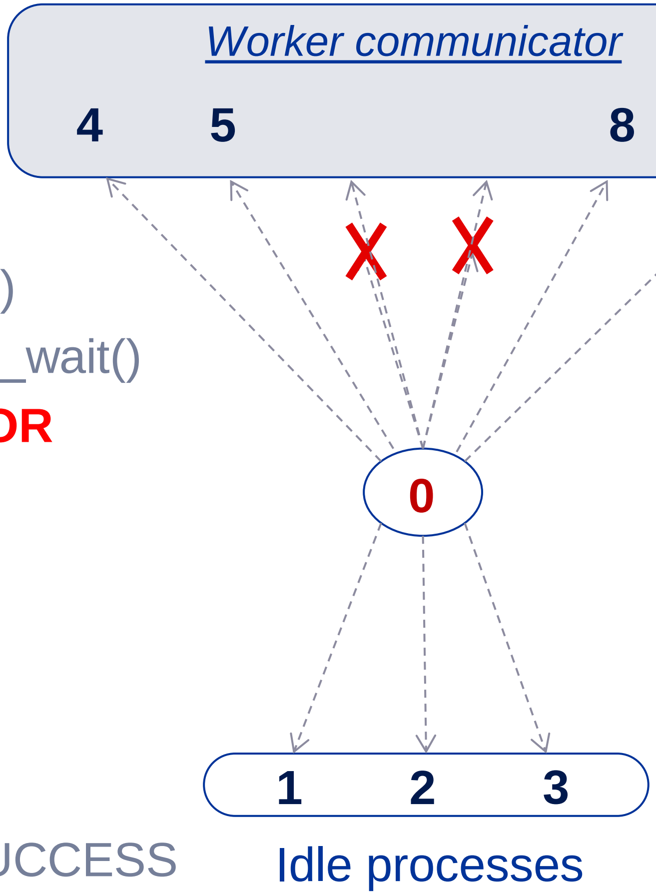
1) GASPI_SUCCESS
2) GASPI_TIMEOUT
3) GASPI_ERROR

Failure detector:

gaspi_write()

return_val = gaspi_wait()

GASPI_ERROR



Failure detector process

Failed Proc(s) IDs	Rescue Proc(s) IDs
6, 7	1, 2

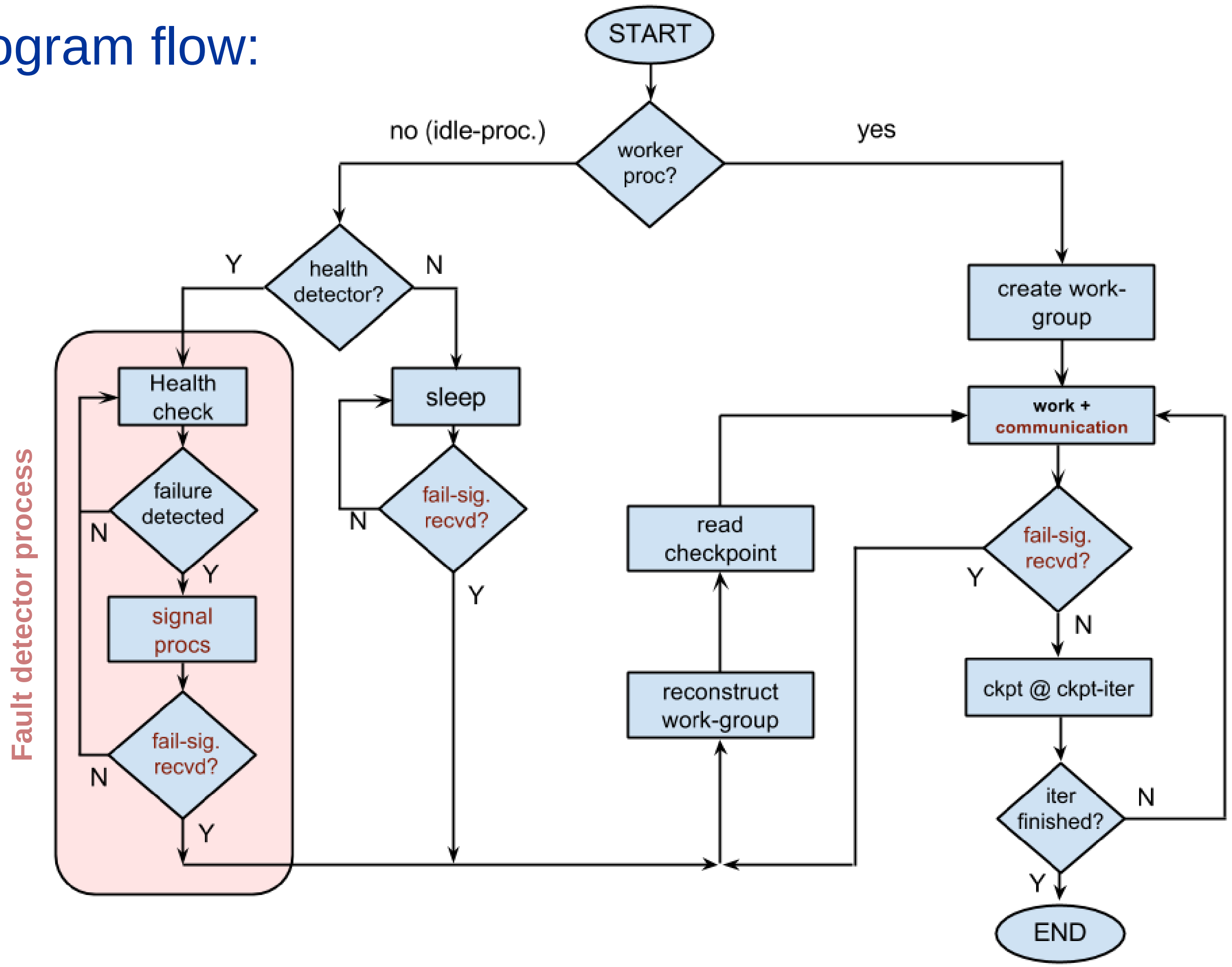
- Detector processes informs every process about failure details via gaspi_write().

return_val:

1) GASPI_SUCCESS
2) GASPI_TIMEOUT
3) GASPI_ERROR

Automatic Fault Tolerance Application

- Program flow:



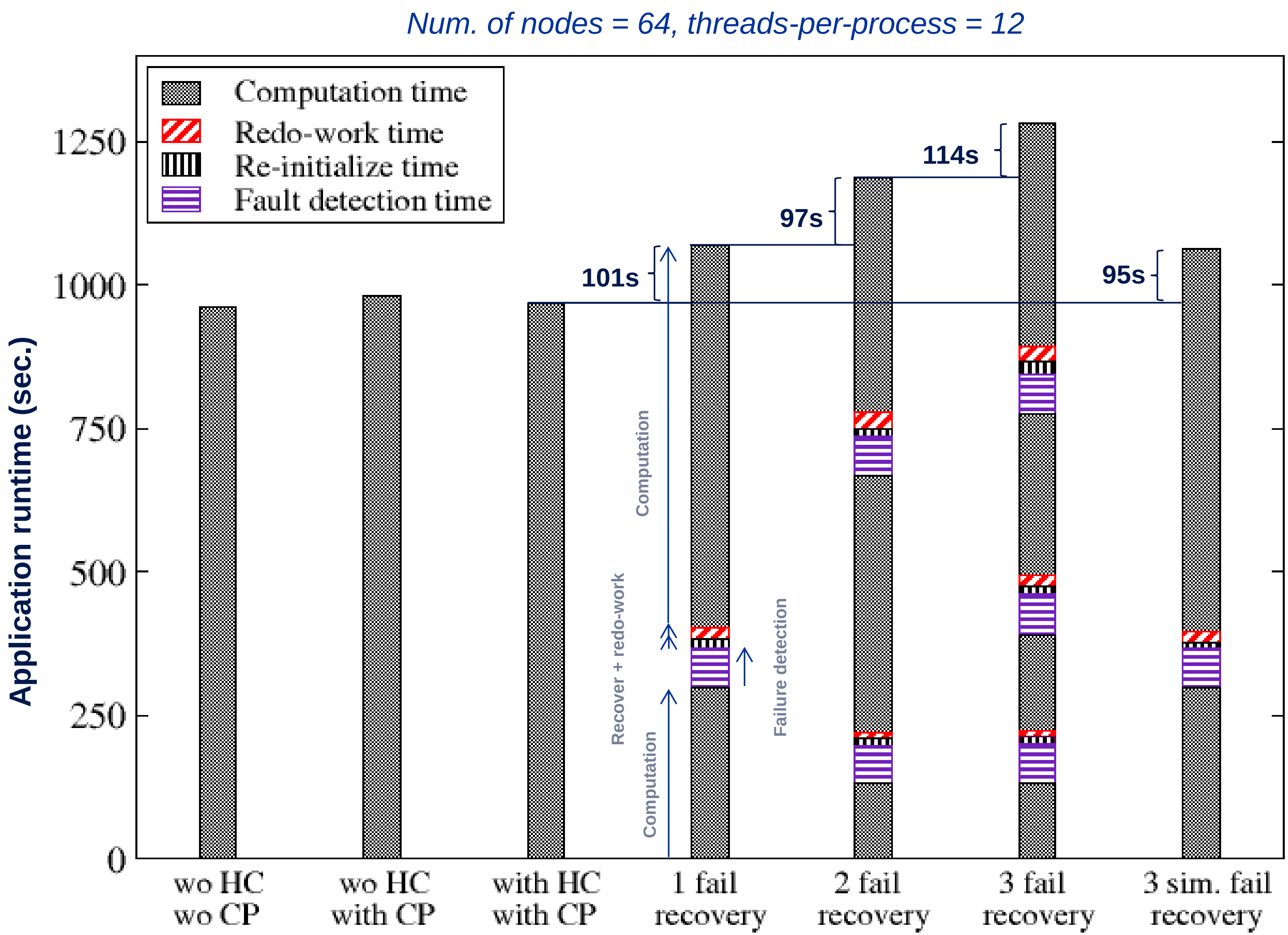
Benchmarks: Test bed

- Lanczos algorithm:

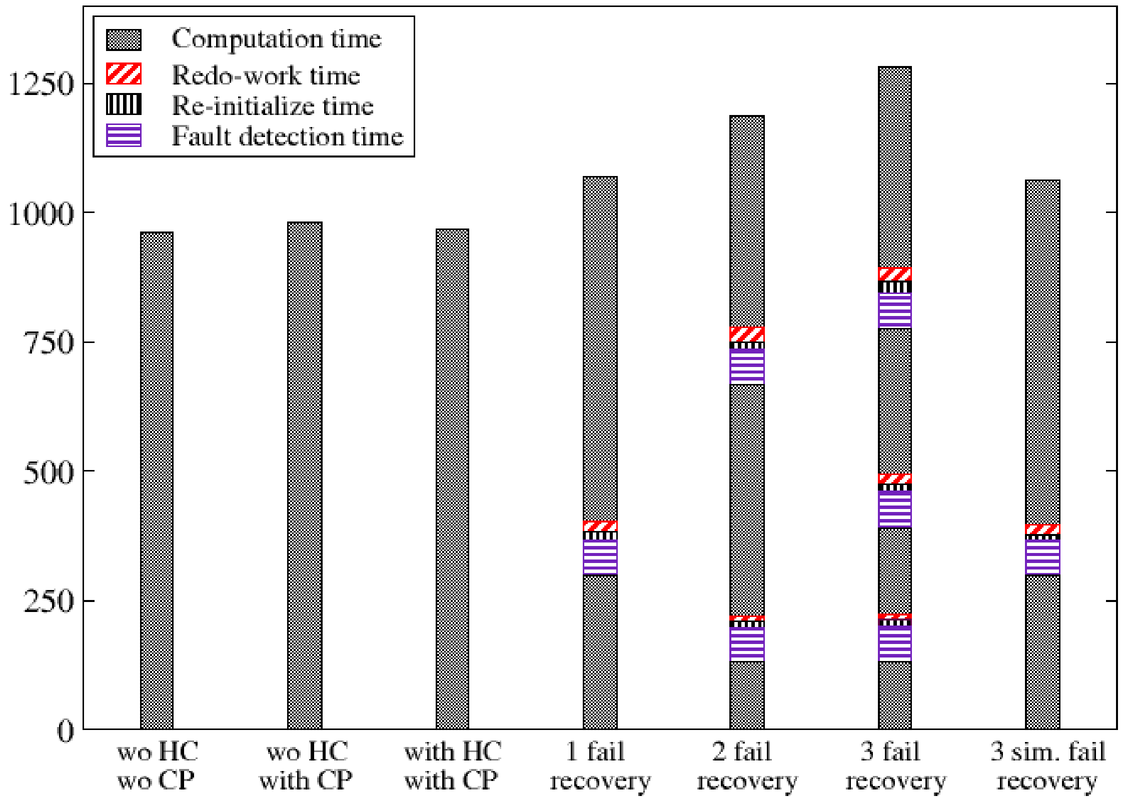
for i:=1,2, ..., ConvergenceCriterion **do**
  function LANCZOS-STEP
    $\omega_j \leftarrow A\nu_j$
    $\alpha_j \leftarrow \omega_j.\nu_j$
    $\omega_j \leftarrow \omega_j - \alpha_j\nu_j - \beta_j\nu_{j-1}$
    $\beta_{j+1} \leftarrow \|\omega_j\|$
    $\nu_{j+1} \leftarrow \omega_j/\beta_{j+1}$
  end function
  $CalcMinimumEigenVal()$
end for

- Checkpoint data structure:
  - After startup: Every process once stores matrix communication data structure.
  - Two recent Lanczos vectors are stored at each checkpoint iteration.
  - Recently calculated eigenvalues.
- Test cluster:
  - LiMa – RRZE, Erlangen

Benchmark:


Num. of nodes = 64, threads-per-process = 12
Computation time
Redo-work time
Re-initialize time
Fault detection time
Application runtime (sec.)
0
250
500
750
1000
1250
101s
97s
114s
95s
Computation
Recover + redo-work
Computation
Failure detection
wo HC wo CP
wo HC with CP
with HC with CP
1 fail recovery
2 fail recovery
3 fail recovery
3 sim. fail recovery

Benchmark:



- Avg. fault detection time (by gaspi_wait): 67 sec.
- Avg. re-initialize time: 16 sec.
- Avg. failure recovery time (without redo-work): 83 sec.
- Redo work: dependent on instant of failure between 2 checkpoints

Remarks:

- Worker processes remain undisturbed in failure-free application run.
- Overhead only in case of worker failure(s).
- Scalable.
- Redo-Work after failure recovery ⇔ Checkpoint Frequency.

- MPI-ULFM:
  - On going work by MPI Forum's fault tolerance working group to incorporate FT features in MPI-4.
  - Prototype implementation in form of User Level Failure Mitigation (ULFM).

Thank you!

Questions?

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SPPEXA

ESSEX

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ASYNCHRONOUS CHECKPOINTING IN GHOST (ESSEX)

Equipping Sparse Scalable Solvers for Exascale (ESSEX)

Hardware

Fault tolerance
Energy efficiency
New levels of parallelism

Quantum Physics Applications

Extremely large sparse matrices:
eigenvalues, spectral properties,
time evolution

ESSEX

Exascale Sparse Solver Repository (ESSR)

- FT concepts, programming for extreme parallelism
- Sparse eigensolvers, preconditioners, spectral methods
- Quantum physics / chemistry
- ESSEX applications: Graphene, topological insulators, …

Basic building blocks library: GHOST

General, Hybrid and Optimized Sparse Toolkit

GHOST

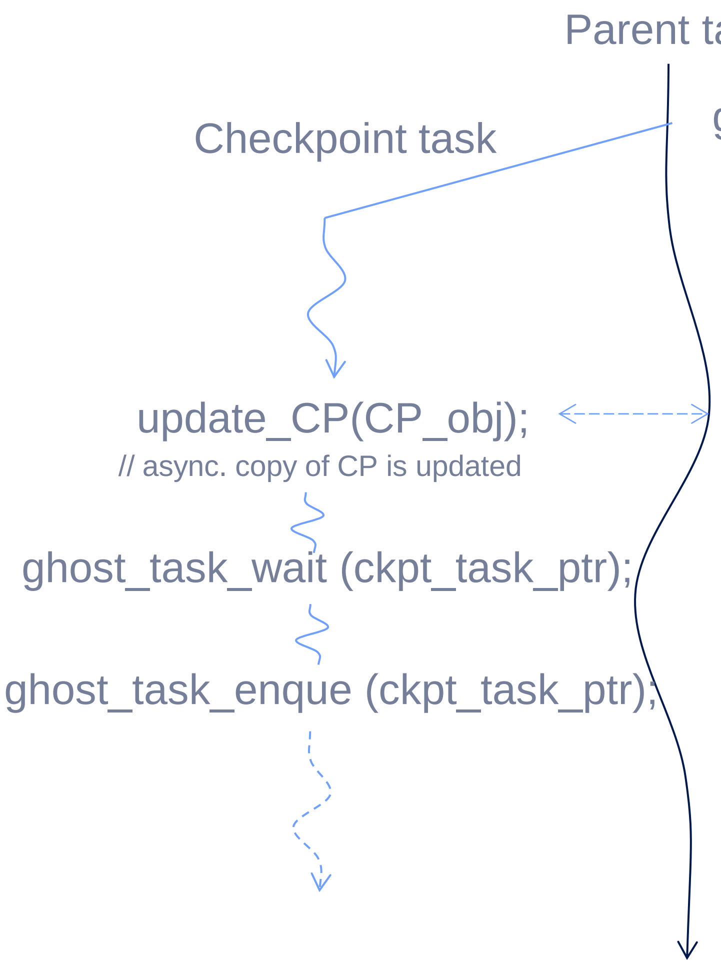
- Basic tailored sparse matrix / vector operations
- CRS or **SELL-C-σ*** (**unified format**) storage schemes
- (Block-)SpMVM: SIMD intrinsic (AVX, SSE, MIC) & CUDA kernels
- Dense vector /matrices: row-/column-major storage

- **Supports** data & **task parallelism** (up to application level)
- MPI + OpenMP + **tasks for concurrent execution**
- **Generic and hardware-aware task management**

- **Application layer triggered checkpoint / restart**
- **Asynchronous checkpointing via tasks**
- **Various checkpoint locations (node, filesystem)**

*****M. Kreutzer, G. Hager, G. Wellein, H. Fehske, and A. R. Bishop: *A unified sparse matrix data format for efficient general sparse matrix-vector multiplication on modern processors with wide SIMD units.* SIAM Journal on Scientific Computing **36**(5), C401–C423 (2014).

Asynchronous checkpoints via GHOST-task thread:



CP_obj:

- object of ckpt_t type
- ckpt_t class is defined by programmer
- checkpoint object contains the aynchronous copy of the checkpoint

CP_func:

- This function takes an updated copz of CP_obj as argument and writes to PFS..