Coupling failure prediction, proactive and preventive checkpoint for current production HPC systems.

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Motivation

- Prediction is feasible
  - ELSA: Signal analysis with data mining
    - 90% precision and 45% recall
    - At least 10 seconds delay
- Fast checkpointing strategies exist
  - FTI (Fault Tolerance Interface)
    - Capable of taking a checkpoint in ~5s for 1GB memory
    - Multi-level checkpoint with 8% overhead
- Plan
  - Merging FTI with ELSA

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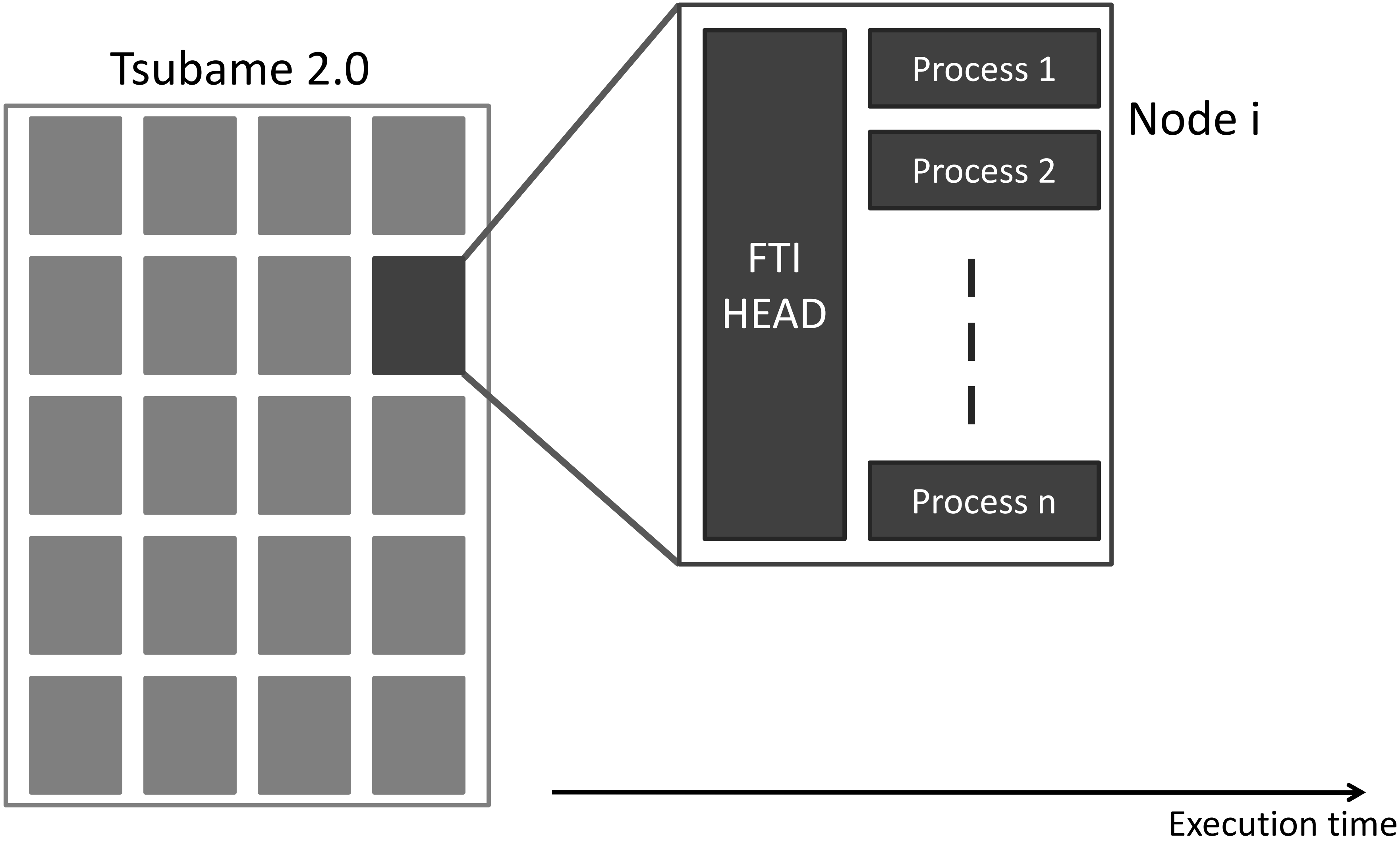
Let's remember FTI



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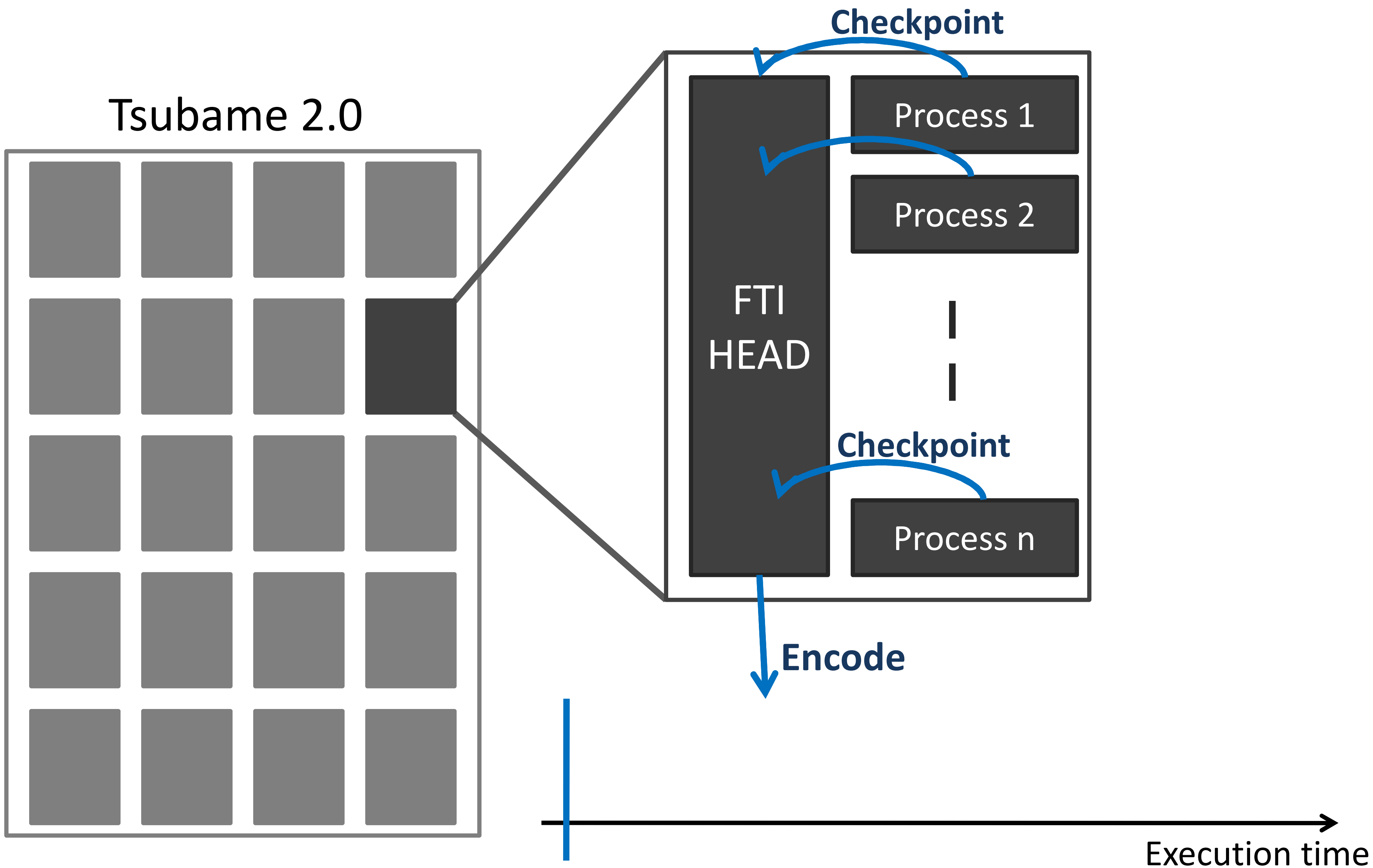

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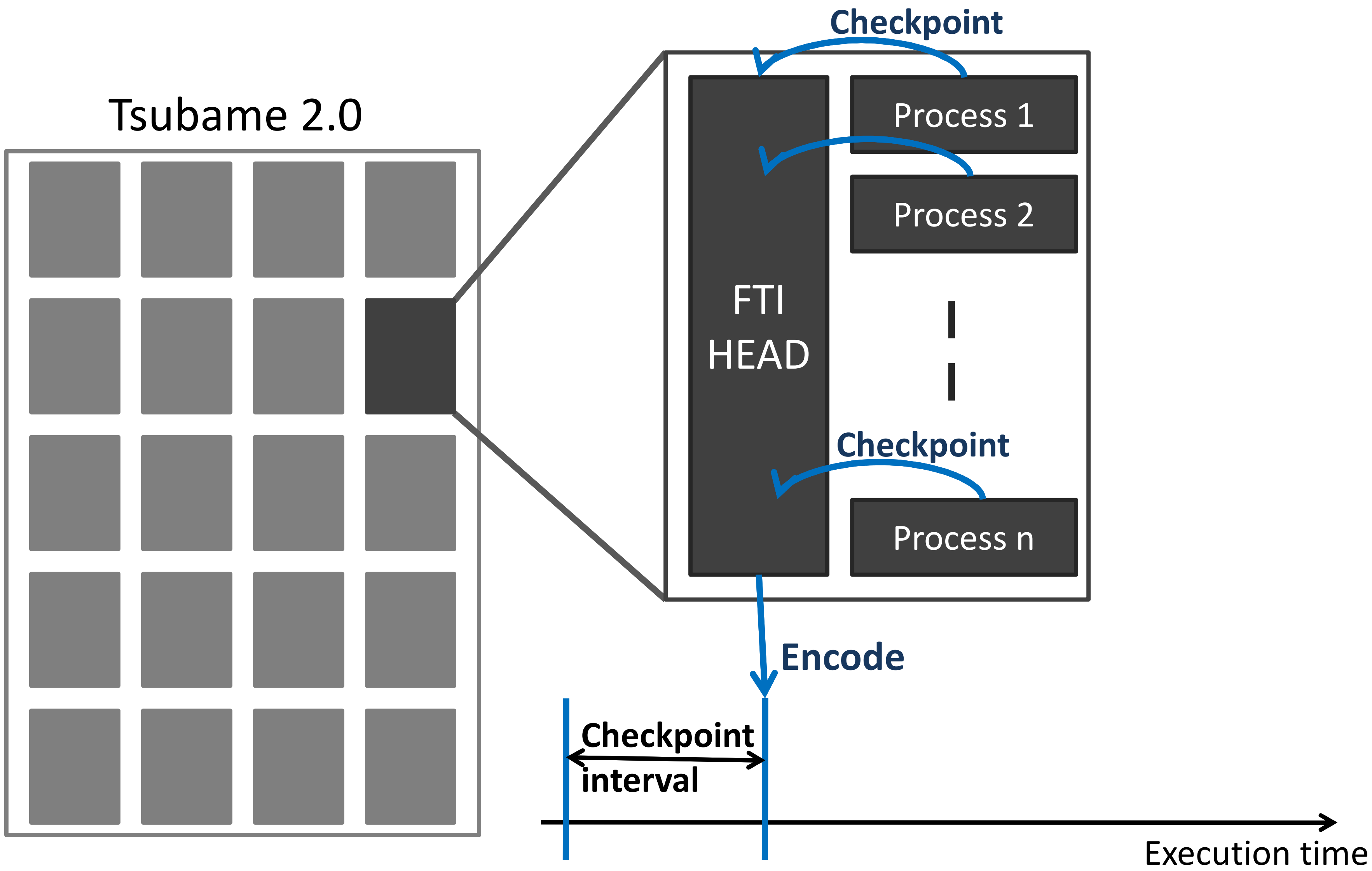

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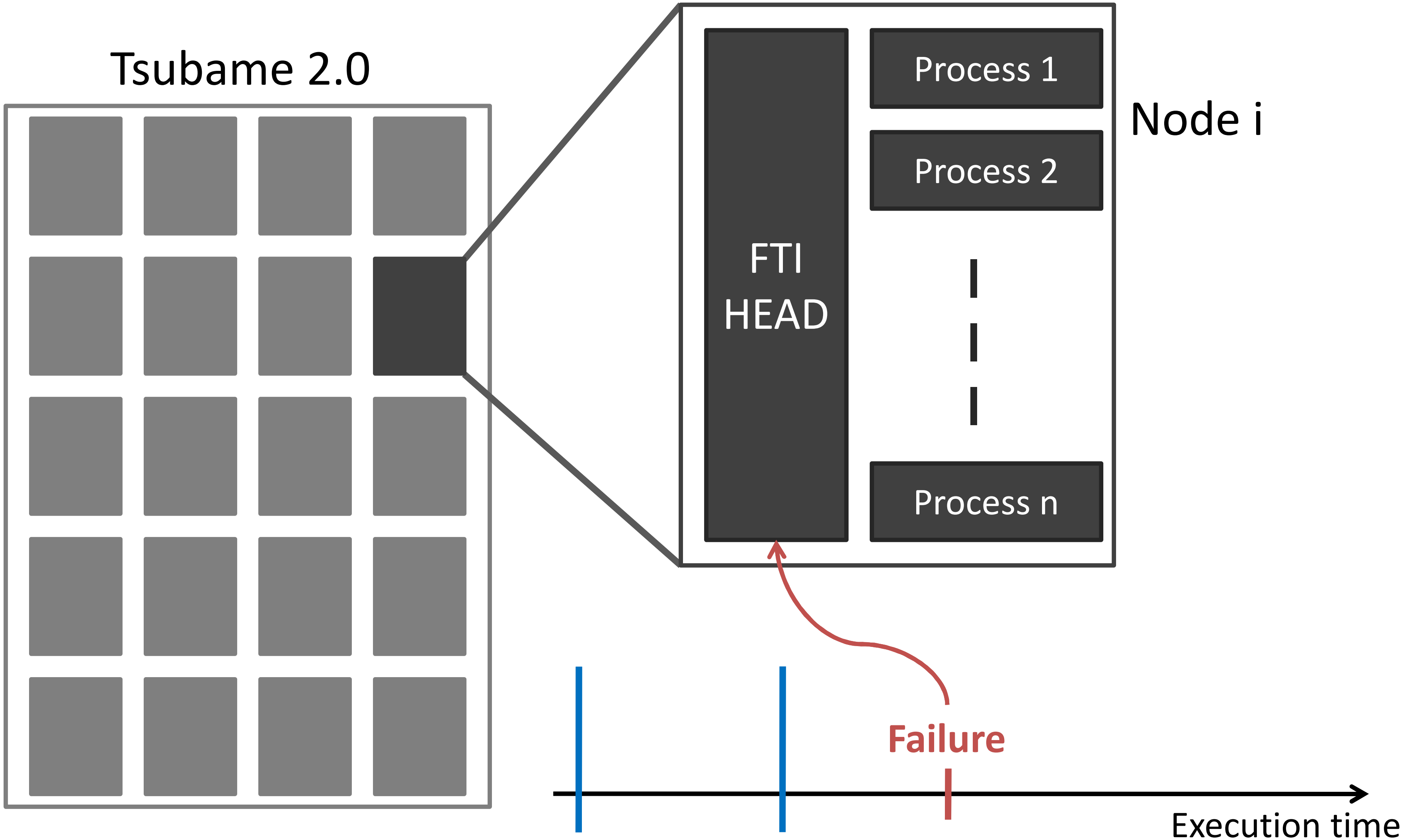

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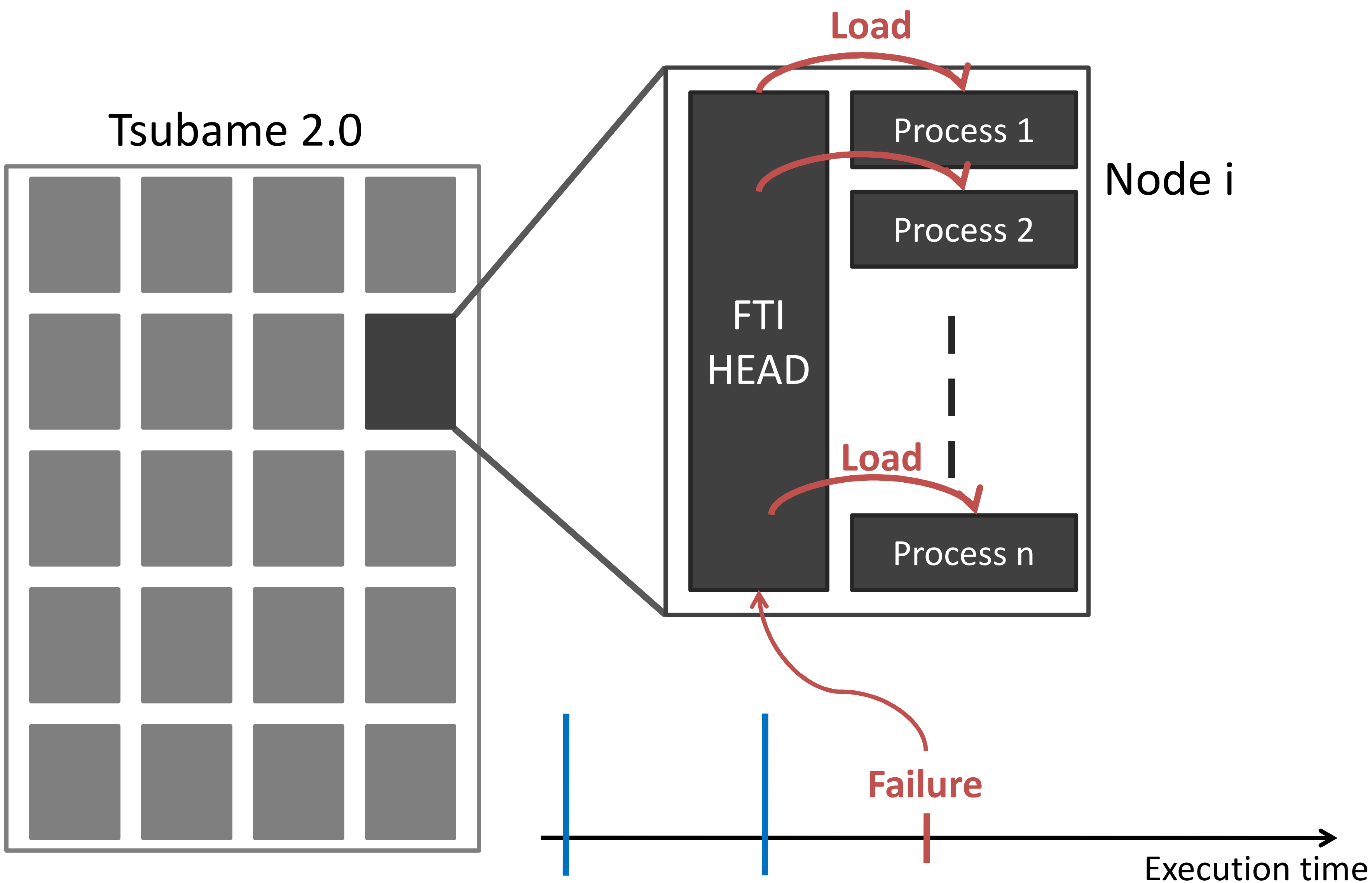
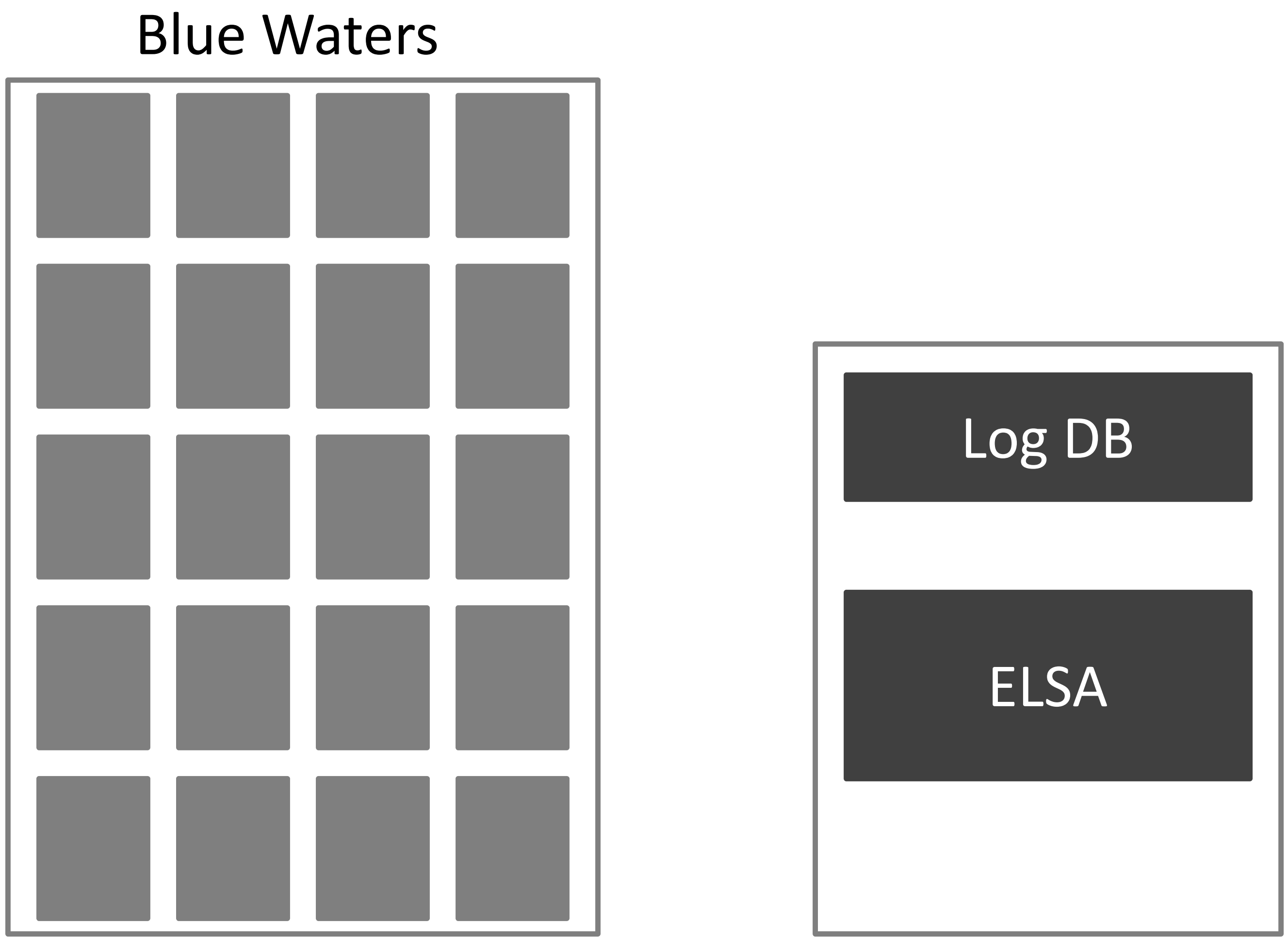


Let’s remember ELSA



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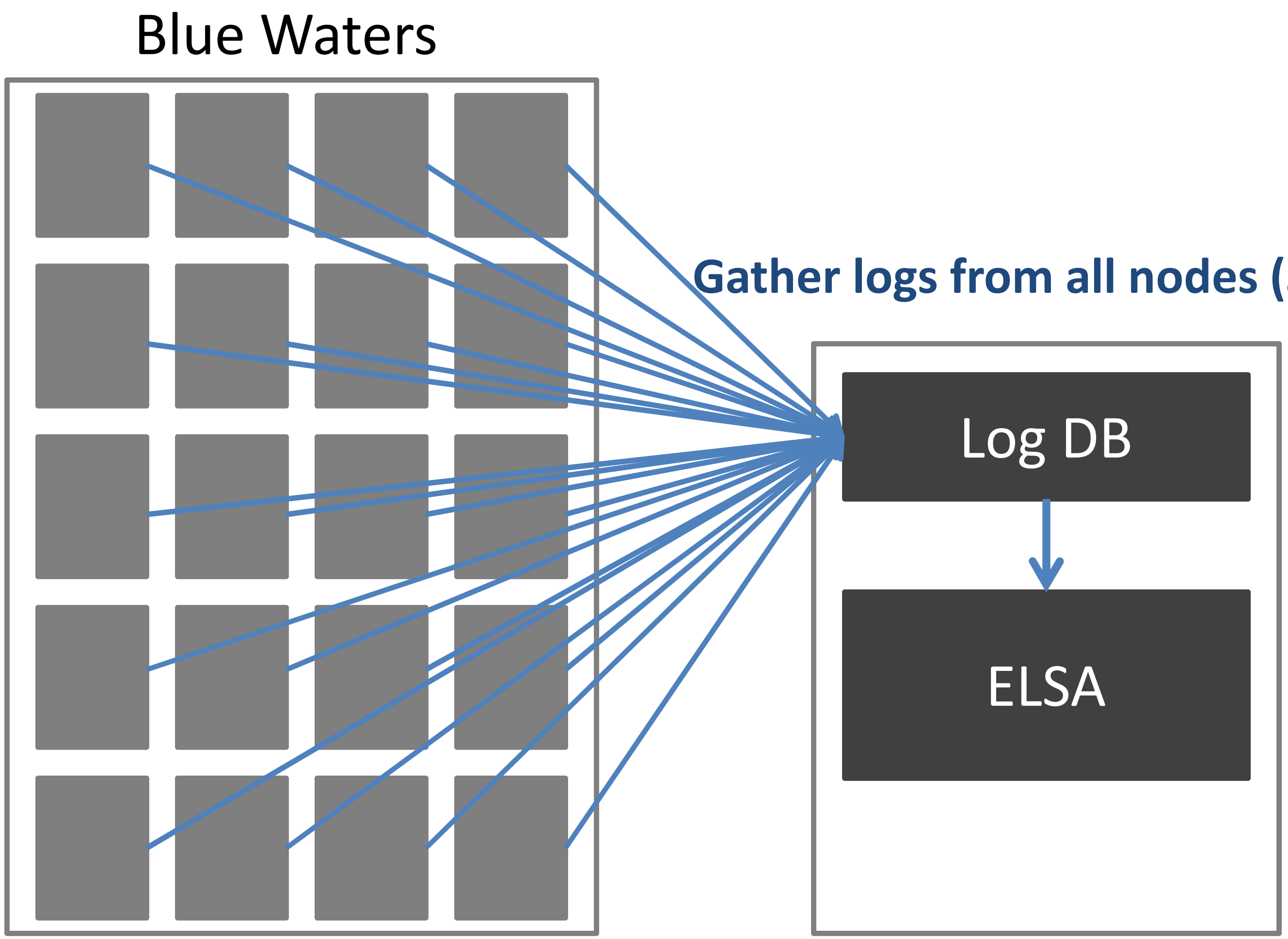

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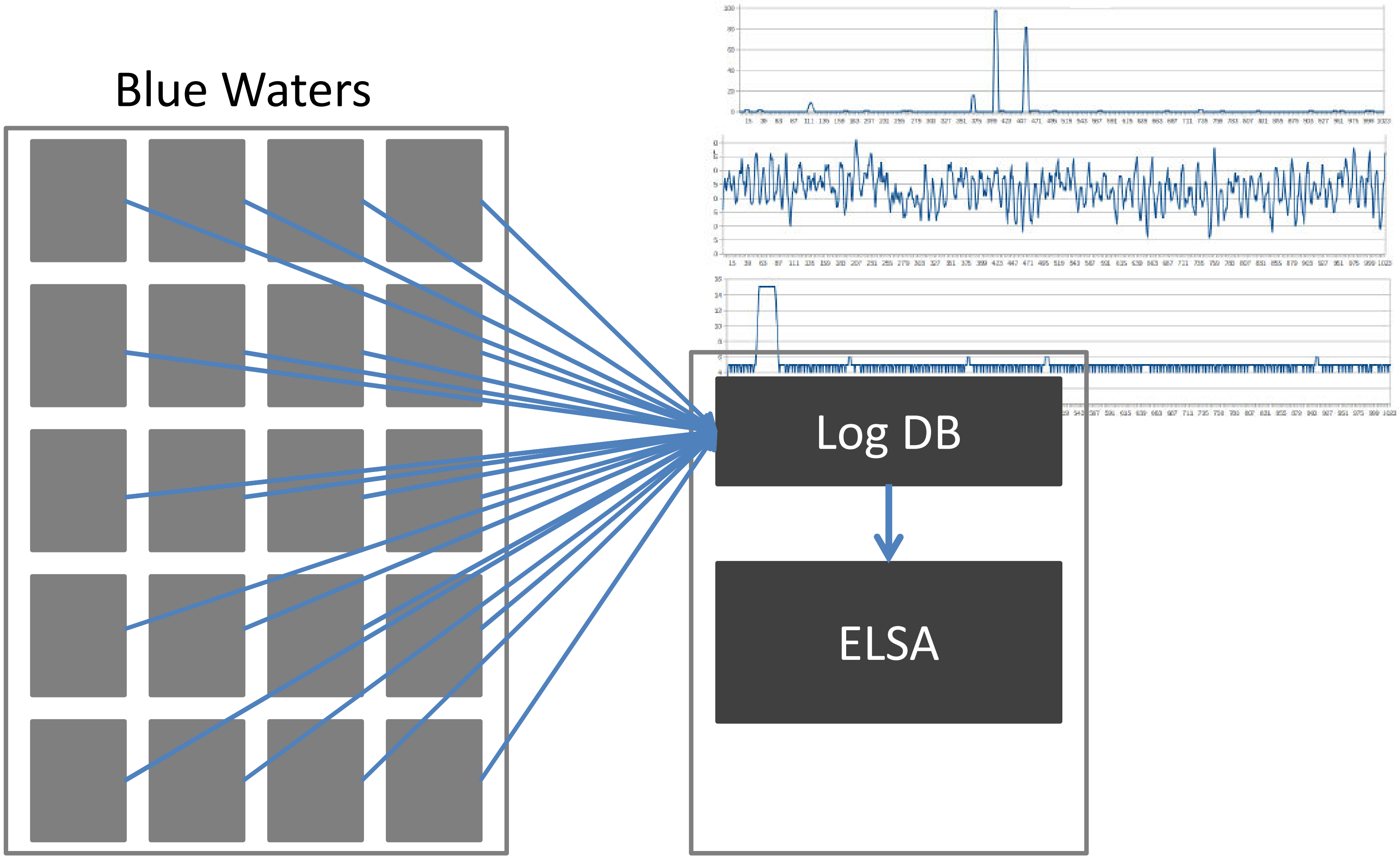

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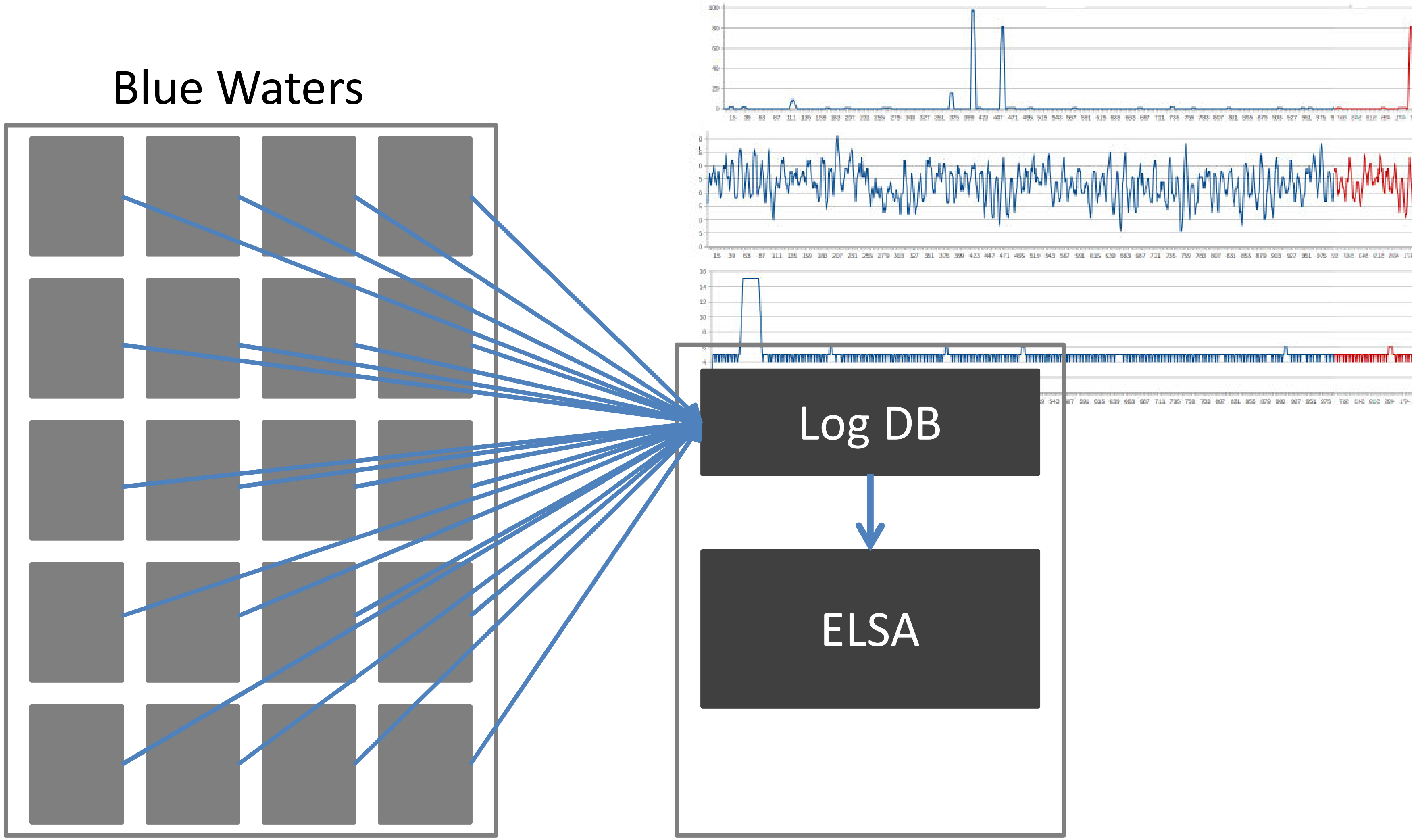

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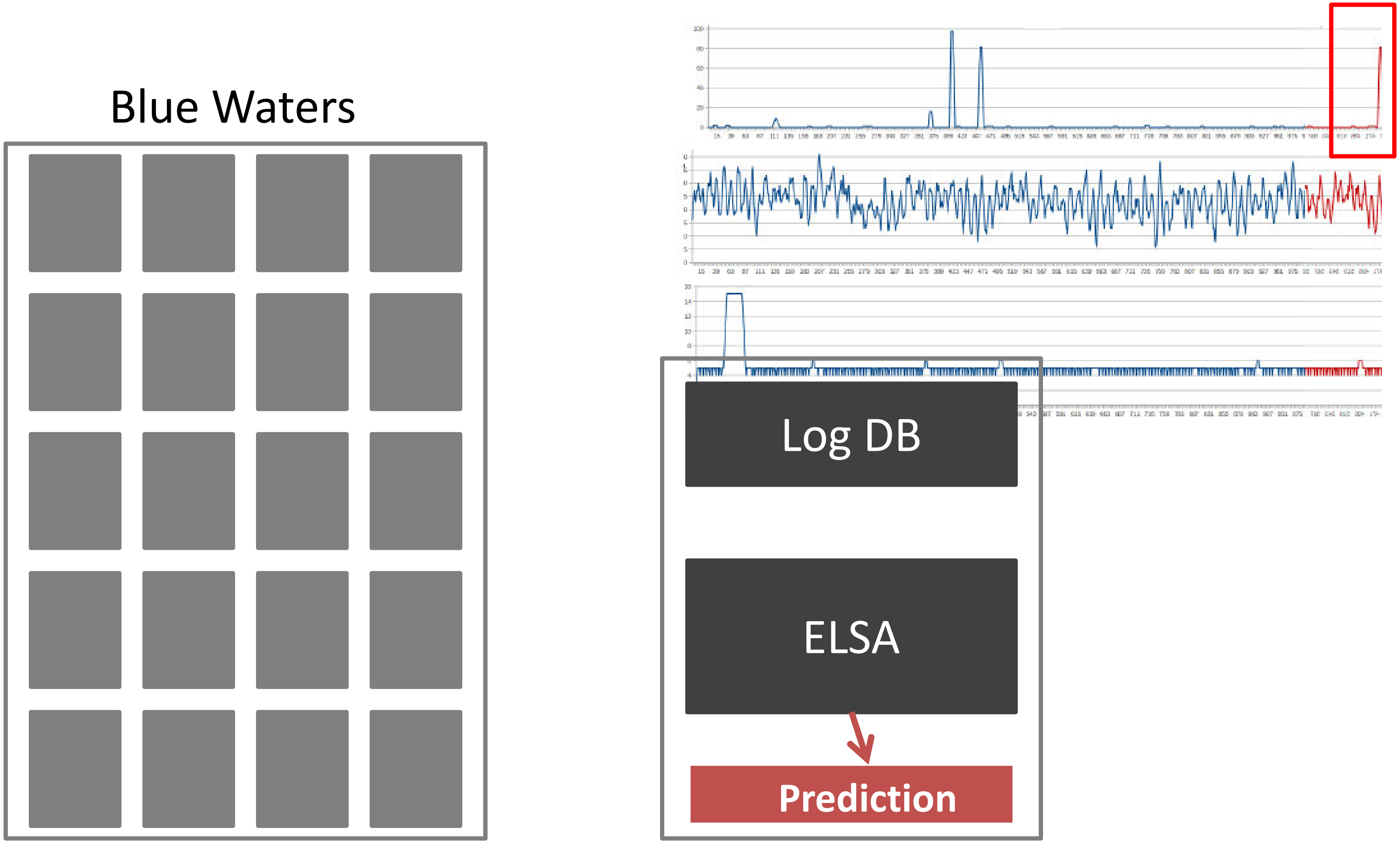

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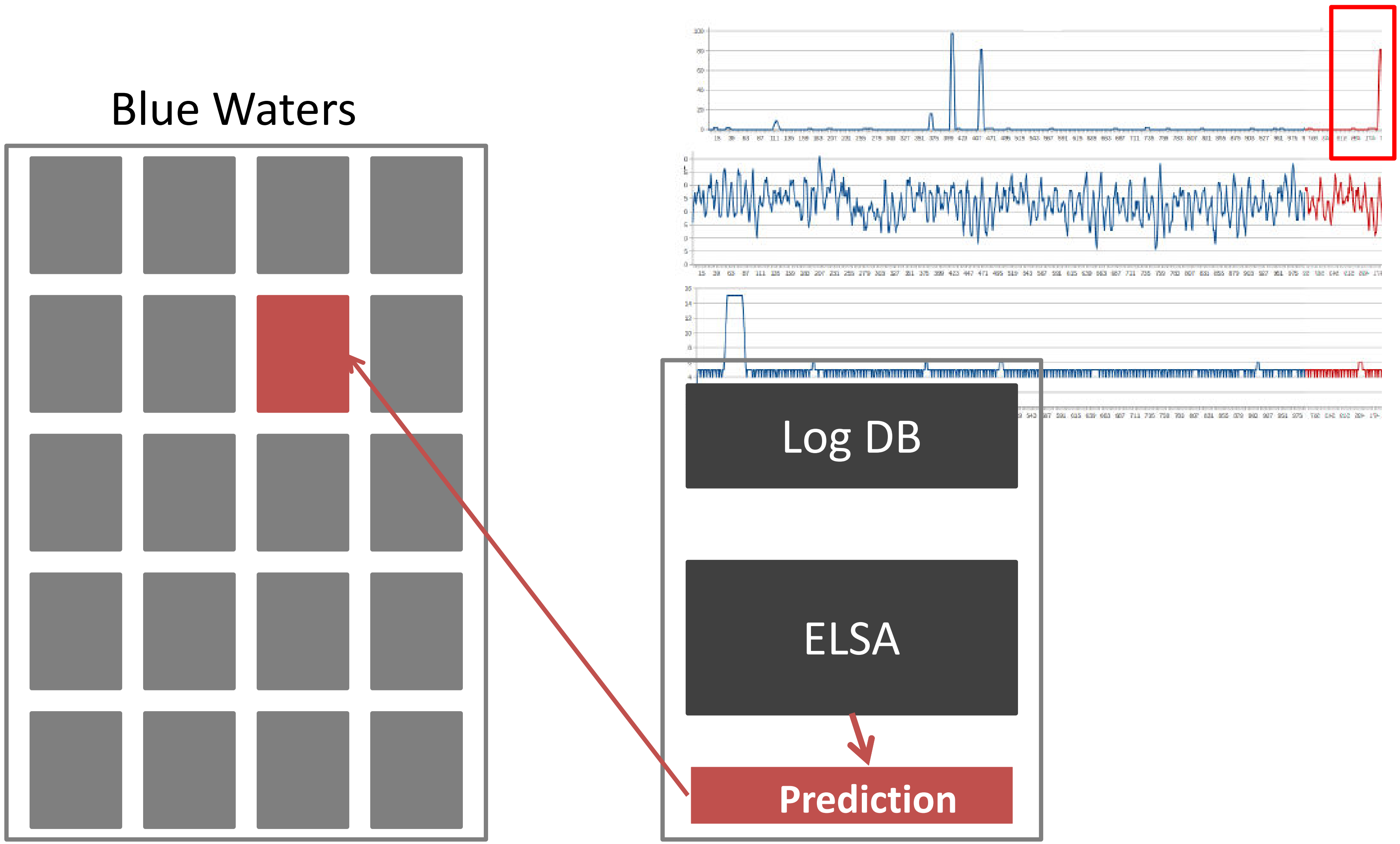

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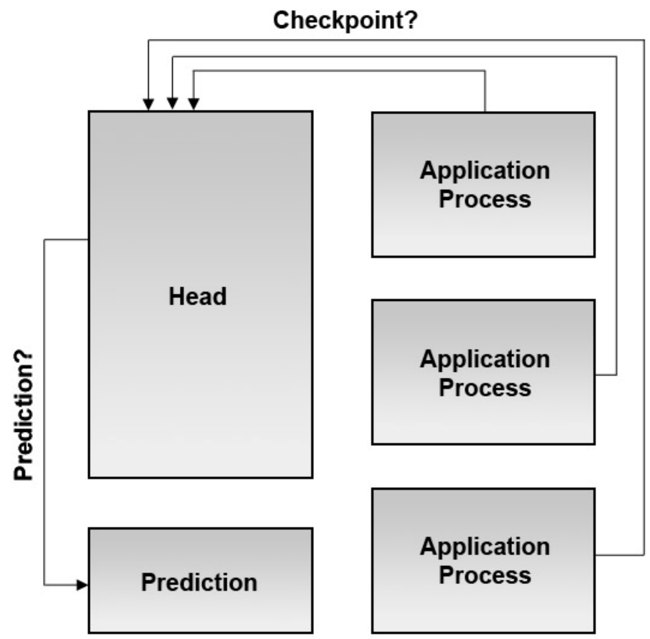
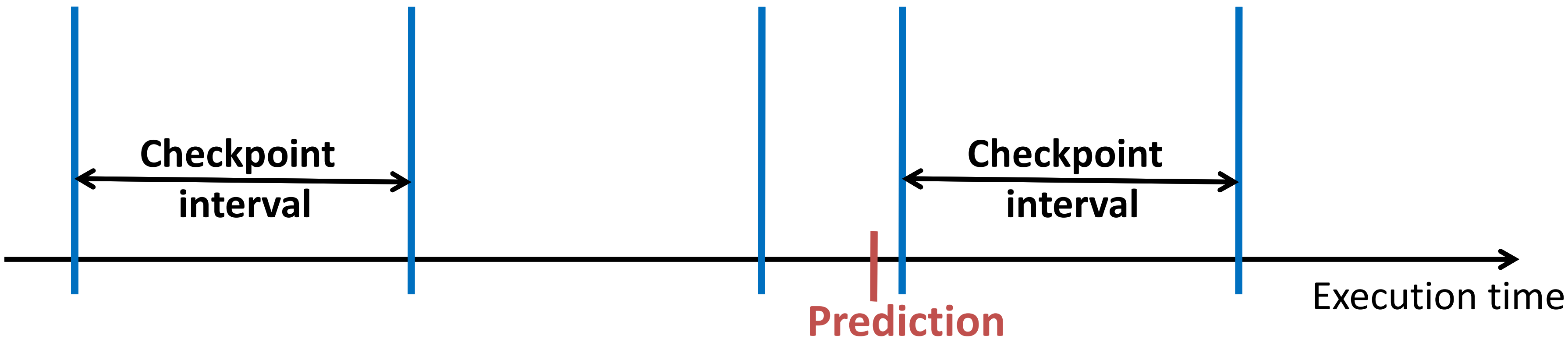
Plan

- Solution:
  - Include ELSA in the Head process
  - Every x seconds the Head checks predictions
  - The Head requests a checkpoint from the app processes
- 3 possible methodologies:
  - Fixed checkpoint interval:
    - Set w/o considering prediction
    - Resets after each prediction
    - Established by the recall value
  - Additional checkpoints for each prediction

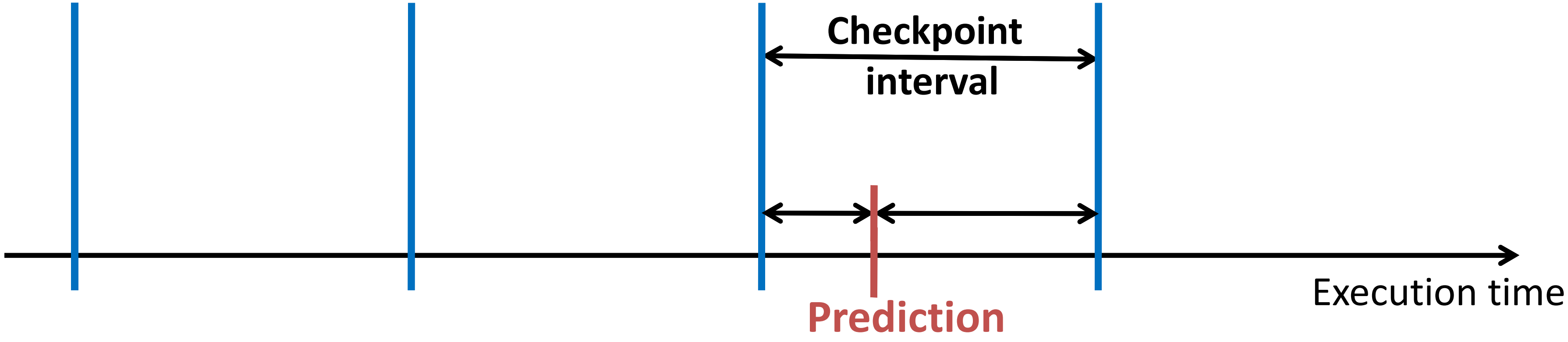


Possible model



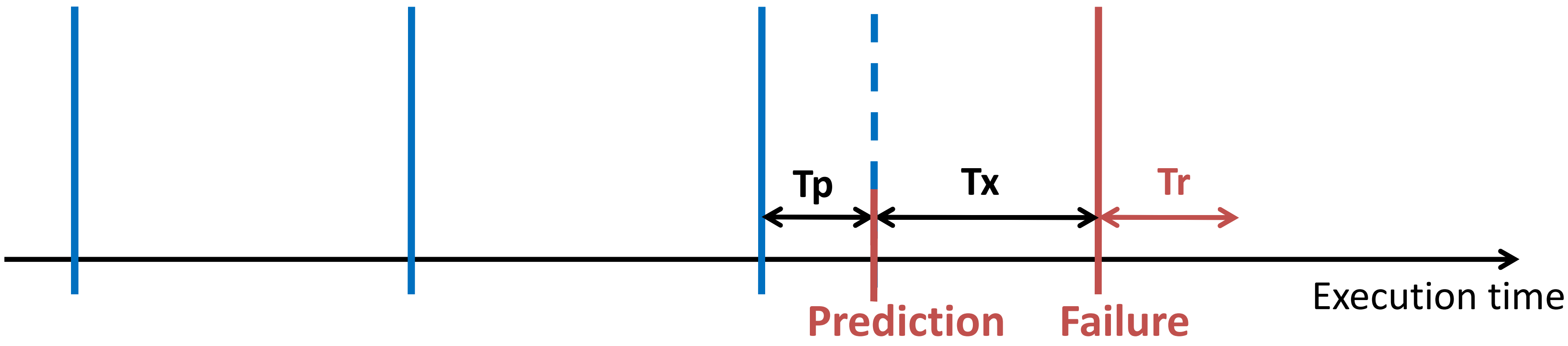
- Checkpoint interval:
  - Given by the MTBF and the checkpoint time
- Prediction:
  - Recall gives the MTB false negative F
    - Depending on the distribution of the failures after prediction

Possible model



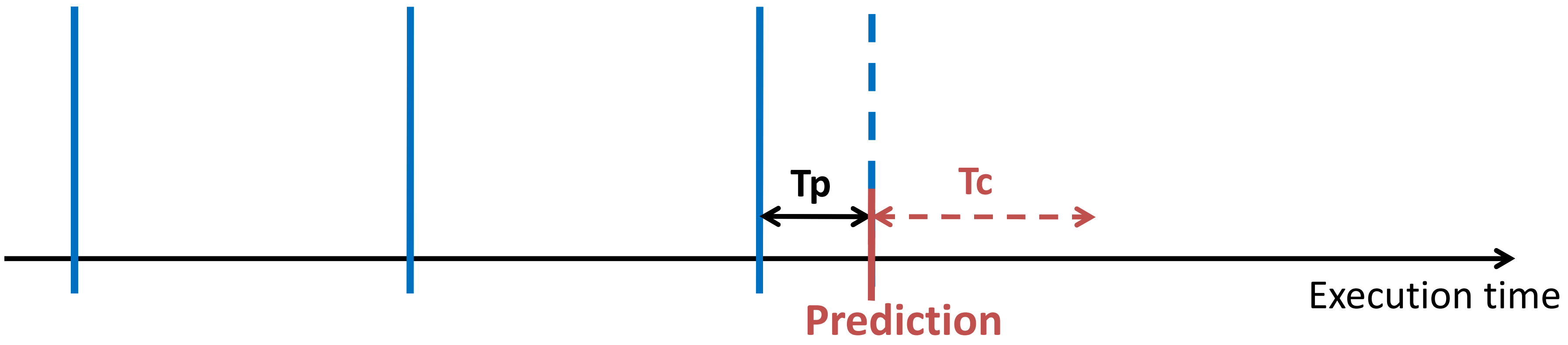
- Depending on the moment of the prediction
  - Decide to take or not a checkpoint
  - Analytical model for 2 cases:
    - Decide to take an extra checkpoint due to the prediction
    - Do not take a checkpoint and just leave the failure to occur without doing any action

Possible model



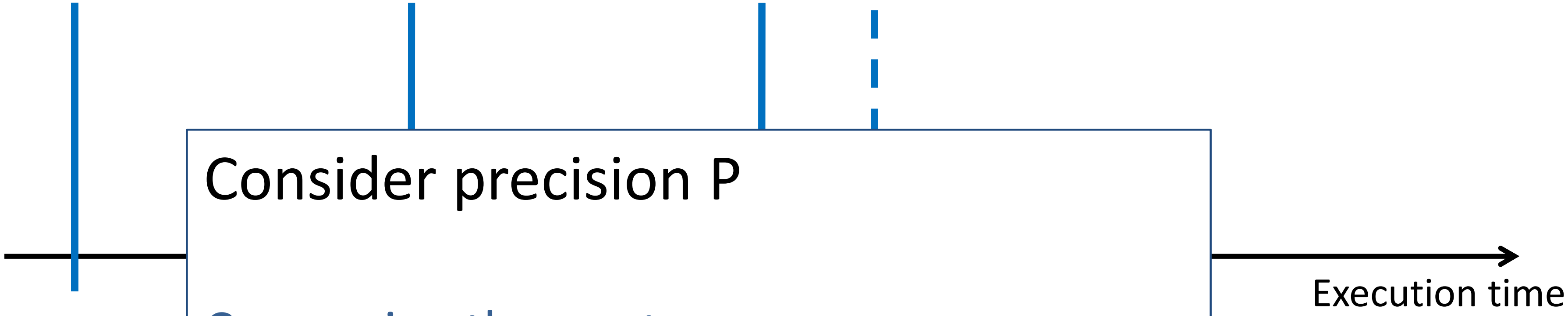
- First case: Prediction is correct
  - Do not checkpoint
    - Waste = Tp + Tx + Tr
  - Take a checkpoint
    - Waste = Tx + Tr

Possible model



- First case: Prediction is wrong
  - Do not checkpoint
    - Waste = 0
  - Take a checkpoint
    - Waste = Tc

Possible model



Consider precision P

Comparing the wastes:

- If $T_p < (1-P)/P * T_c$ - not worth taking a checkpoint

- Firs
  – D
    - Waste = 0
  – Take a checkpoint
    - Waste = Tc

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Modifications to FTI

- 2 main contributions:
  - Communication between the Head and application processes
  - Checking predictions regularly

Modifications to FTI

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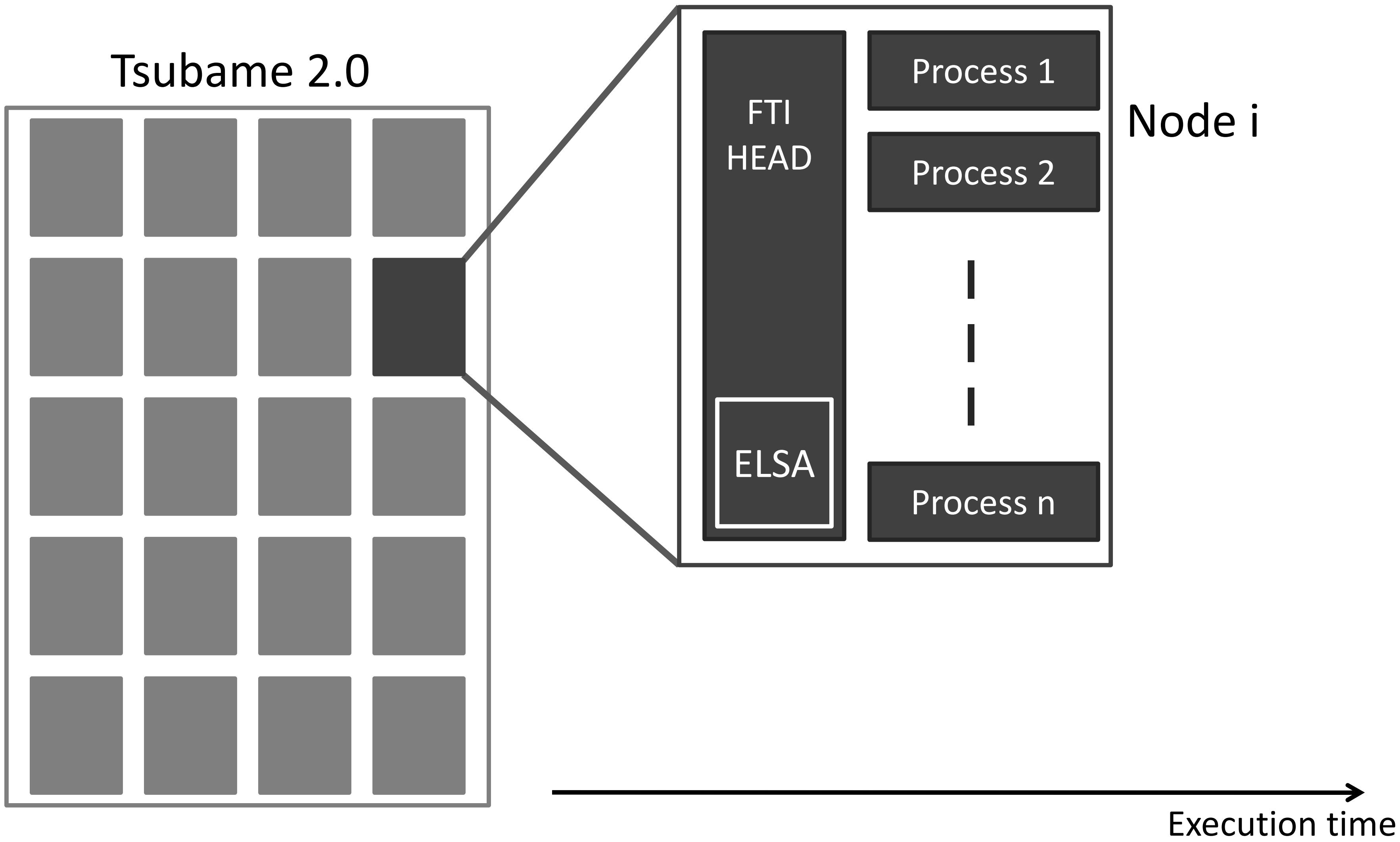
  - **Communication between the Head and application processes**
  - Checking predictions regularly

- Communication
  - On prediction the Head must force the app processes to checkpoint

Modifications to FTI



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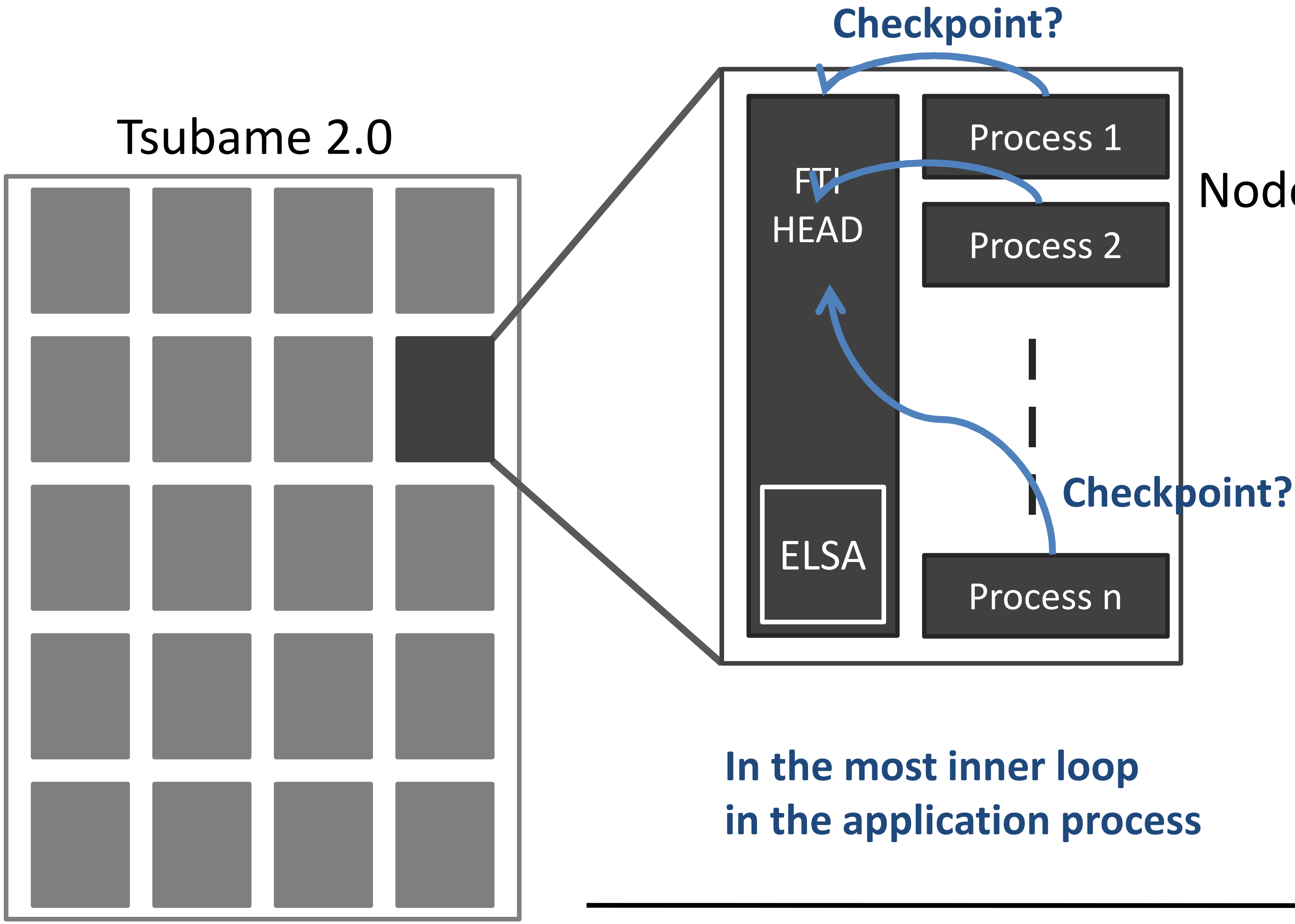
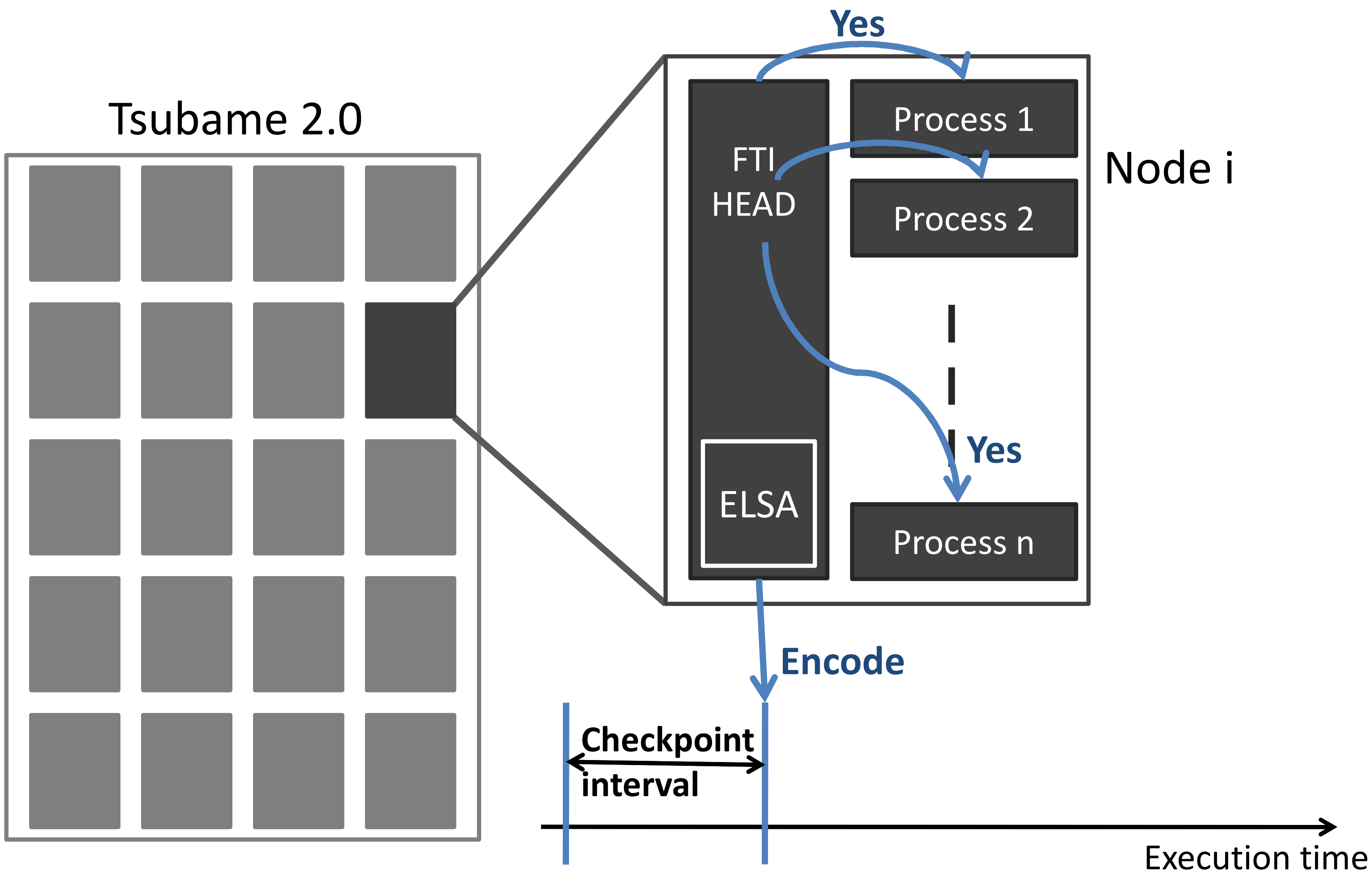


In the most inner loop
in the application process

Modifications to FTI

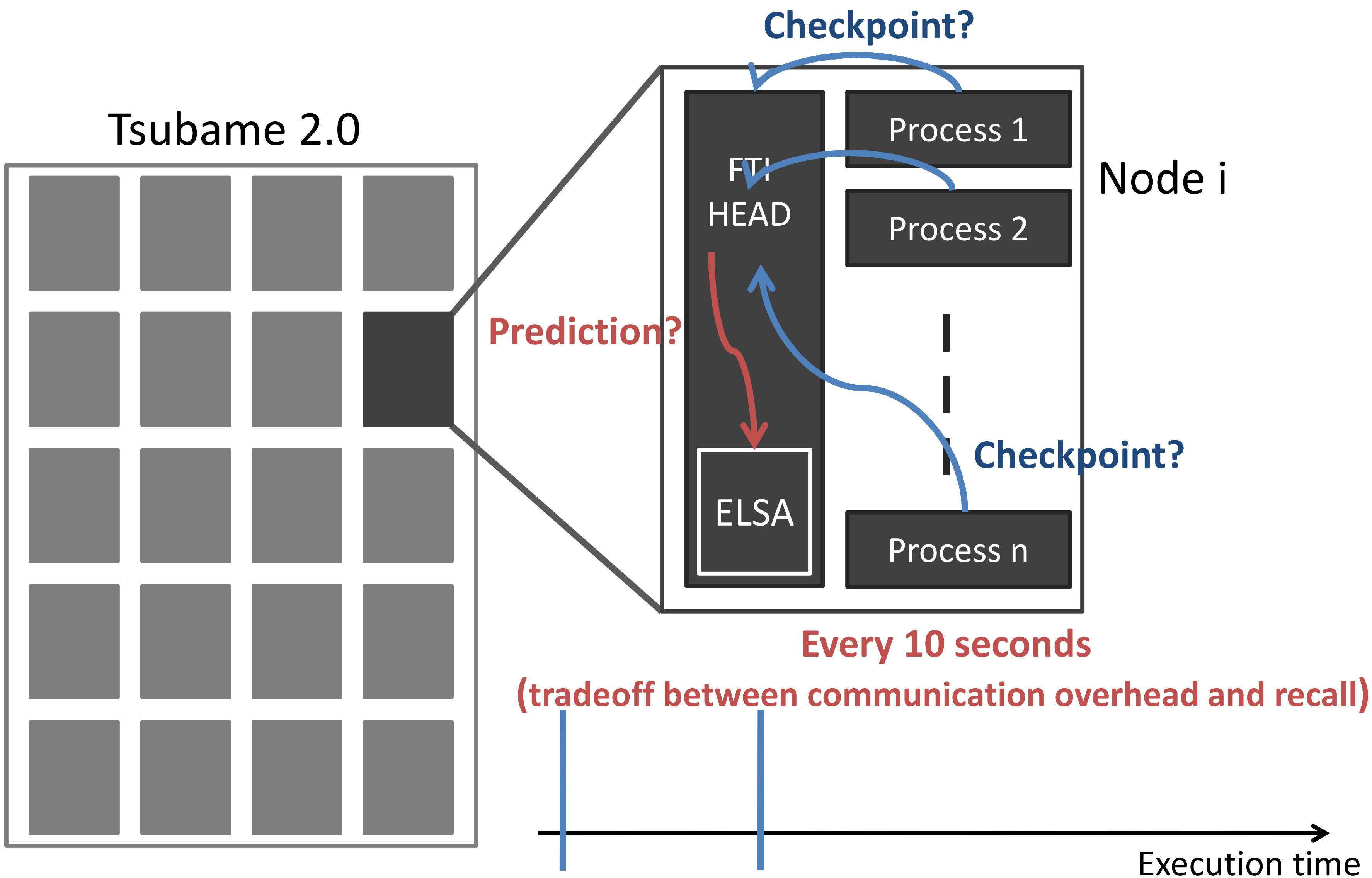


Modifications to FTI

- 2 main contributions:
  - Communication between the Head and application processes
  - **Checking predictions regularly**

- Predictions
  - Every 10s
  - App processes ask every x no of iterations
  - Adapt x dynamically to correspond to 10s

Modifications to FTI



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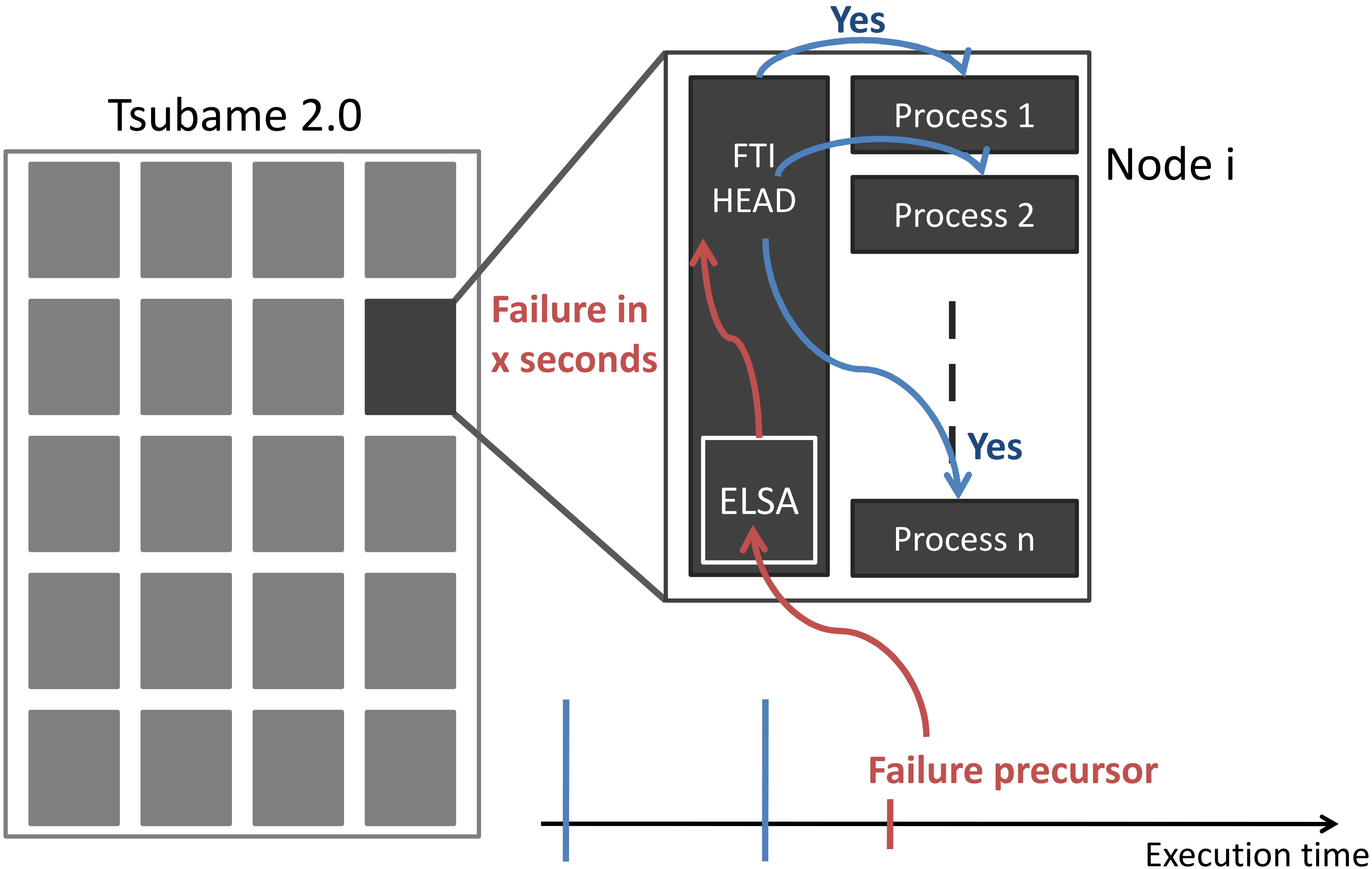

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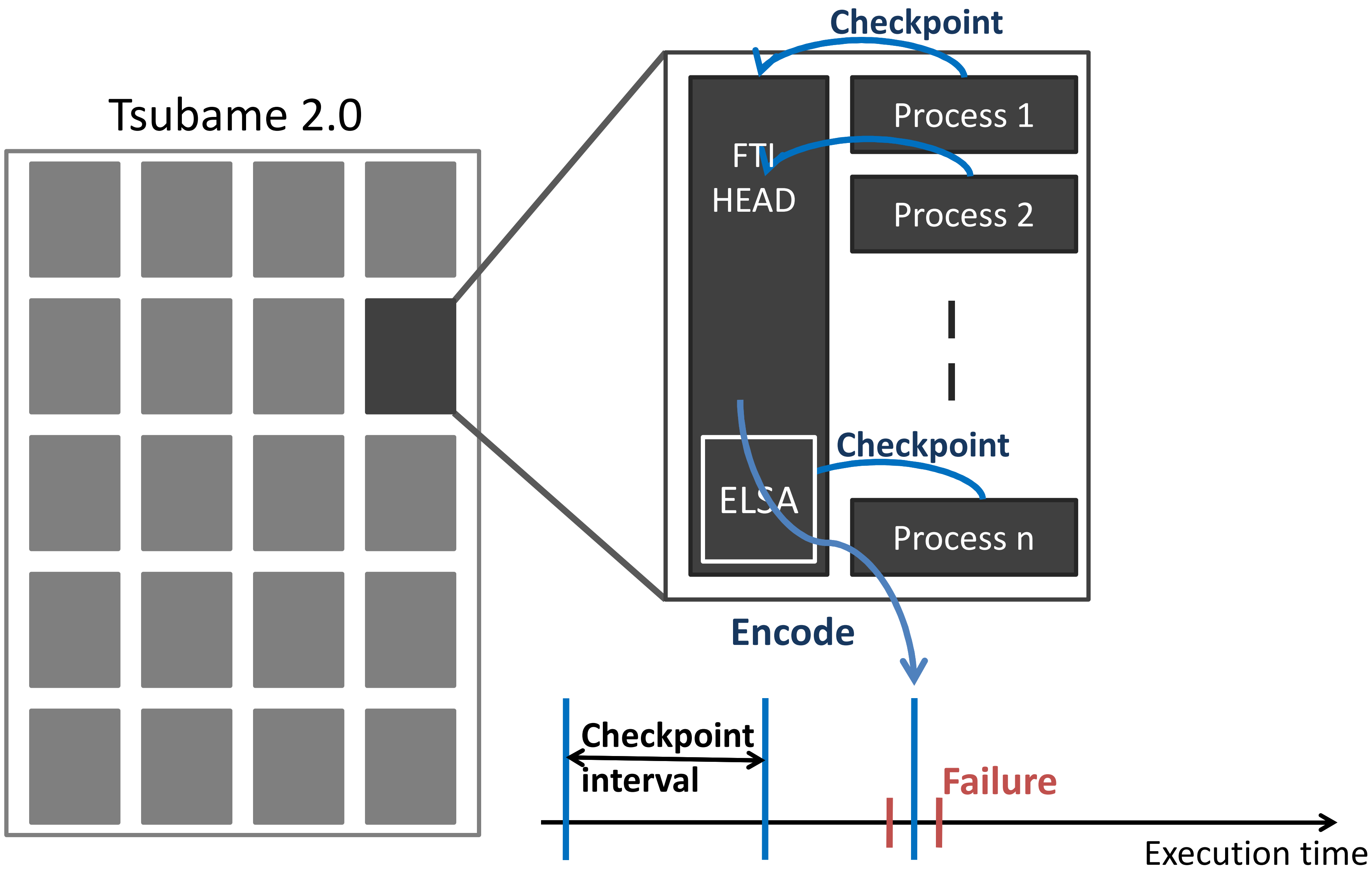

Modifications to ELSA

- As daemon:
  - Monitor the logs at all time
    - Adapt the correlation set
  - Reacts to the incoming stream of events
- Running distributed – application based
  - Looses multi-node errors
  - Save current predictions: Active chains
    - In case the prediction was wrong (FP) – adapts correlations
    - For true positives: positive precursors
  - Reads the log file bottom-up for 10s
    - More general view: Accurate anomaly detection

Modifications to ELSA

- Filtering the prediction send to the Head
  - According to the analytical model
    - Too early cases
  - Predictions that don't leave enough time to take a checkpoint
  - Predictions with low confidence
    - Are added in the suspicious list and are monitored
    - In case a suspicious list is confirmed
      - Adapt true positives cases
  - Predictions with high time lags
    - To decrease the waste – trigger the prediction later

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Experiments

- On Tsubame 2.0
- Logs:
  - Tsubame2 logs with synthetic / Tsubame2 correlations
- Different nodes, threads/node
  - 6 executions for each test case – mean
- Overheads include:
  - The preventive and proactive checkpoint waste
  - Protocol specific overheads
    - For example due to the communication between FTI and the application processes
  - Overhead of dedicating 1 extra thread per node for FTI

Test cases

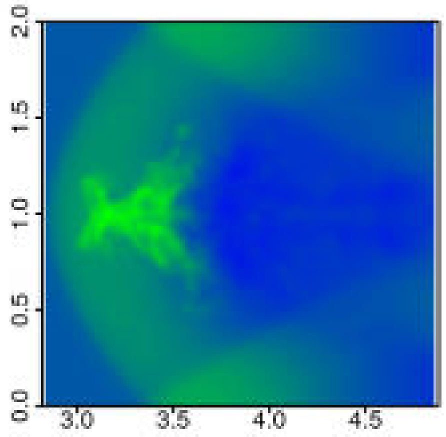
- Failure free execution
  - Measure overheads
    - FTI over no checkpoint
    - ELSA+FTI over initial version of FTI
    - ELSA+FTI over no checkpoint
- False positives
  - Triggers un-necessary checkpoints
  - Measure the overhead

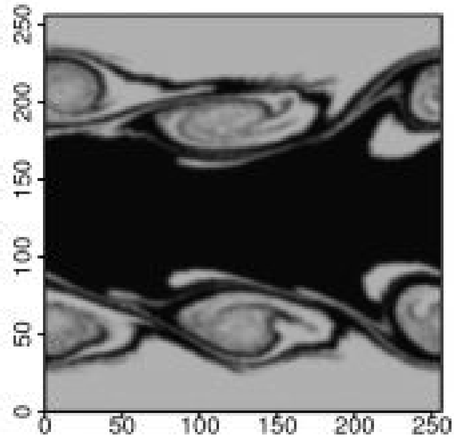
Applications

- Gadget2
  - Code for cosmological N-body simulations on massively parallel computers
  - Uses MPI
  - The same code can be used for
    - studies of isolated systems, for simulations of the cosmological expansion of space
  - Was used for the Millennium Run
    - One of the largest N-body simulation used to investigate how matter in the universe evolved over time
- We use 3 different tests based on Gadget2

Applications

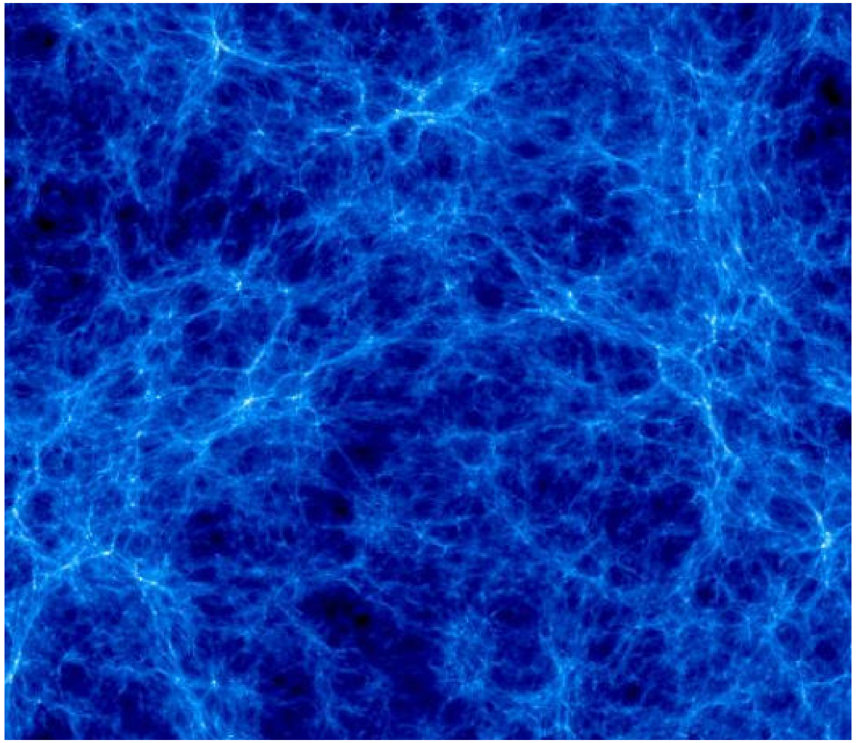
- Test cases
  - Blob test: A spherical cloud of gas is placed in a wind-tunnel with periodic boundary conditions.
    - 100MB checkpoint size
  - Kelvin-Helmholtz test: Two fluids in pressure equilibrium with opposing velocities. The interface between the fluids is perturbed. Records the evolution of mixing the fluids.
    - 100MB checkpoint size





Applications

- Test cases
  - LCM - The galaxy formation process
  - We only ran it for a small number of particles
  - Small example: 10 MB checkpoint size
  - Communication overhead



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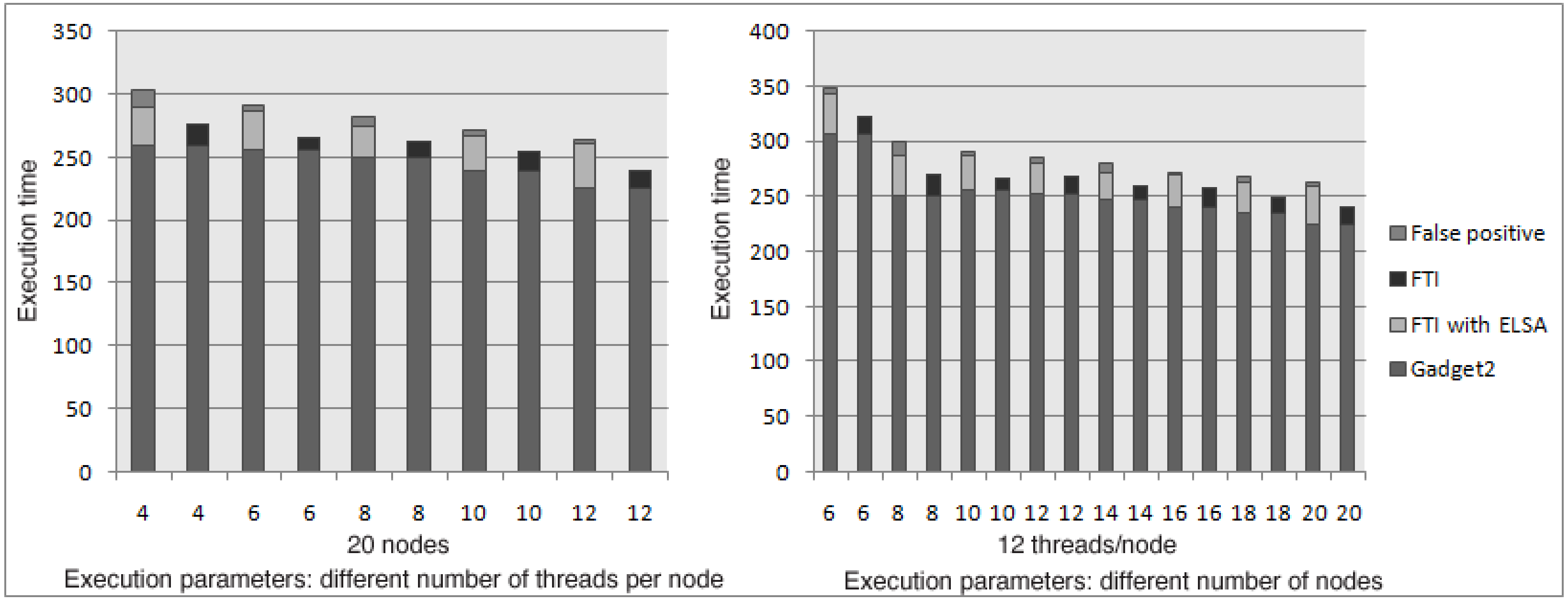
Results

- Changing
  - Number of threads in each node
  - Number of nodes the application executes on



Blob test

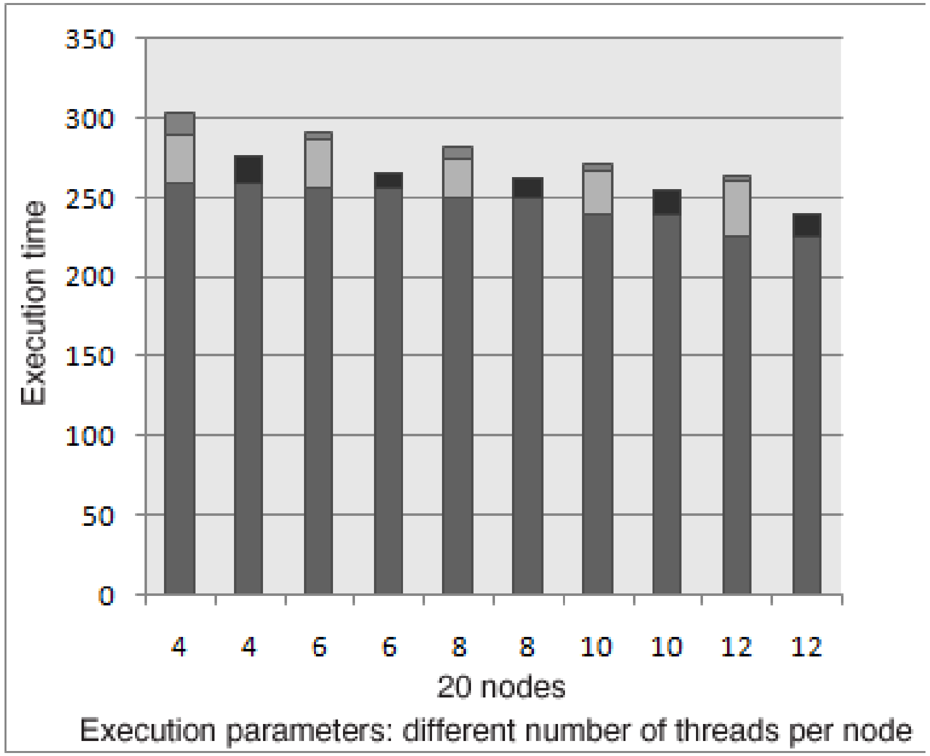
Results

- Changing
  - **Number of threads in each node**
  - Number of nodes the application executes on

Same number of Heads

- Same inter-node communication
- Same checkpoint size per node
- Higher intra-node communication

Constant execution difference



Blob test

Results

- Changing
  - **Number of threads in each node**
  - Number of nodes the application executes on

Same number of Heads

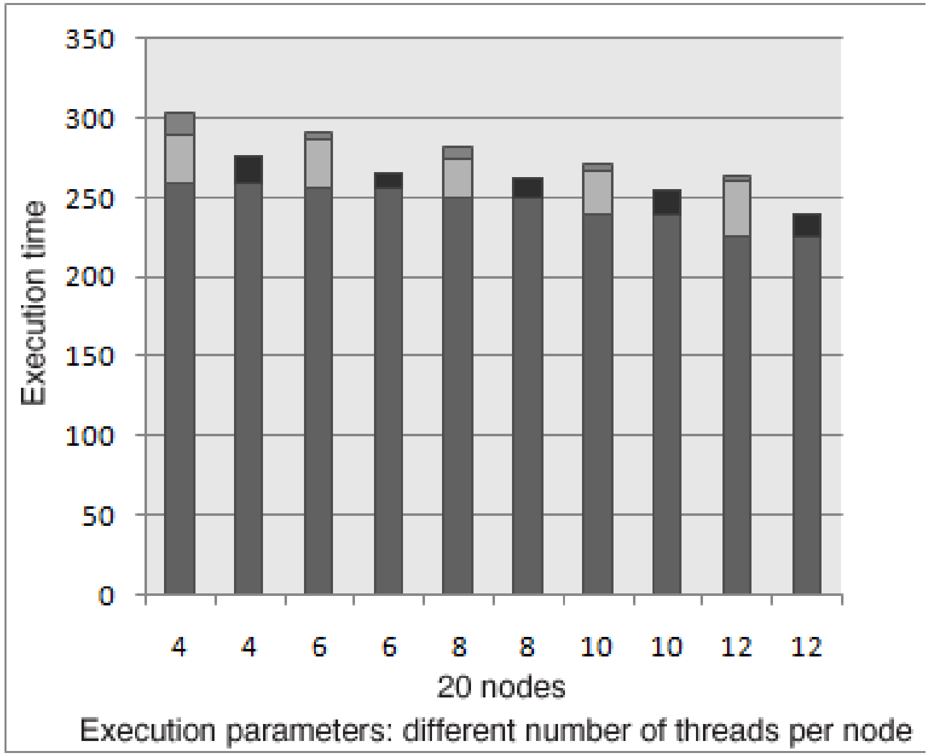
-
-
-

Co

Specific to the Blob test

- Irregular application: iterations have different execution times.
- FTI needs to adapt the check window

No patterns in the overhead



Blob test

Results

- Changing
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Same number of Heads

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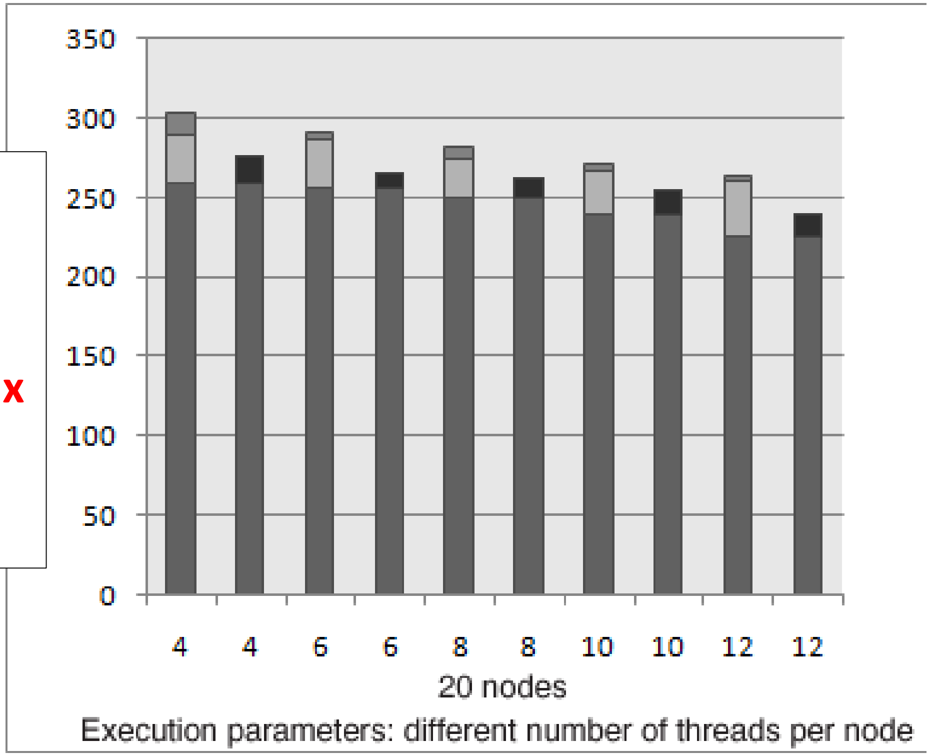
Overheads

FTI has around 6%

FTI and ELSA have min 8% and max 11%

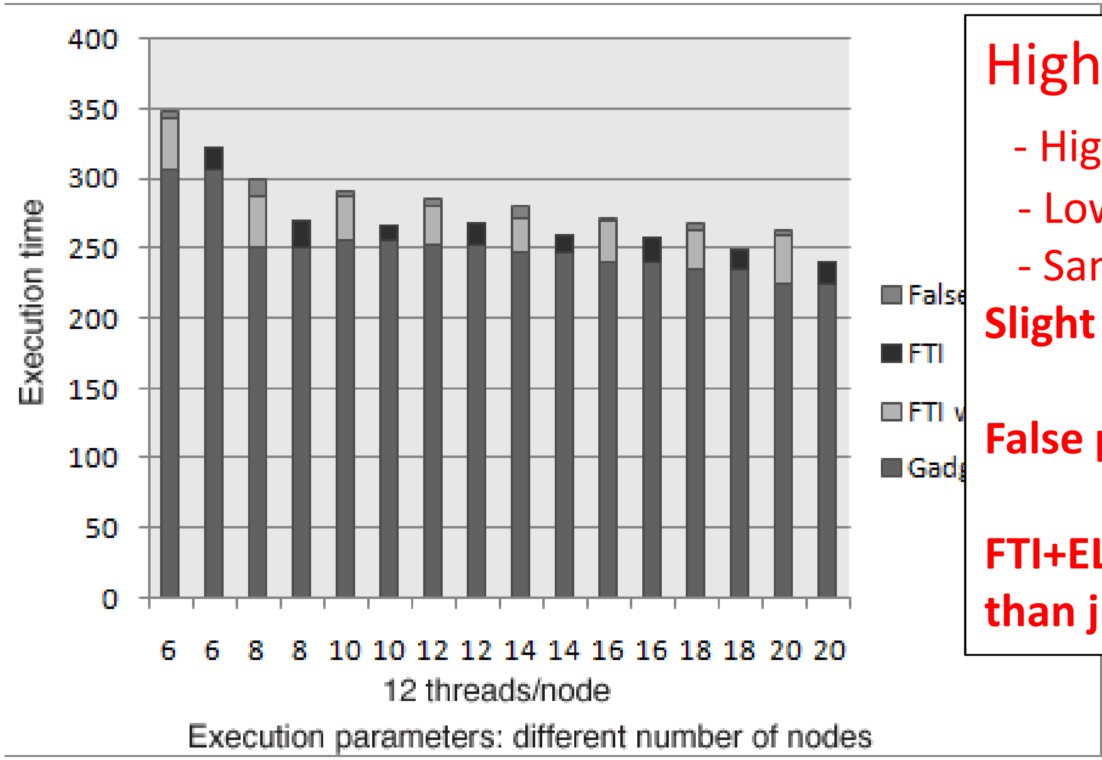
False positives add around 2%



Blob test

Results

- Changing
  - Number of threads in each node
  - **Number of nodes the application executes on**



Higher number of Heads

- Higher inter-node communication
- Lower checkpoint size per node
- Same intra-node communication

Slight increase in overhead

False positives add ~1.5%

FTI+ELSA overhead higher with 2-6% than just FTI

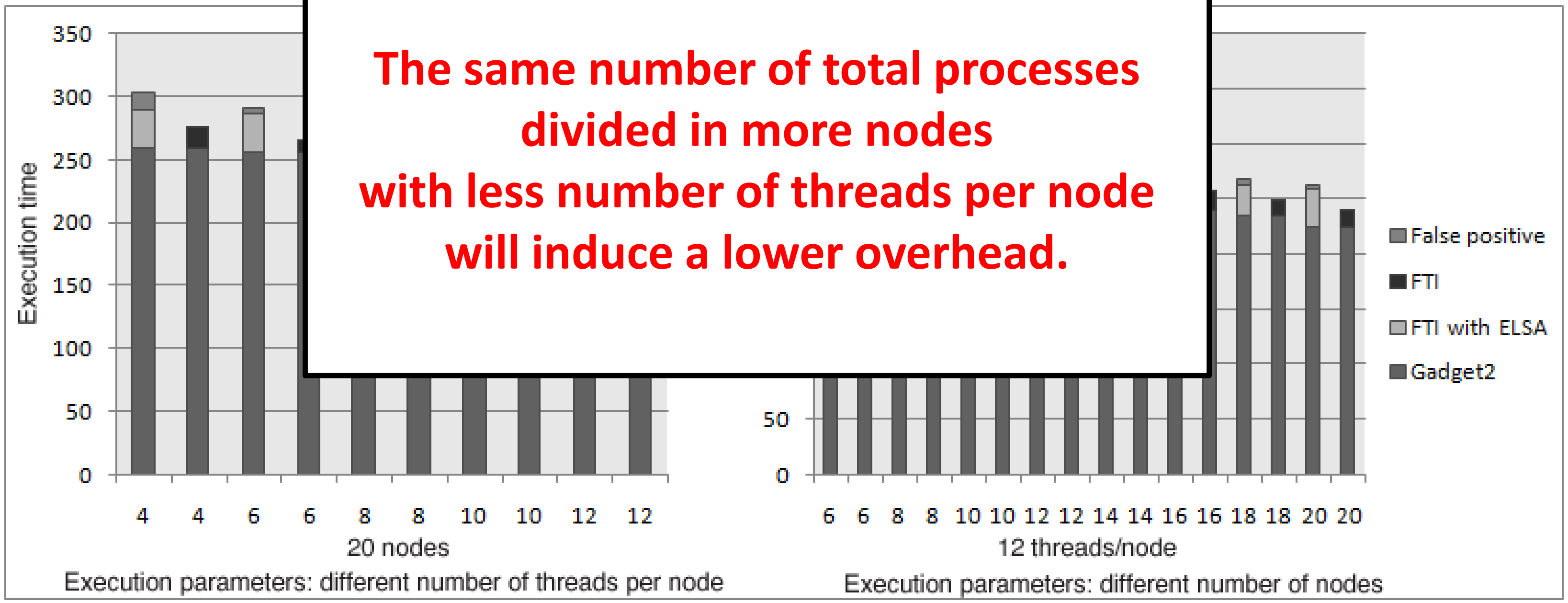
Blob test

Results

- Changing
  - Number of threads in each node
  - Numb tes on

Observation

The same number of total processes divided in more nodes with less number of threads per node will induce a lower overhead.



Blob test

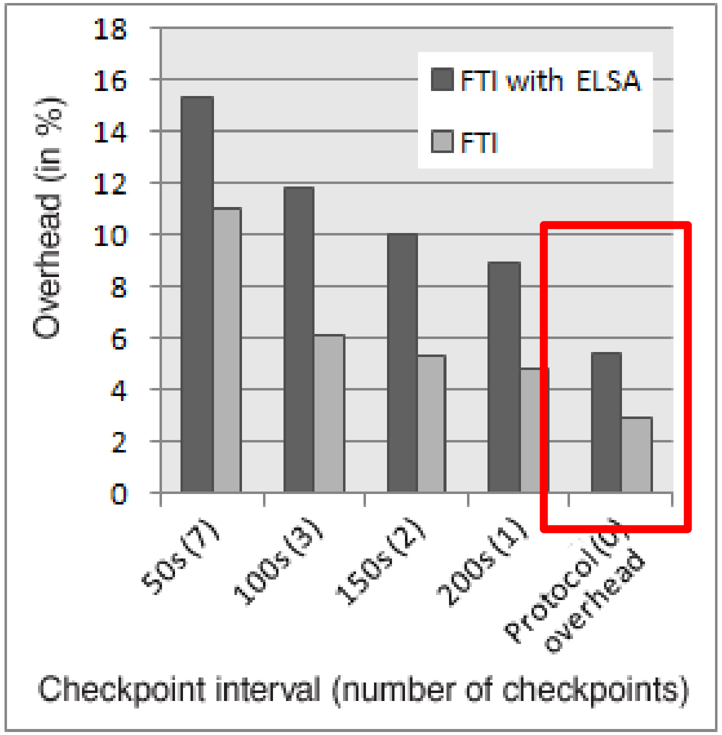
Results

- Overhead for different checkpoint intervals
  - Same number of total processes

Lower bound

- FTI and ELSA running
- No checkpoints are taken
- The overhead is 5.44%

Communication overhead
- Observed on LCM



Blob test

Results

- Different correlation and template set
  - If the analysis of the correlation is <10s
    - No extra overhead
    - For the Tsubame2 correlations the analysis time is ~2s
  - Stress test:
    - 10 times more correlations – 1.3% overhead to ELSA+FTI
- Impact of the checking interval on the number of usable predictions
  - Results for ELSA daemon as baseline
    - Compared with FTI+ELSA with 10s check intervals
    - Recall difference of <1%
    - For check values > 30s the recall value drops
    - Depends on the system

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- Possible merging methodologies
- Modifications to FTI and ELSA
- Experiments test cases
- Results
- **Conclusions**
- **Future directions**

Conclusion

- FTI + ELSA
  - Shows ~12% overhead
    - Compared with no-chekpoint
  - With just 2-6% more than FTI alone
    - Mostly because the increase in intra-node communication
  - Baseline of ~5% overhead
  - Small extra overhead due to false positives (~1-2%)
- ELSA
  - Looses multi-node failures – Recall of 40%
  - Looses predictions with small lead time
    - Recall of 32%

Future work

- Fault distribution after prediction
- Include multi-node predictions
  - Without increasing inter-node communication
- Include statistic metrics into the prediction process
  - Precursor detectors for the prediction
  - System degradation prediction
- Predict the un-error periods
  - Decrease the waste due to taking unnecessary checkpoints

Collaboration directions

1) Mathematical models for computing the benefits
   – Collaboration with INRIA / UIUC

2) Combining prediction with other solutions
   2.1) Live migration
   - Collaboration with ANL / INRIA (also IBM)

   2.2) Charm++ fault tolerance
   - Collaboration with UIUC

3) Using ELSA for root cause analysis
   – Collaboration with UIUC / ANL (also Sandia)

4) Understanding failures in HPC: precursor detectors
   – Collaboration with UIUC / ANL

Additional Q&A

Thank you

Ana Gainaru

Coupling failure prediction, proactive and preventive checkpoint for current production HPC systems

Applications

Blob test

Kelvin-Helmholtz test