BSC Barcelona Supercomputing Center
Centro Nacional de Supercomputación

EXCELENCIA SEVERO OCHOA

Understanding applications with Paraver

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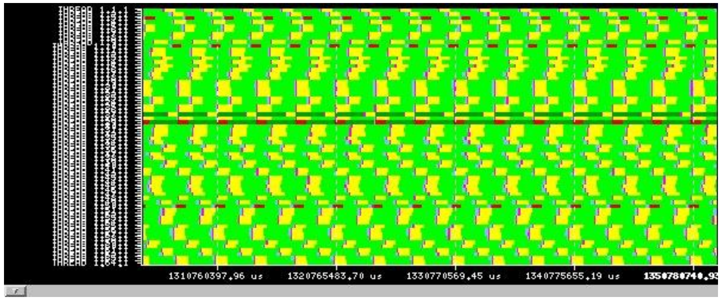
ANF Evaluation workshop

Humans are visual creatures

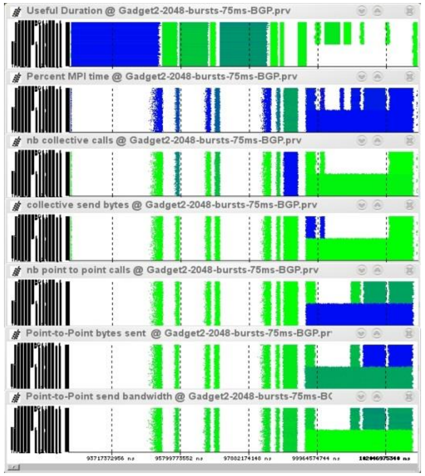
- Films or books? PROCESS
  - Two hours vs. days (months)
- Memorizing a deck of playing cards STORE
  - Each card translated to an image (person, action, location)
- Our brain loves pattern recognition IDENTIFY
  - What do you see on the pictures?

Our Tools

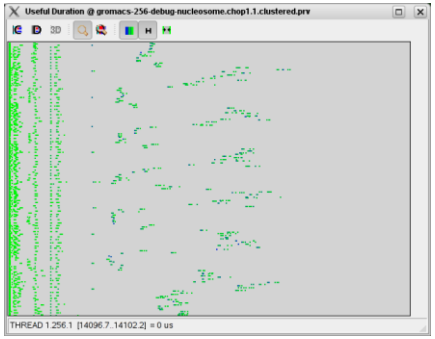
- Since 1991
- Based on traces
- Open Source
- http://tools.bsc.es



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


Useful Duration @ Gadget2-2048-bursts-75ms-BGP.prv
Percent MPI time @ Gadget2-2048-bursts-75ms-BGP.prv
nb collective calls @ Gadget2-2048-bursts-75ms-BGP.prv
collective send bytes @ Gadget2-2048-bursts-75ms-BGP.prv
nb point to point calls @ Gadget2-2048-bursts-75ms-BGP.prv
Point-to-Point bytes sent @ Gadget2-2048-bursts-75ms-BGP.pr
Point-to-Point send bandwidth @ Gadget2-2048-bursts-75ms-BC

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


Useful Duration @ gromacs-256-debug-nucleosome.chop1.1.clustered.prv
3D
THREAD 1.256.1 [14096.7..14102.2] = 0 us

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Paraver

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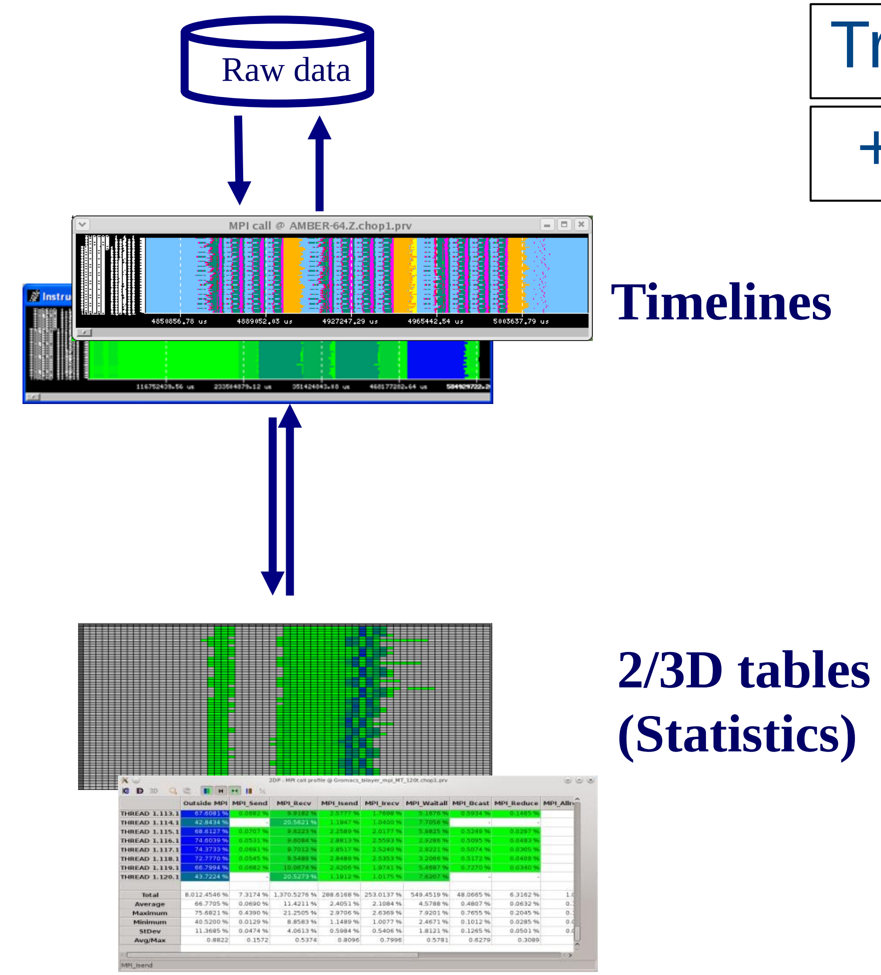
Paraver – Performance data browser



Raw data

Timelines

2/3D tables (Statistics)

2DP - MPI call profile @ Gromacs_bilayer_mpi_MT_120t.chop1.prv

	Outside MPI	MPI_Send	MPI_Recv	MPI_Isend	MPI_Irecv	MPI_Waitall	MPI_Bcast	MPI_Reduce	MPI_Allr
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 %	9.8223 %	2.2589 %	2.0177 %	5.9825 %	0.5249 %	0.0297 %	
THREAD 1.116.1	74.6039 %	0.0531 %	9.8084 %	2.8813 %	2.5593 %	2.9286 %	0.5095 %	0.0483 %	
THREAD 1.117.1	74.3733 %	0.0691 %	9.7012 %	2.8517 %	2.5240 %	2.9221 %	0.5074 %	0.0305 %	
THREAD 1.118.1	72.7770 %	0.0545 %	9.5489 %	2.8489 %	2.5353 %	3.2066 %	0.5172 %	0.0409 %	
THREAD 1.119.1	66.7994 %	0.0682 %	10.0674 %	2.4206 %	1.9741 %	5.4687 %	0.7270 %	0.0340 %	
THREAD 1.120.1	43.7224 %	-	20.5273 %	1.1912 %	1.0175 %	7.6207 %	-	-	
Total	8,012.4546 %	7.3174 %	1,370.5276 %	288.6168 %	253.0137 %	549.4519 %	48.0665 %	6.3162 %	1.0
Average	66.7705 %	0.0690 %	11.4211 %	2.4051 %	2.1084 %	4.5788 %	0.4807 %	0.0632 %	0.
Maximum	75.6821 %	0.4390 %	21.2505 %	2.9706 %	2.6369 %	7.9201 %	0.7655 %	0.2045 %	0.
Minimum	40.5200 %	0.0129 %	8.8583 %	1.1489 %	1.0077 %	2.4671 %	0.1012 %	0.0285 %	0.0
StDev	11.3685 %	0.0474 %	4.0613 %	0.5984 %	0.5406 %	1.8121 %	0.1265 %	0.0501 %	0.0
Avg/Max	0.8822	0.1572	0.5374	0.8096	0.7996	0.5781	0.6279	0.3089	

MPI_Isend

Trace visualization/analysis

+ trace manipulation

Goal = Flexibility

No semantics

Programmable

Comparative analyses

Multiple traces

Synchronize scales

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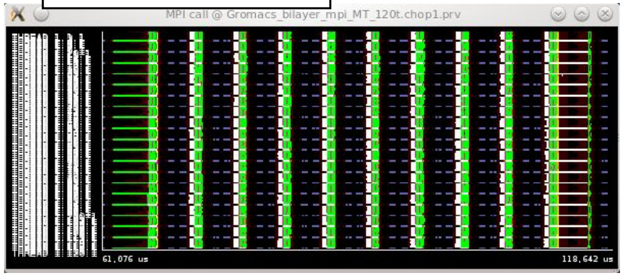
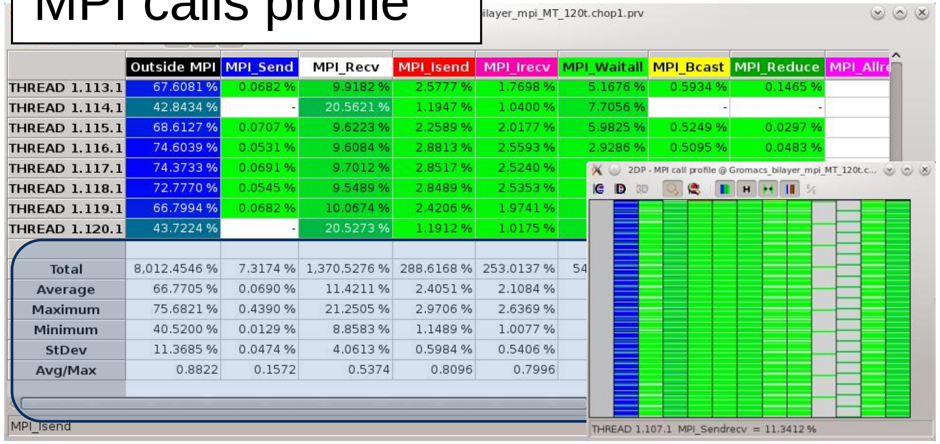
From timelines to tables

MPI calls



MPI calls profile

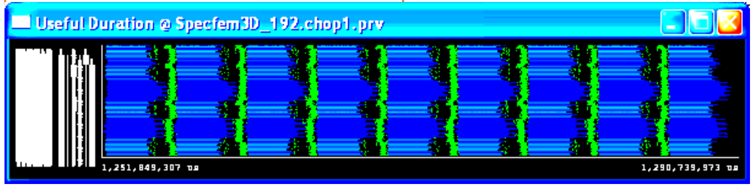

ilayer_mpi_MT_120t.chop1.prv
2DP - MPI call profile @ Gromacs_bilayer_mpi_MT_120t.c...
3D
H

	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				

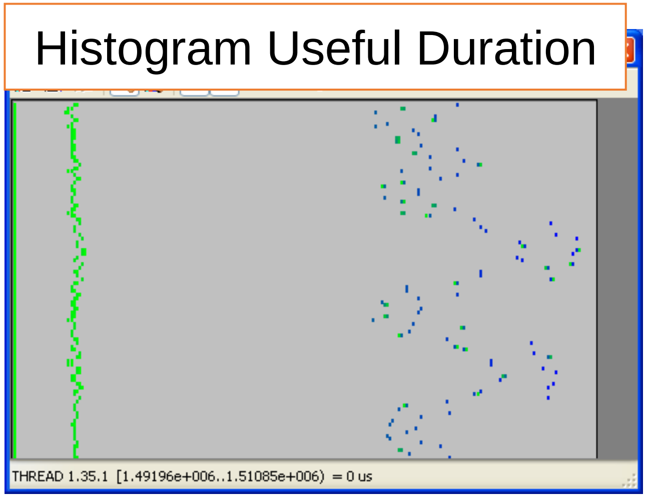
MPI_Isend

THREAD 1.107.1 MPI_Sendrecv = 11.3412 %

Useful Duration

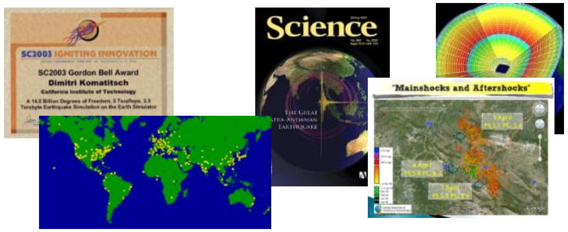


Histogram Useful Duration



THREAD 1.35.1 [1.49196e+006..1.51085e+006) = 0 us

Analyzing variability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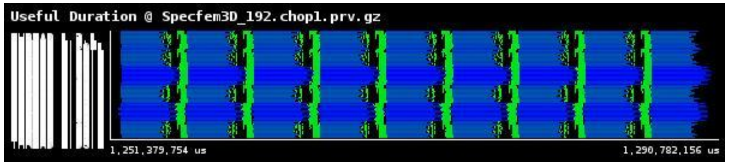
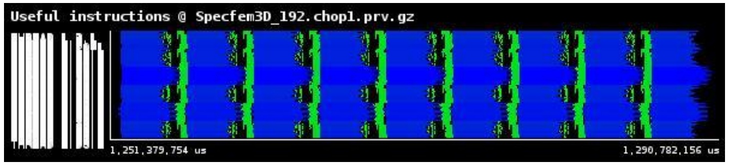
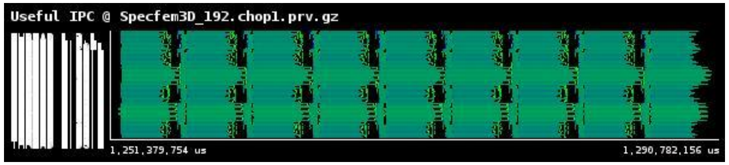
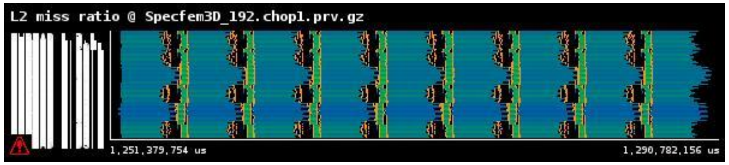
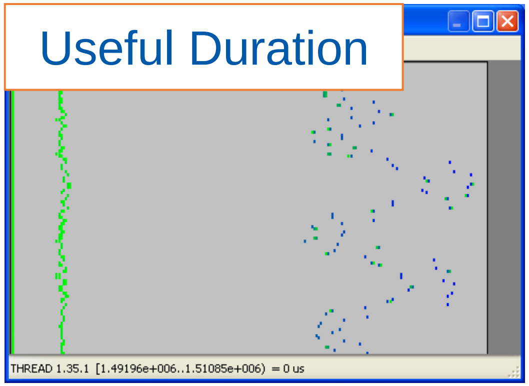
Dimitri Komatitsch
Science
THE GREAT SUMATRA-ANDAMAN EARTHQUAKE
"Mainshocks and Aftershocks"


Useful Duration @ Specfem3D_192.chop1.prv.gz

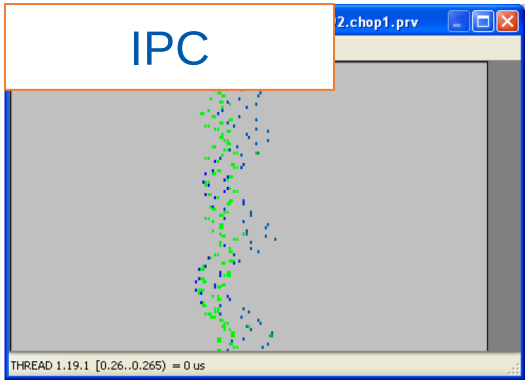

Useful instructions @ Specfem3D_192.chop1.prv.gz


Useful IPC @ Specfem3D_192.chop1.prv.gz

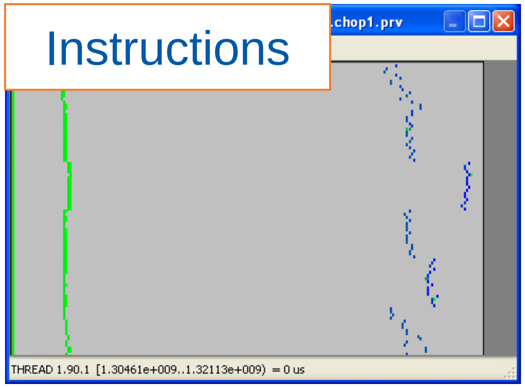

L2 miss ratio @ Specfem3D_192.chop1.prv.gz


Useful Duration

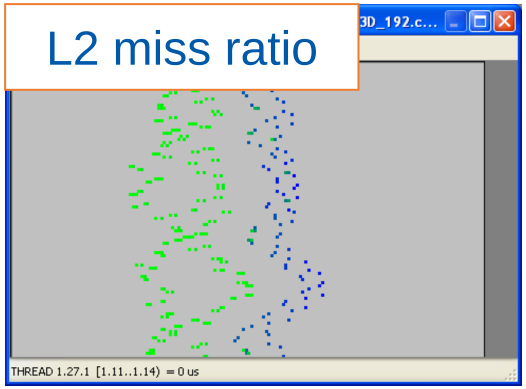
THREAD 1.35.1 [1.49196e+006..1.51085e+006) = 0 us


IPC

THREAD 1.19.1 [0.26..0.265) = 0 us


Instructions

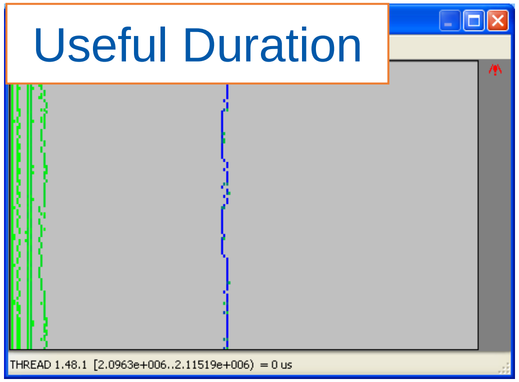
THREAD 1.90.1 [1.30461e+009..1.32113e+009) = 0 us


L2 miss ratio

THREAD 1.27.1 [1.11..1.14) = 0 us

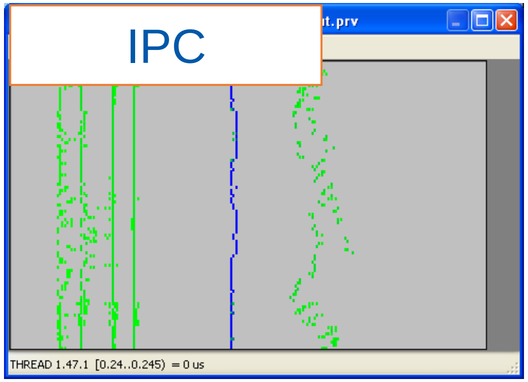
Analyzing variability

- By the way: six months later ….



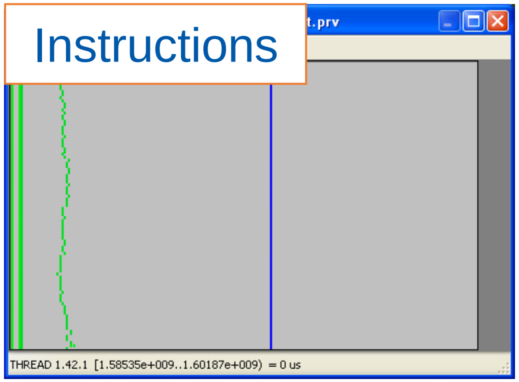
Useful Duration

```
THREAD 1.48.1 [2.0963e+006..2.11519e+006) = 0 us
```



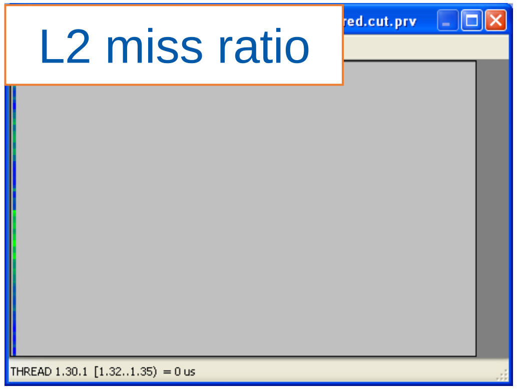
IPC

```
THREAD 1.47.1 [0.24..0.245) = 0 us
```



Instructions

```
THREAD 1.42.1 [1.58535e+009..1.60187e+009) = 0 us
```



L2 miss ratio

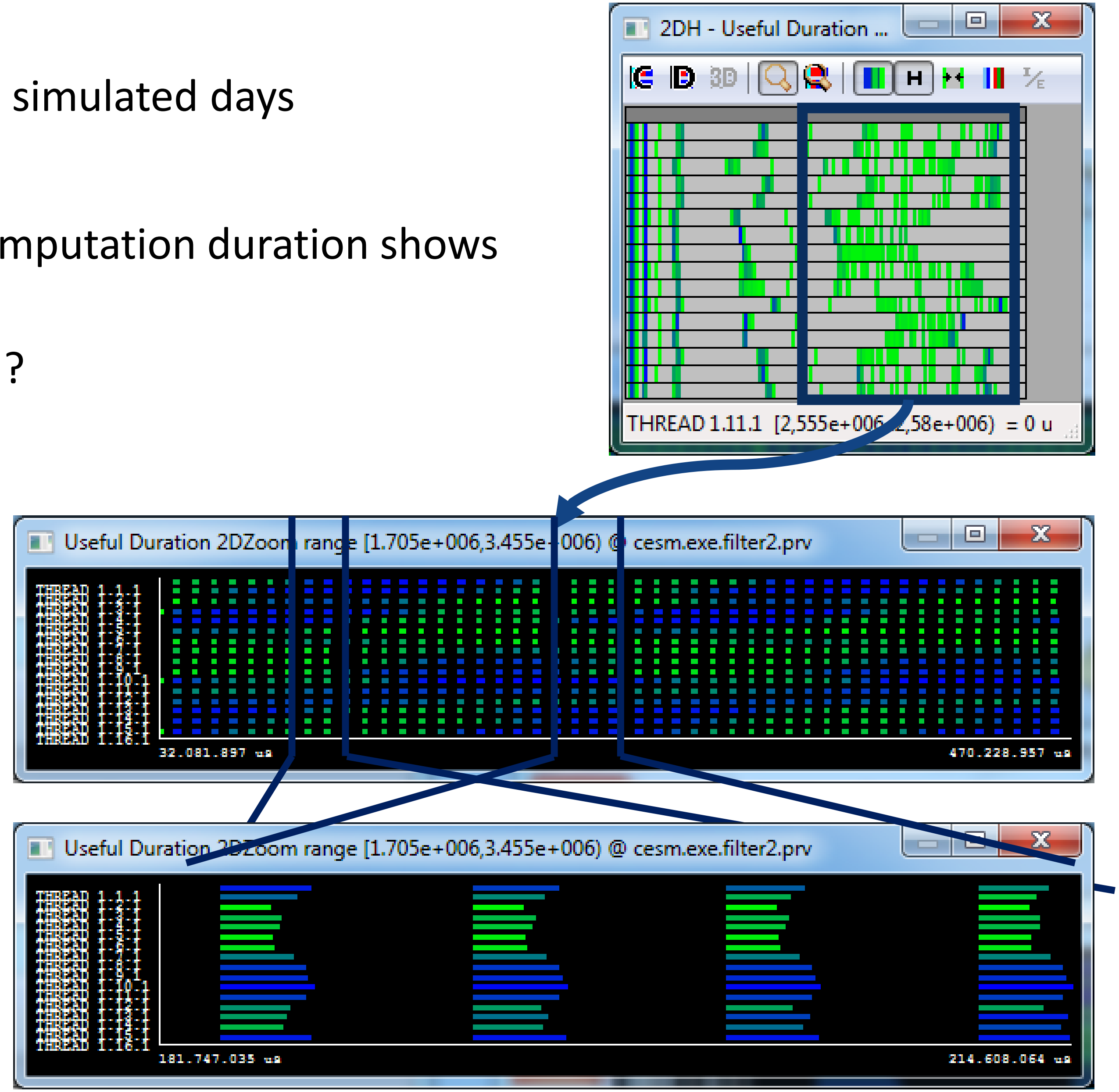
```
THREAD 1.30.1 [1.32..1.35) = 0 us
```

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 ? ☺


2DH - Useful Duration ...
3D
H
THREAD 1.11.1 [2,555e+006,2,58e+006) = 0 u
Useful Duration 2DZoom range [1.705e+006,3.455e+006) @ cesm.exe.filter2.prv
THREAD 1.1.1
THREAD 1.16.1
32.081.897 us
470.228.957 us
Useful Duration 2DZoom range [1.705e+006,3.455e+006) @ cesm.exe.filter2.prv
THREAD 1.1.1
THREAD 1.16.1
181.747.035 us
214.608.064 us

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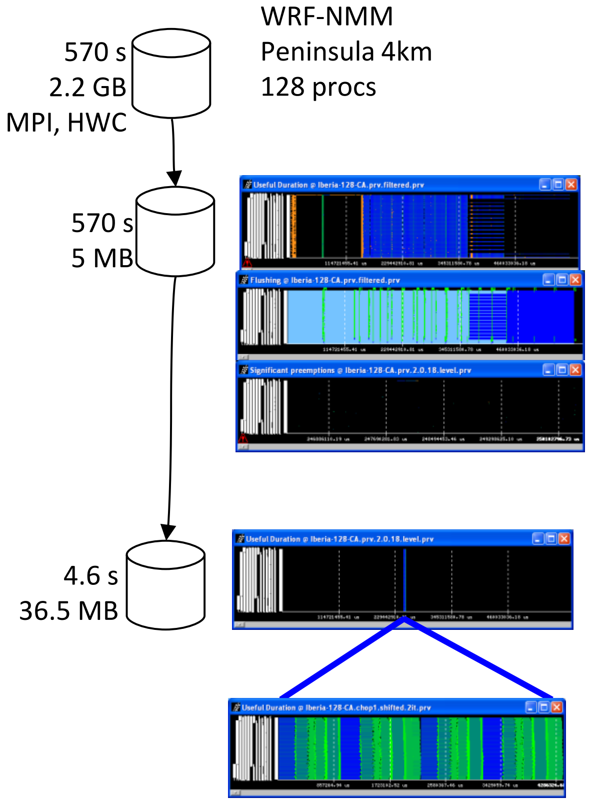
Trace manipulation

- 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,…


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

Dimemas

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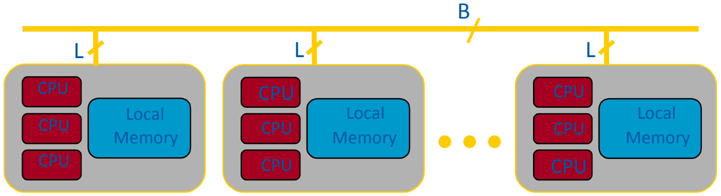
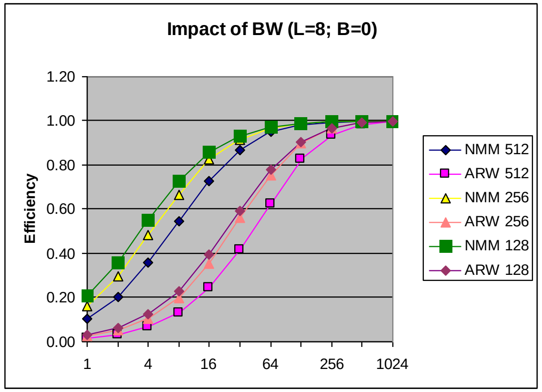
Dimemas – Coarse grain, Trace driven simulation

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



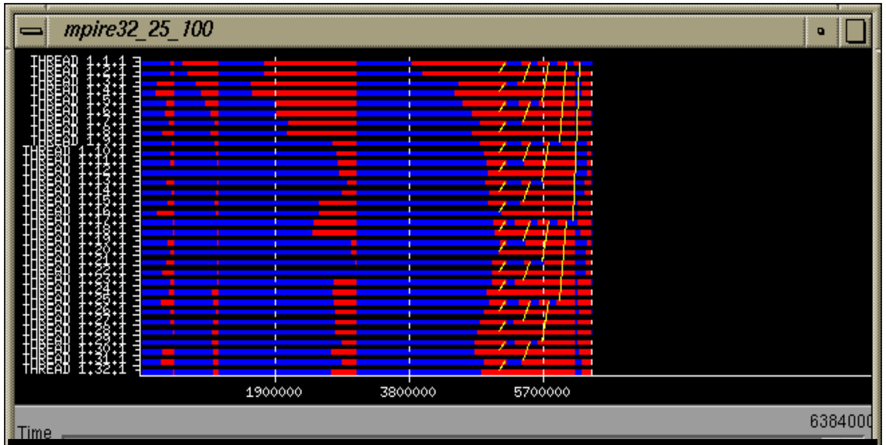
- Parametric sweeps
  - On abstract architectures
  - On application computational regions
- What if analysis
  - Ideal machine (instantaneous network)
  - Estimating impact of ports to MPI+OpenMP/CUDA/…
  - Should I use asynchronous communications?
  - Are all parts equally sensitive to network?
- MPI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



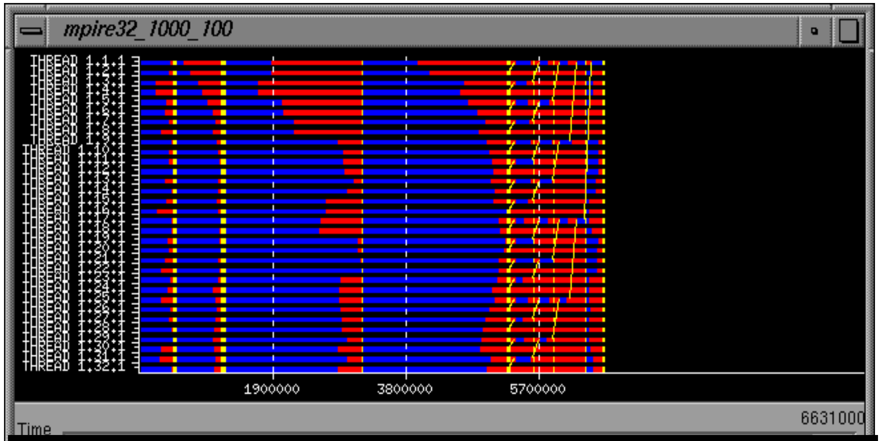
Detailed feedback on simulation (trace)

Network sensitivity

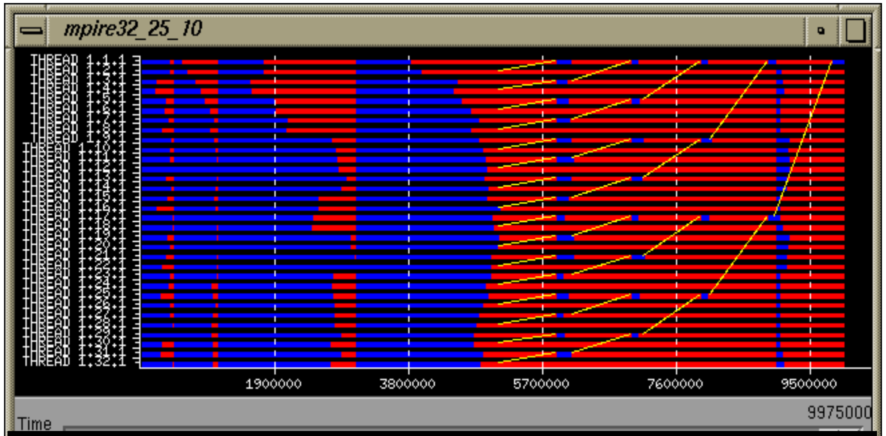
- MPIRE 32 tasks, no network contention



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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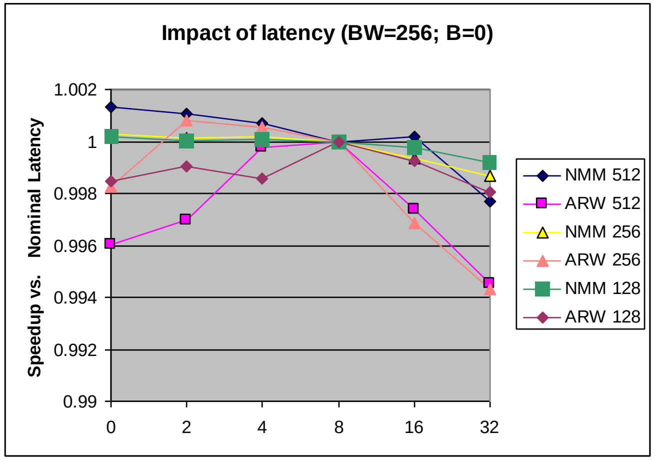
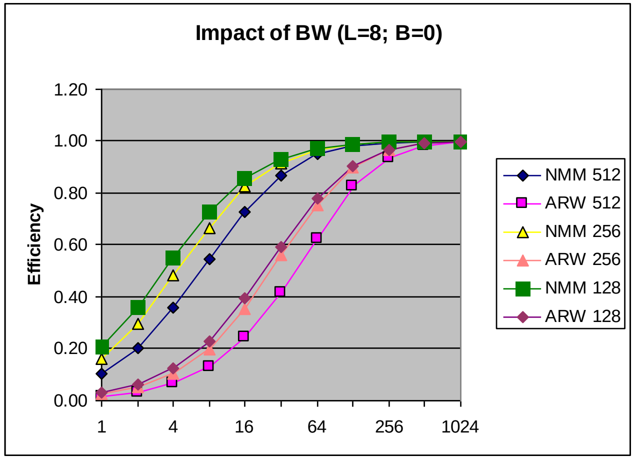
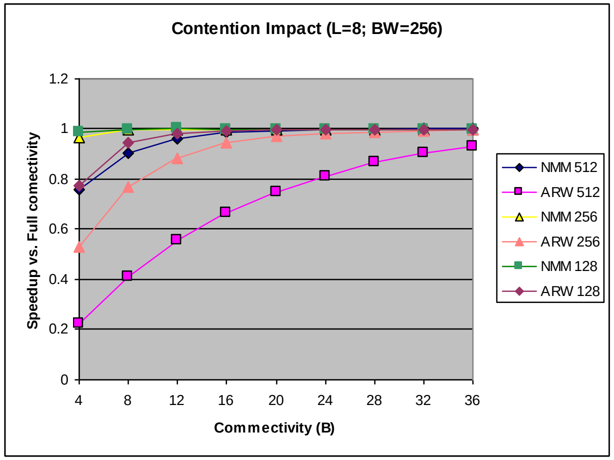
Network sensitivity

- 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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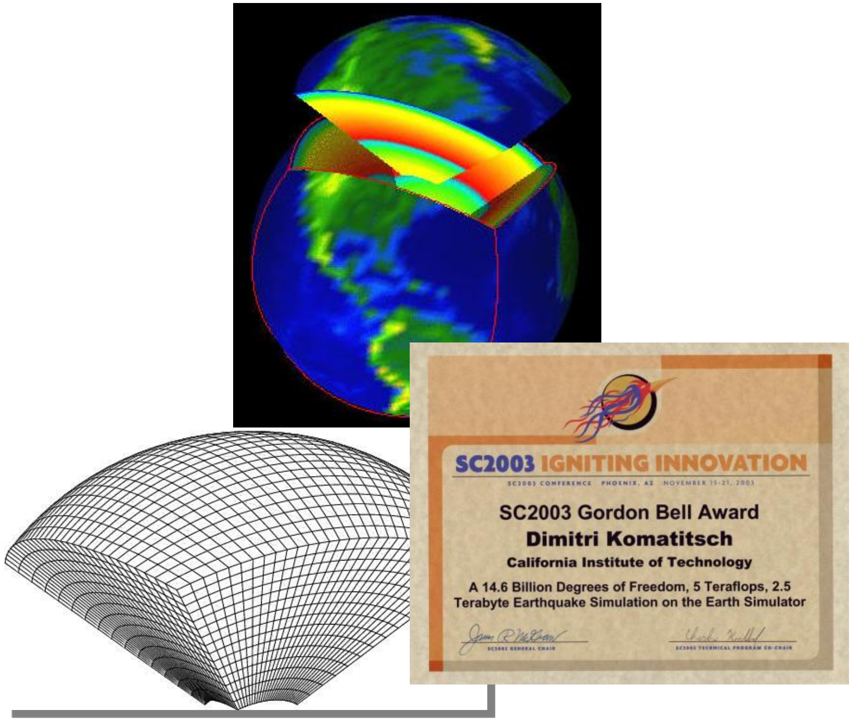
Would I will benefit from asynchronous communications?

SPECFEM3D



SC2003 IGNITING INNOVATION

SC2003 CONFERENCE PHOENIX, AZ NOVEMBER 15-21, 2003

SC2003 Gordon Bell Award

Dimitri Komatitsch

California Institute of Technology

A 14.6 Billion Degrees of Freedom, 5 Teraflops, 2.5 Terabyte Earthquake Simulation on the Earth Simulator

SC2003 GENERAL CHAIR

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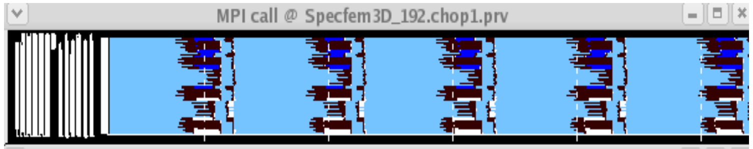
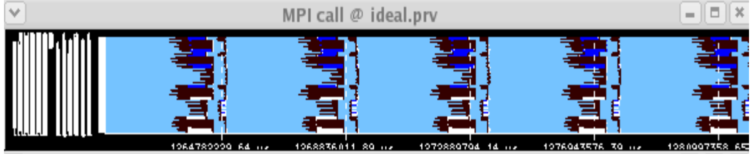
Courtesy Dimitri Komatitsch

Real



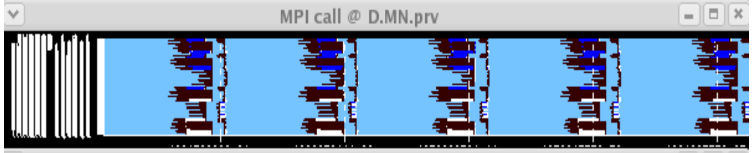
MPI call @ Specfem3D_192.chop1.prv

Ideal



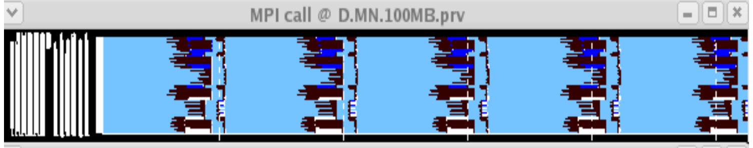
MPI call @ ideal.prv

Prediction MN



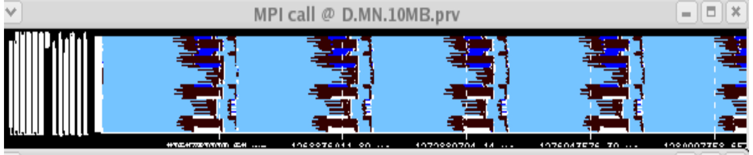
MPI call @ D.MN.prv

Prediction 100MB/s



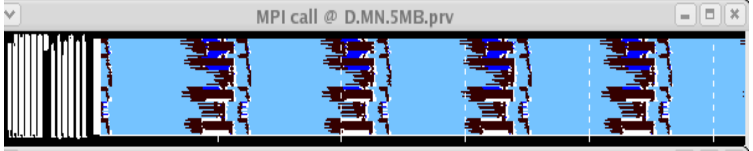
MPI call @ D.MN.100MB.prv

Prediction 10MB/s



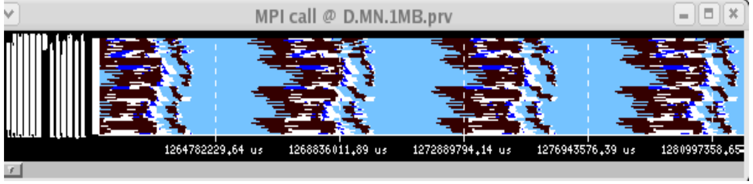
MPI call @ D.MN.10MB.prv

Prediction 5MB/s



MPI call @ D.MN.5MB.prv

Prediction 1MB/s



MPI call @ D.MN.1MB.prv

Ideal machine

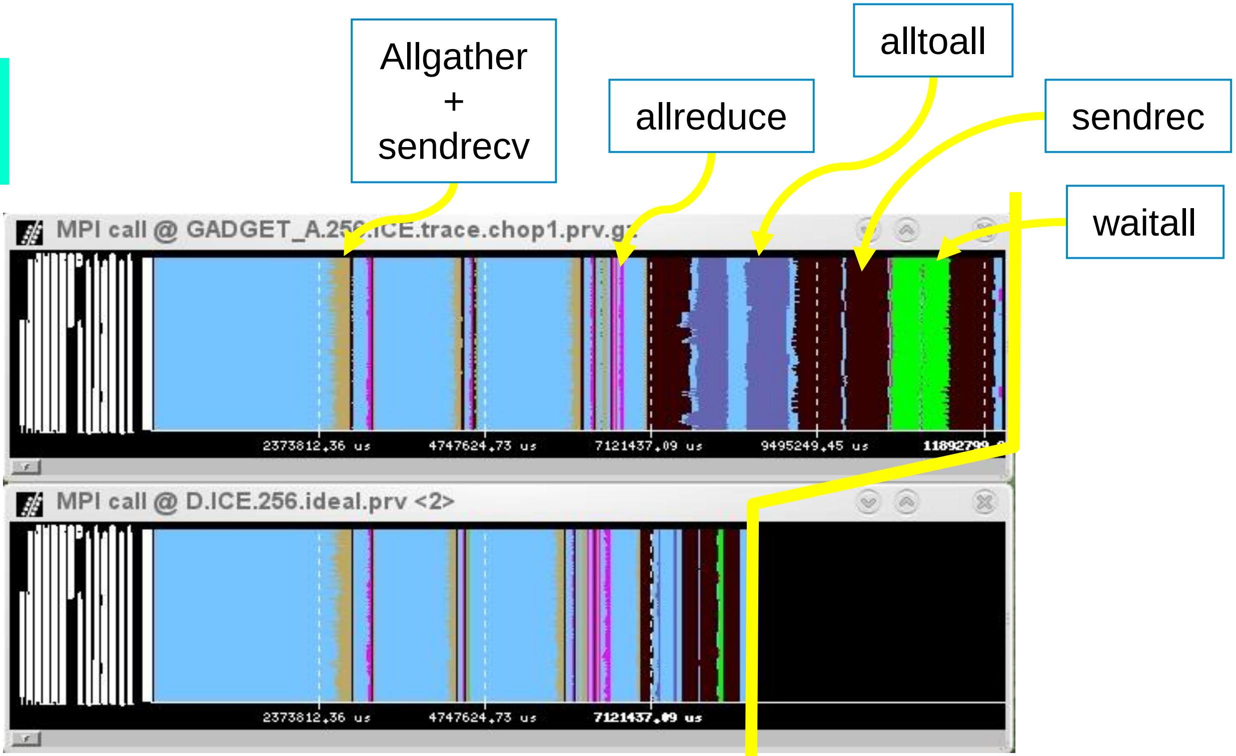
The impossible machine: BW = ∞, L = 0

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

GADGET @ Nehalem cluster
256 processes

Real run

Ideal network



Allgather + sendrecv

allreduce

alltoall

sendrec

waitall

MPI call @ GADGET_A.256.ICE.trace.chop1.prv.gz

2373812,36 us 4747624,73 us 7121437,09 us 9495249,45 us 11892799

MPI call @ D.ICE.256.ideal.prv <2>

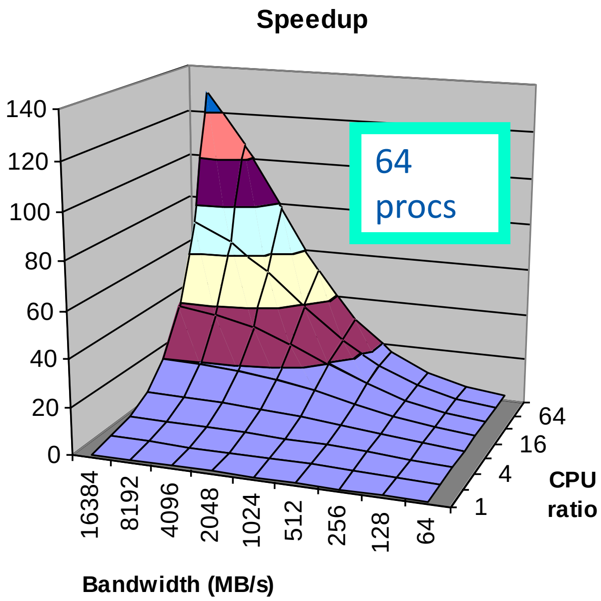
2373812,36 us 4747624,73 us 7121437,09 us

Impact on practical machines?

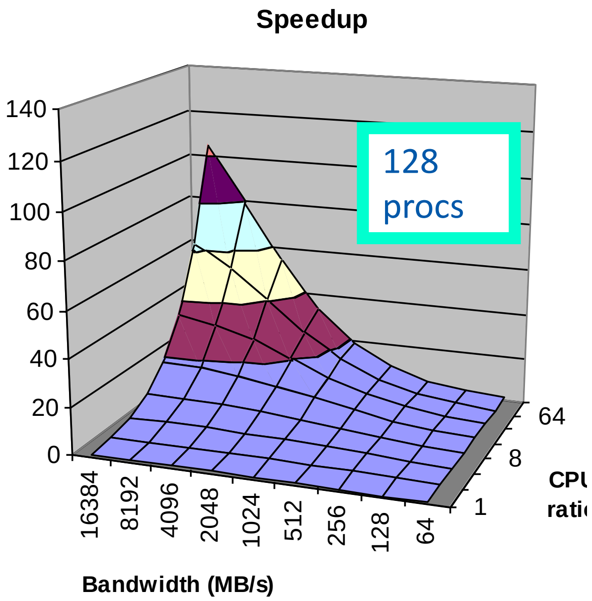
Impact of architectural parameters

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

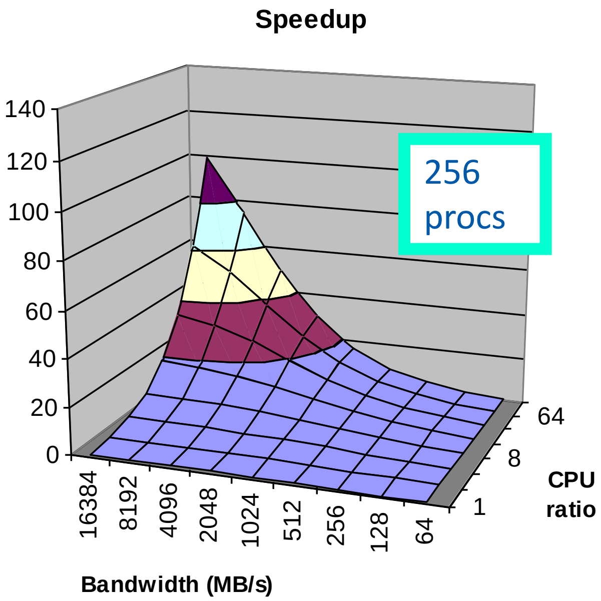
GADGET


Speedup

64 procs


Speedup

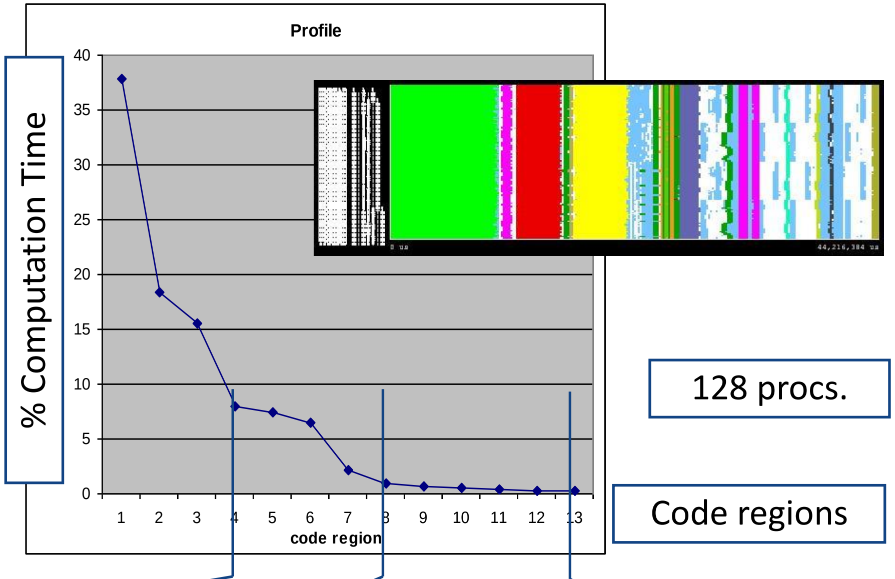
128 procs

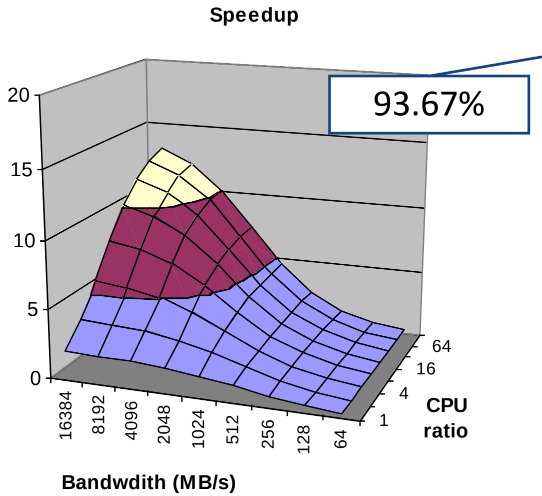

Speedup

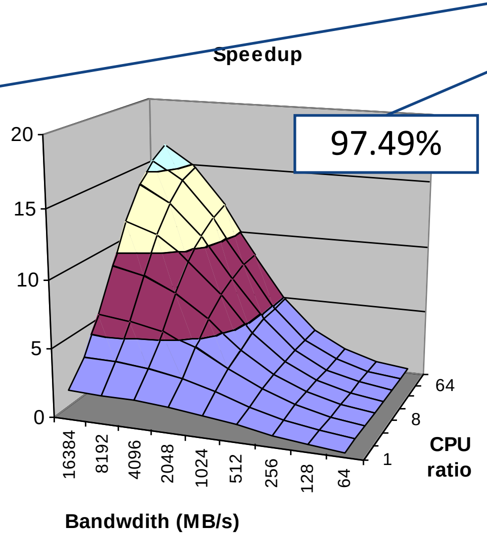
256 procs

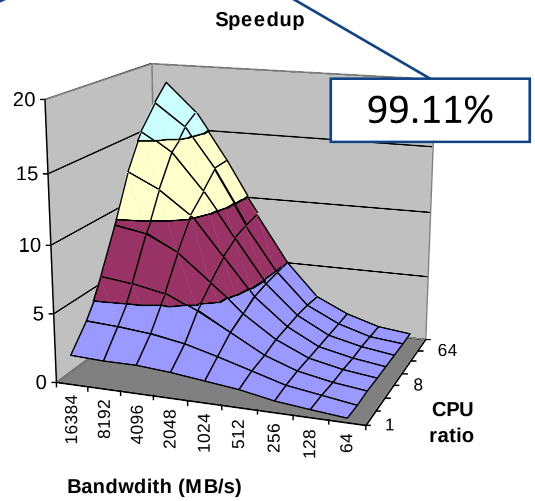
Hybrid parallelization

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









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

Efficiency Model

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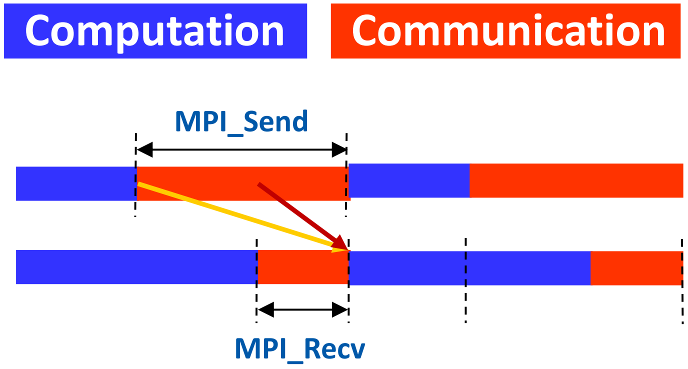
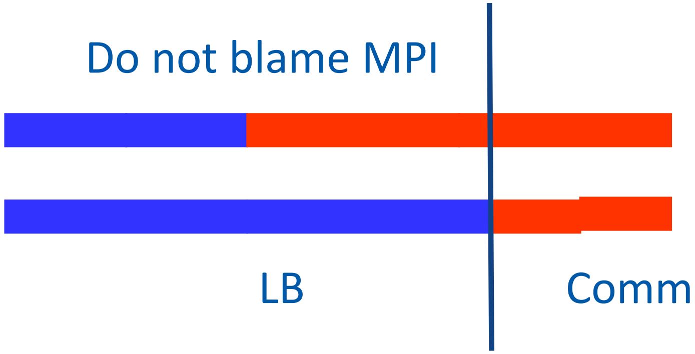
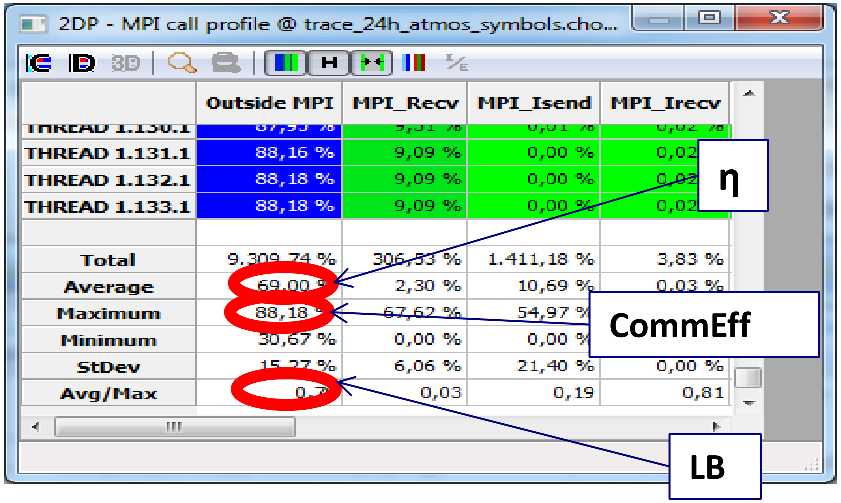
Parallel efficiency model





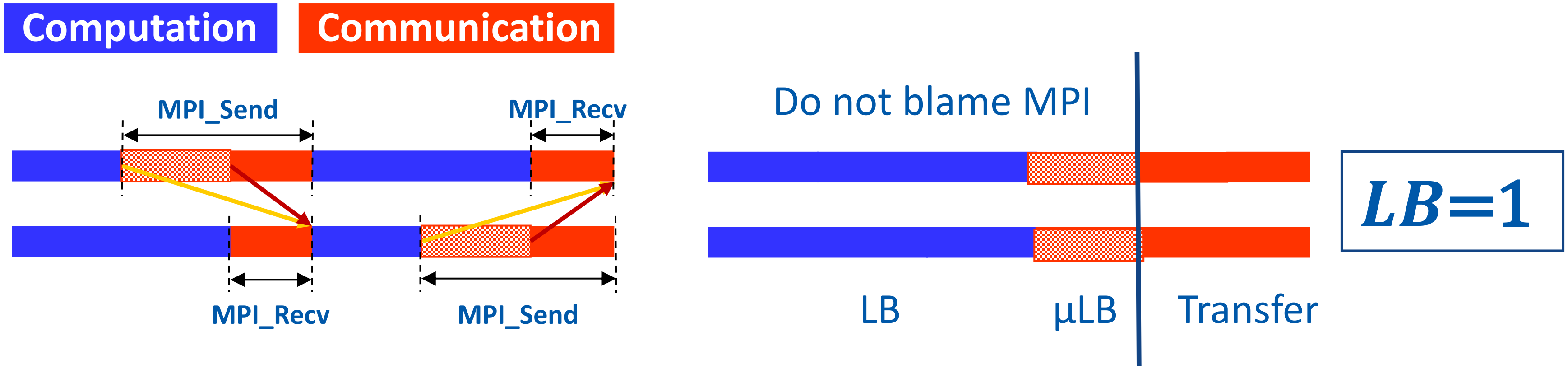
- Parallel efficiency = LB eff * Comm eff



2DP - MPI call profile @ trace_24h_atmos_symbols.cho...

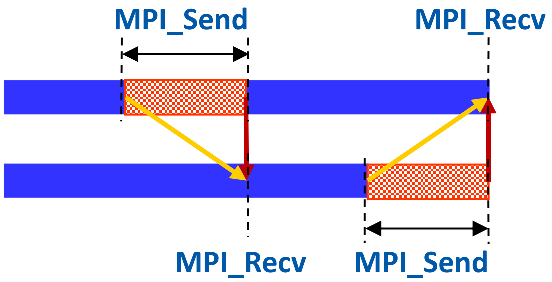
	Outside MPI	MPI_Recv	MPI_Isend	MPI_Irecv
THREAD 1.130.1	87,95 %	9,31 %	0,01 %	0,02 %
THREAD 1.131.1	88,16 %	9,09 %	0,00 %	0,02
THREAD 1.132.1	88,18 %	9,09 %	0,00 %	0,02
THREAD 1.133.1	88,18 %	9,09 %	0,00 %	0,02
Total	9.309,74 %	306,53 %	1.411,18 %	3,83 %
Average	69,00 %	2,30 %	10,69 %	0,03 %
Maximum	88,18	67,62 %	54,97 %	
Minimum	30,67 %	0,00 %	0,00 %	
StDev	15,27 %	6,06 %	21,40 %	0,00 %
Avg/Max	0,7	0,03	0,19	0,81

Parallel efficiency refinement: LB * µLB * Tr



$$\boxed{LB=1}$$

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

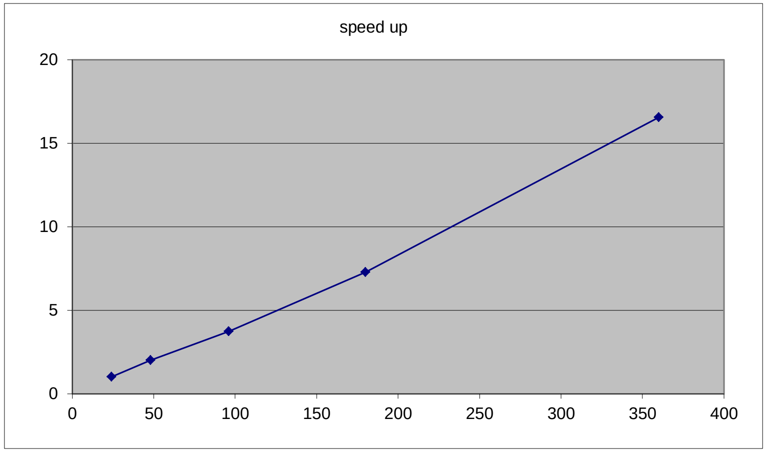


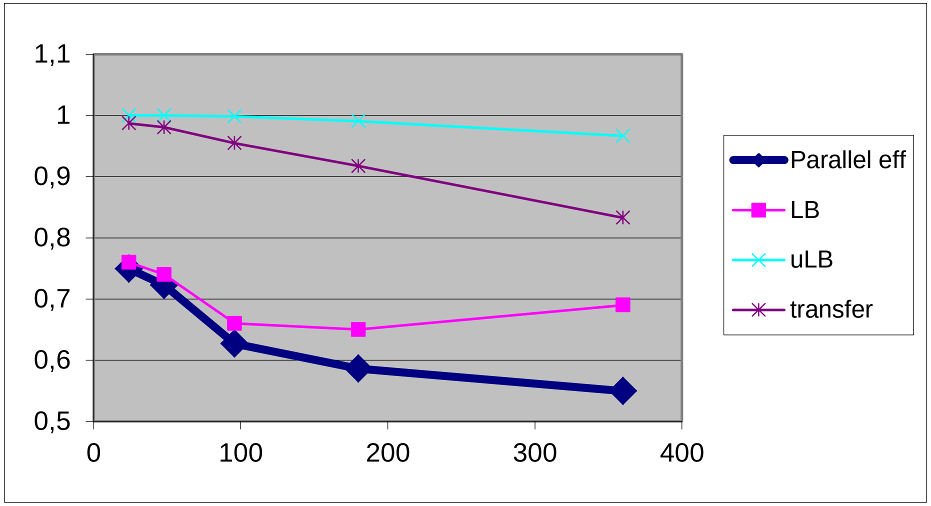
Why scaling?

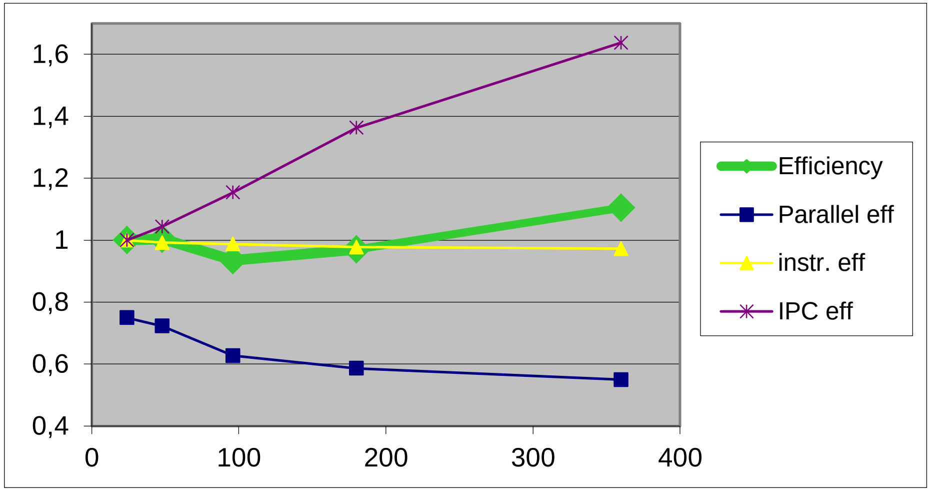
$$\eta_{\parallel} = LB * Ser * Trf$$

CG-POP mpi2s1D - 180x120

Good scalability !!
Should we be happy?







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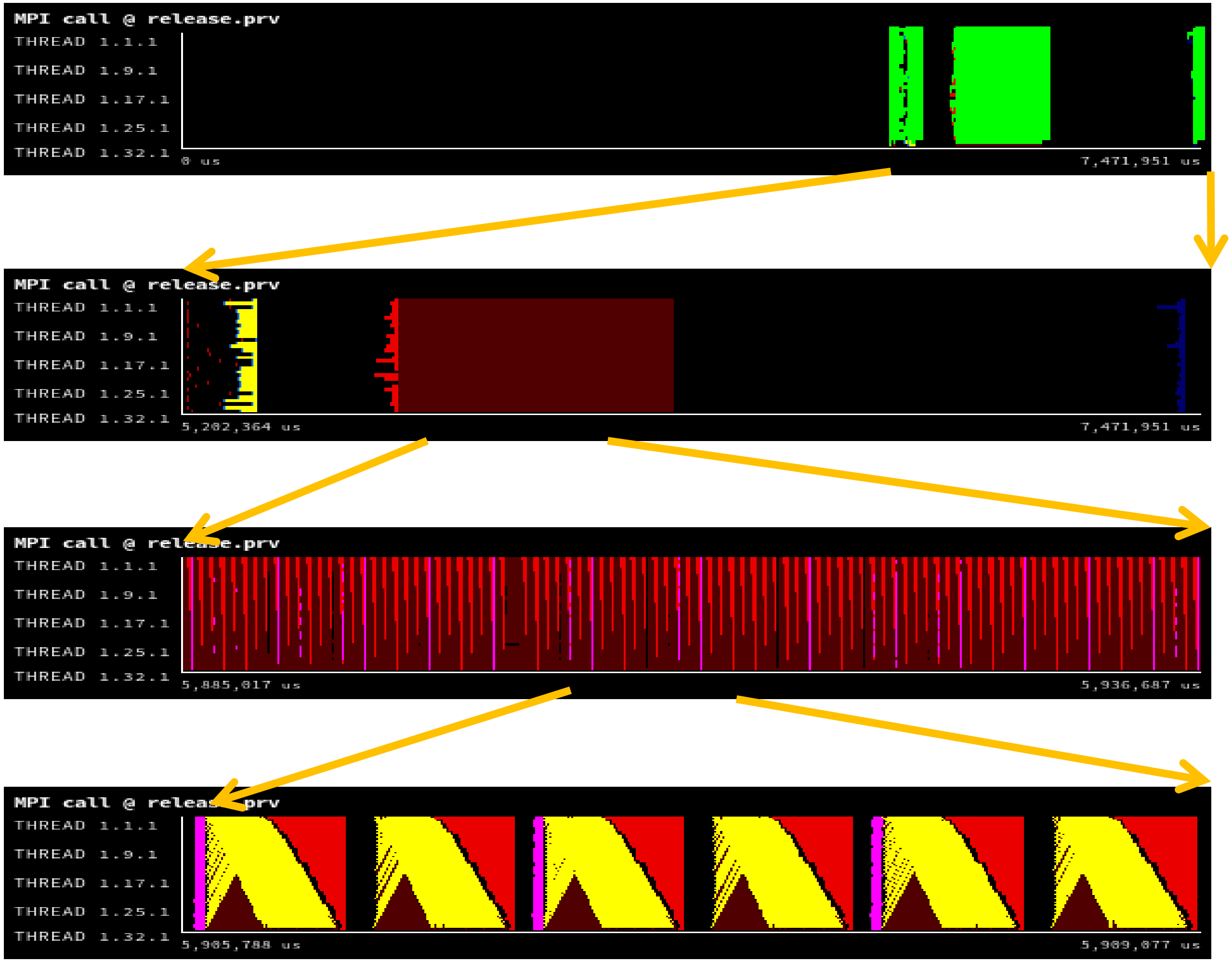
Why efficient?

Parallel efficiency =93.28
Communication = 93.84

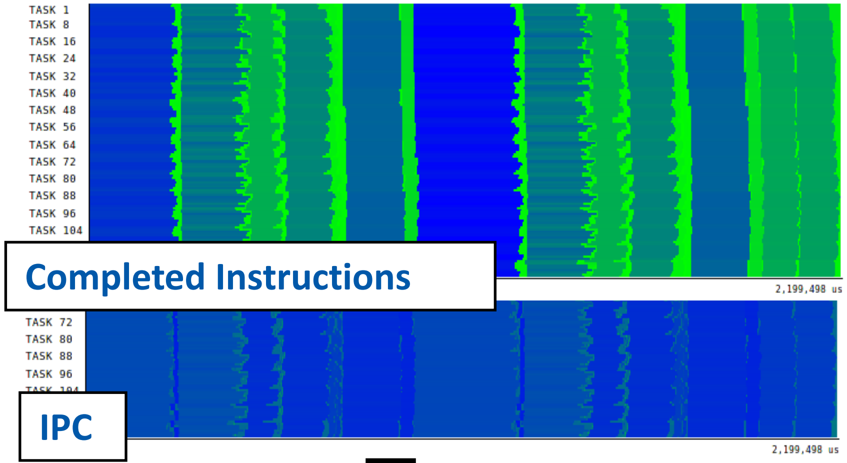
Parallel efficiency = 77.93
Communication = 79.79

Parallel efficiency = 28.84
Communication eff = 30.42



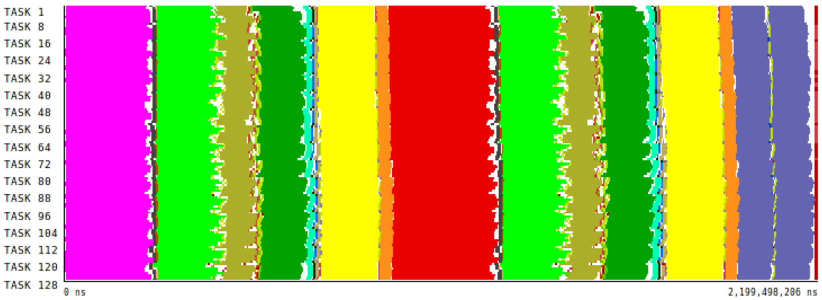
Analytics

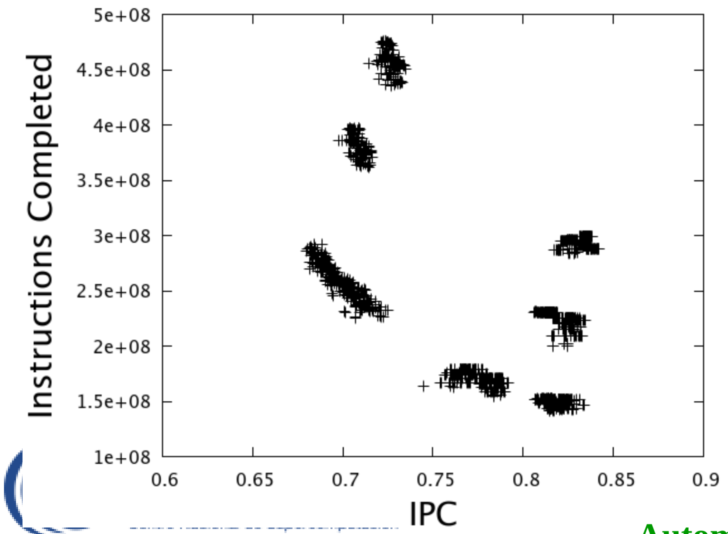
Using Clustering to identify structure

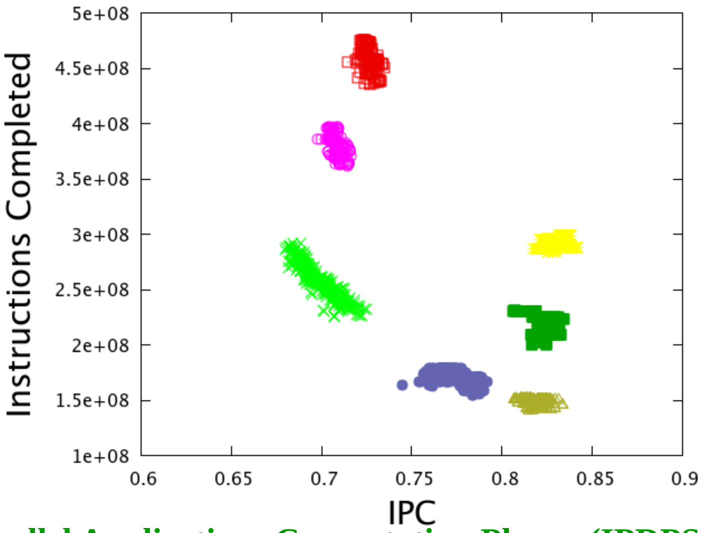


Completed Instructions

IPC





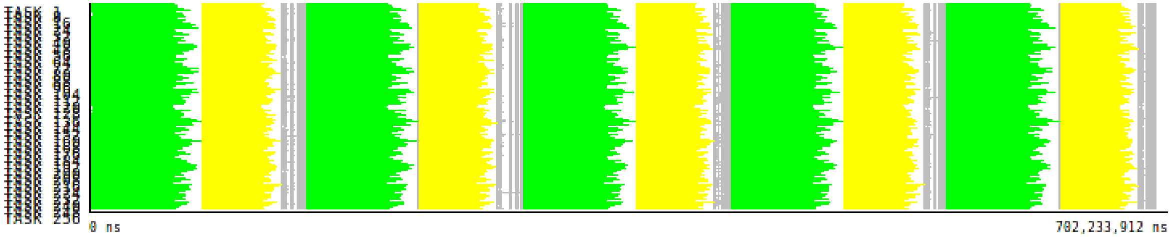


Automatic Detection of Parallel Applications Computation Phases (IPDPS 2009)

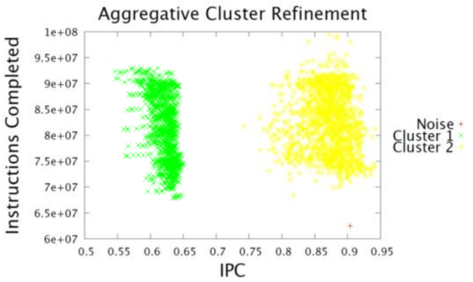
What should I improve?

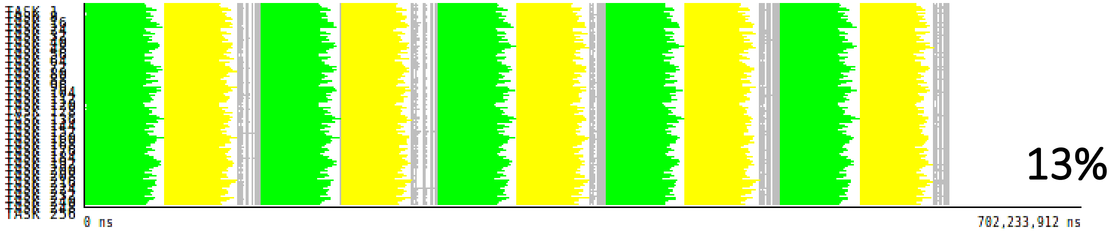
What if ….

PEPC



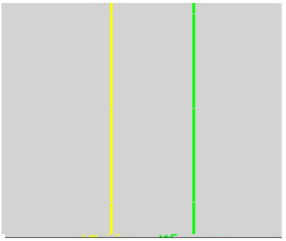
… we increase the IPC of Cluster1?

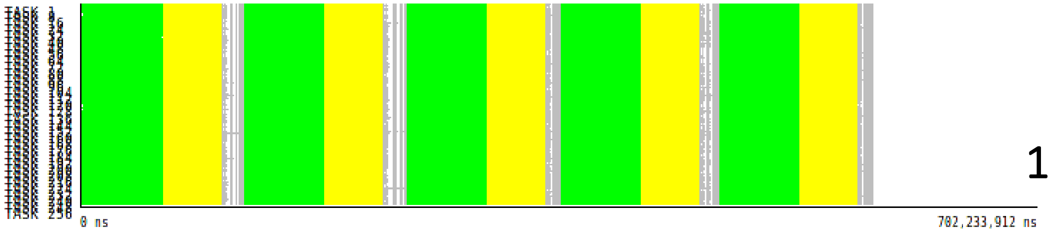




13% gain

… we balance Clusters 1 & 2?

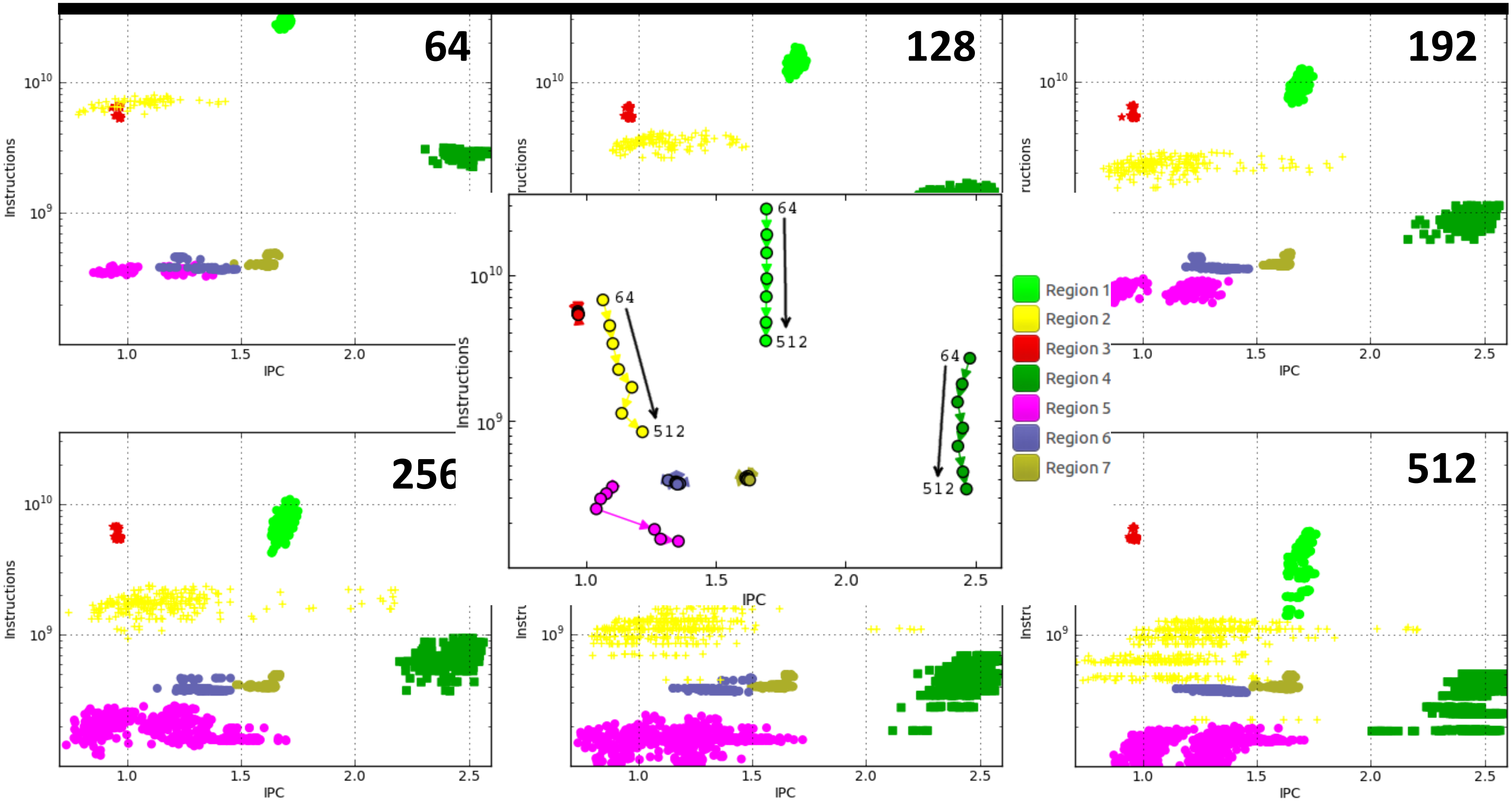




19% gain

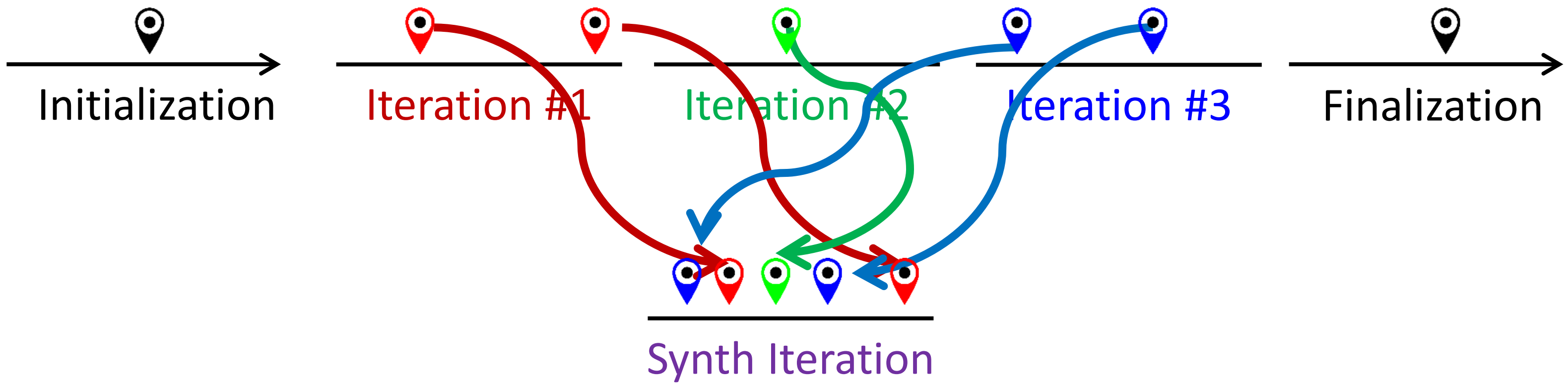
Tracking scability through clustering

- OpenMX (strong scale from 64 to 512 tasks)



Folding

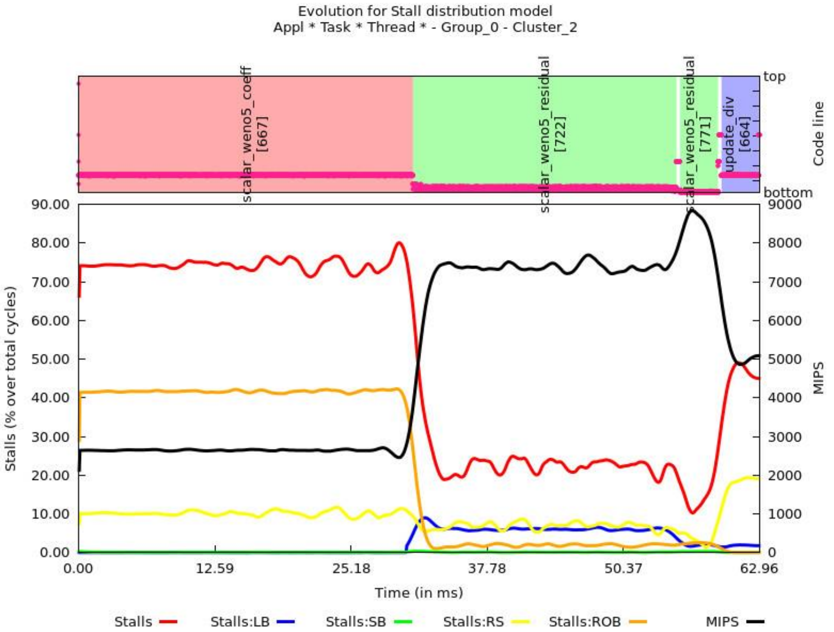
- Instantaneous metrics with minimum overhead
  - Combine instrumentation and sampling
    - Instrumentation delimits regions (routines, loops, …)
    - Sampling exposes progression within a region
  - Captures performance counters and call-stack references

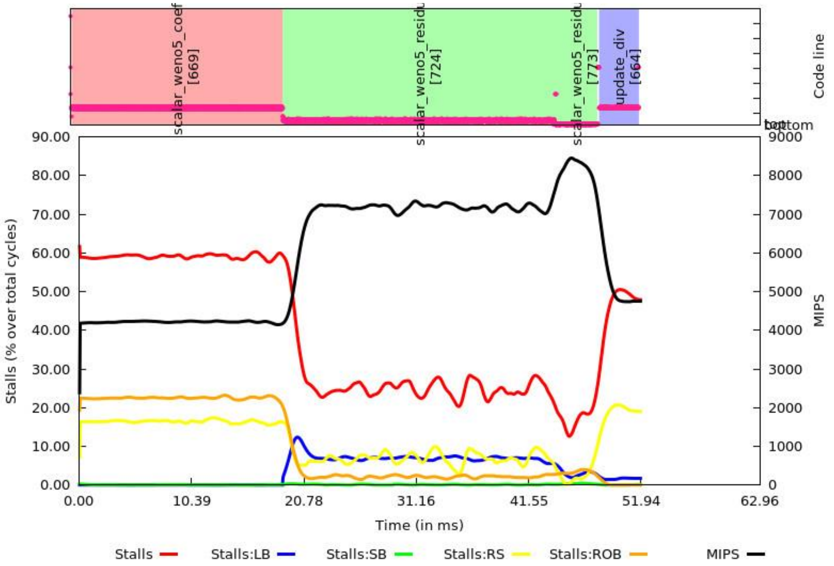


“Blind” optimization

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

Recommendation without access to source code





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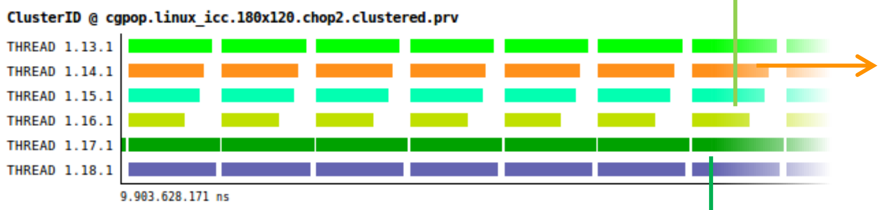
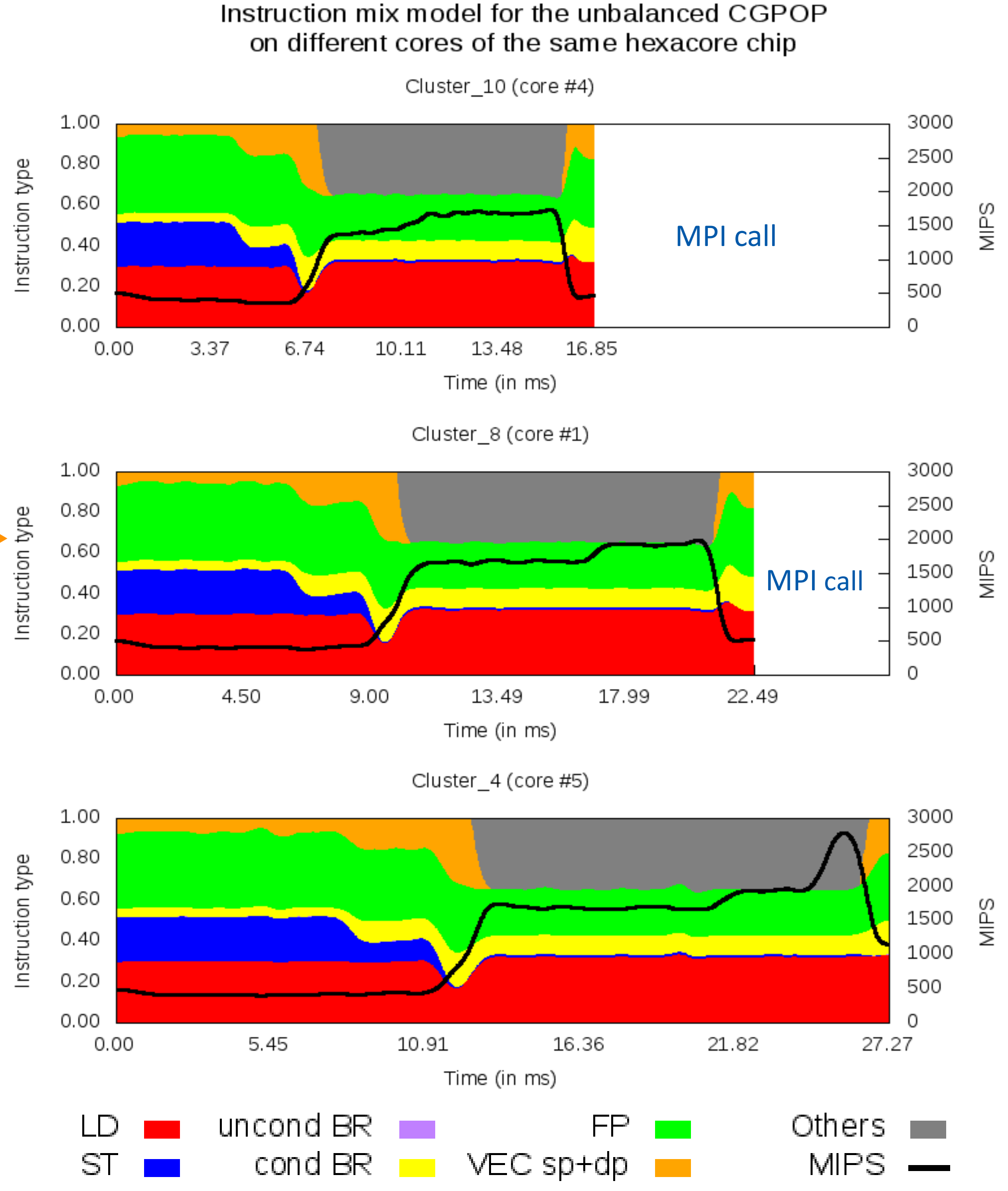
CG-POP multicore MN3 study

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



```
ClusterID @ cgpop.linux_icc.180x120.chop2.clustered.prv
THREAD 1.13.1
THREAD 1.14.1
THREAD 1.15.1
THREAD 1.16.1
THREAD 1.17.1
THREAD 1.18.1
9.903.628.171 ns
```



Instruction mix model for the unbalanced CGPOP on different cores of the same hexacore chip

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Methodology

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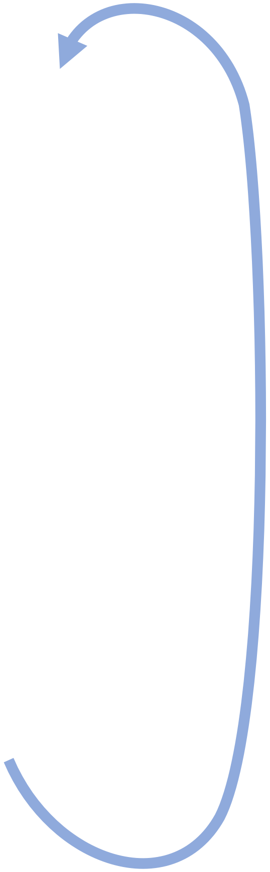
Performance analysis tools objective



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?

Paraver Tutorial:

Introduction to Paraver and Dimemas methodology

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

Demo

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Same code, different behaviour

Code	Parallel efficiency	Communication eff.	Load Balance eff.
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
lulesh@archer	88.01	97.95	89.86
lulesh@romeo	89.56	99.01	90.45
lulesh@mn4	**91.02**	98.38	**92.52**
lulesh@ stampede2 (skl)	85.76	97.63	87.84
lulesh@ stampede2 (knl)	89.21	98.42	90.64
lulesh@isambard	90.32	97.16	92.96

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