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EXCELENCIA SEVERO OCHOA

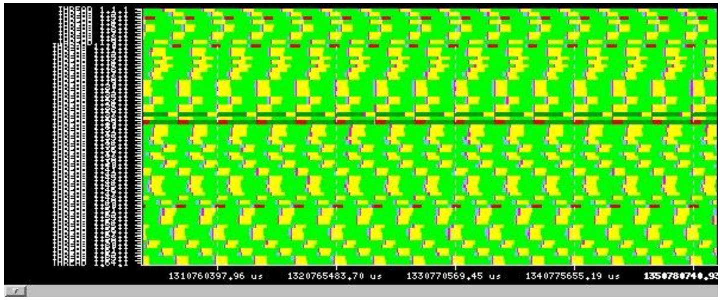
Understanding applications with Paraver

tools@bsc.es

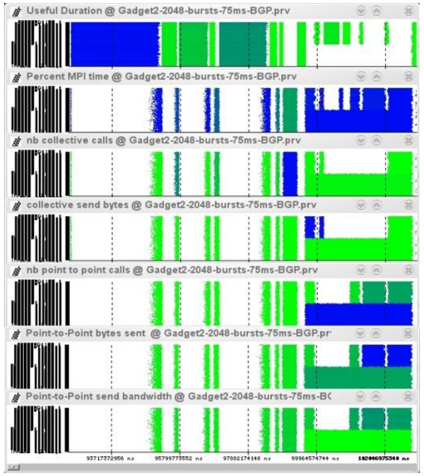
2018

Our Tools

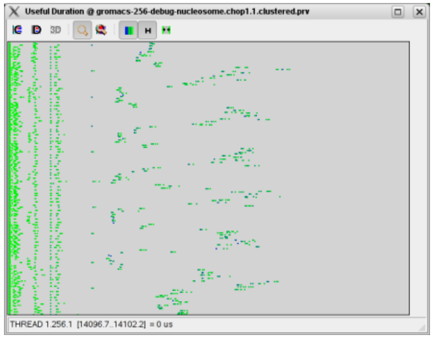
- Since 1991
- Based on traces
- Open Source
- http://tools.bsc.es



- Core tools:
  - Paraver (paramedir) – offline trace analysis
  - Dimemas – message passing simulator
  - Extrae – instrumentation



- Focus
  - Detail, variability, flexibility
  - Behavioral structure vs. syntactic structure
  - Intelligence: Performance Analytics



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Paraver

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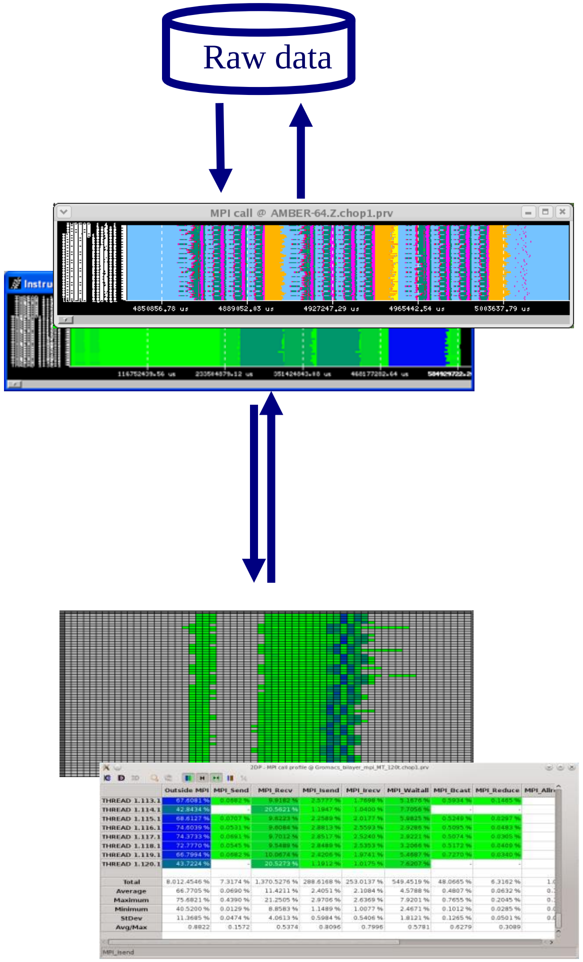
Paraver – Performance data browser



Timelines

2/3D tables (Statistics)

Trace visualization/analysis

+ trace manipulation

Goal = Flexibility

No semantics

Programmable

Comparative analyses

Multiple traces

Synchronize scales

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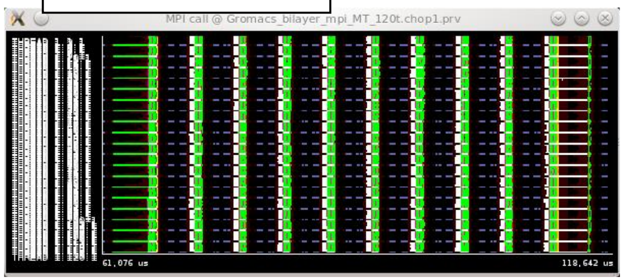
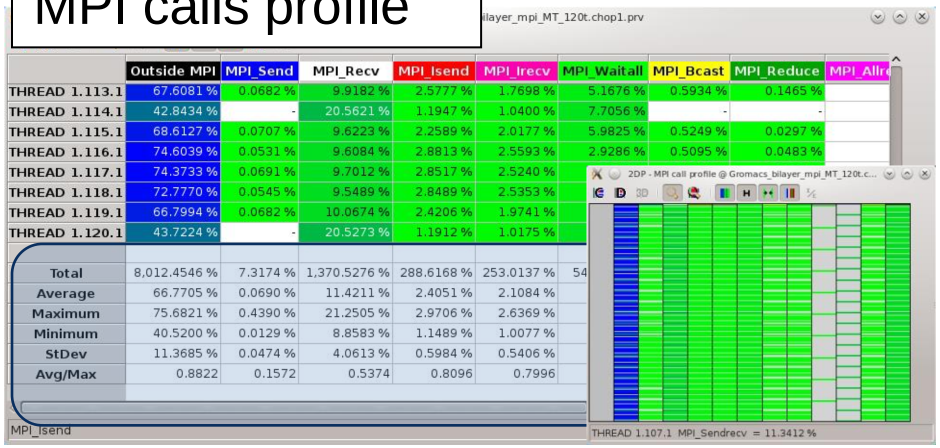
From timelines to tables

MPI calls

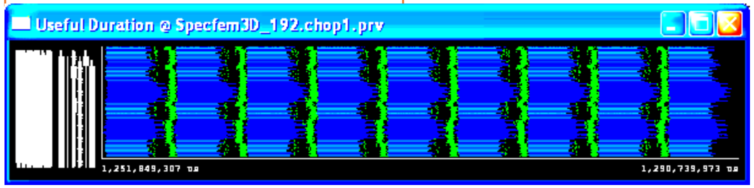


MPI calls profile

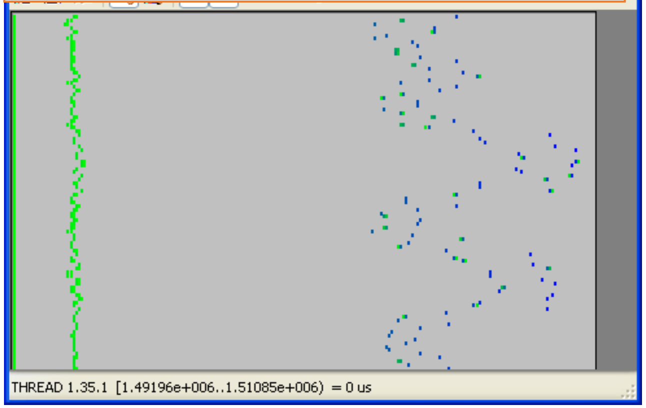


	Outside MPI	MPI_Send	MPI_Recv	MPI_Isend	MPI_Irecv	MPI_Waitall	MPI_Bcast	MPI_Reduce	MPI_Allre
THREAD 1.113.1	67.6081 %	0.0682 %	9.9182 %	2.5777 %	1.7698 %	5.1676 %	0.5934 %	0.1465 %	
THREAD 1.114.1	42.8434 %	-	20.5621 %	1.1947 %	1.0400 %	7.7056 %	-	-	
THREAD 1.115.1	68.6127 %	0.0707 %	9.6223 %	2.2589 %	2.0177 %	5.9825 %	0.5249 %	0.0297 %	
THREAD 1.116.1	74.6039 %	0.0531 %	9.6084 %	2.8813 %	2.5593 %	2.9286 %	0.5095 %	0.0483 %	
THREAD 1.117.1	74.3733 %	0.0691 %	9.7012 %	2.8517 %	2.5240 %				
THREAD 1.118.1	72.7770 %	0.0545 %	9.5489 %	2.8489 %	2.5353 %				
THREAD 1.119.1	66.7994 %	0.0682 %	10.0674 %	2.4206 %	1.9741 %				
THREAD 1.120.1	43.7224 %	-	20.5273 %	1.1912 %	1.0175 %				
Total	8,012.4546 %	7.3174 %	1,370.5276 %	288.6168 %	253.0137 %	54			
Average	66.7705 %	0.0690 %	11.4211 %	2.4051 %	2.1084 %				
Maximum	75.6821 %	0.4390 %	21.2505 %	2.9706 %	2.6369 %				
Minimum	40.5200 %	0.0129 %	8.8583 %	1.1489 %	1.0077 %				
StDev	11.3685 %	0.0474 %	4.0613 %	0.5984 %	0.5406 %				
Avg/Max	0.8822	0.1572	0.5374	0.8096	0.7996				

Useful Duration



Histogram Useful Duration



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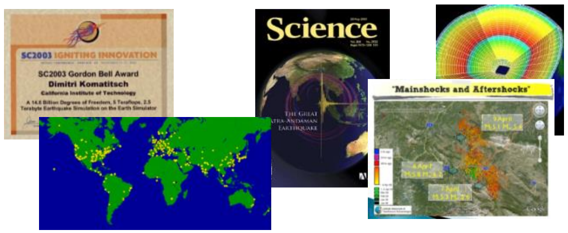
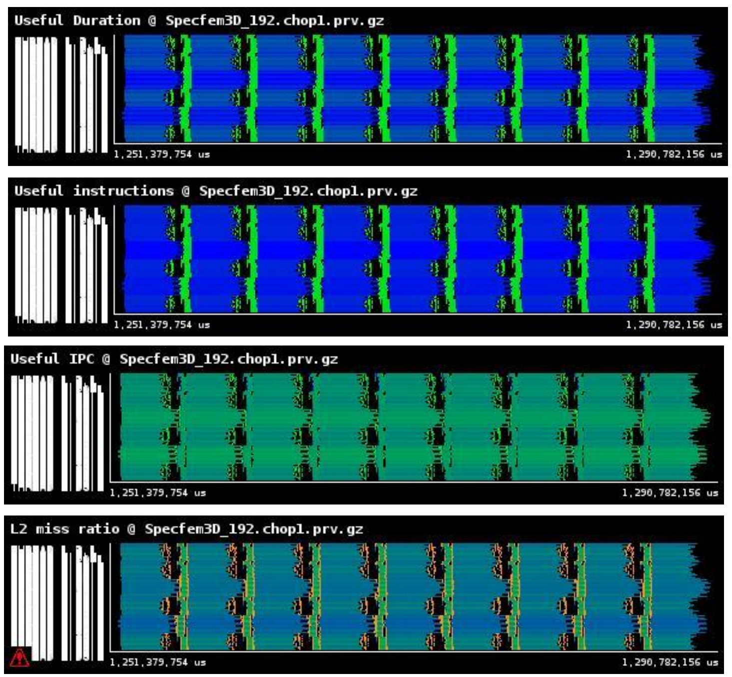
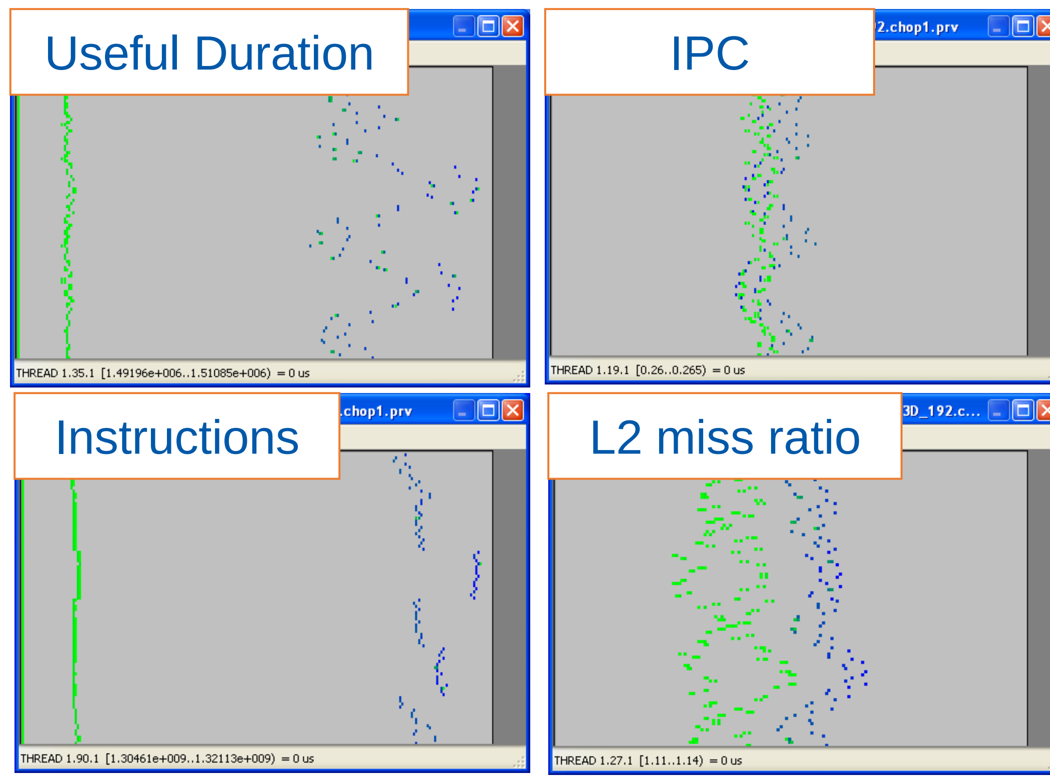
Analyzing variability







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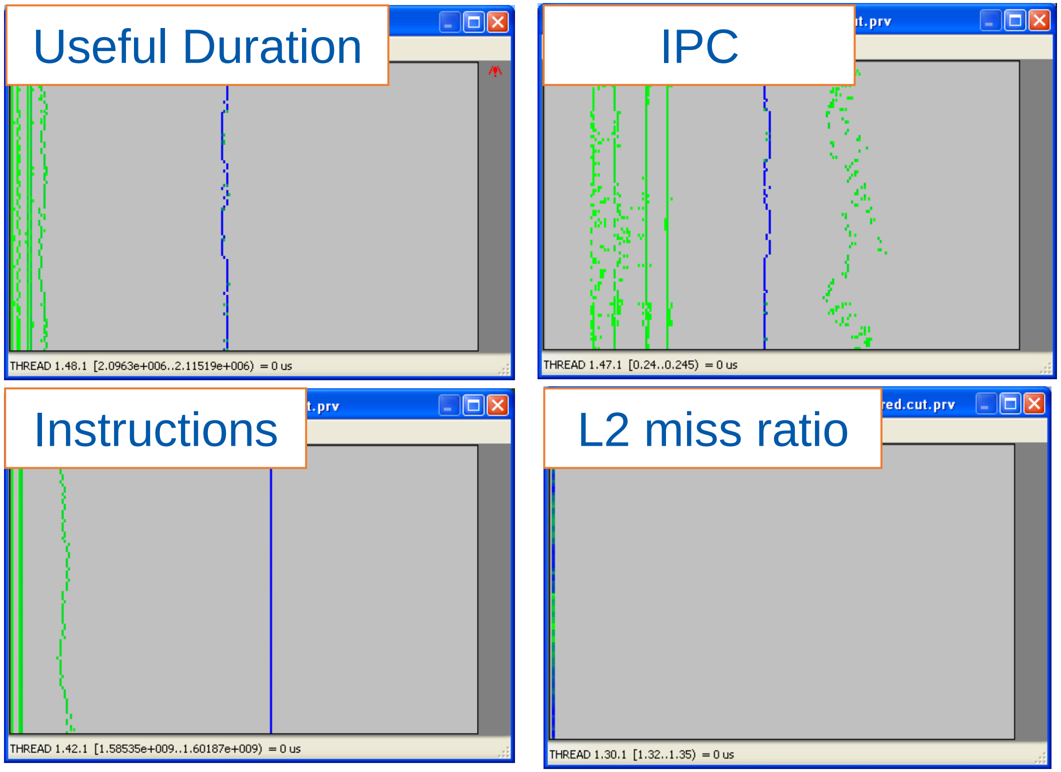
Analyzing variability

- By the way: six months later ….

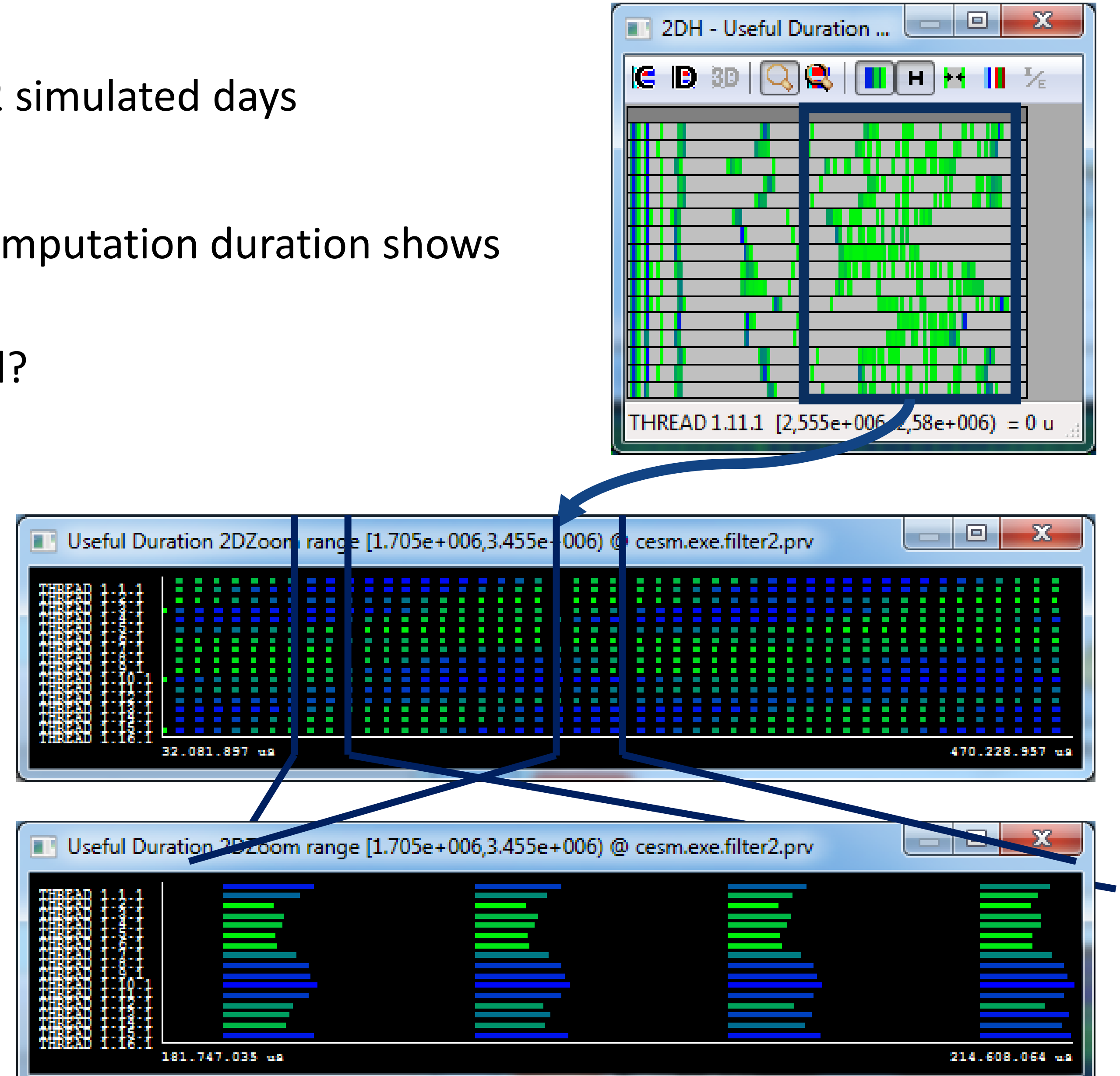


From tables to timelines

CESM: 16 processes, 2 simulated days

- Histogram useful computation duration shows high variability
- How is it distributed?

- Dynamic imbalance
  - In space and time
  - Day and night.
  - Season ? ☺



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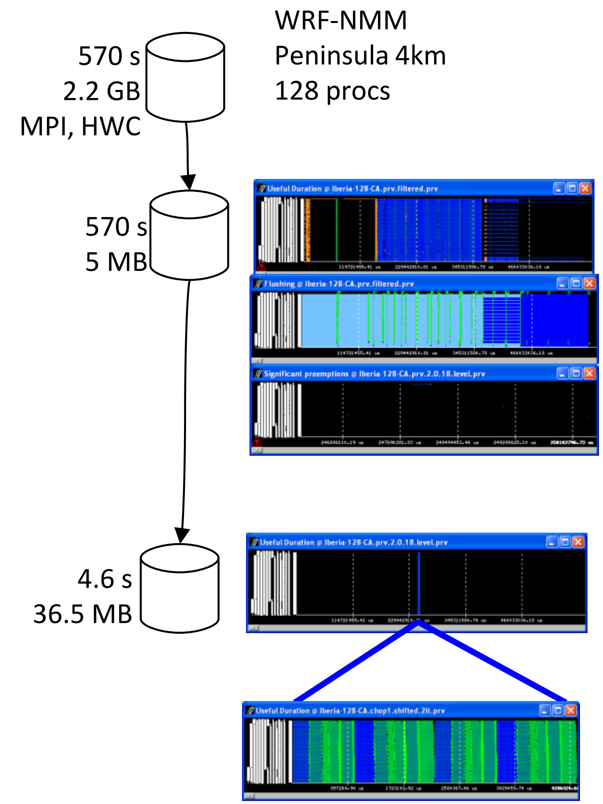
Trace manipulation

- Data handling/summarization capability
  - Filtering
    - Subset of records in original trace
    - By duration, type, value,…
    - Filtered trace IS a paraver trace and can be analysed with the same cfgs (as long as needed data kept)
  - Cutting
    - All records in a given time interval
    - Only some processes
  - Software counters
    - Summarized values computed from those in the original trace emitted as new even types
    - #MPI calls, total hardware count,…



Extrae

Extrae features

- Platforms
  - Intel, Cray, BlueGene, MIC, ARM, Android, Fujitsu Sparc…
- Parallel programming models
  - MPI, OpenMP, pthreads, OmpSs, CUDA, OpenCL, Java, Python…
- Performance Counters
  - Using PAPI interface
- Link to source code
  - Callstack at MPI routines
  - OpenMP outlined routines
  - Selected user functions (Dyninst)
- Periodic sampling
- User events (Extrae API)

No need to recompile / relink!

Extrae overheads

	Average values
Event	150 – 200 ns
Event + PAPI	750 ns – 1.5 us
Event + callstack (1 level)	1 us
Event + callstack (6 levels)	2 us

How does Extrae work?

- Symbol substitution through LD_PRELOAD
  - Specific libraries for each combination of runtimes
    - MPI
    - OpenMP
    - OpenMP+MPI
    - …

Recommended

- Dynamic instrumentation
  - Based on Dyninst (developed by U.Wisconsin / U.Maryland)
    - Instrumentation in memory
    - Binary rewriting

- Alternatives
  - Static link (i.e., PMPI, Extrae API)

Extrae XML configuration

```
<mpi enabled="yes">
  <counters enabled="yes" />
</mpi>

<openmp enabled="yes">
  <locks enabled="no" />
  <counters enabled="yes" />
</openmp>

<pthread enabled="no">
  <locks enabled="no" />
  <counters enabled="yes" />
</pthread>

<callers enabled="yes">
  <mpi enabled="yes">1-3</mpi>
  <sampling enabled="no">1-5</sampling>
</callers>
```

Trace the MPI calls
(What's the program doing?)

Trace the call-stack
(Where in my code?)

Extrae XML configuration (II)

```
<counters enabled="yes">
  <cpu enabled="yes" starting-set-distribution="1">
    <set enabled="yes" domain="all" changeat-time="500000us">
      PAPI_TOT_INS, PAPI_TOT_CYC, PAPI_L1_DCM, PAPI_L2_DCM, PAPI_L3_TCM
    </set>
    <set enabled="yes" domain="all" changeat-time="500000us">
      PAPI_TOT_INS, PAPI_TOT_CYC, PAPI_BR_MSP, PAPI_BR_UCN,
      PAPI_BR_CN, RESOURCE_STALLS
    </set>
    <set enabled="yes" domain="all" changeat-time="500000us">
      PAPI_TOT_INS, PAPI_TOT_CYC, PAPI_VEC_DP, PAPI_VEC_SP,
      PAPI_FP_INS
    </set>
    <set enabled="yes" domain="all" changeat-time="500000us">
      PAPI_TOT_INS, PAPI_TOT_CYC, PAPI_LD_INS, PAPI_SR_INS
    </set>
    <set enabled="yes" domain="all" changeat-time="500000us">
      PAPI_TOT_INS, PAPI_TOT_CYC, RESOURCE_STALLS:LOAD,
      RESOURCE_STALLS:STORE, RESOURCE_STALLS:ROB_FULL, RESOURCE_STALLS:RS_FULL
    </set>
  </cpu>
  <network enabled="no" />
  <resource-usage enabled="no" />
  <memory-usage enabled="no" />
</counters>
```

Select which HW counters are measured

(How's the machine doing?)

Extrae XML configuration (III)

```
<buffer enabled="yes">
  <size enabled="yes">500000</size>
  <circular enabled="no" />
</buffer>

<sampling enabled="no" type="default" period="50m" variability="10m" />

<merge enabled="yes"
       synchronization="default"
       tree-fan-out="16"
       max-memory="512"
       joint-states="yes"
       keep-mpits="yes"
       sort-addresses="yes"
       overwrite="yes"
>
  $TRACE_NAME$
</merge>
```

Trace buffer size
(Flush/memory trade-off)

Enable sampling
(Want more details?)

Automatic post-processing to generate the Paraver trace

Dimemas

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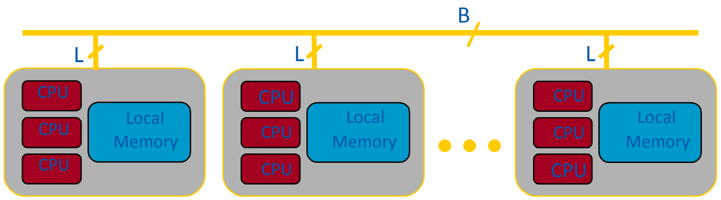
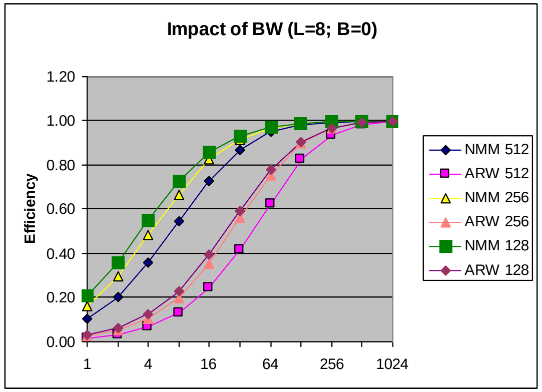
Dimemas – Coarse grain, Trace driven simulation

- Simulation: Highly non linear model
  - MPI protocols, resource contention…



- Parametric sweeps
  - On abstract architectures
  - On application computational regions
- What if analysis
  - Ideal machine (instantaneous network)
  - Estimating impact of ports to MPI+OpenMP/CUDA/…
  - Should I use asynchronous communications?
  - Are all parts equally sensitive to network?
- MPI sanity check
  - Modeling nominal
- Paraver – Dimemas tandem
  - Analysis and prediction
  - What-if from selected time window



Detailed feedback on simulation (trace)

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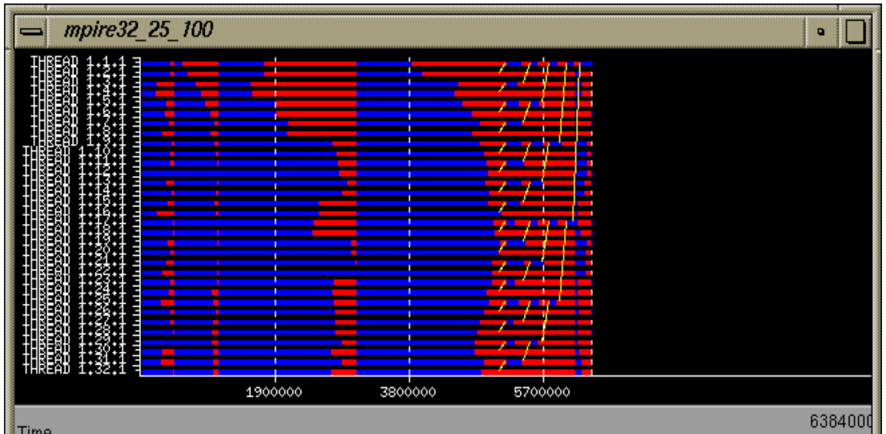
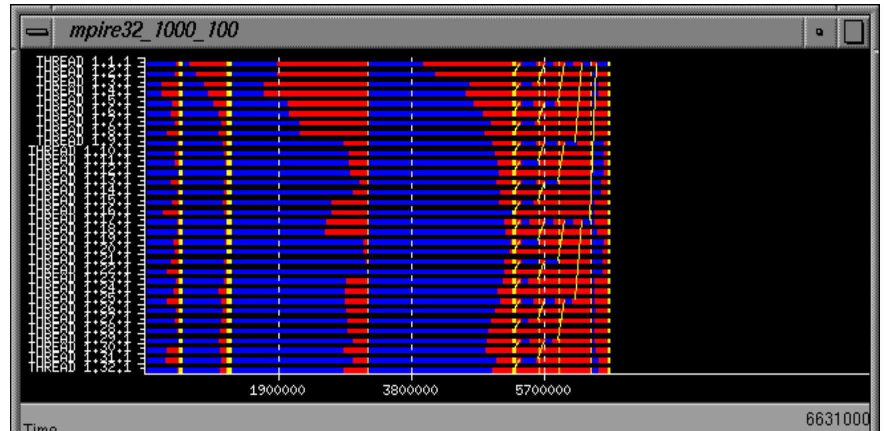
Network sensitivity

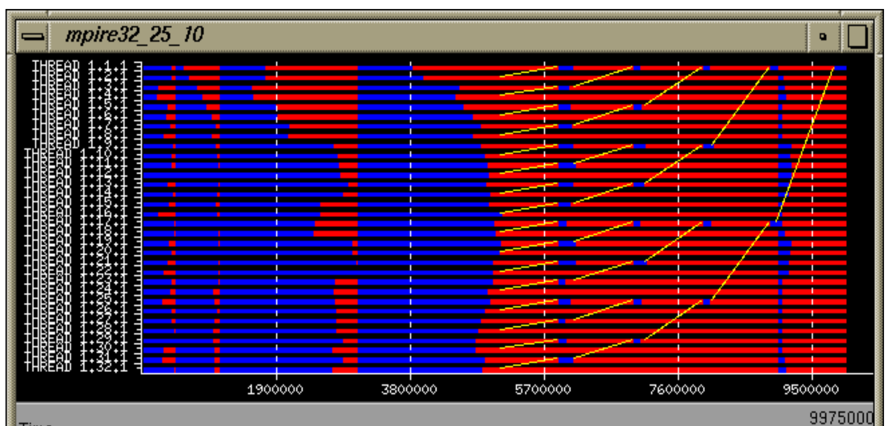
- MPIRE 32 tasks, no network contention



L = 5μs – BW = 1 GB/s



L = 1000μs – BW = 1 GB/s



L = 5μs – BW = 100MB/s

All windows same scale

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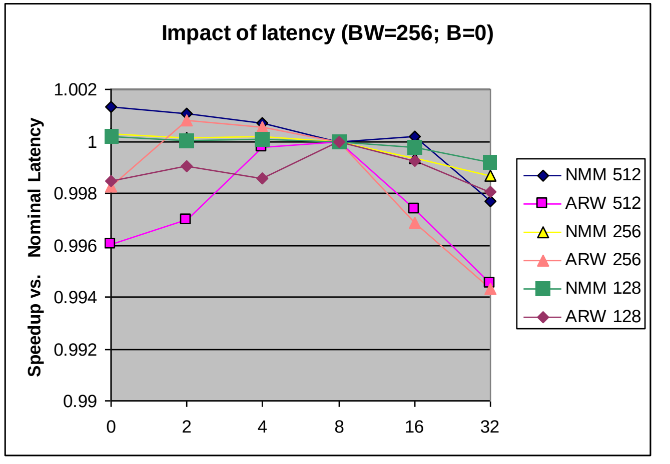
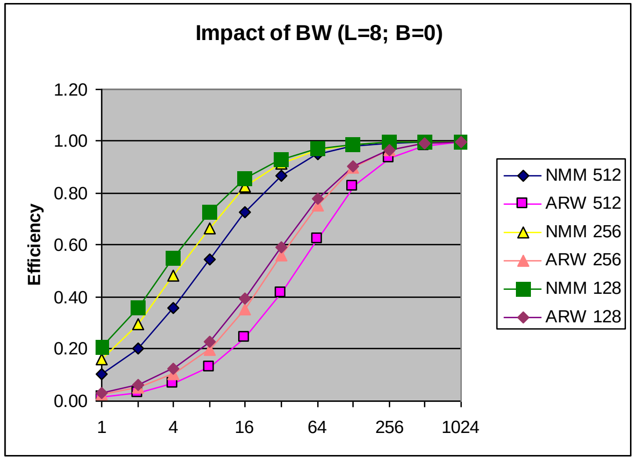
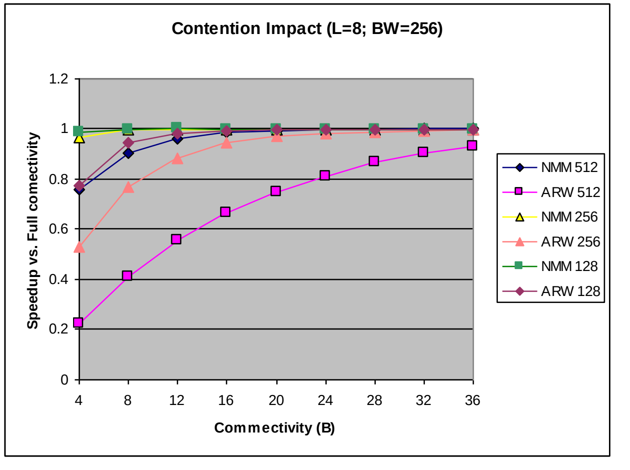
Network sensitivity

- WRF, Iberia 4Km, 4 procs/node
  - Not sensitive to latency
  - NMM
    - BW – 256MB/s
    - 512 – sensitive to contention
  - ARW
    - BW - 1GB/s
    - Sensitive to contention







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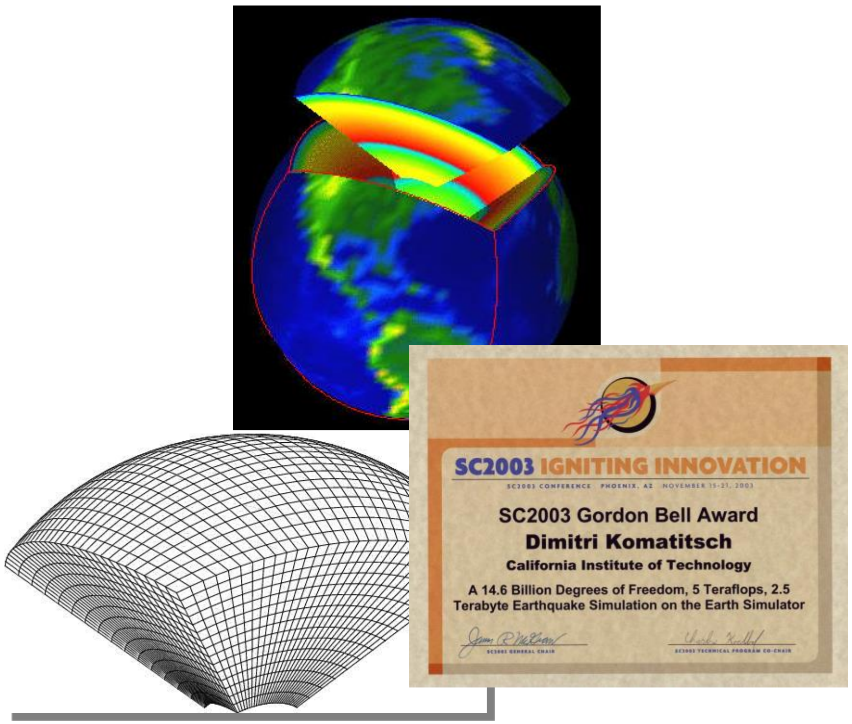
Would I will benefit from asynchronous communications?

SPECFEM3D



Courtesy Dimitri Komatitsch

Real

Ideal

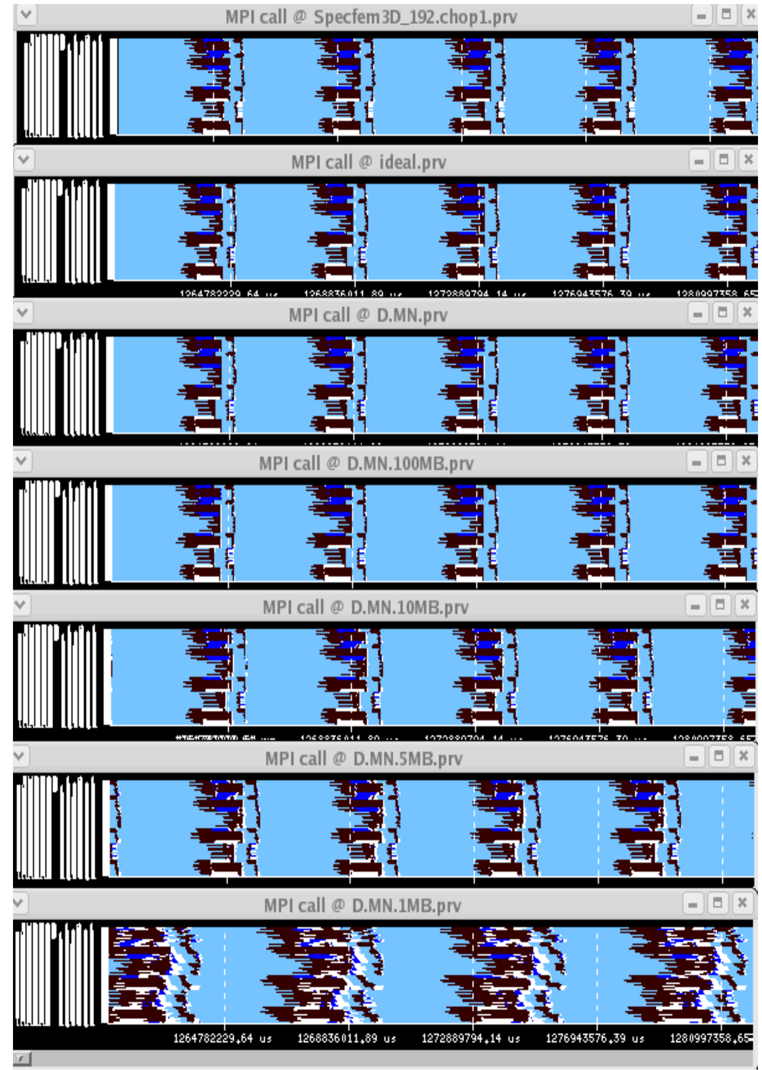
Prediction MN

Prediction 100MB/s

Prediction 10MB/s

Prediction 5MB/s

Prediction 1MB/s



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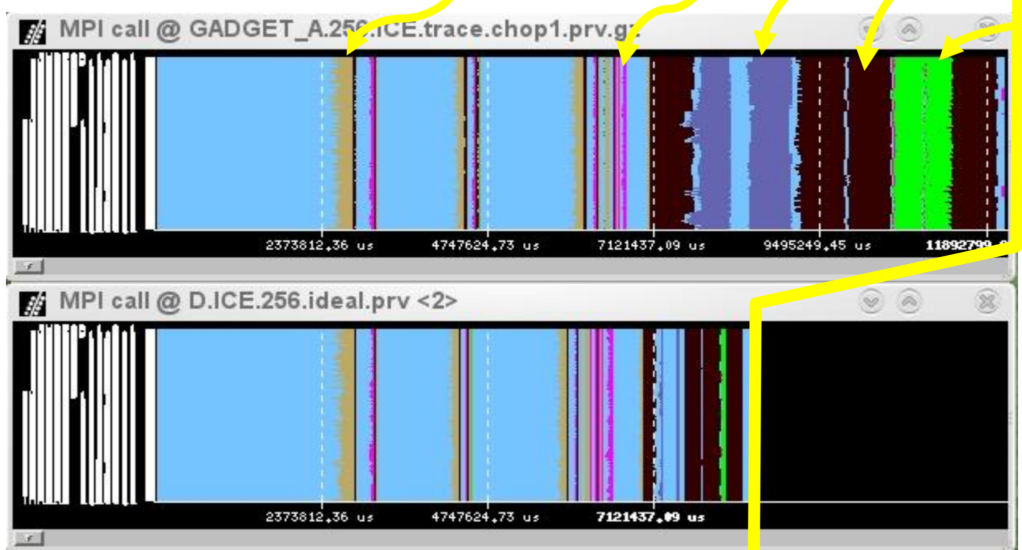
Ideal machine

The impossible machine: BW = ∞, L = 0

- Actually describes/characterizes Intrinsic application behavior
  - Load balance problems?
  - Dependence problems?

GADGET @ Nehalem cluster
256 processes



Impact on practical machines?

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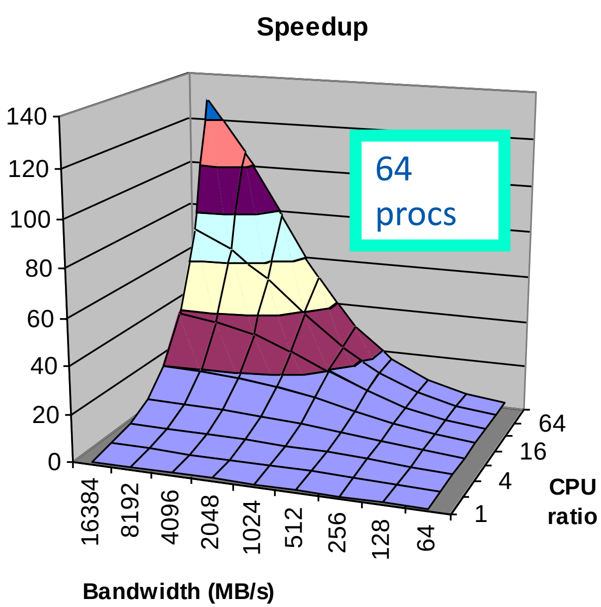
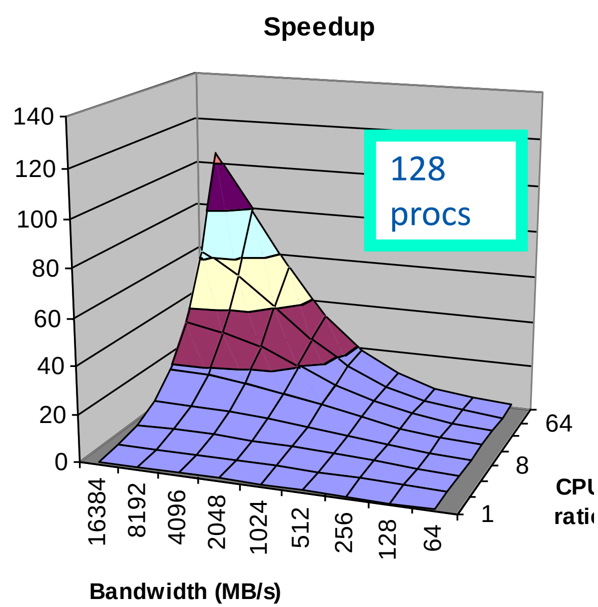
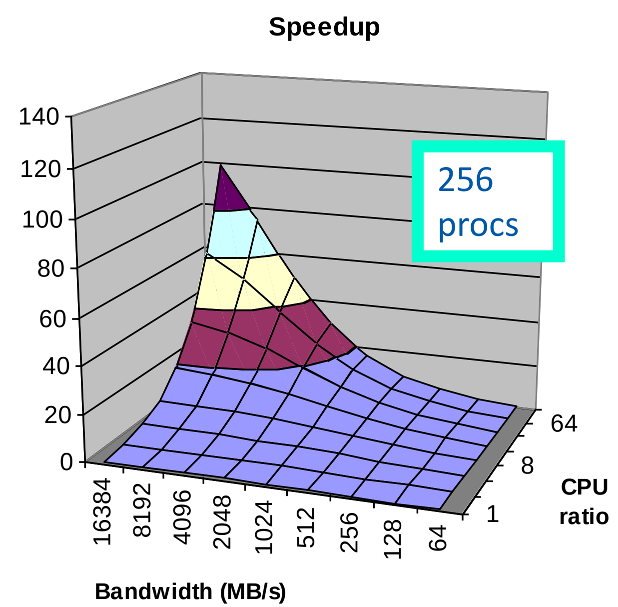
Impact of architectural parameters

- **Ideal speeding up ALL** the computation bursts by the CPUratio factor
  - The more processes the less speedup (higher impact of bandwidth limitations) !!

GADGET

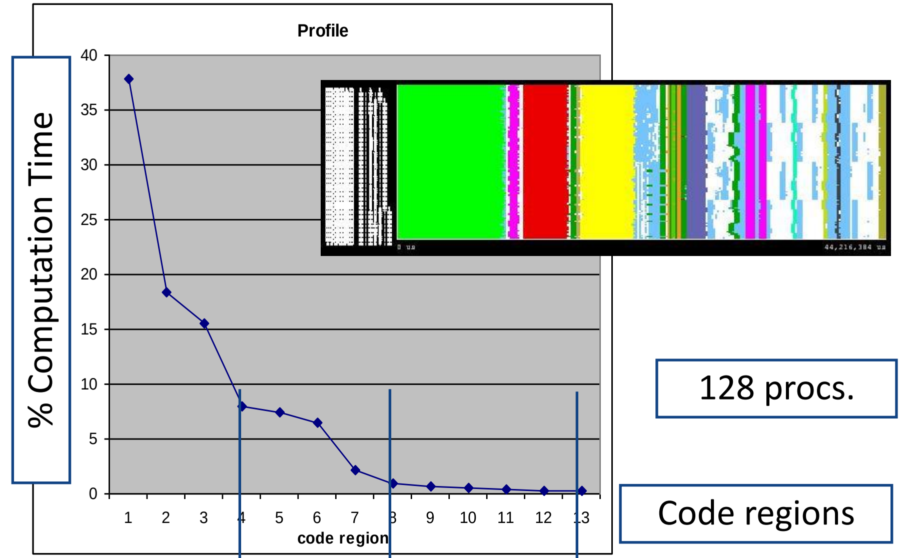


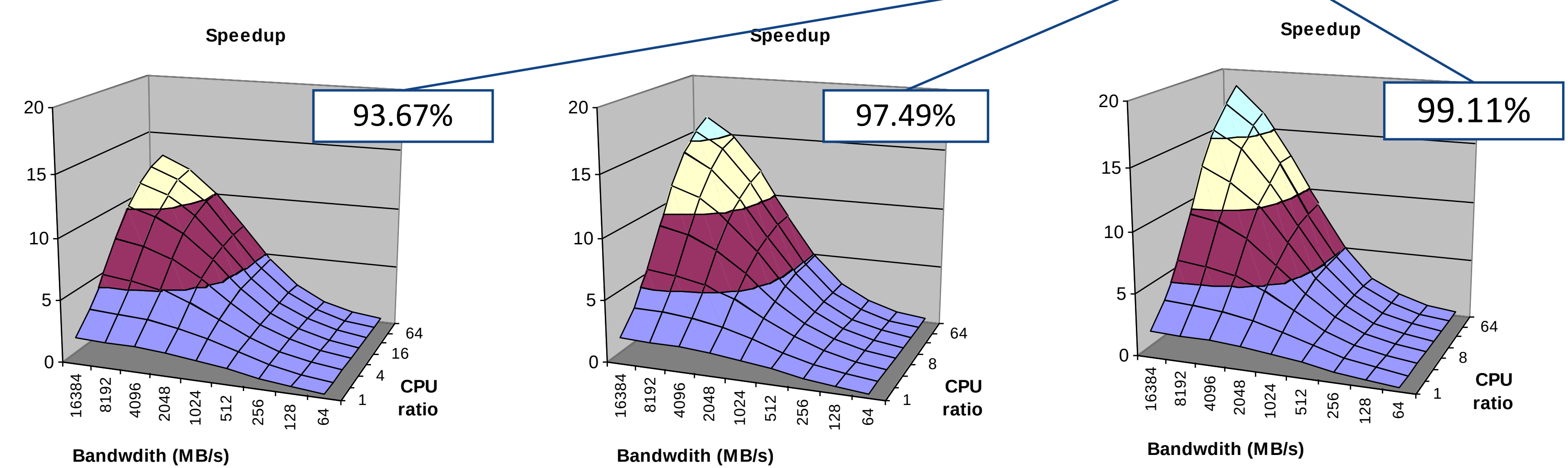




Hybrid parallelization

- Hybrid/accelerator parallelization
  - Speed-up SELECTED regions by the CPUratio factor





(Previous slide: speedups **up to 100x**)

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Efficiency Models

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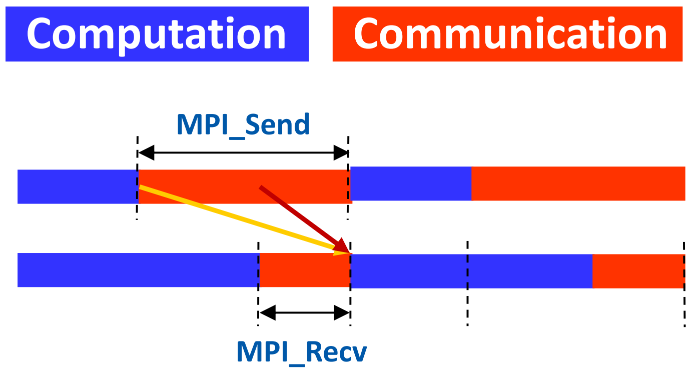
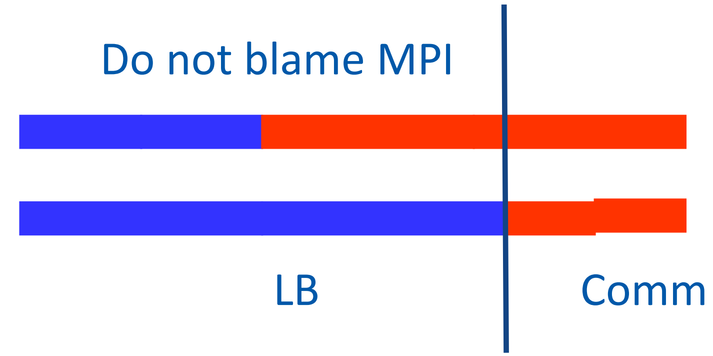
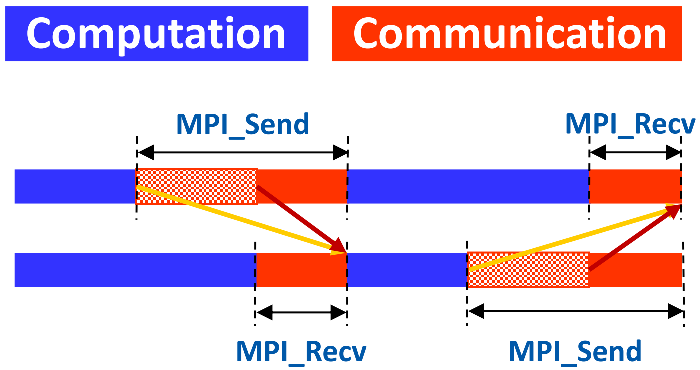
Parallel efficiency model

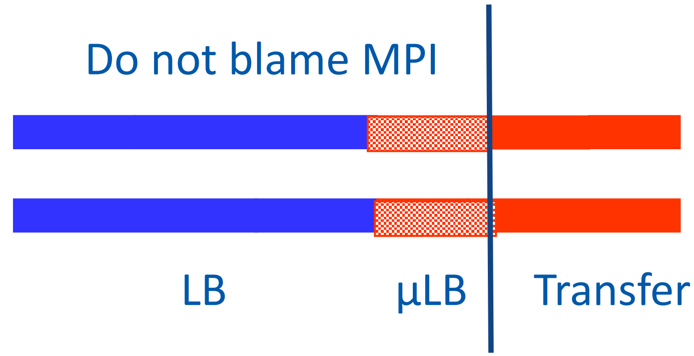




- Parallel efficiency = LB eff * Comm eff

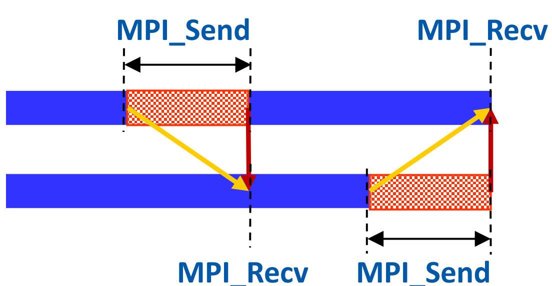
Parallel efficiency refinement: LB * µLB * Tr





$LB = 1$

- Serializations / dependences (µLB)
- Dimemas ideal network → Transfer (efficiency) = 1



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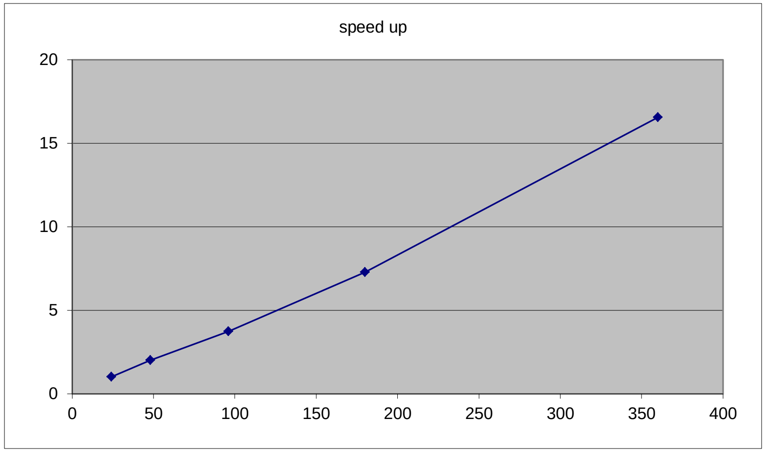
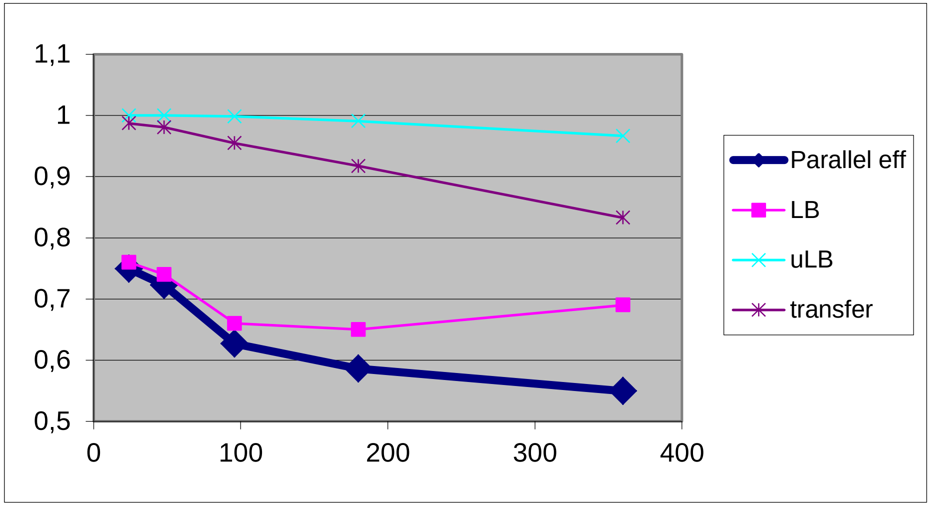
Why scaling?

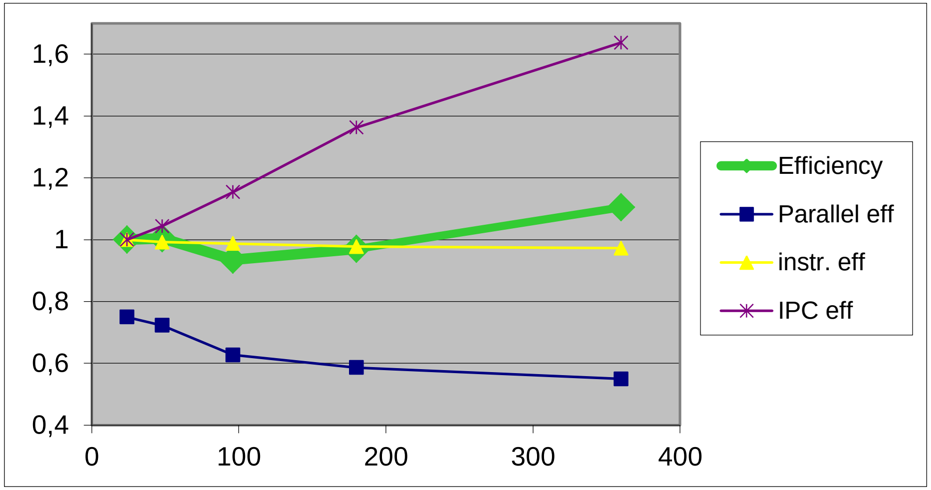
$$\eta_{\parallel} = LB * Ser * Trf$$

CG-POP mpi2s1D - 180x120

Good scalability !!
Should we be happy?







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Some examples of efficiencies

Code	Parallel efficiency	Communication efficiency	Load Balance efficiency
Gromacs@mt	66.77	75.68	88.22
BigDFT@altamira	59.64	78.97	75.52
CG-POP@mt	80.98	98.92	81.86
ntchem_mini@pi	92.56	94.94	97.49
nicam@pi	87.10	75.97	89.22
cp2k@jureca	75.34	81.07	92.93
icon@mistral	79.86	84.02	95.05
k-Wave@salomon	89.08	92.84	95.96
fleur@claix	76.22	90.66	84.07

Same code, different behaviour

Code	Parallel efficiency	Communication efficiency	Load Balance efficiency
lulesh@mn3	90.55	**99.22**	91.26
lulesh@leftraru	**69.15**	99.12	**69.76**
lulesh@uv2 (mpt)	70.55	96.56	73.06
lulesh@uv2 (impi)	85.65	95.09	90.07
lulesh@mt	83.68	95.48	87.64
lulesh@cori	**90.92**	98.59	**92.20**
lulesh@thunderX	73.96	97.56	75.81
lulesh@jetson	75.48	**88.84**	84.06
lulesh@claix	77.28	92.33	83.70
lulesh@jureca	88.20	98.45	89.57
lulesh@mn4	86.59	98.77	87.67
lulesh@inti	88.16	98.65	89.36

Warning::: Higher parallel efficiency does not mean faster!

Analytics

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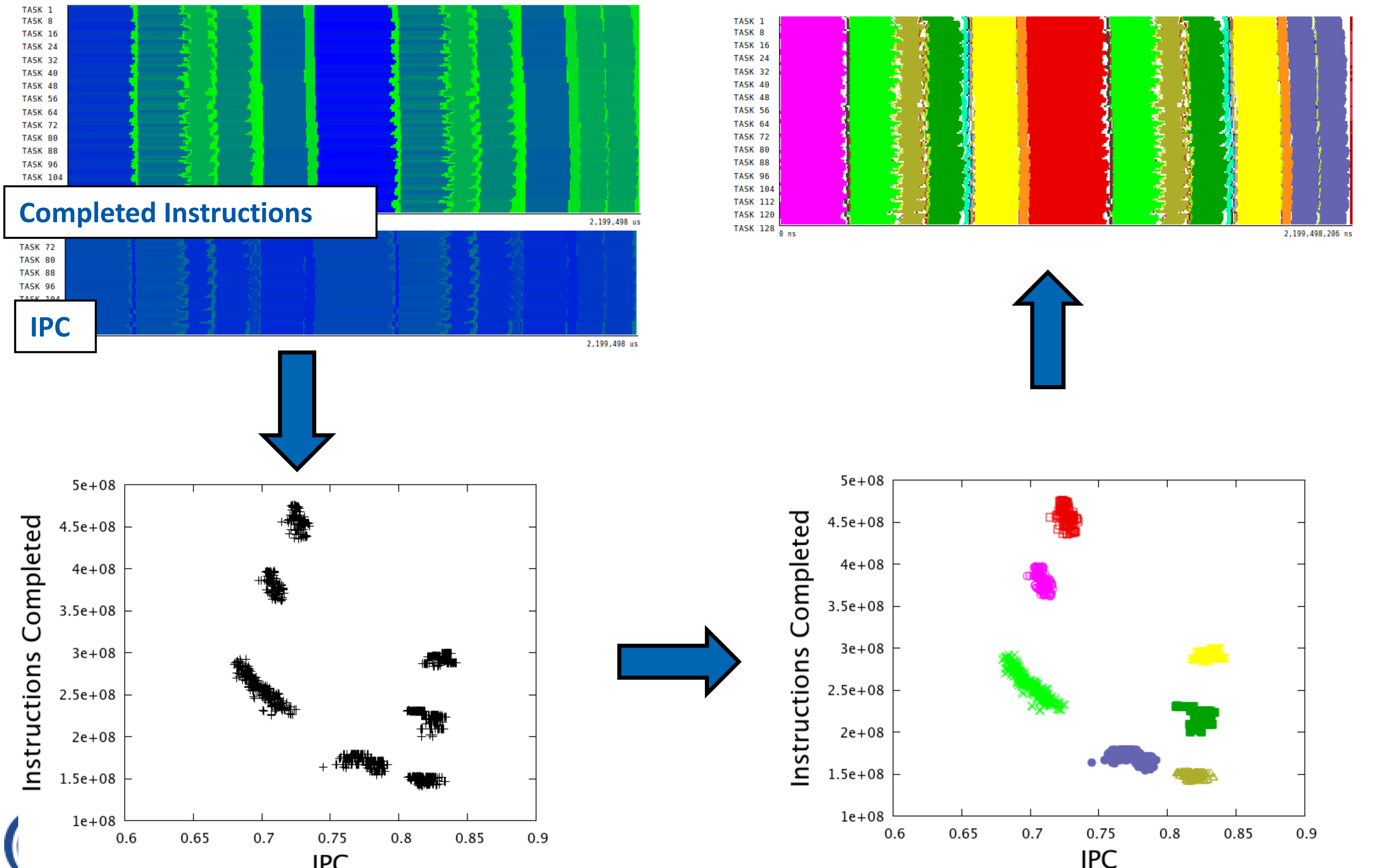
Using Clustering to identify structure



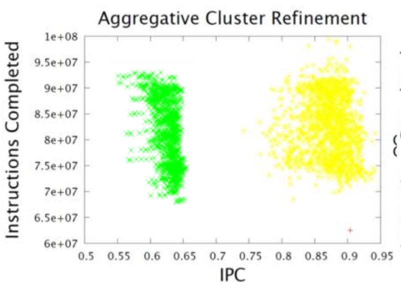
Automatic Detection of Parallel Applications Computation Phases (IPDPS 2009)

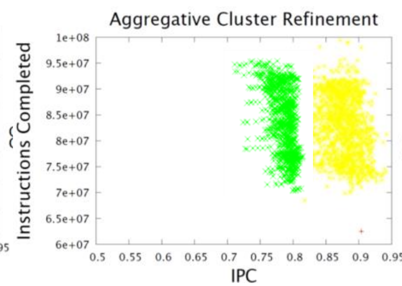
What should I improve?

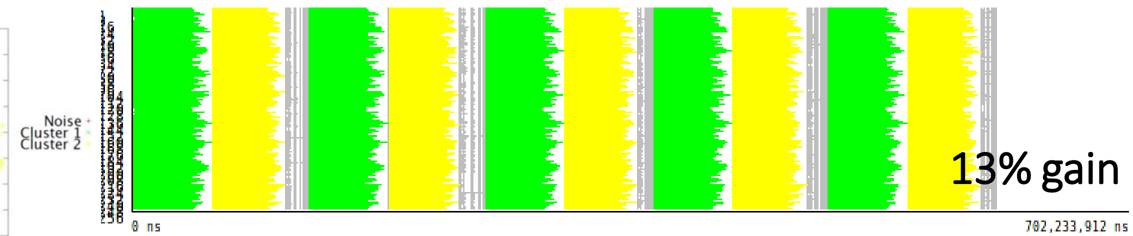
What if ….

PEPC

… we increase the IPC of Cluster1?

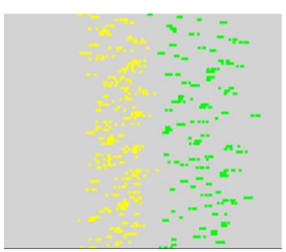


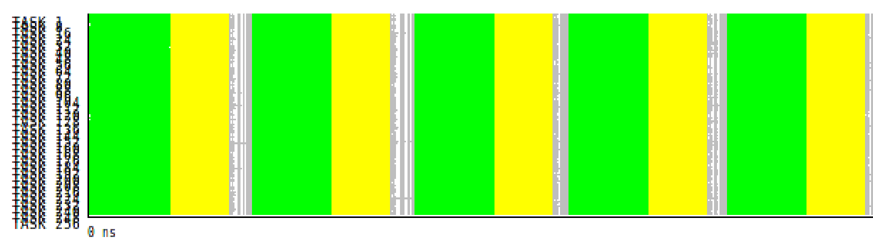




13% gain

… we balance Clusters 1 & 2?

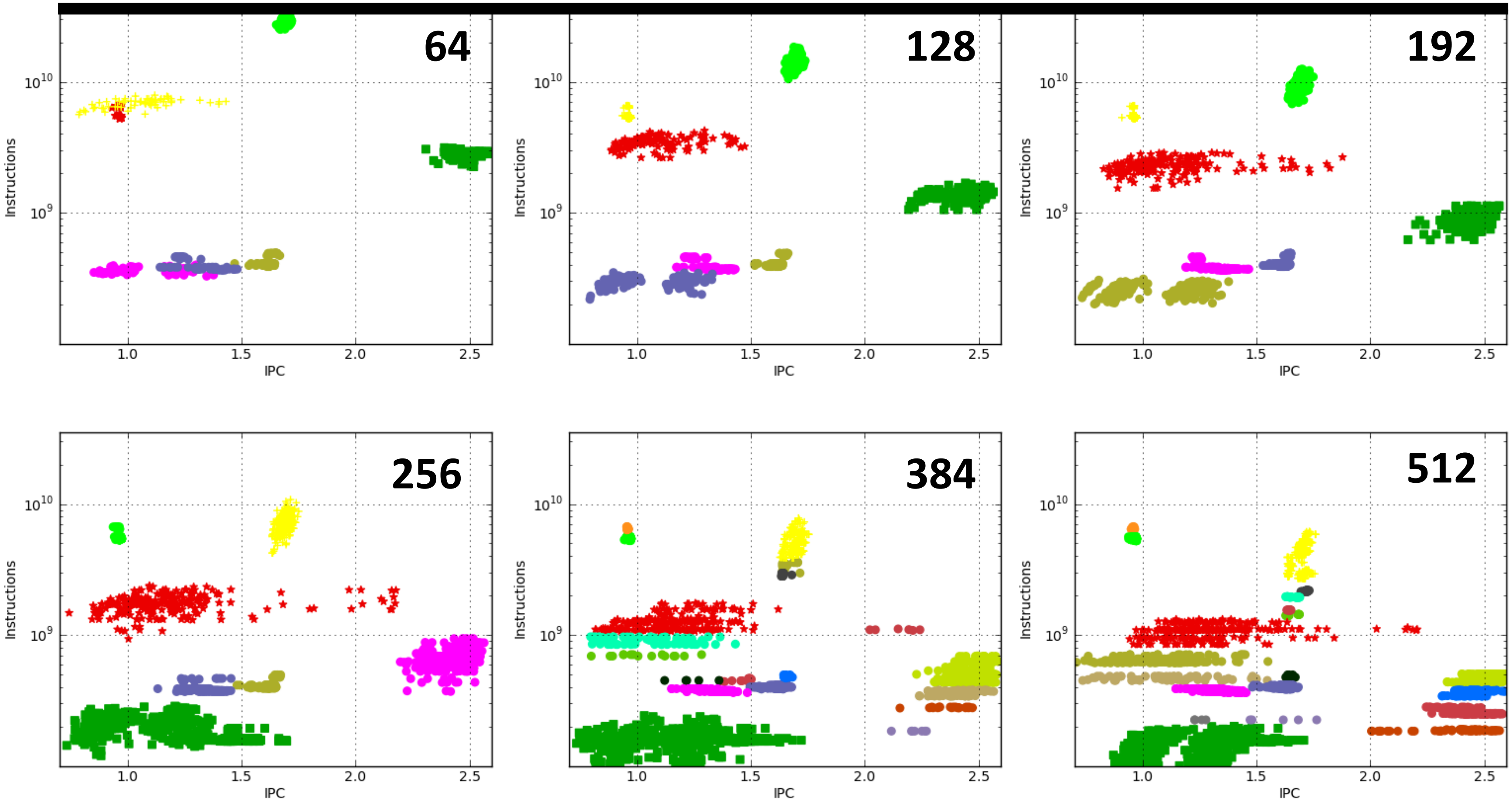




19% gain

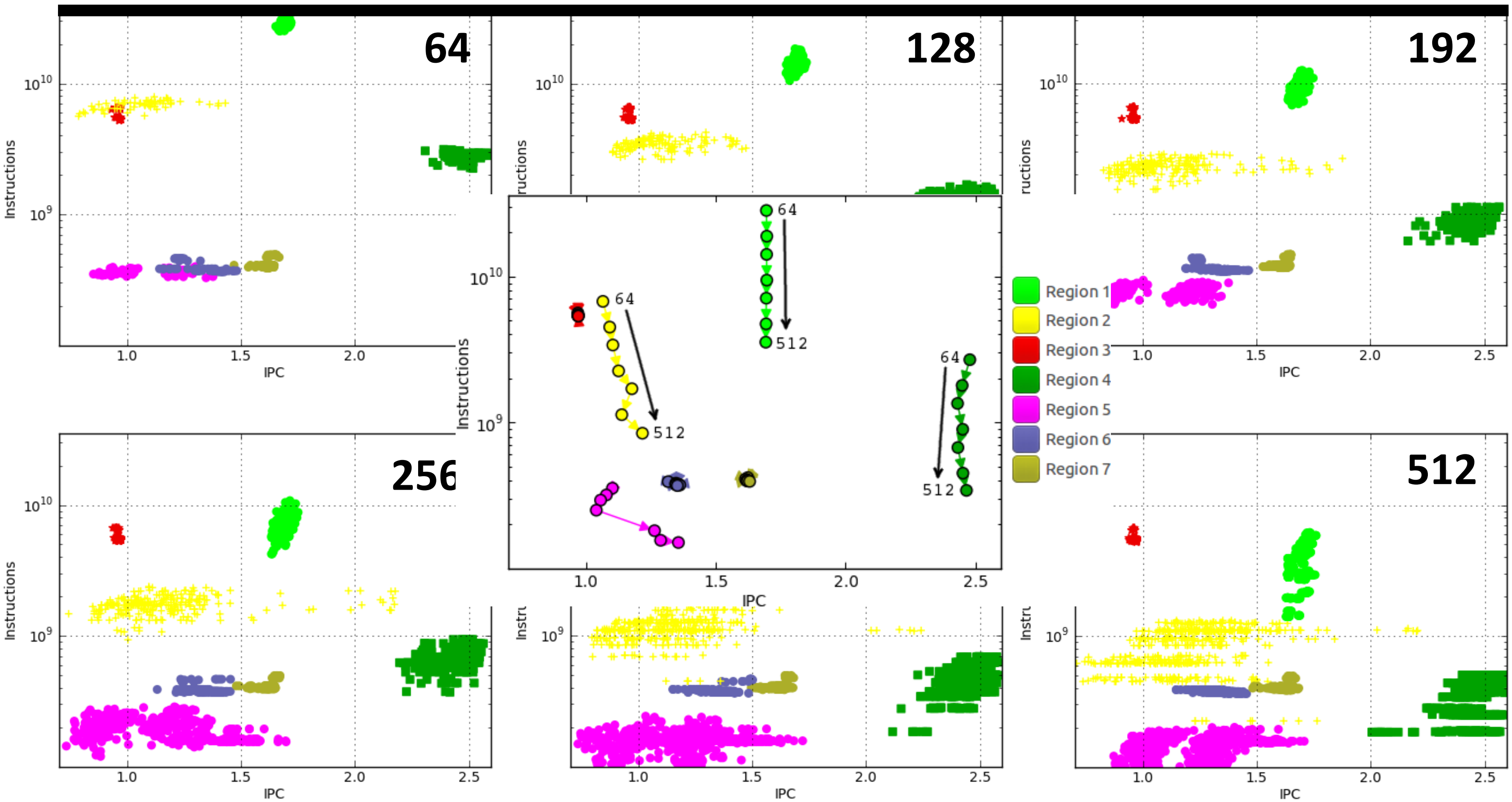
Tracking scability through clustering

- OpenMX (strong scale from 64 to 512 tasks)



Tracking scability through clustering

- OpenMX (strong scale from 64 to 512 tasks)



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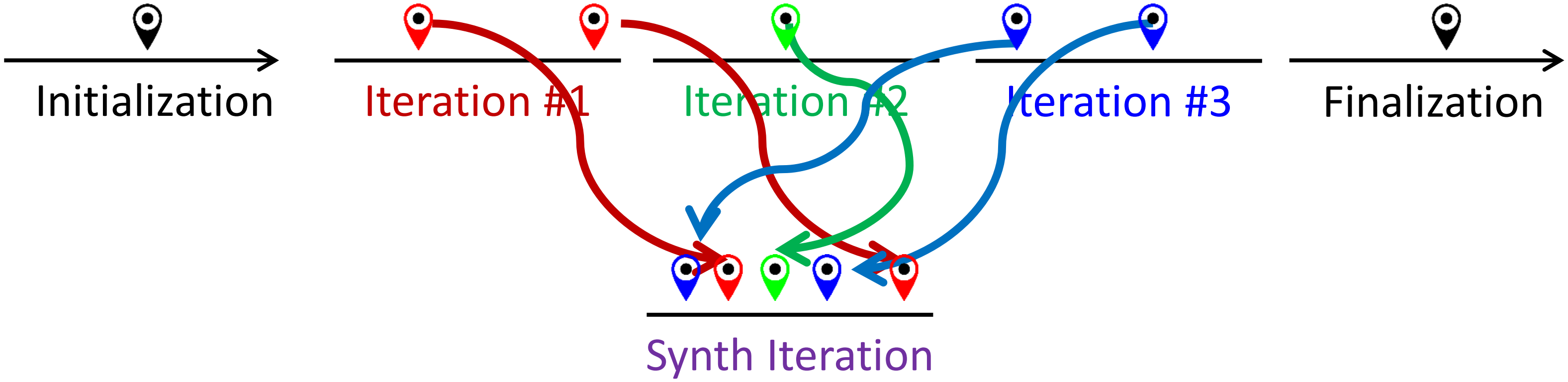
Folding

- Instantaneous metrics with minimum overhead
  - Combine instrumentation and sampling
    - Instrumentation delimits regions (routines, loops, …)
    - Sampling exposes progression within a region
  - Captures performance counters and call-stack references



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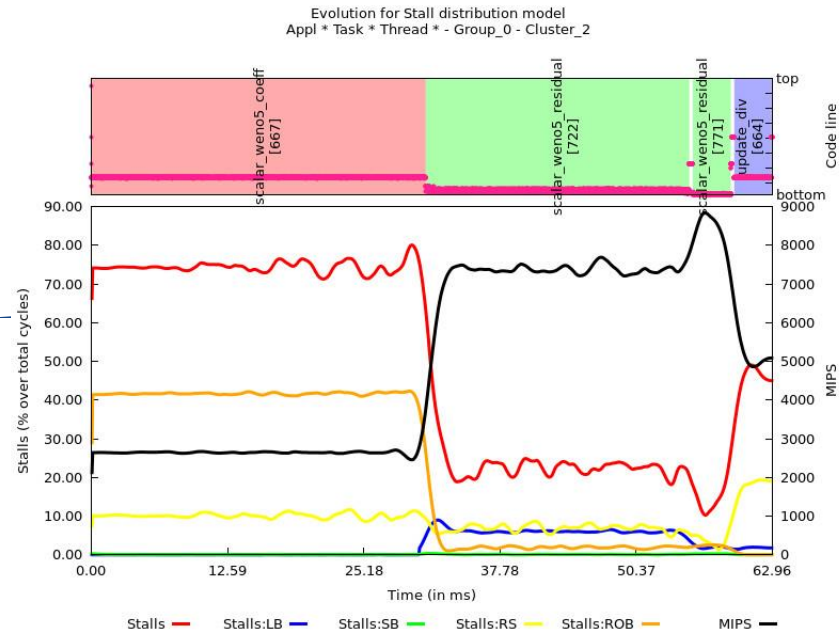
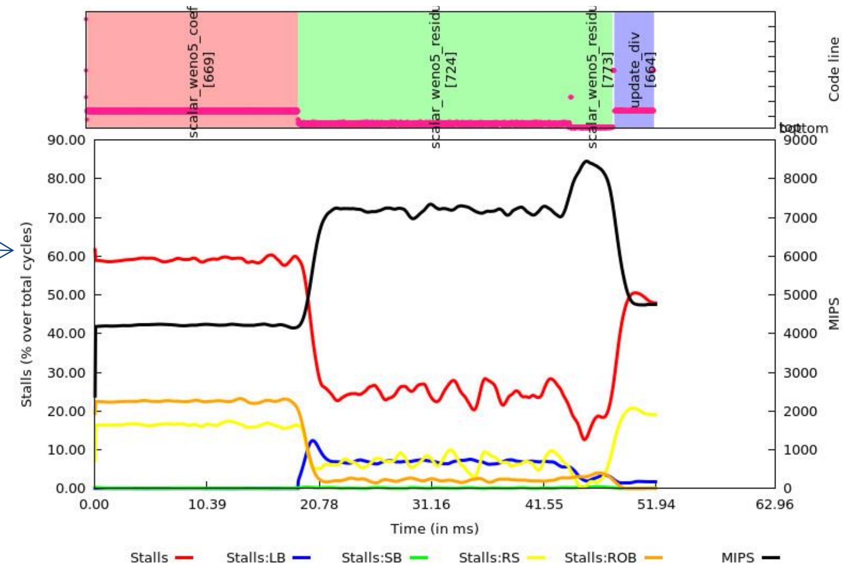
“Blind” optimization

- From folded samples of a few levels to timeline structure of “relevant” routines



Recommendation without access to source code



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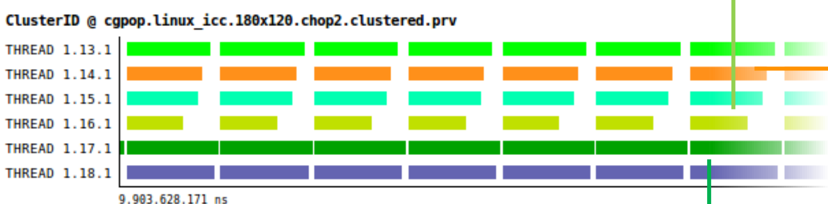
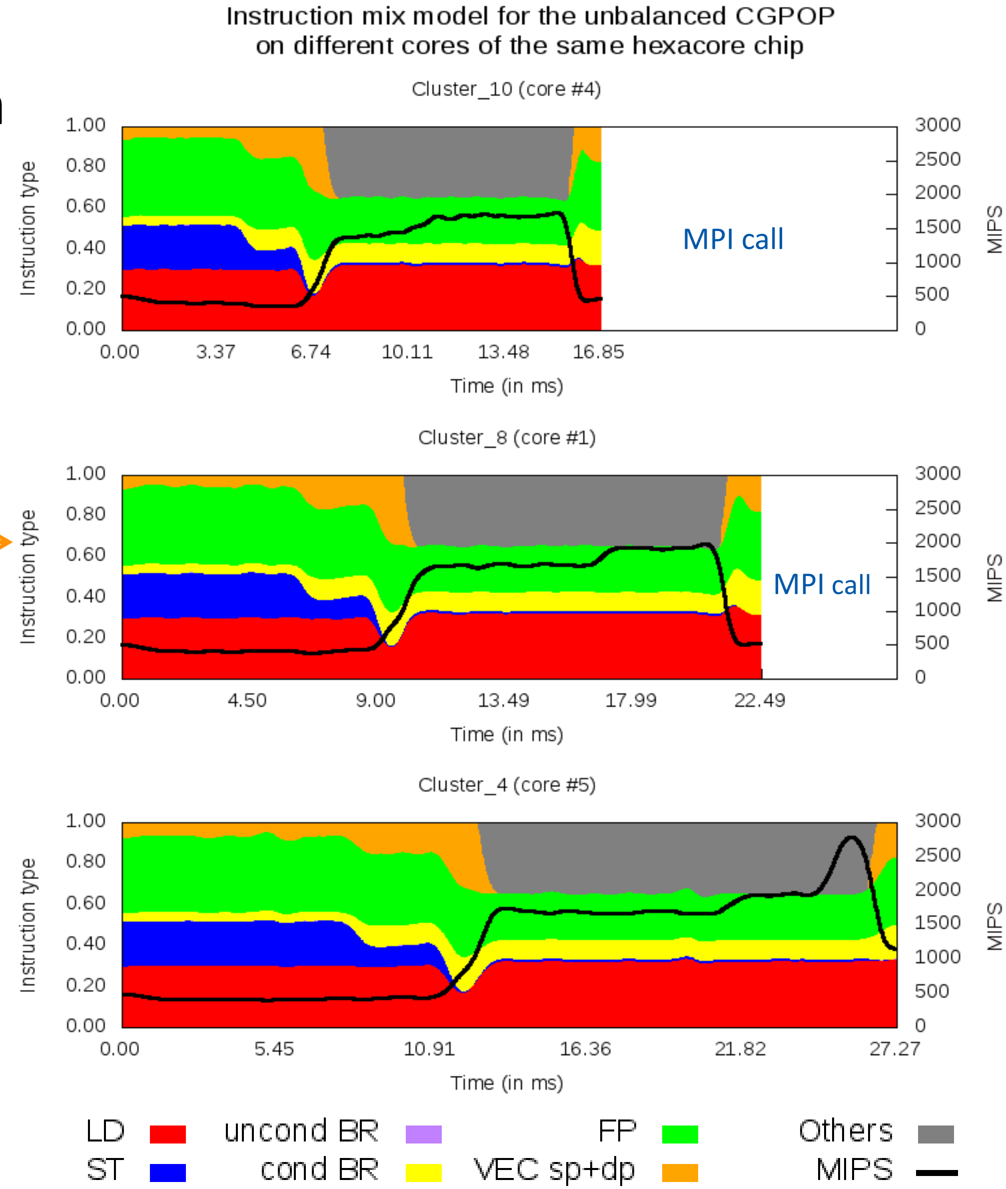
CG-POP multicore MN3 study

- Unbalanced MPI application
- Same code
- Different duration
- Different performance





Methodology

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Performance analysis tools objective

Help generate hypotheses

Help validate hypotheses

Qualitatively

Quantitatively

First steps

- Parallel efficiency – percentage of time invested on computation
  - Identify sources for “inefficiency”:
    - load balance
    - Communication /synchronization
- Serial efficiency – how far from peak performance?
  - IPC, correlate with other counters
- Scalability – code replication?
  - Total #instructions
- Behavioral structure? Variability?

BSC Tools web site

- tools.bsc.es
  - downloads
    - Sources / Binaries
    - Linux / windows / MAC
  - documentation
    - Training guides
    - Tutorial slides

- Getting started
  - Start wxparaver
  - Help → tutorials and follow instructions
  - Follow training guides
    - Paraver introduction (MPI): Navigation and basic understanding of Paraver operation