Automatic Phase Detection and Structure Extraction of Parallel Applications

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2012

Outline

- Background and Context.
- Automated Phase Detection of MPI Applications through Spectral Analysis.
- Other applications of Spectral Analysis.
  - Mutliplexing Hardware Counters.
  - Detecting Representative Sections for Architecture Simulation.
- Conclusions.

Performance Tools Overview

Acquisition

Presentation

Profile land

Sampling land

$\int_a^b f(t)dt$

Processors/processes

Time

Event types

Instrumentation land

$f(t, p)$

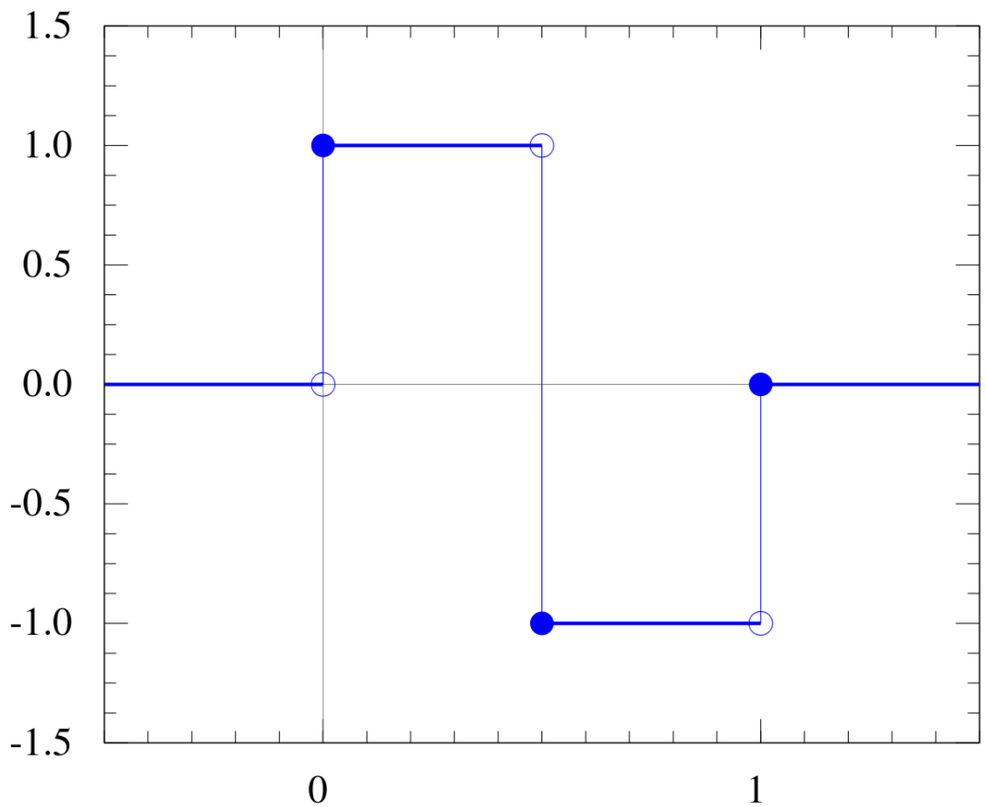
Timeline land

Signal Processing Overview. Wavelet Transform.

- Applied in many topics: image compression, sensor networks, signal processing

- It gives information not only about frequencies but also about their physical location within signal's domain.

- Definition:



$$x(t) = \sum_{k=-\infty}^{\infty} \sum_{n=-\infty}^{\infty} d_{k,n} \psi_{k,n}(t)$$

$$d_{k,n} = \langle \psi_{k,n}(t), x(t) \rangle = \int_{-\infty}^{\infty} \psi_{k,n}(t) x(t) dt$$

$$\psi_{k,n} = 2^{-\frac{k}{2}} \psi(2^{-k} t - n)$$

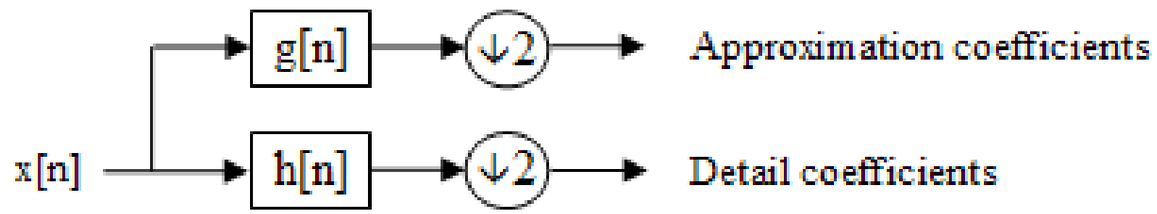
Signal Processing Overview. Fast Wavelet Transform.

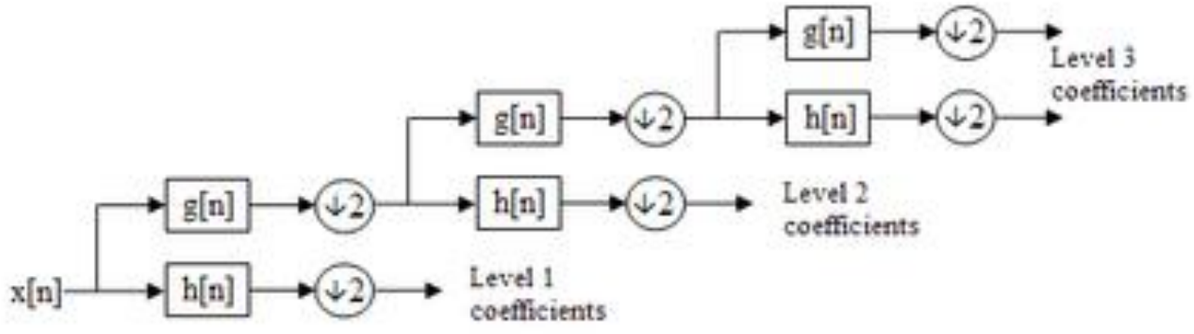
- It is not possible to obtain directly the wavelet transform coefficients.

- Given a signal, we sample it obtaining N=2^J points, using a sampling frequency α.

- From this information we obtain J sets of coefficients:
  - N/2 coefficients containing information about [α/2, α/4]
  - N/4 coefficients containing information about [α/4, α/8]
  - ...

- We can detect high-frequency regions of signals.

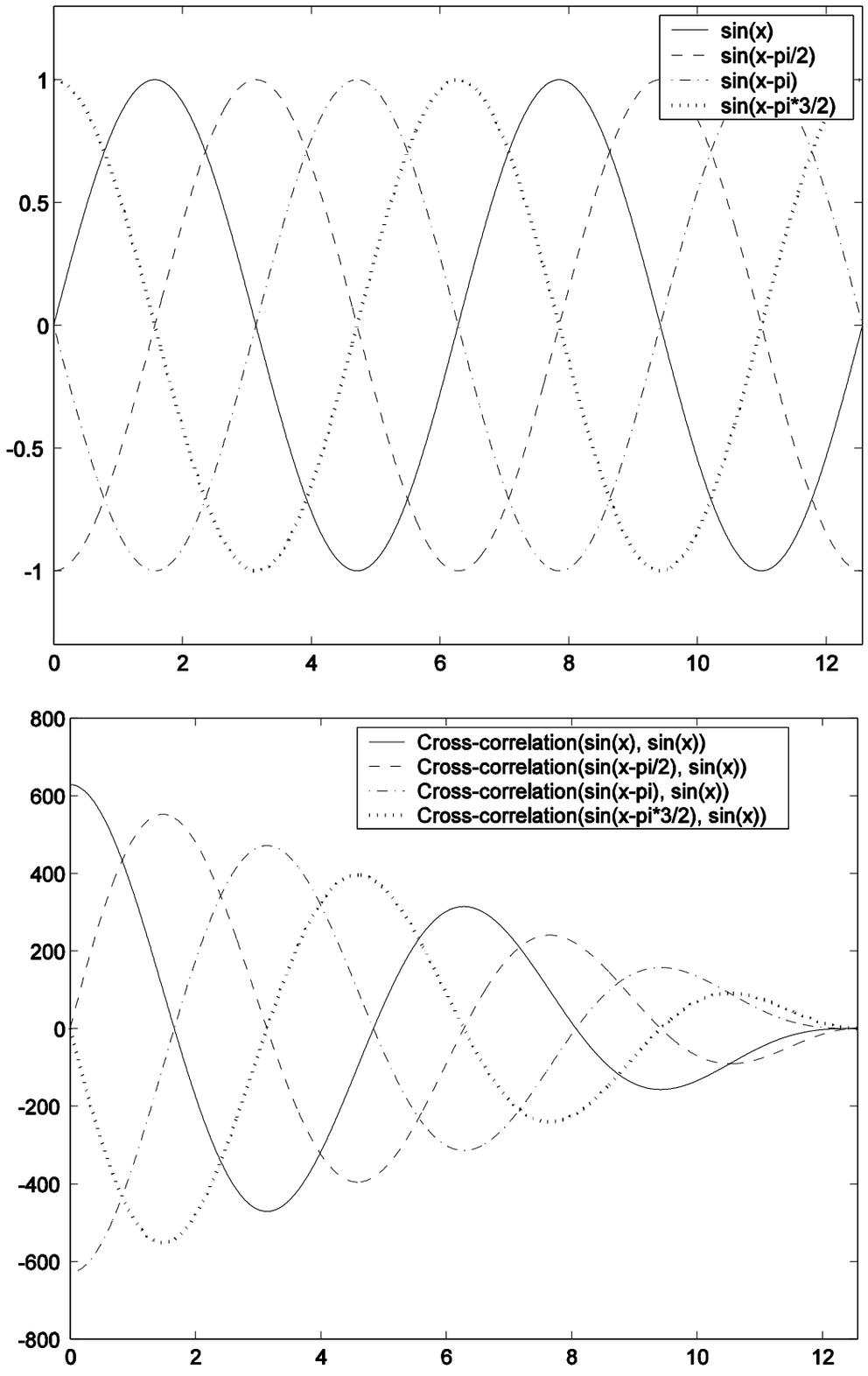




Signal Processing Overview. Cross-correlation

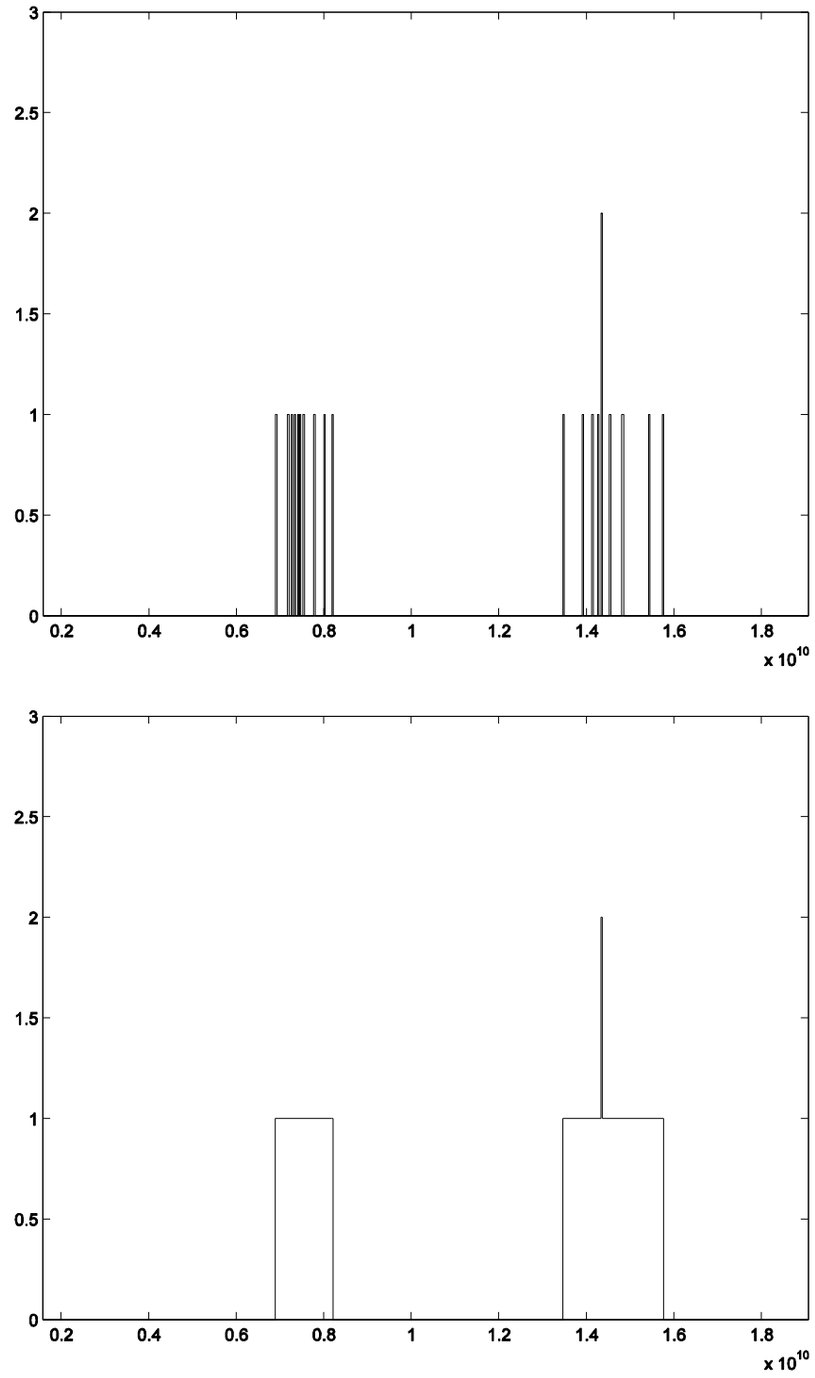
- It is used to evaluate the degree of similarity between two signals.
- It reaches high values at the points where the similarity between two signals is also high.
- Definition:

$$(f \star g)[n] = \sum_{m=-\infty}^{\infty} f^*[m]\, g[n+m]$$



Signal Processing Overview. Mathematical Morphology.

- Its main focus is to extract automatically useful information from images or signals.
- It has to main operators: Erosion and Dilation
- From these two, we can define interesting operations, such us Opening and Closing.



- Opening eliminates small regions where input signals are different from zero.
- Closing unifies non-zero regions of the input signals.

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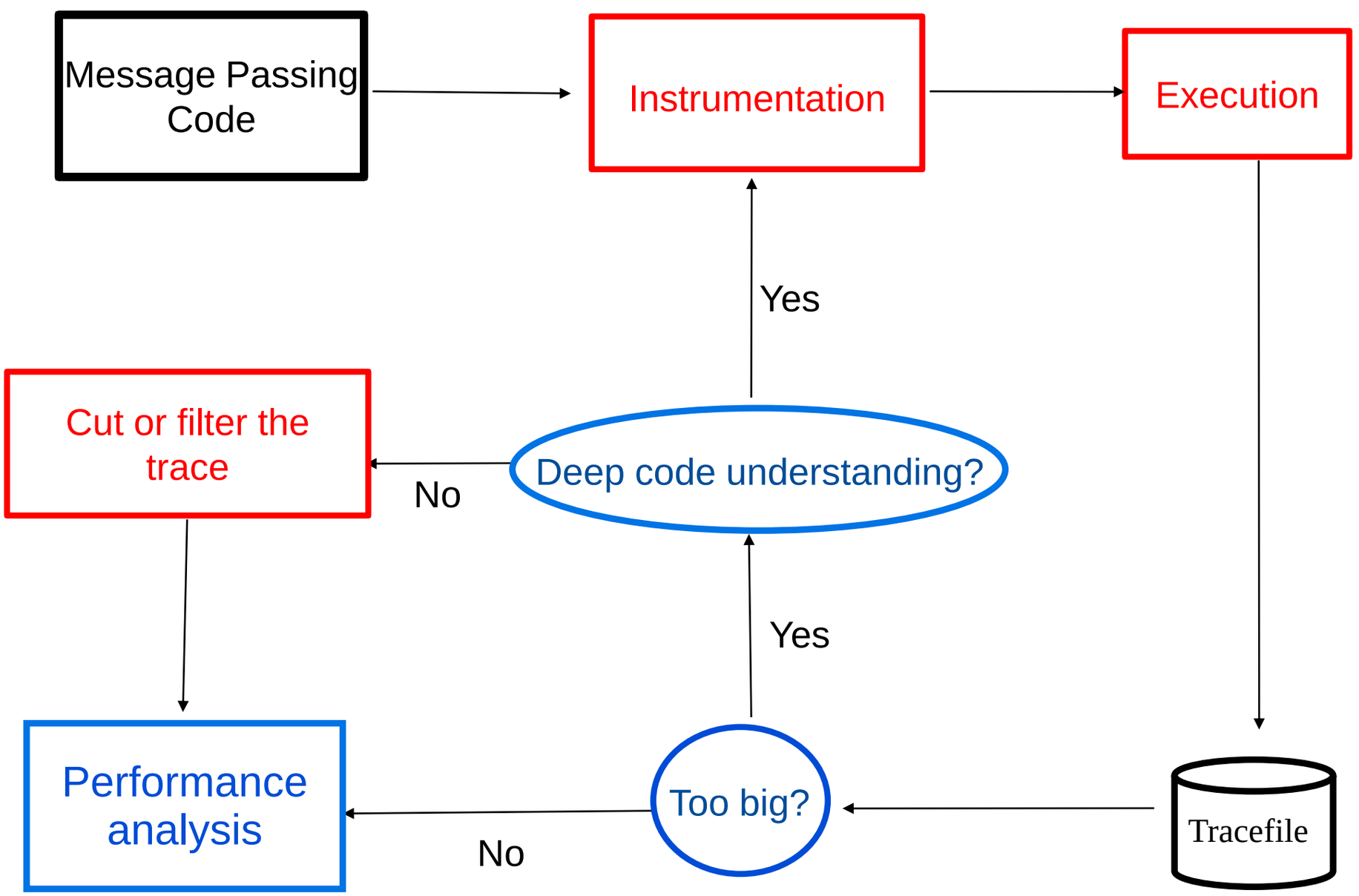
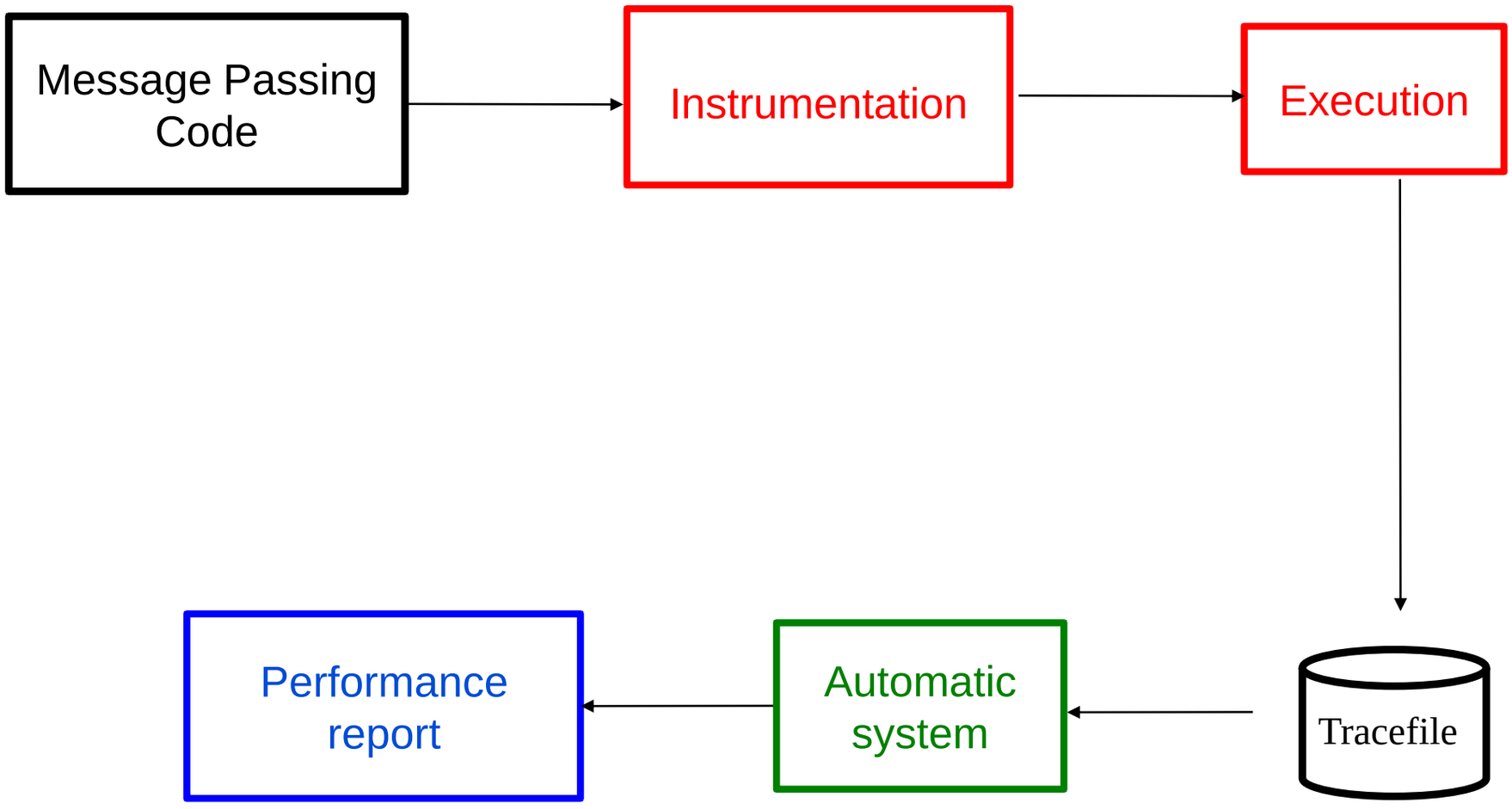
Motivation

Manual Performance Analysis



Motivation

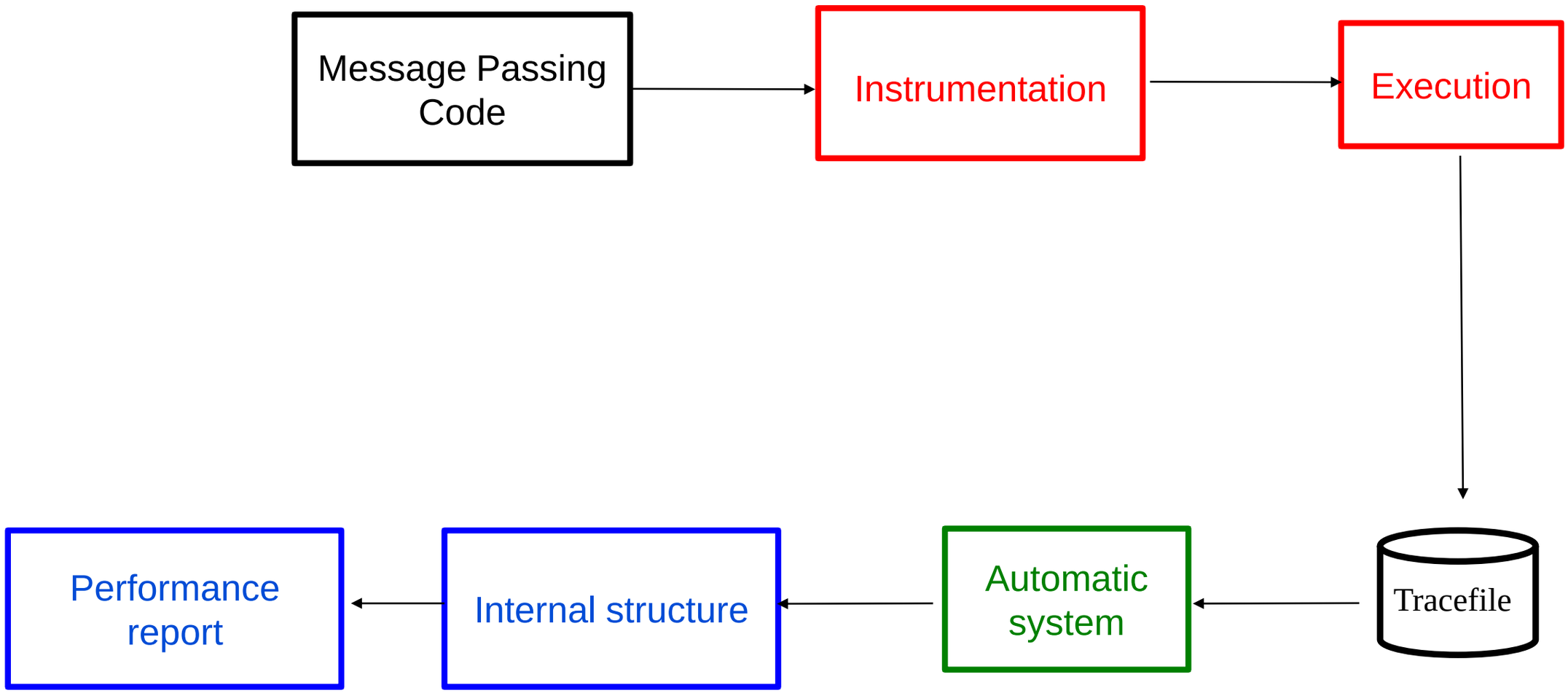
Related Work



KOJAK, TAU, ...

Motivation

Our Proposal



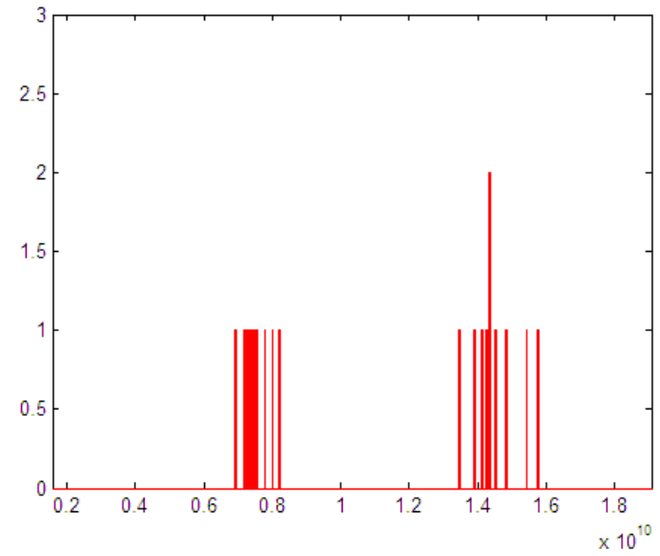
Analysis of internal structure

- This analysis has two main phases:
  - Clean – up:
    - Identification of the corrupted regions of the trace file.
    - This phase is important to detect regions which can affect the statistics.
  - Search for Structure:
    - Identification of the internal structure of the trace file.
    - It is important because allows us to identify a small but representative region.

Filtering: perturbed regions

- Applicable to signals such as
  - Flushing processes
  - Cycles/Time (preemptions)
  - #msgs/BW (clogged system)

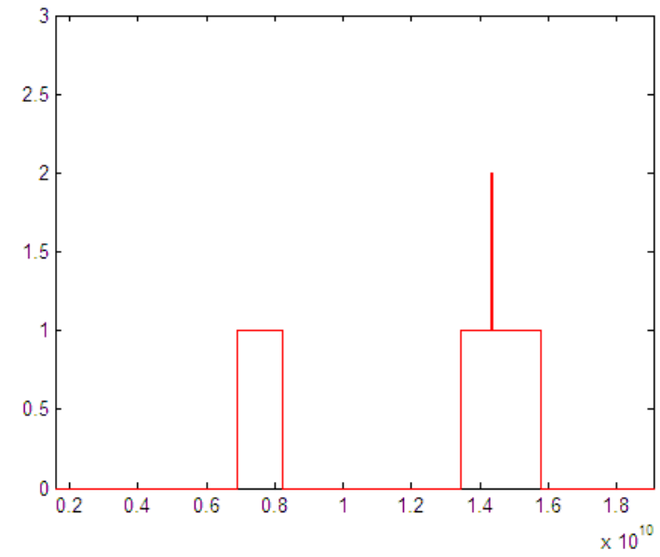
- Typically, these signals have many small bursts



Number of processes flushing

- Mathematical morphology
  - Non linear filtering: max (Dilation), min (erosion)
  - Merge nearby perturbed regions of sufficient width
  - Discard non-perturbed regions if very small

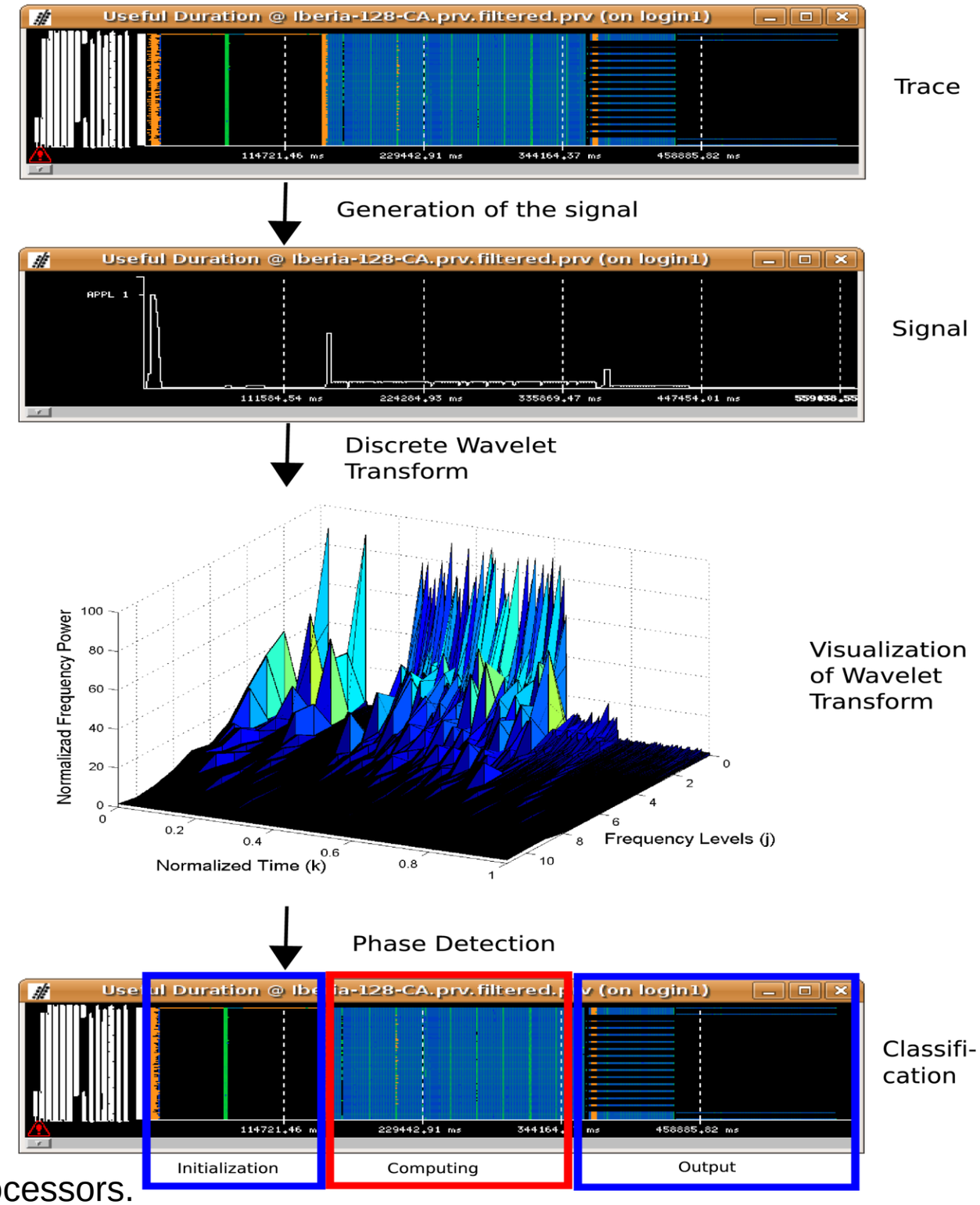
- Parameter: diameter
  - 1/1000 of application time



Globally perturbed regions

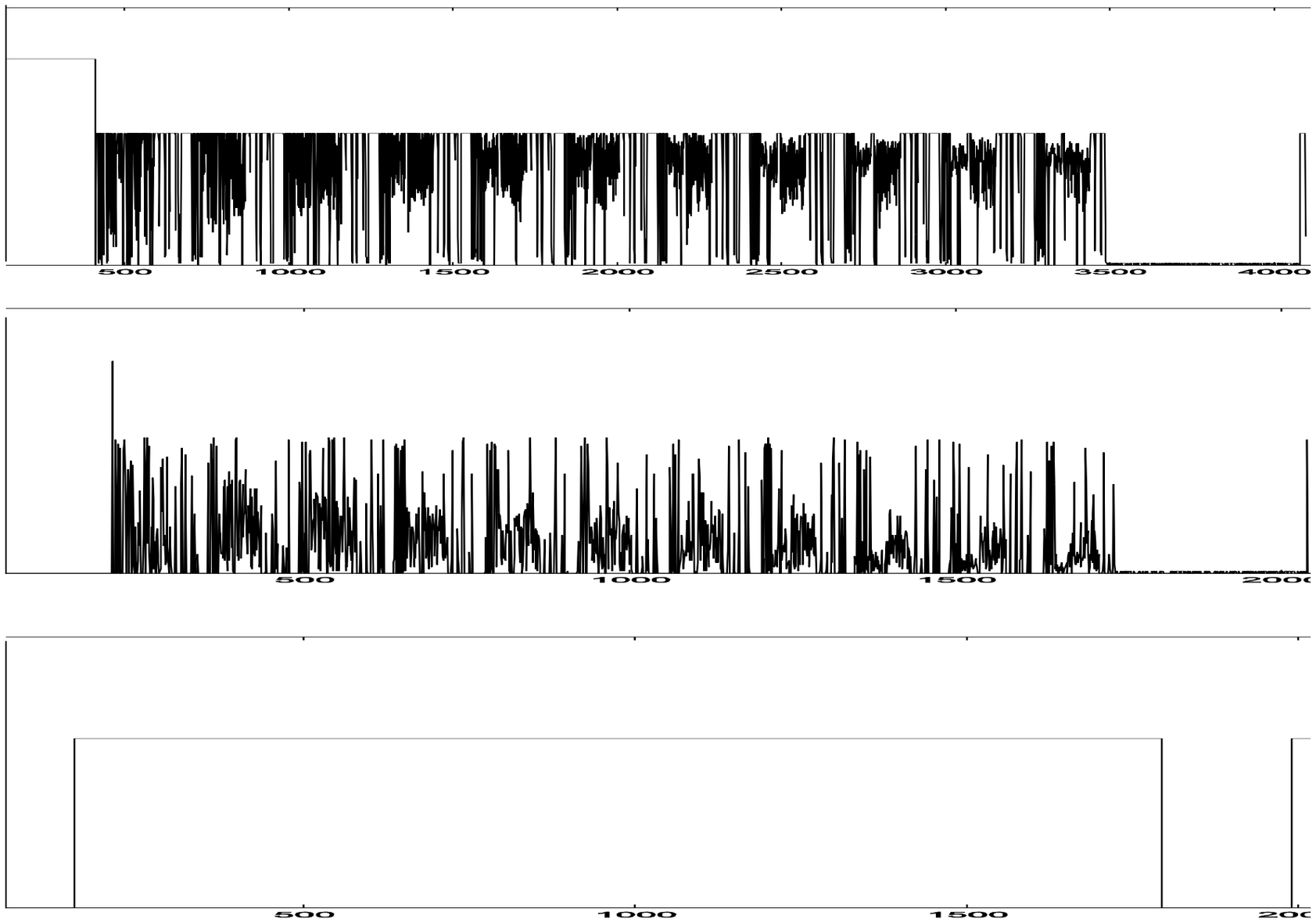
Execution phases

- Main Execution Phases:
  - Initialization: Low Frequency
  - Computing: High frequency
  - Output: Low Frequency
- Wavelet transform
  - Frequency levels ~10
  - High Frequencies at level 0



WRF-NMM over a 4 km of the Iberian Peninsula with 128 processors.

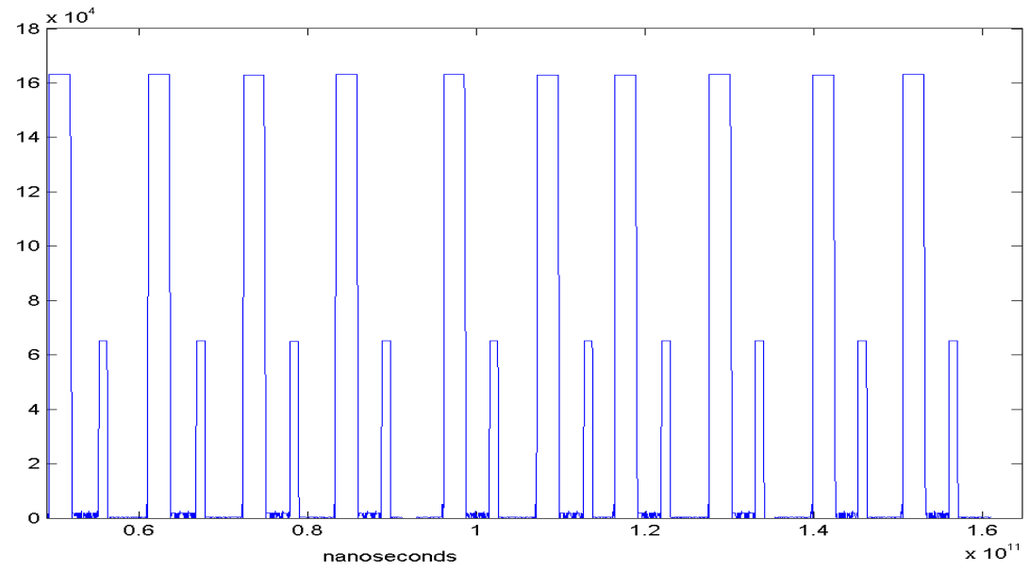
Detection of Computing Phases. Example.

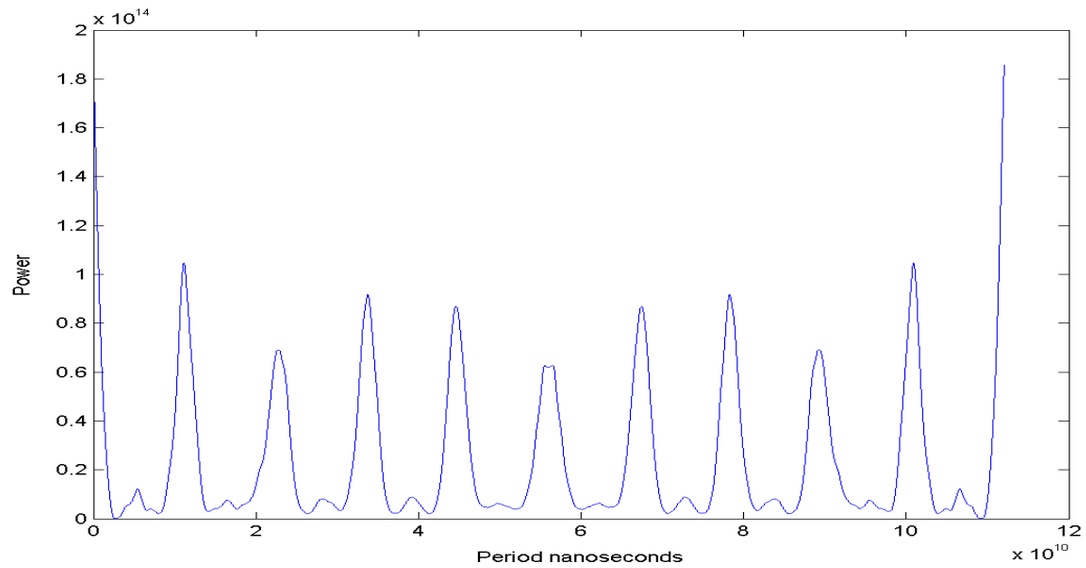


- Input Signal
  - Low Frequency at the beginning
  - High Frequency in the middle
- Fast Wavelet Transform:
  - High Frequency Coefficients
- Selection
  - Closing Operator

Detection of Iterative Patterns

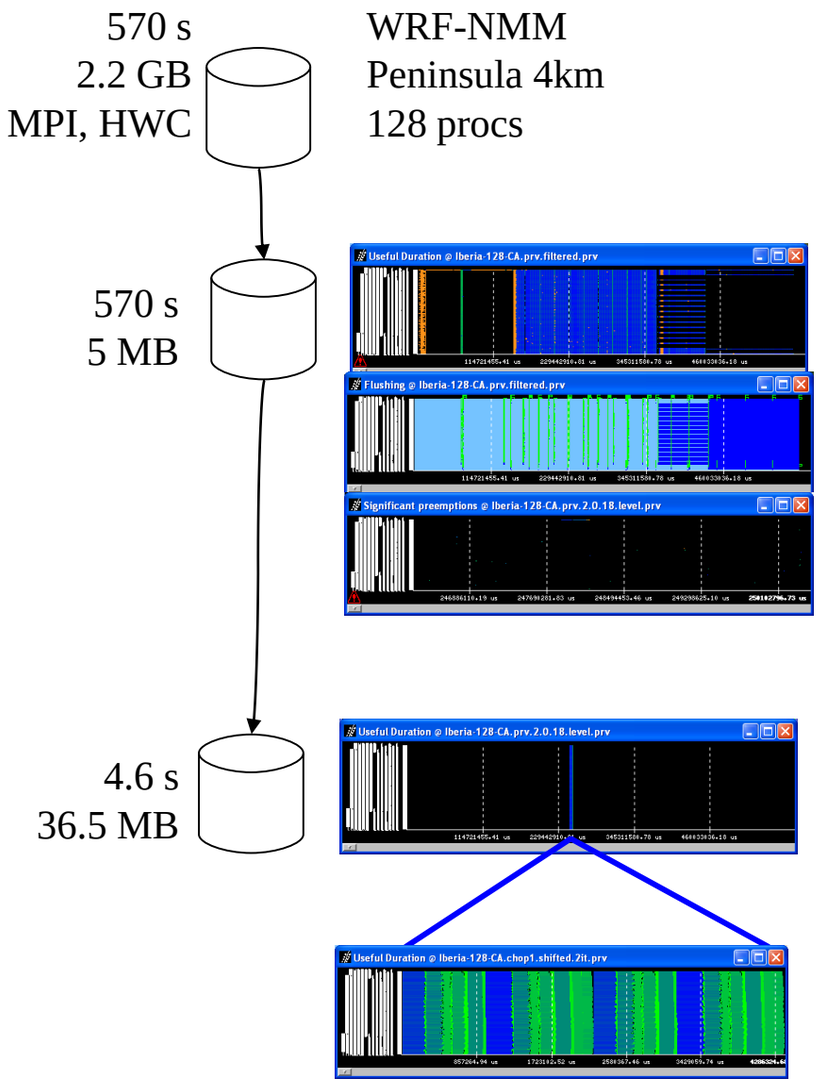
- Compute autocorrelation
- Search for largest local maximum (!=0)
- Refinement criteria in case of multiple non harmonic maxima of similar magnitude
  - Within 90%
  - Filter high frequencies and repeat (trying to identify large periodic patterns)
- Cross-correlation to detect several representative iterations



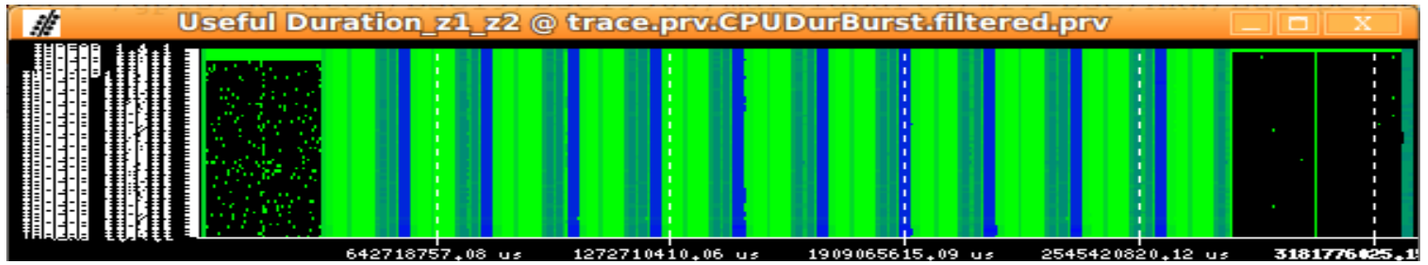


Summary of the Methodology

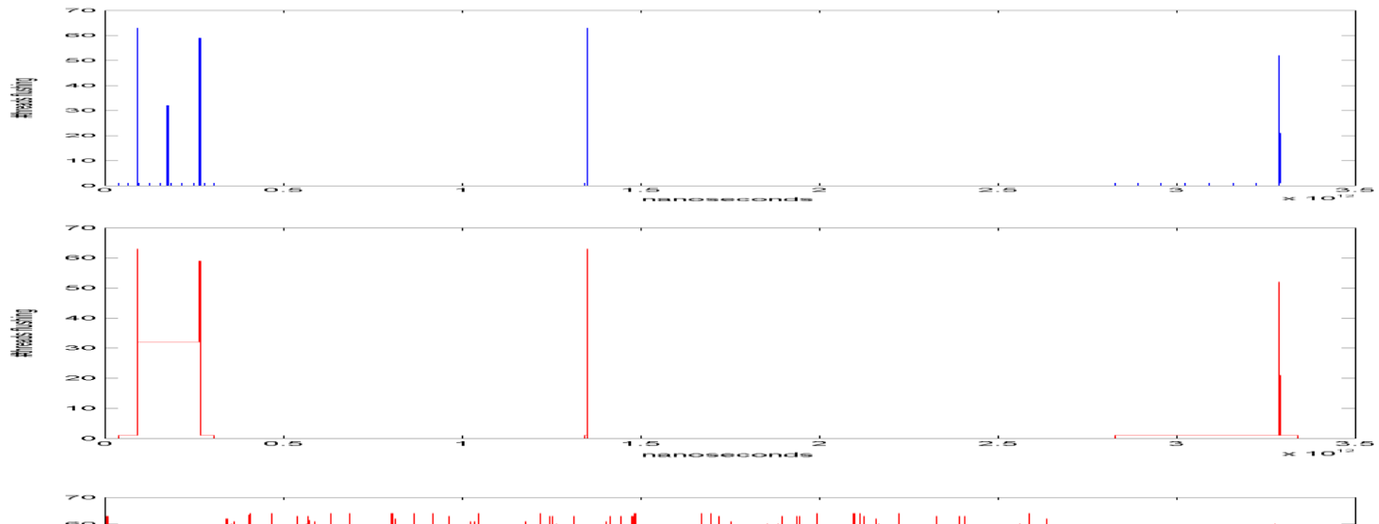
- Generation of metrics.
  - Flushing, number of processes computing, etc...
- Application of signal processing techniques:
  - Mathematical morphology to clean up perturbed regions.
  - Wavelet transform to identify high-frequency regions.
  - Autocorrelation analysis to detect detailed periodic patterns.
  - Cross-correlation to detect representative iterations.
  - Automatically generate a representative subtrace of a few iterations.
- Recursion to detect hierarchical structure.



An Example (CPMD)

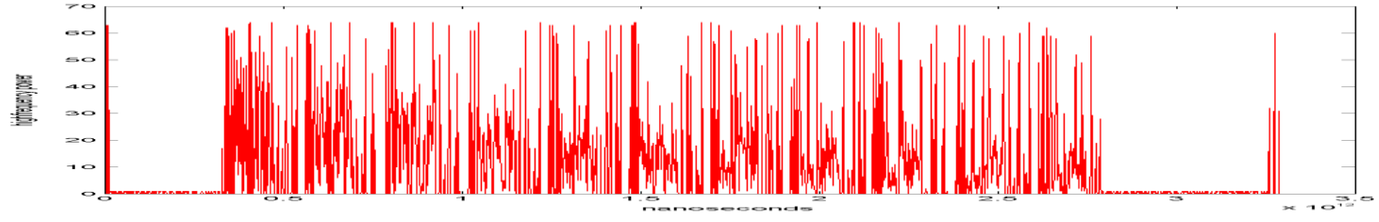


Flushing

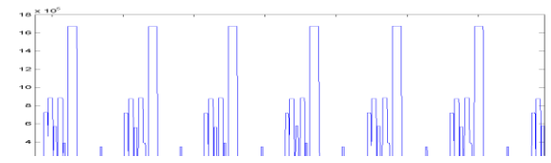


Flushing filtered

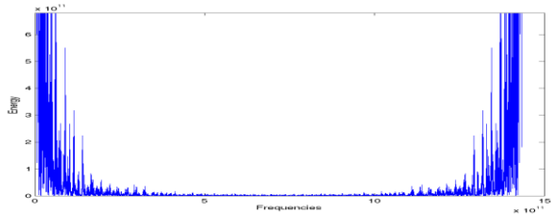
Wavelet
high frequency



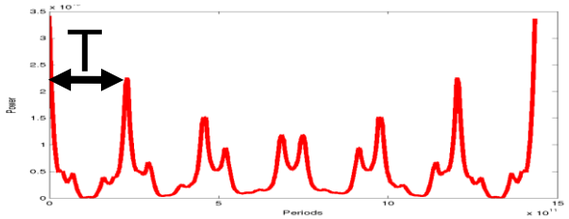
Σ Useful Duration



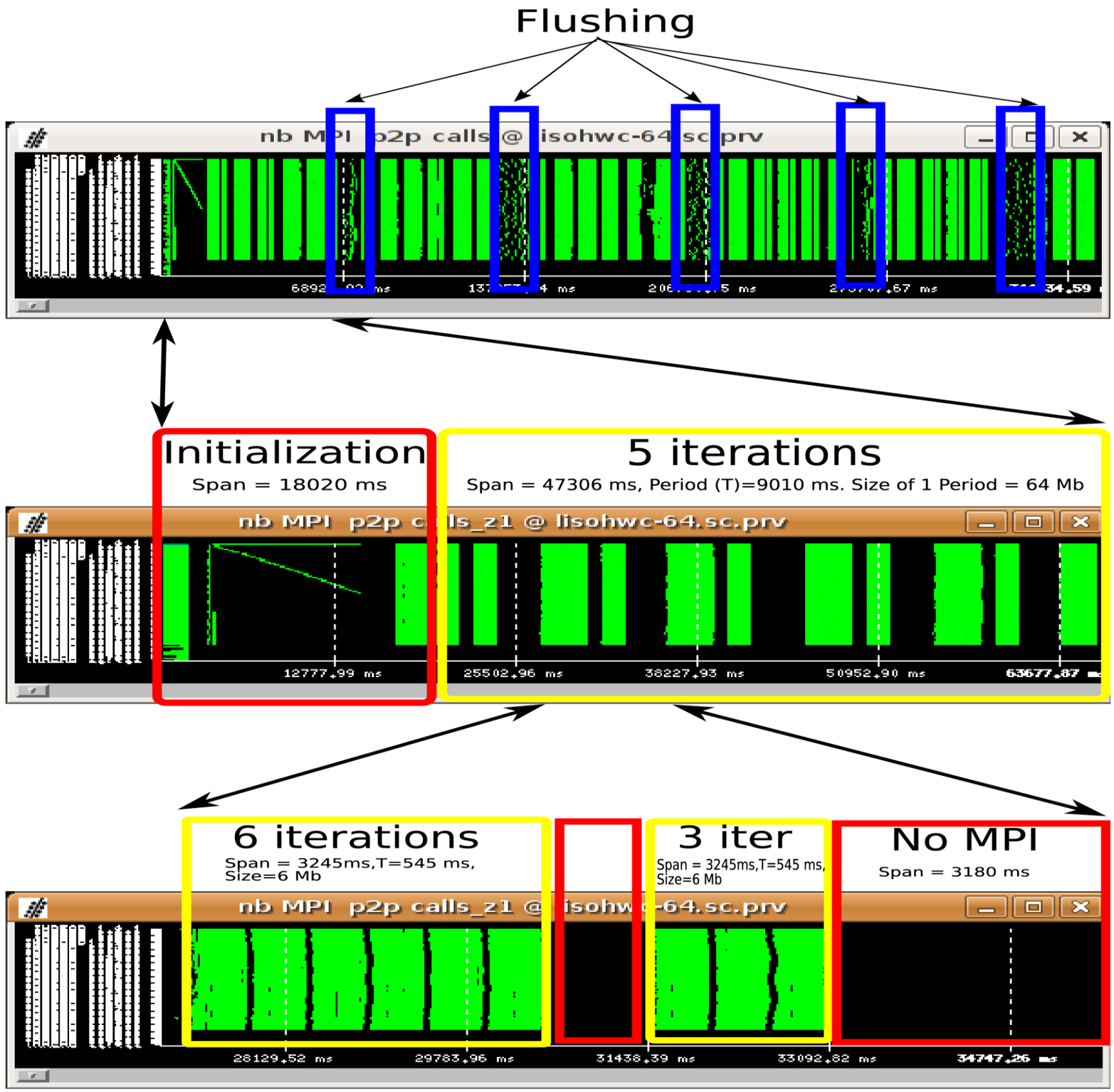
Spectral density



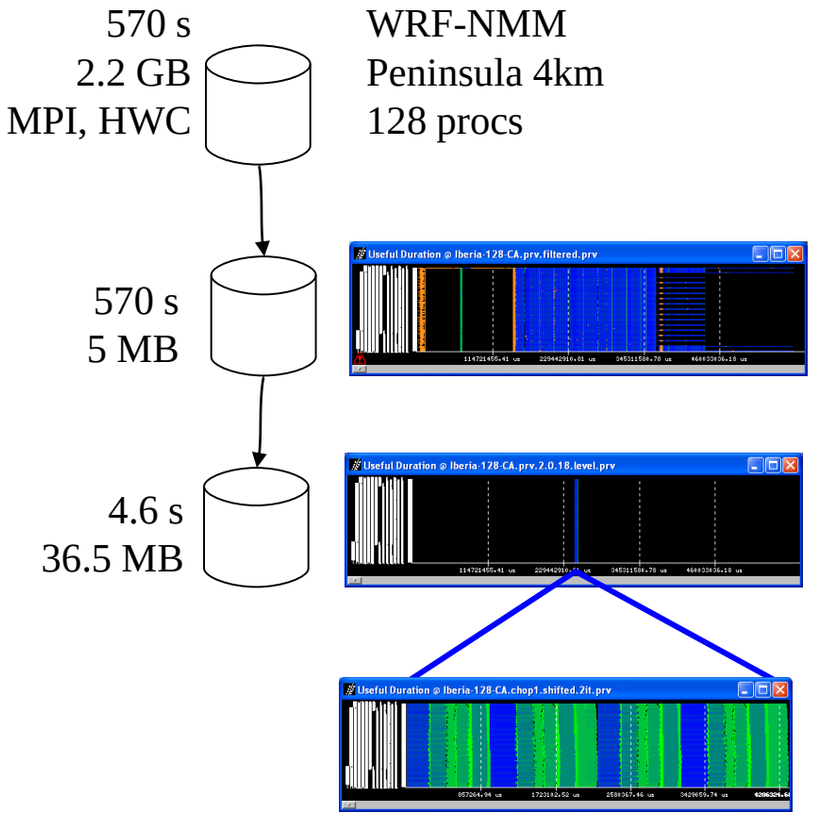
Autocorrelation

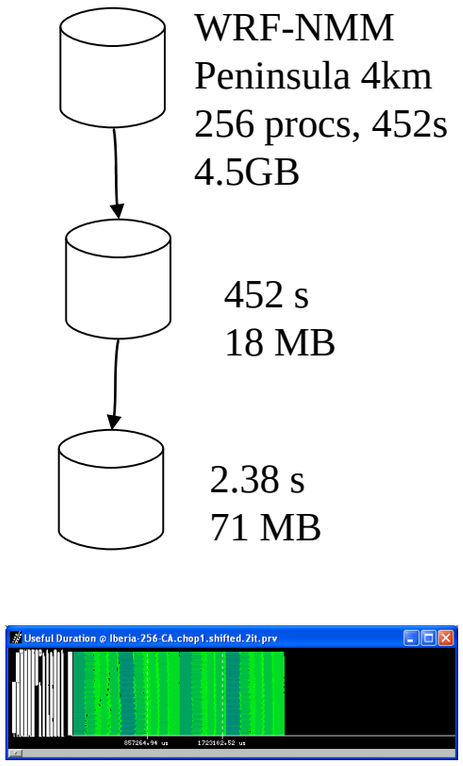


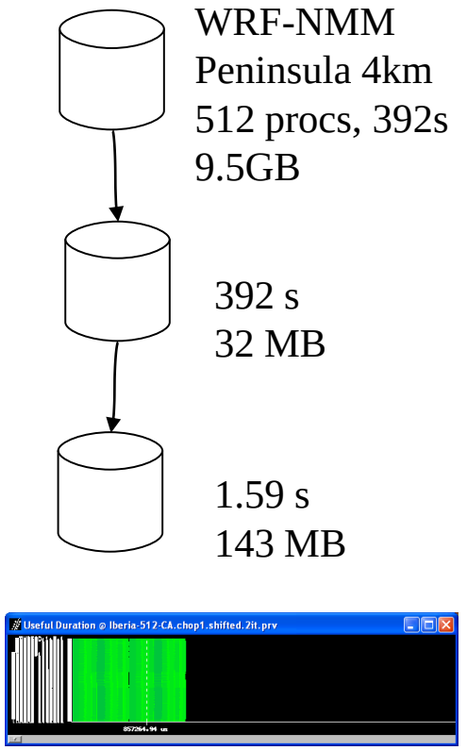
Results: Example of Complete Application Structure



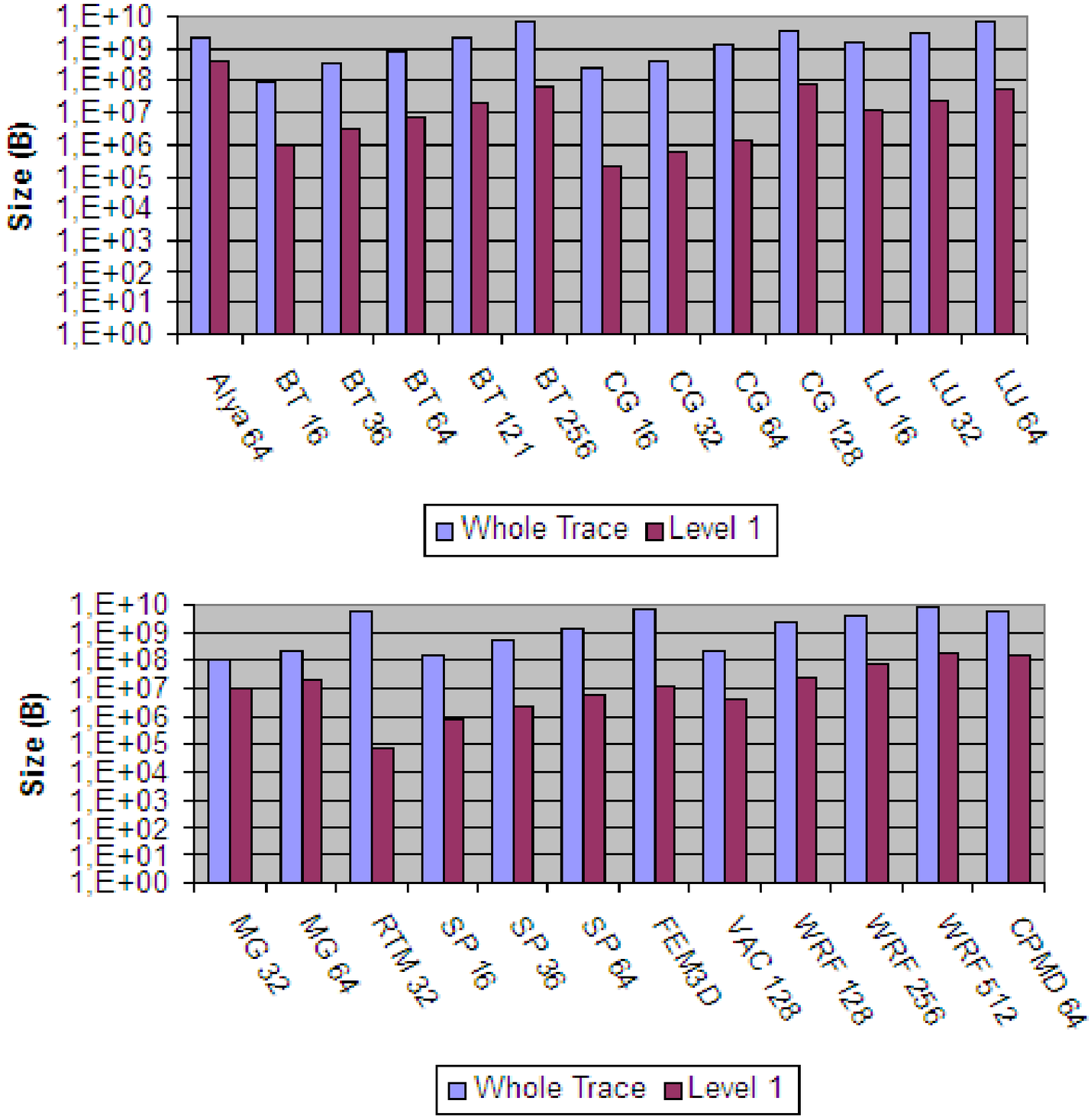
Results


570 s
2.2 GB
MPI, HWC
WRF-NMM
Peninsula 4km
128 procs
570 s
5 MB
4.6 s
36.5 MB
Useful Duration @ Iberia-128-CA.prv.filtered.prv
Useful Duration @ Iberia-128-CA.prv.2.0.18.level.prv
Useful Duration @ Iberia-128-CA.chop1.shifted.2it.prv

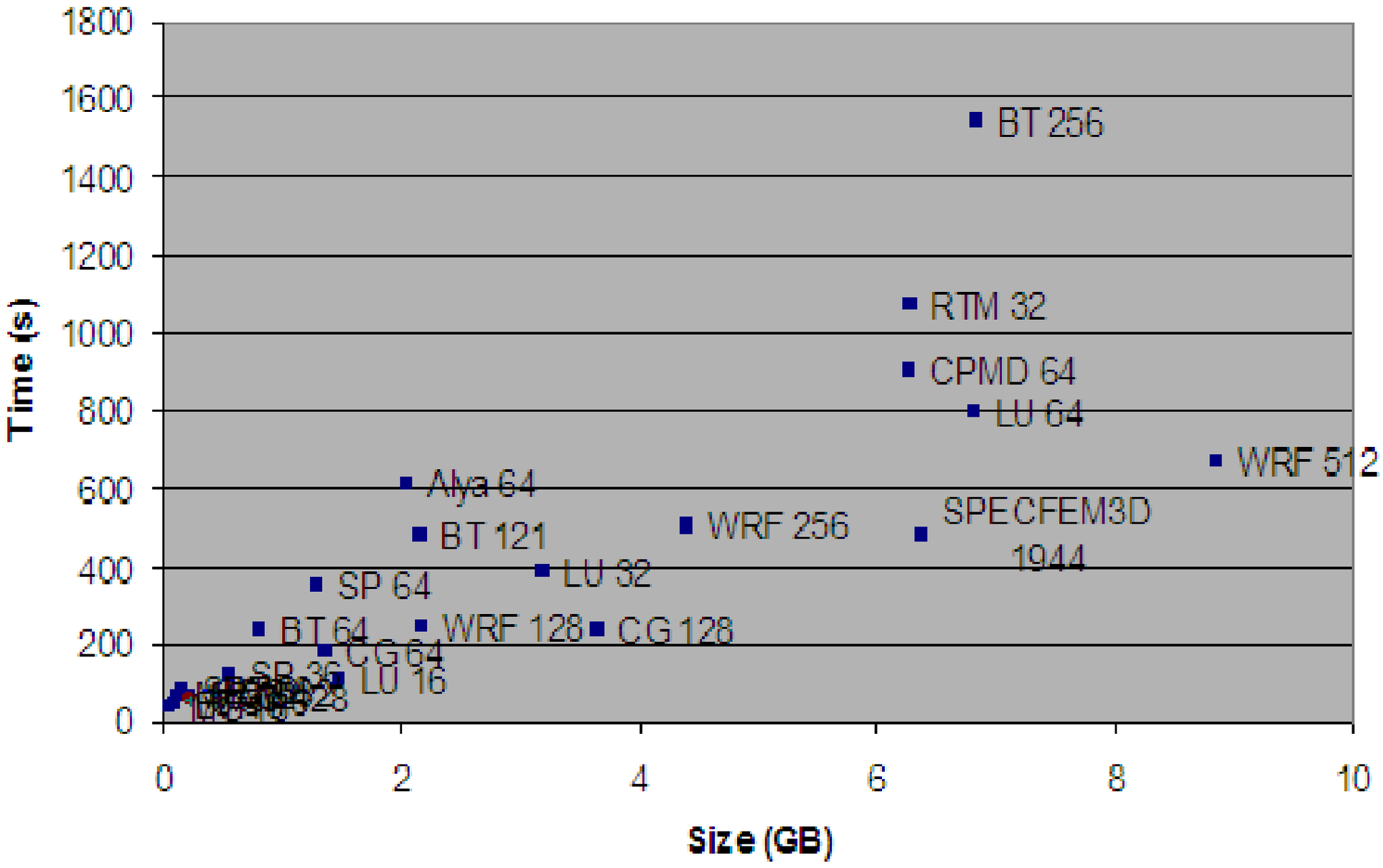

WRF-NMM
Peninsula 4km
256 procs, 452s
4.5GB
452 s
18 MB
2.38 s
71 MB
Useful Duration @ Iberia-256-CA.chop1.shifted.2it.prv


WRF-NMM
Peninsula 4km
512 procs, 392s
9.5GB
392 s
32 MB
1.59 s
143 MB
Useful Duration @ Iberia-512-CA.chop1.shifted.2it.prv

Results. Size Reduction.



Results. Scalability of the Analysis.



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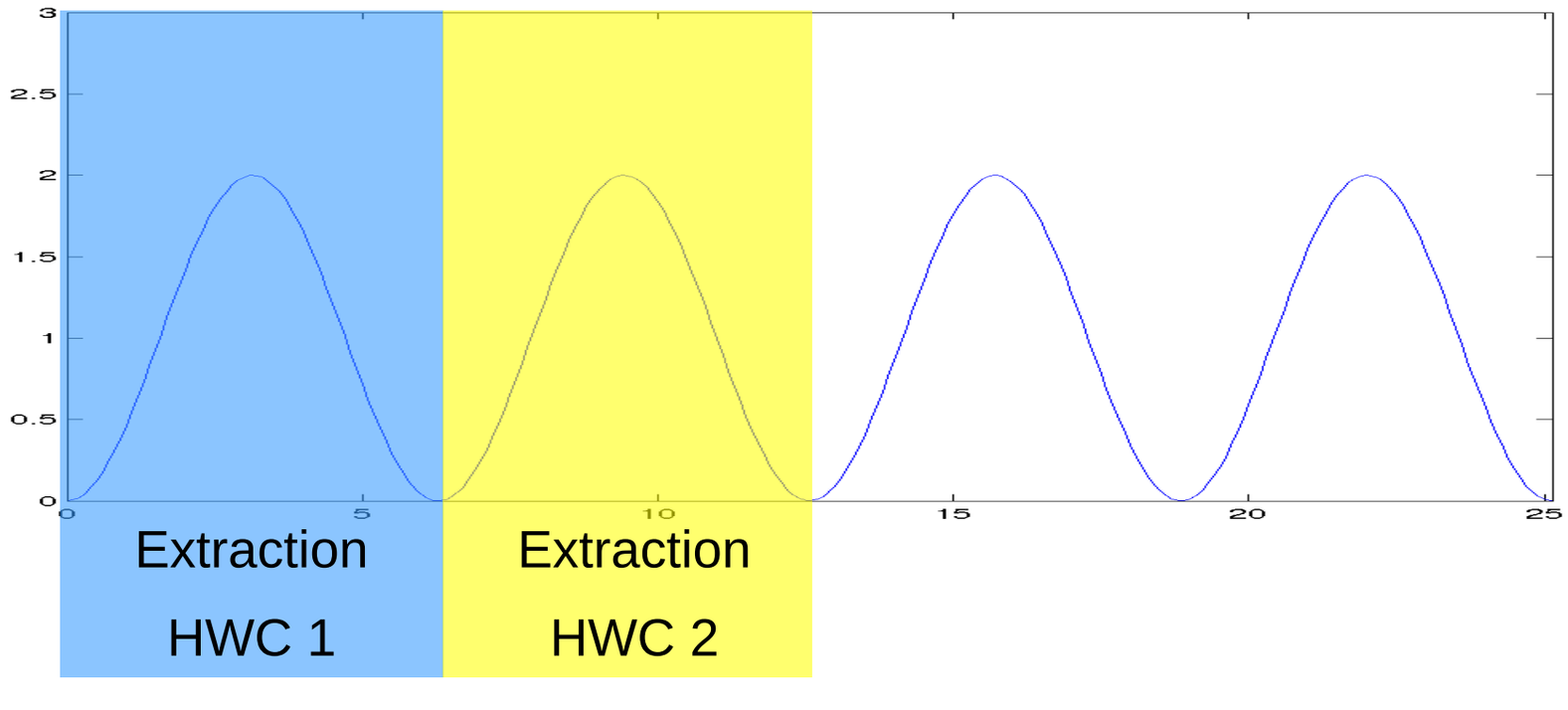
Multiplexing Hardware Counters

- Multiplexing hardware counters is a technique that makes possible to extract values of several incompatible hardware counters from a single run.

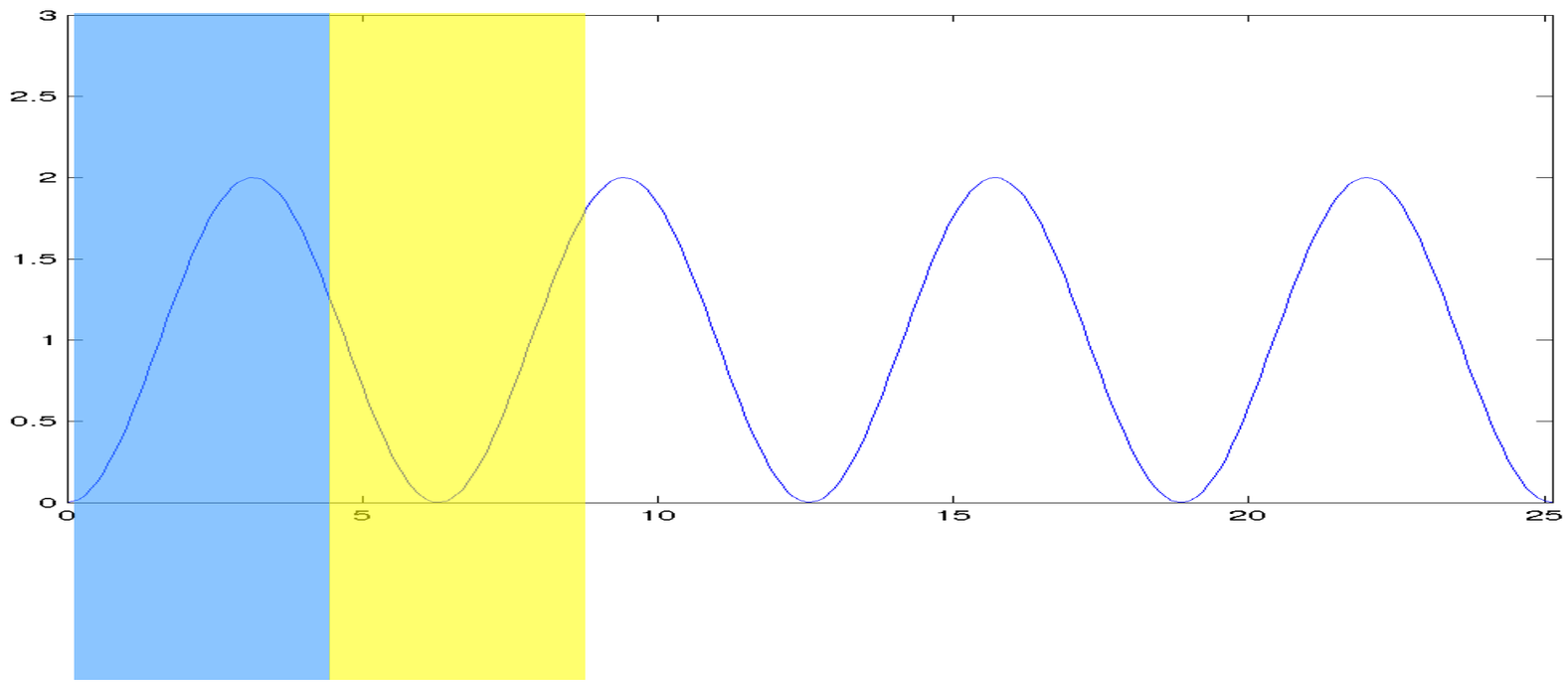
- This technique requires the user to provide with the sampling time slice for multiplexing.

Multiplexing Hardware Counters

- We use the length of one iteration as the sampling time slice for multiplexing.

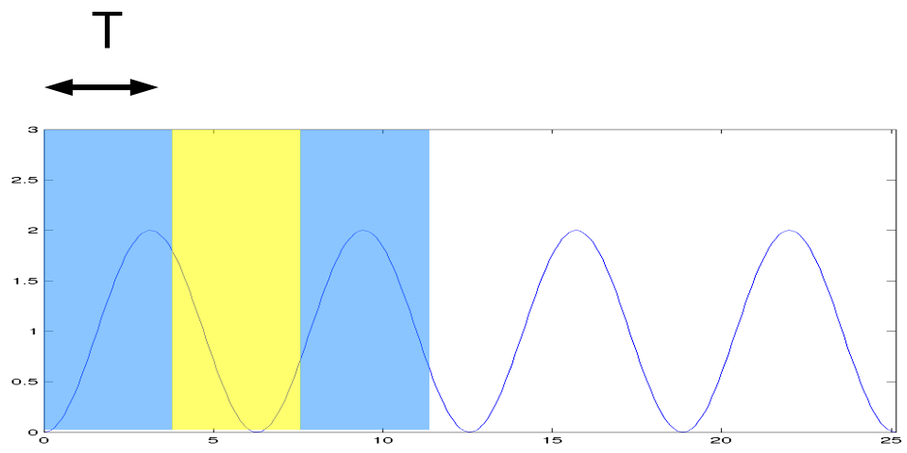


- We compare the accuracy of results obtained by different lengths.



Impact of Sampling Time

Sampling length T



$HWC1_1$ $HWC2_1$ $HWC1_2$ • • •

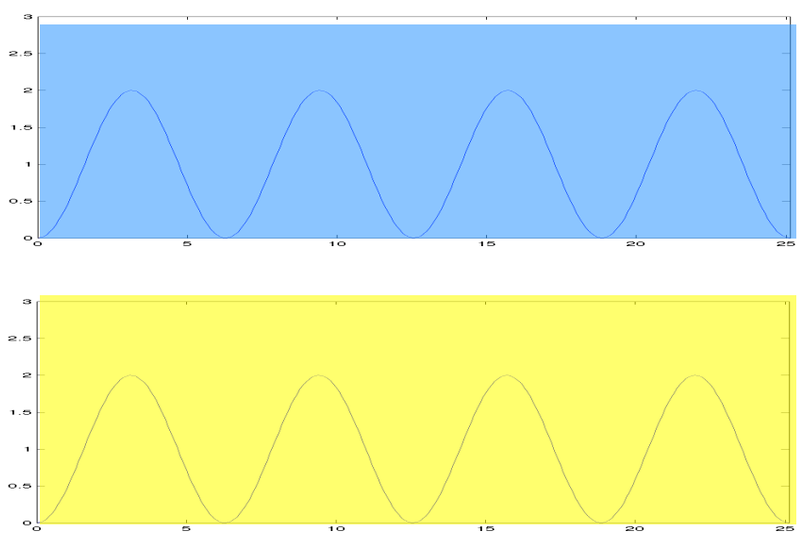
$$AverageHWC1 = \frac{\sum_{i=1}^{n} HWC1_i}{n}$$

$$AverageHWC2 = \frac{\sum_{i=1}^{n} HWC2_i}{n}$$

Error HWC1

Error HWC2

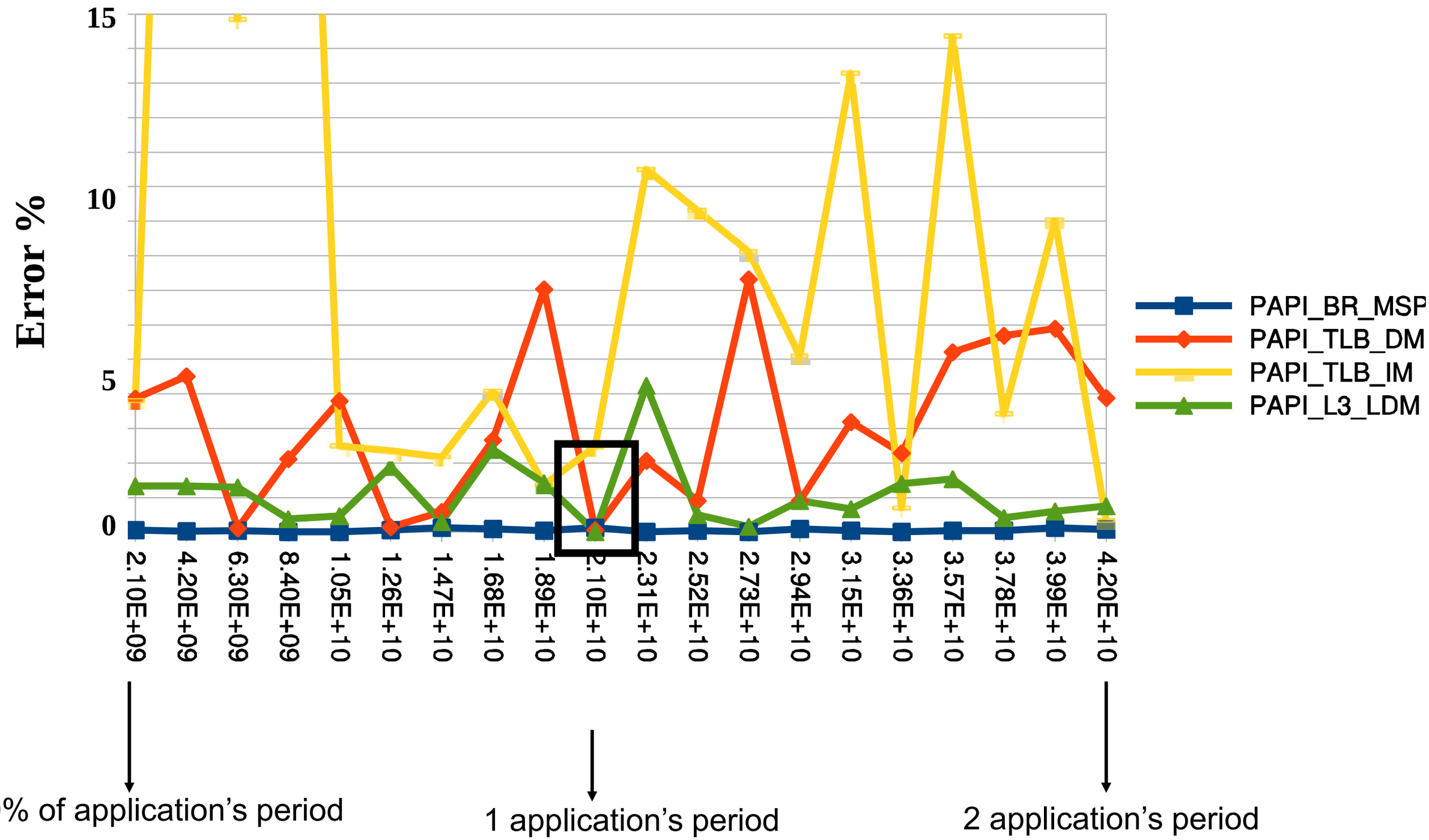
Executions without multiplexing



Global Average Value HWC1

Global Average Value HWC2

Multiplex HWC. H264ref.

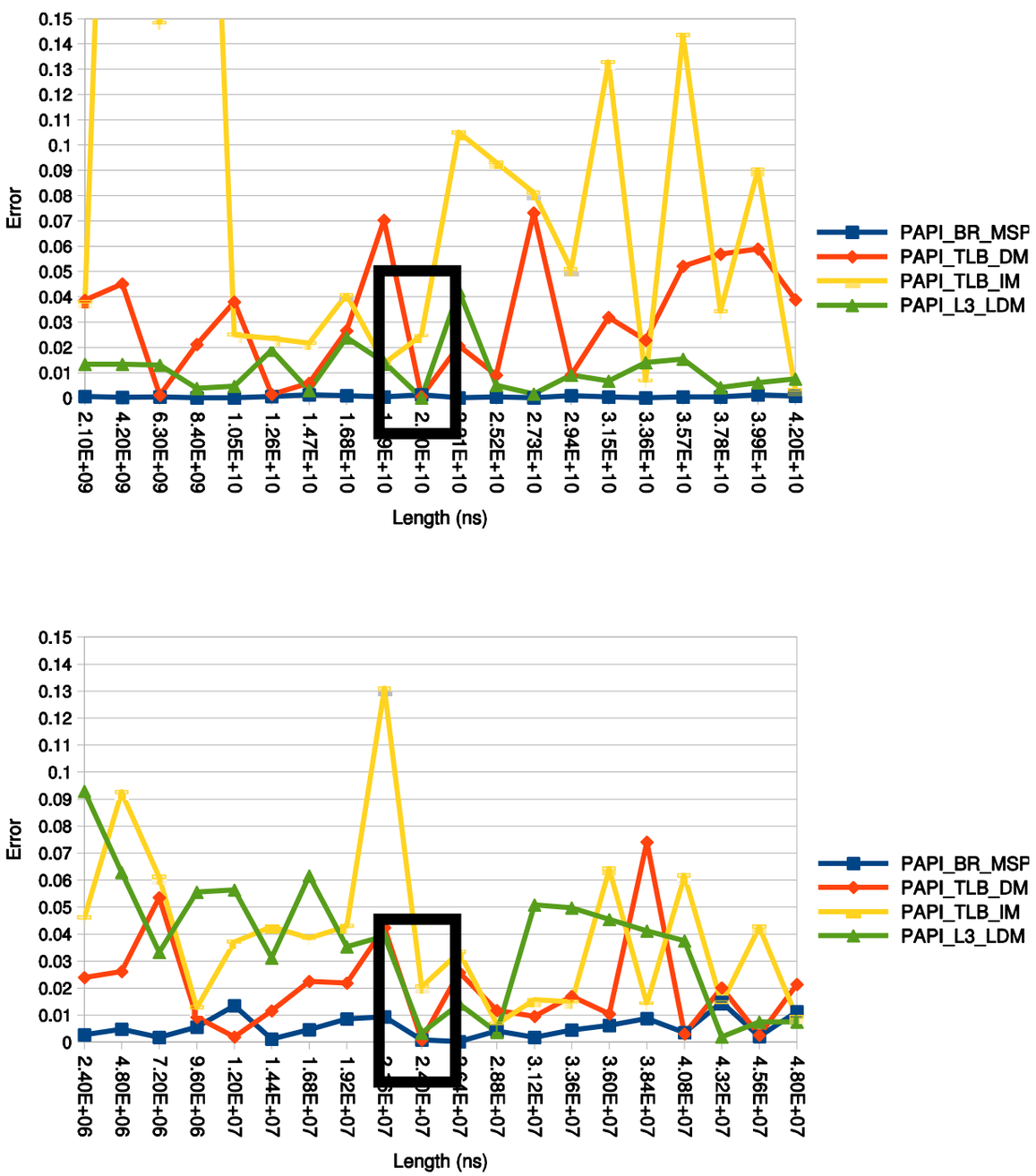


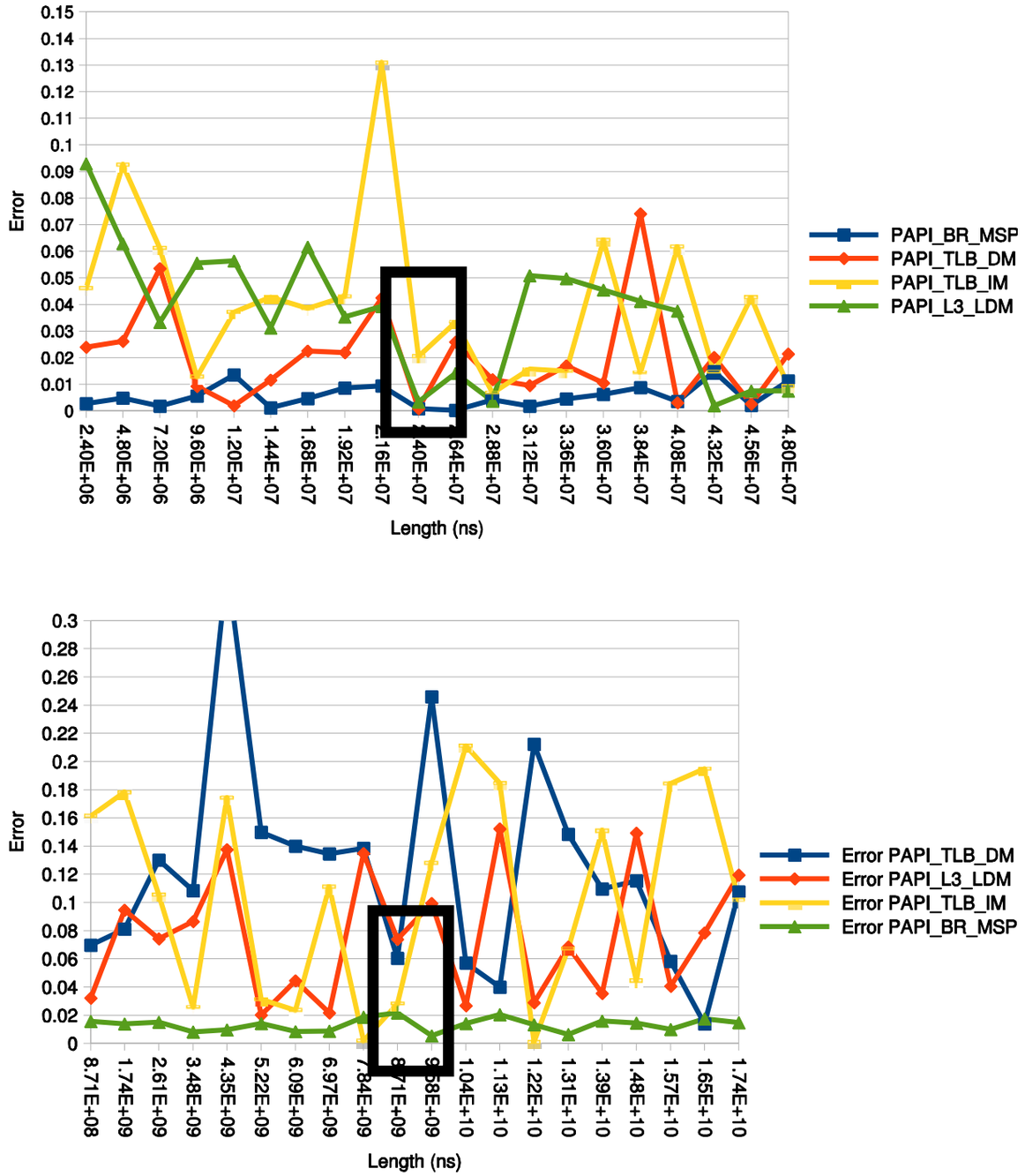
10% of application's period

1 application's period

2 application's period

Multiplex HWC. H264ref, Libquantum, Namd , Milc





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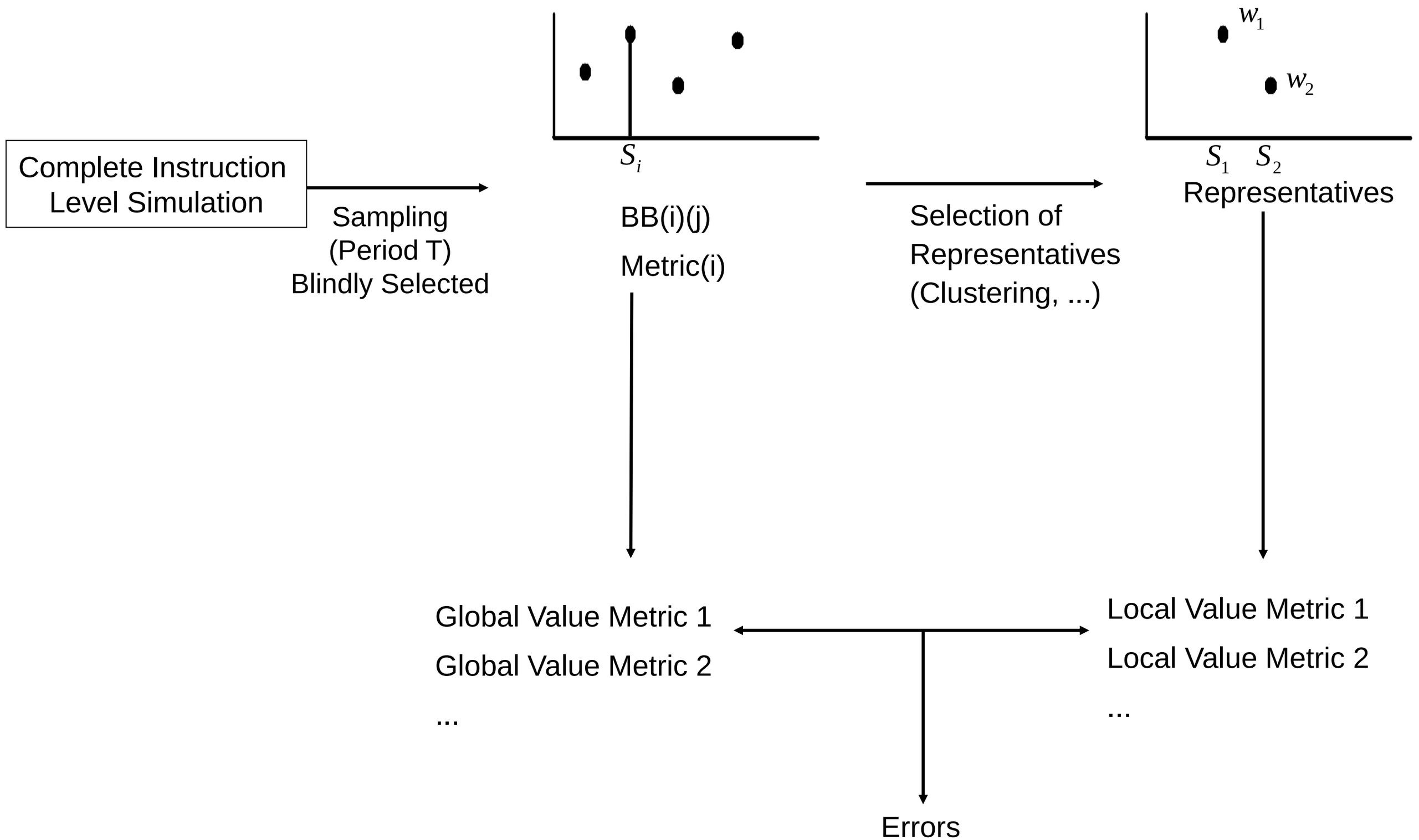
SimPoint Scheme



Selection Techniques

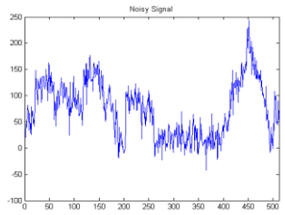
- Simpoint uses three techniques to select the representatives:
  - MultipleSimPoint, uses clustering.
  - SingleSimPoint, consists on taking the closest point to the average.
  - LongSimPoint, consists on taking several consecutive points. Such points are the closest ones to the average.

Impact of Sampling Period (T)

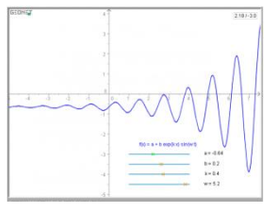
Complete Execution

Sampling
(Period T)

hwc 1



hwc 2



...

Selection of
Representatives
(Clustering, ...)

Representatives

Global Value Metric 1

Global Value Metric 2

...

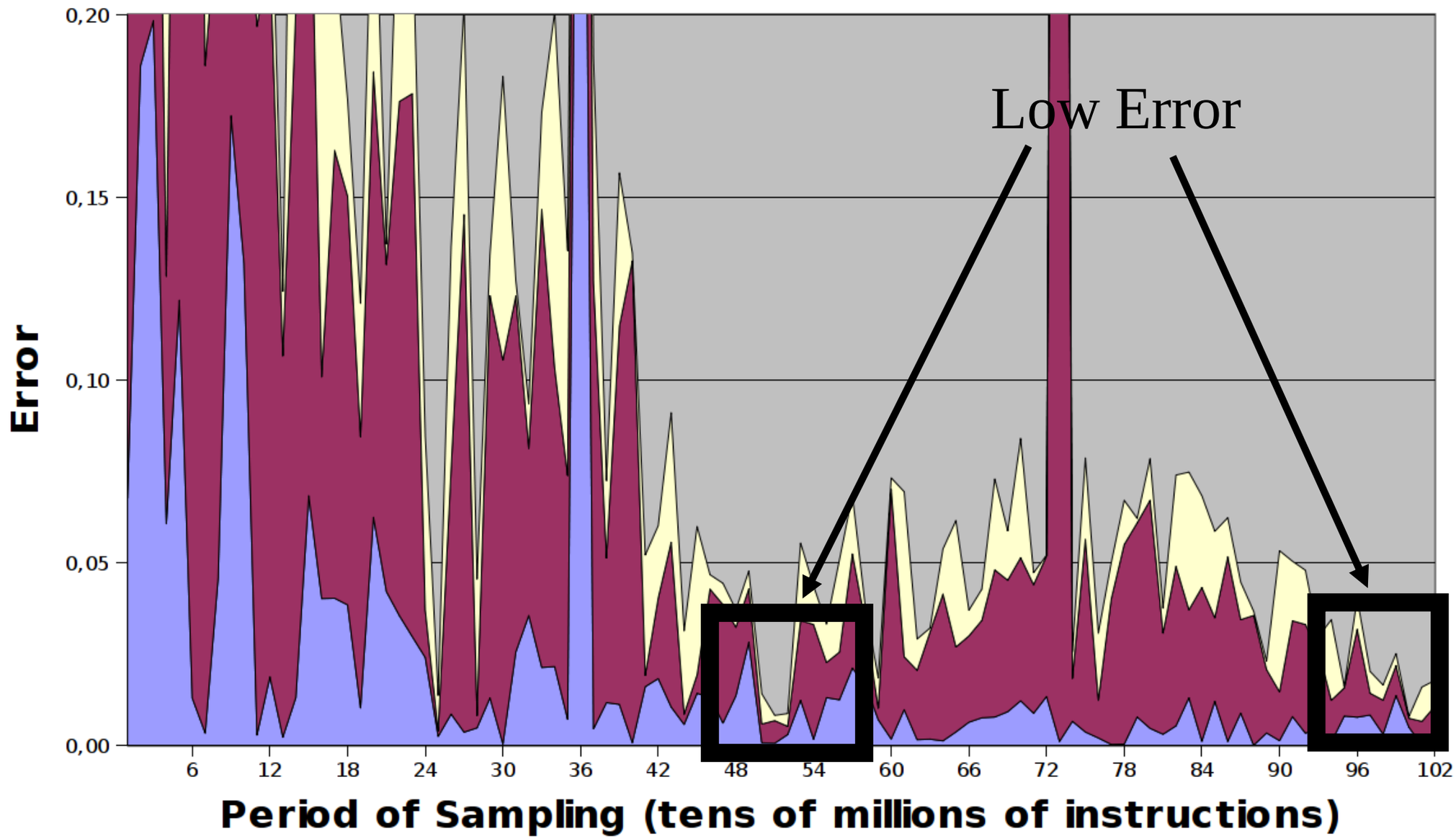
Local Value Metric 1

Local Value Metric 2

...

Errors = *f(T)*

Impact of Sampling Period (T). Results. Applu (SPEC 2000)



- LongSimPoint
- SingleSimPoint
- MultipleSimPoint

Better accuracy as large is the representative.
Better accuracy matching application period.

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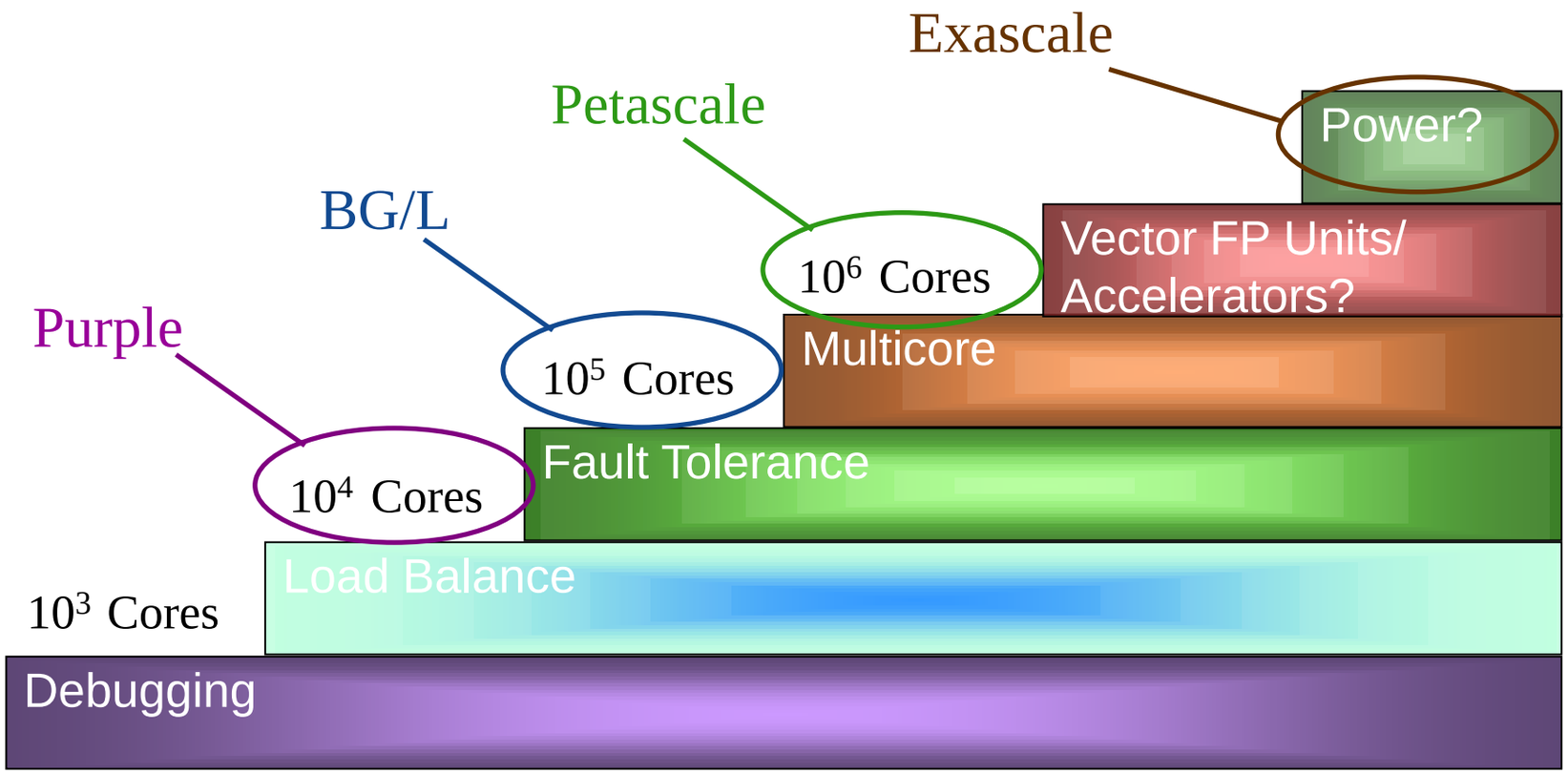
The Road to Exascale: A General Perspective



Questions?