

Master thesis
Master in Research and Innovation

**Inferring programs structure from
an execution trace**

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Outline

1 Introduction

- Context
- Motivations
- Objectives
- State of the Art

2 Proposal

- Application structure by classification
- Implementation
- Refinement

3 Best features analysis

4 Validation

- Lulesh 2.0
- CG

5 Scalability

6 Conclusions

7 Future work

Performance Analysis

- Aid to detect **bottlenecks**
 - That prevents from better performance
- Requires high skilled analyst...
- ... so developers are not used to work with them
 - But derive this work to actual specialist
 - Analyst are used to **work with codes they are not familiar with.**
 - e.g. POP project: Provides **performance optimisation and productivity** services for academic and industrial code(s).



Motivations

About improving understandability

Providing application structure will lead to better understanding about what the application is doing.

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About improving reports

Having the structure of the application, the communication between analyst and developer can be improved.

Objective

The objective for this thesis is...

Expose the structure of the application, by means of a post-mortem trace analysis.

State of the Art

First step is always to explore what is over there...

- Some previous research have been driven in this field.
- Since traces are ordered sequences...
- ... Natural choice has been **sequential pattern mining** in general.

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Looking to the trend of increasing trace sizes...

- This sort of algorithms, **used to present high complexity**.
- From $O(n^2)$ to $O(2^n)$.

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Looking to the trend of increasing trace sizes...

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Finally...

The decision has been to explore a new approach!

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Application structure by classification

The key idea

Use communications as **proxies** for the observation of iterations and clustering them **by its behaviour**.

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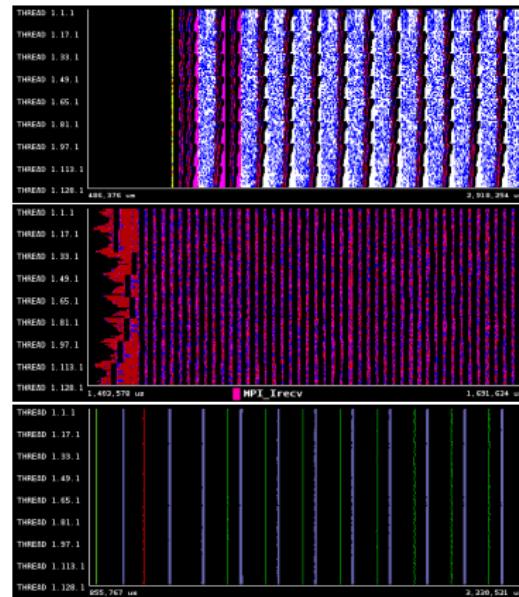
Why?

HPC applications idiosyncracy

- Big outer loop
- Repetitive and stable executions
- Communications (MPI) lies on loops that drives the execution

So...

- **Similar behaviour for all iterations** in a given loop
- Loops by **monitoring the communications**.



Application structure by classification

What will define **behaviour**?

Selected features must be able to

- Join MPIs from the same loop
- Separate MPIs from different loops

Application structure by classification

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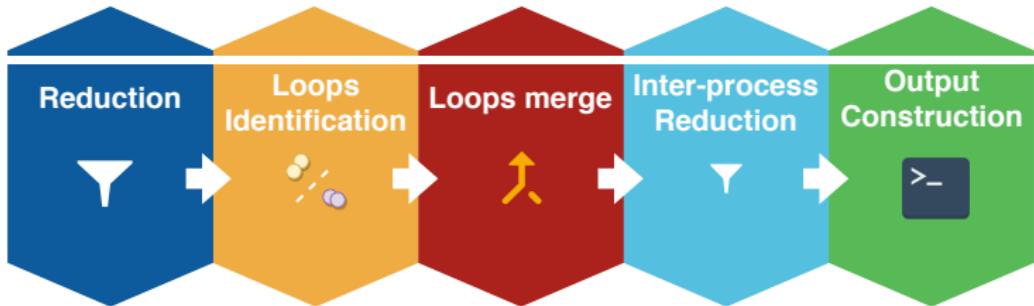
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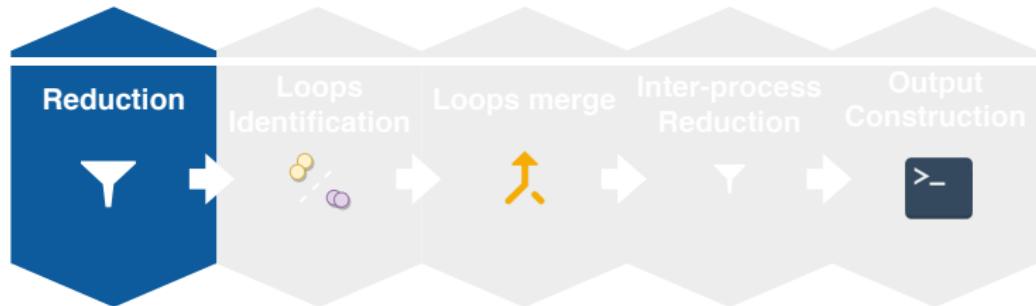
As a starting point ...

- ① **Number of repetitions:** Two different mpi calls in same loop will be executed the same number of times.
- ② **Mean time between repetitions:** Two different loops will, presumably, execute different work.

Workflow

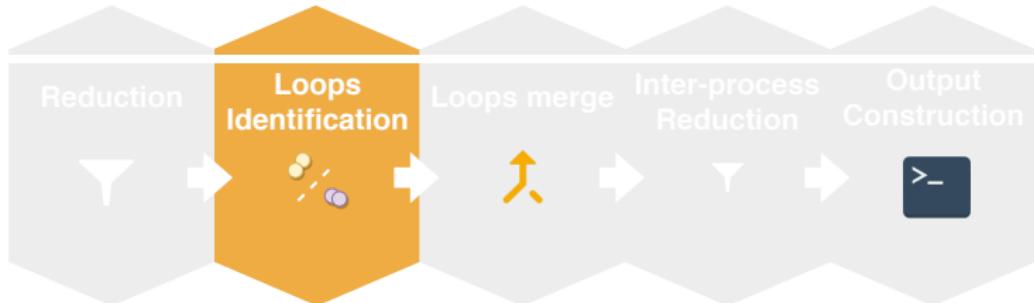


Workflow



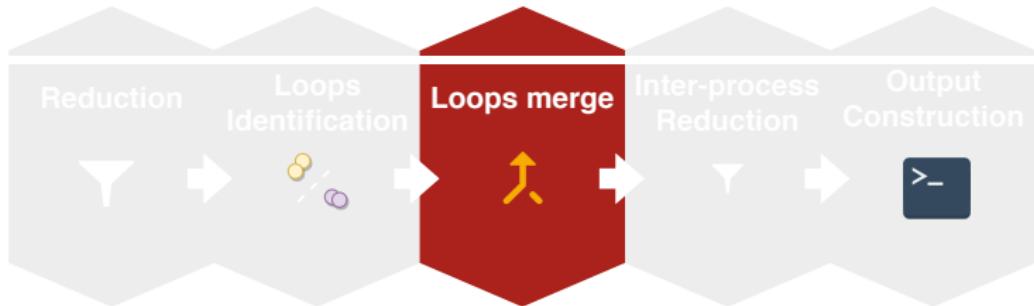
- Parsing and reducing information from trace

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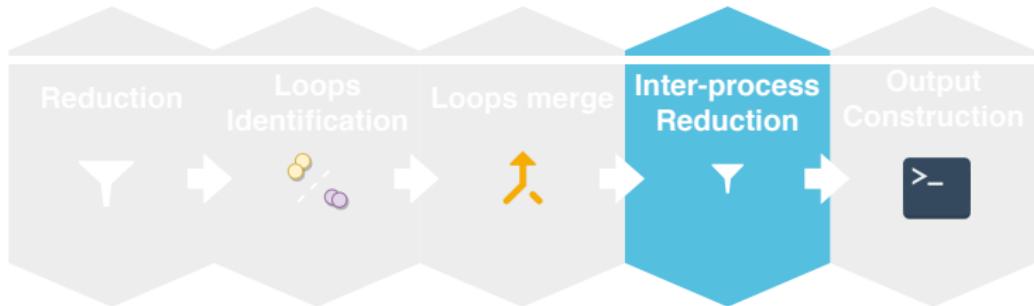
- Identify loops by MPI call sites classification

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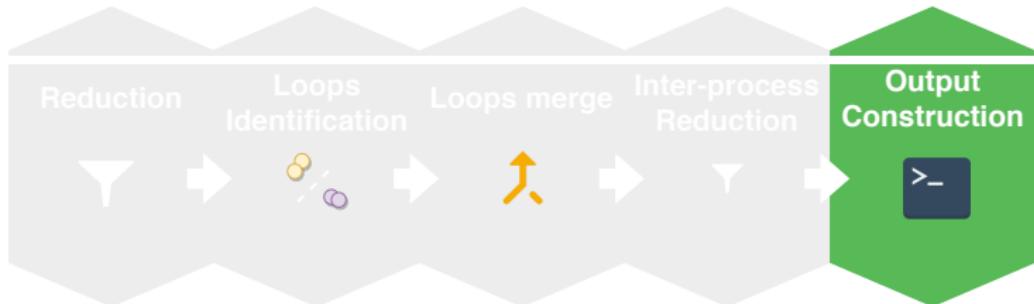
- Find out the hierarchical relations between loops

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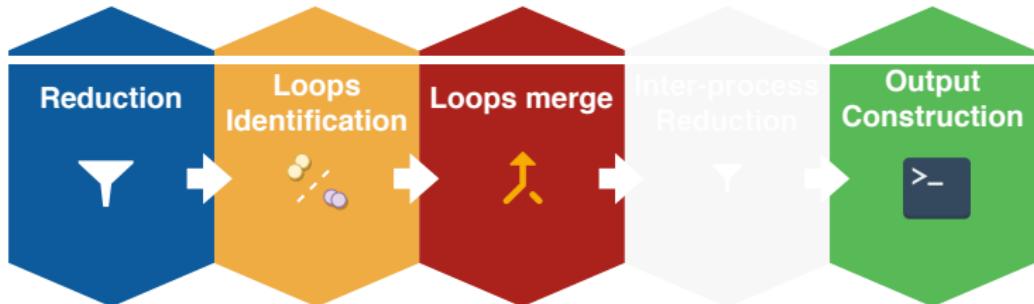


- Collapse same MPI call site from different processes

Workflow



- Construction of the output



- Parsing and reducing information from trace
- Identify loops by MPI call sites classification
- Find out the hierarchical relations between loops
- Construction of the output



Workflow

Trace reduction step

Input Tracefile, i.e. Sequence of timestamped events ordered by time.
Output Set of unique MPI calls sites with attached information.

```
for 1 to 50
  do { for 1 to 2
        do { MPI_A 
              MPI_B 
            }
      }
for 1 to 100
  do { for 1 to 2
        do { for 1 to 2
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                    MPI_D
                  }
            }
      }
            MPI_E
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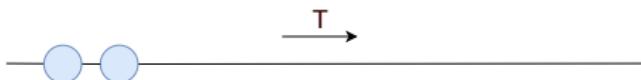
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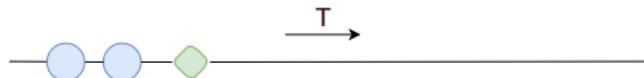
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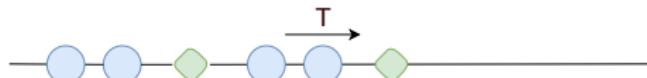


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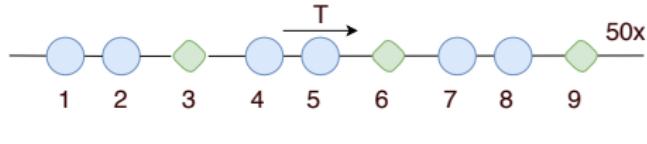
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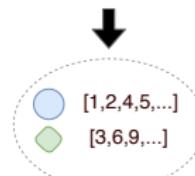
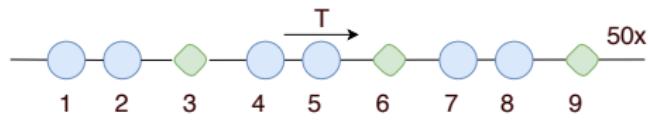
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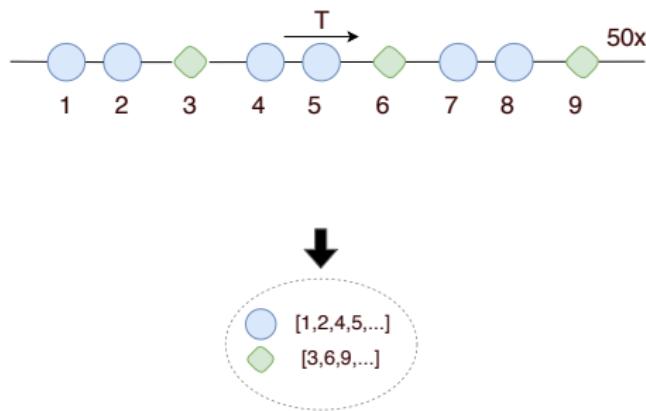




Workflow

Trace reduction step

- Is a sort of Map & Reduce
- Every MPI call is identified by its **signature**: Ordered sequence of pairs (*file, line*) that define the call path, i.e. The dynamic position
- Additionally **less representative MPI calls are filtered** (10%).

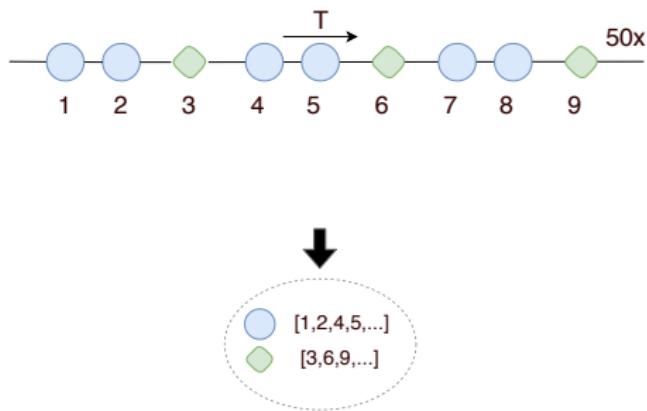




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Keynote

Trace reduction is **the key step for scalability** because repetitiveness of HPC applications.



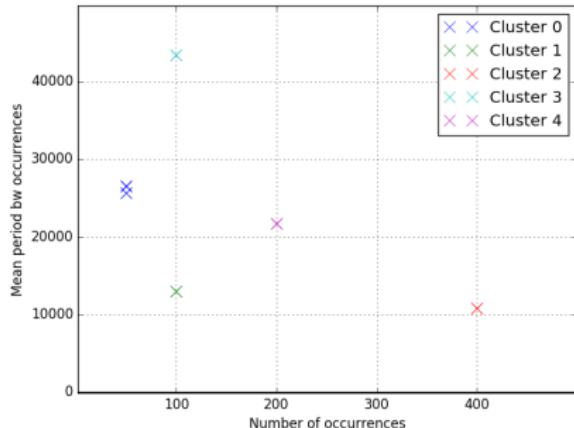
Workflow

Loops identification

Input Set of unique MPI calls sites with attached information.

Output Set of clusters of MPI call sites → Loops

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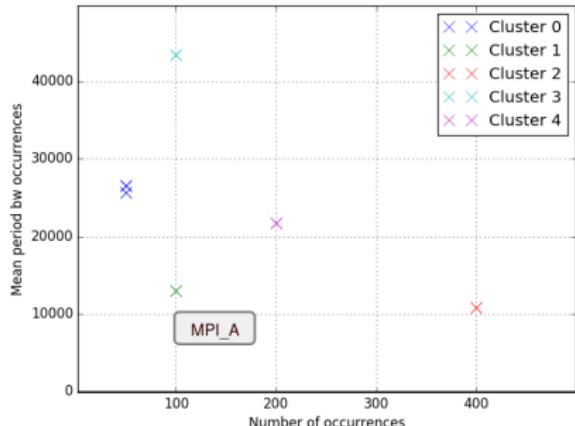
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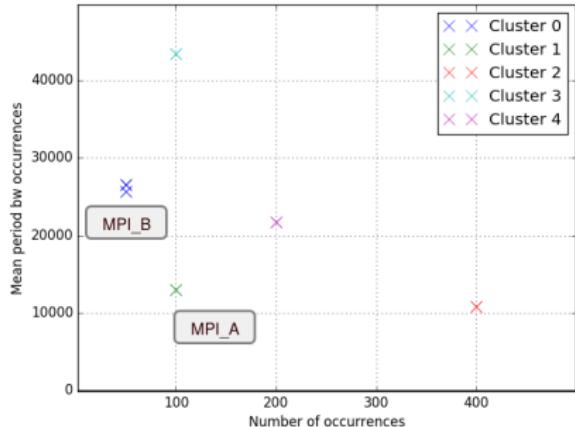
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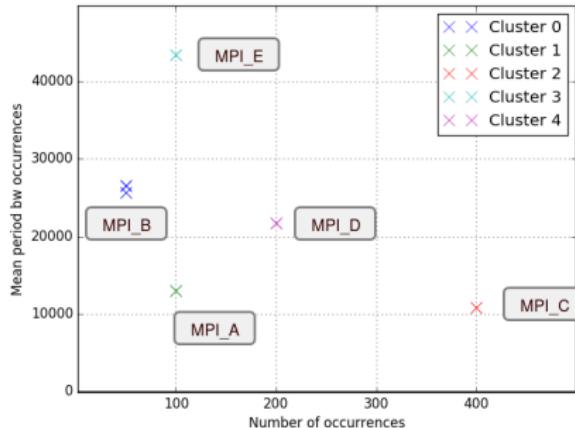


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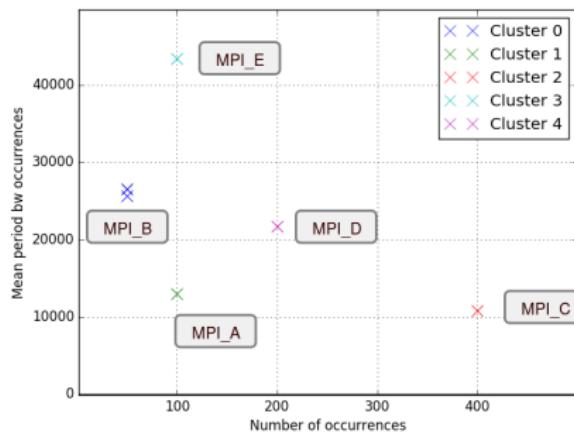




Workflow

Loops identification

- Need for some classification algorithm
- **DBSCAN** as clustering algorithm (preferred to K-means)
 - ϵ empirically set to 0.2 (in general)
 - minPts set to 1
- Resulting clusters **will be considered loops.**
 - Number of repetitions → Number of iterations.
 - Mean time between repetitions → Mean iterations time.





Workflow

Loops merge

Input Set of loops.

Output Set of top level loops with its related nested loops.



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Intuition

- Isolated loops are just **pieces of the overall puzzle**.
- By discovering its hierarchical relations **the structure of the application will be revealed...**
- As well as the different phases



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We can assume

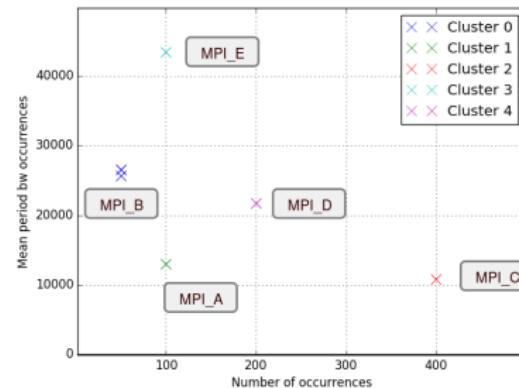
- Outer loop will have **less iterations** than nested one.
- Outer loop will spend **more time** per iteration.

Workflow



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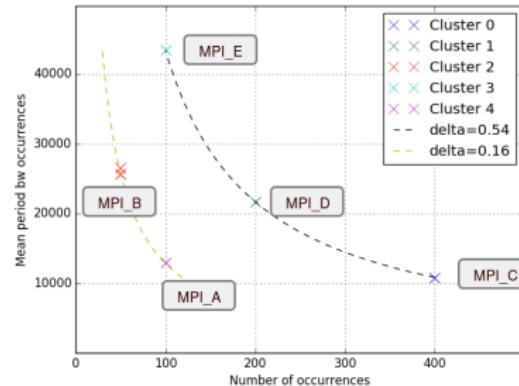


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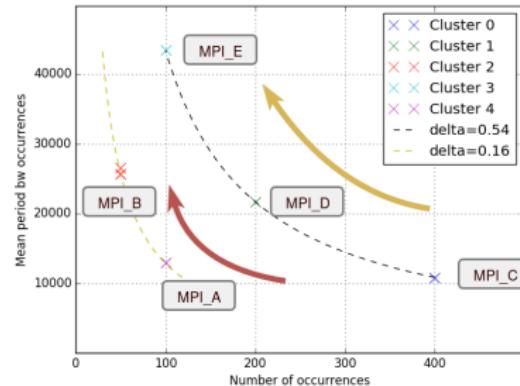
- Classify loops by its delta
 - All lies on same $f(x) = \frac{\delta * T_{exe}}{x}$ being $0 < \delta < 1$
- And then merge them in a less to more iterations fashion
 - Always checking iterations interleaving

Workflow



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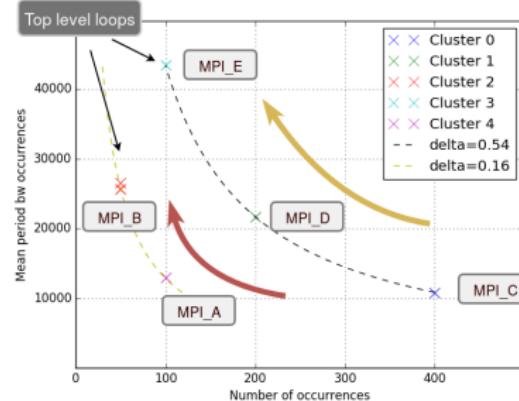
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Keynote

This mechanism is used for phases detection.



Workflow

Pseudocode construction

Input Set of top level loops with rank conditional structures.

Output Pseudocode representing the actual application structure.



Workflow

Pseudocode construction

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Output Pseudocode representing the actual application structure.

- Straightforward construction
- Just a refinement of the data is needed
 - ① Extracting common call path levels from code block (loops and conditional blocks)
 - ② Removing **contiguous repetitive information** what has not been removed in previous step

Workflow



Pseudocode construction

FILE	LINE	PSEUDOCODE	E(TIME)	E(SIZE)	E(IPC)
	0	main()	-	-	-
	17	: FOR 1 TO 50 : : MPI_Barrier(CommId:1)	26.43us	-	0.3
test-13.c	17	: FOR 1 TO 2.0	-	-	-
	23	: : IF rank in [1] : : : MPI_Send(i:0)	22.8us	4.0B	0.53
test-13.c	23	: : : IF rank in [0]	-	-	-
	25	: : : MPI_Recv()	27.09us	4.0B	0.54
	25	: END LOOP	-	-	-
test-13.c	28	: [- computation -]	10.19ms	-	0.06
test-13.c	28	: : MPI_Barrier(CommId:1)	106.13us	-	1.43
	28	: END LOOP	-	-	-
	0	main()	-	-	-
	1	: FOR 1 TO 100	-	-	-
	2	: : FOR 1 TO 2.0	-	-	-
	3	: : : FOR 1 TO 2.0	-	-	-
	4	: : : : IF rank in [1]	-	-	-
test-13.c	40	: : : : MPI_Send(i:0)	23.0us	4.0B	0.5
	40	: : : : IF rank in [0]	-	-	-
test-13.c	42	: : : : MPI_Recv()	25.1us	4.0B	0.51
	42	: : : END LOOP	-	-	-
test-13.c	45	: : MPI_Barrier(CommId:1)	23.93us	-	0.84
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test-13.c	48	: [- computation -]	50.2ms	-	0.07
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		: : : FOR 1 TO 2.0	-	-	-
		: : : : IF rank in [1]	-	-	-
test-13.c	40	: : : : MPI_Send(i:0)	23.0us	4.0B	0.5
		: : : : IF rank in [0]	-	-	-
test-13.c	42	: : : : MPI_Recv()	25.1us	4.0B	0.51
		: : : END LOOP	-	-	-
test-13.c	45	: : : MPI_Barrier(CommId:1)	23.93us	-	0.84
		: : : END LOOP	-	-	-
test-13.c	48	 : : : [- computation -]	50.2ms	-	0.07
test-13.c	48	: : : MPI_Barrier(CommId:1)	124.99us	-	1.62
		: : : END LOOP	-	-	-

Workflow



Pseudocode construction

FILE	LINE	PSEUDOCODE	E(TIME)	E(SIZE)	E(IPC)
	0 main()		-	-	-
test-13.c	17 : : MPI_Barrier(CommId:1)	: FOR 1 TO 50	26.43us	-	0.3
		: : FOR 1 TO 2.0	-	-	-
		: : : IF rank in [1]	-	-	-
test-13.c	23 : : : MPI_Send(i:0)		22.8us	4.0B	0.53
		: : : IF rank in [0]	-	-	-
test-13.c	25 : : : MPI_Recv()		27.09us	4.0B	0.54
		: : END LOOP	-	-	-
test-13.c	28 : : [~ computation ~]		10.18ms	-	0.06
test-13.c	28 : : MPI_Barrier(CommId:1)		106.13us	-	1.43
		: END LOOP	-	-	-
	0 main()		-	-	-
		: FOR 1 TO 100	-	-	-
		: : FOR 1 TO 2.0	-	-	-
		: : : FOR 1 TO 2.0	-	-	-
		: : : : IF rank in [1]	-	-	-
test-13.c	40 : : : : MPI_Send(i:0)		23.0us	4.0B	0.5
		: : : : IF rank in [0]	-	-	-
test-13.c	42 : : : : MPI_Recv()		25.1us	4.0B	0.51
		: : : END LOOP	-	-	-
test-13.c	45 : : : MPI_Barrier(CommId:1)		23.93us	-	0.84
		: : END LOOP	-	-	-
test-13.c	48 : : [~ computation ~]		150.2ms	-	0.07
test-13.c	48 : : MPI_Barrier(CommId:1)		124.99us	-	1.62
		: END LOOP	-	-	-

```
(struct_detection)> help

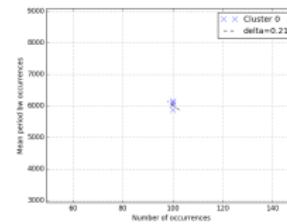
Documented commands (type help <topic>):
=====
clustering help paraver pseudocode q quit

(struct_detection)> help pseudocode
pseudocode commands:
wo-cs: Do not show call paths
w-burst-info: Show CPU burst information
w-burst-threshold: Show burst above threshold
default: Default information
ranks: Show pseudocode just for rank
(struct_detection)> █
```

Refinement

Clustering aliasing → Same behavior

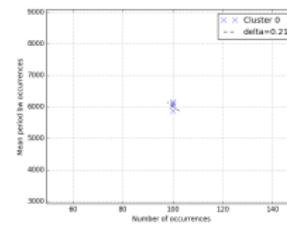
```
for 1to100
  do {MPI_A()
       MPI_B()}
for 1to100
  do {MPI_C()
       MPI_D()}
```



Refinement

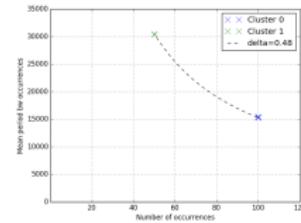
Clustering aliasing → Same behavior

```
for 1 to 100
  do {MPI_A()
       MPI_B()}
for 1 to 100
  do {MPI_C()
       MPI_D()}
```



Clustering split → Data conditions

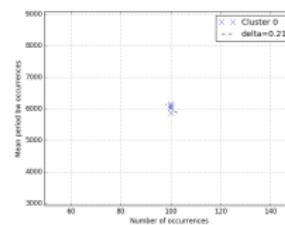
```
for  $i = 1$  to  $10$ 
  do {MPI_B()
       if odd( $i$ )
         then MPI_A()
       MPI_B()}
```



Refinement

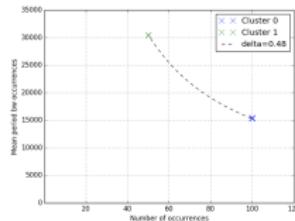
Clustering aliasing → Same behavior

```
for 1 to 100
  do { MPI_A()
        MPI_B()
      for 1 to 100
        do { MPI_C()
              MPI_D()
```



Clustering split → Data conditions

```
for i = 1 to 10
  do { MPI_B()
        if odd(i)
          then MPI_A()
        MPI_B()
```



Keynote

Both **solved** but better to **avoid them**

Outline

1 Introduction

- Context
- Motivations
- Objectives
- State of the Art

2 Proposal

- Application structure by classification
- Implementation
- Refinement

3 Best features analysis

4 Validation

- Lulesh 2.0
- CG

5 Scalability

6 Conclusions

7 Future work

Best features analysis

Are the used features **the best?**

- Number of repetitions and Mean time between repetitions

¹Strictly limited by available hardware

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Can other **additional/alternative** features prevent clustering
split/aliasing?

- IPC, %Loads, %(Cond, Uncond, Total) branches ¹

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- Principal Component Analysis
- Random Forest Variable Importance → Needs labeled MPI call sites with loop identification.

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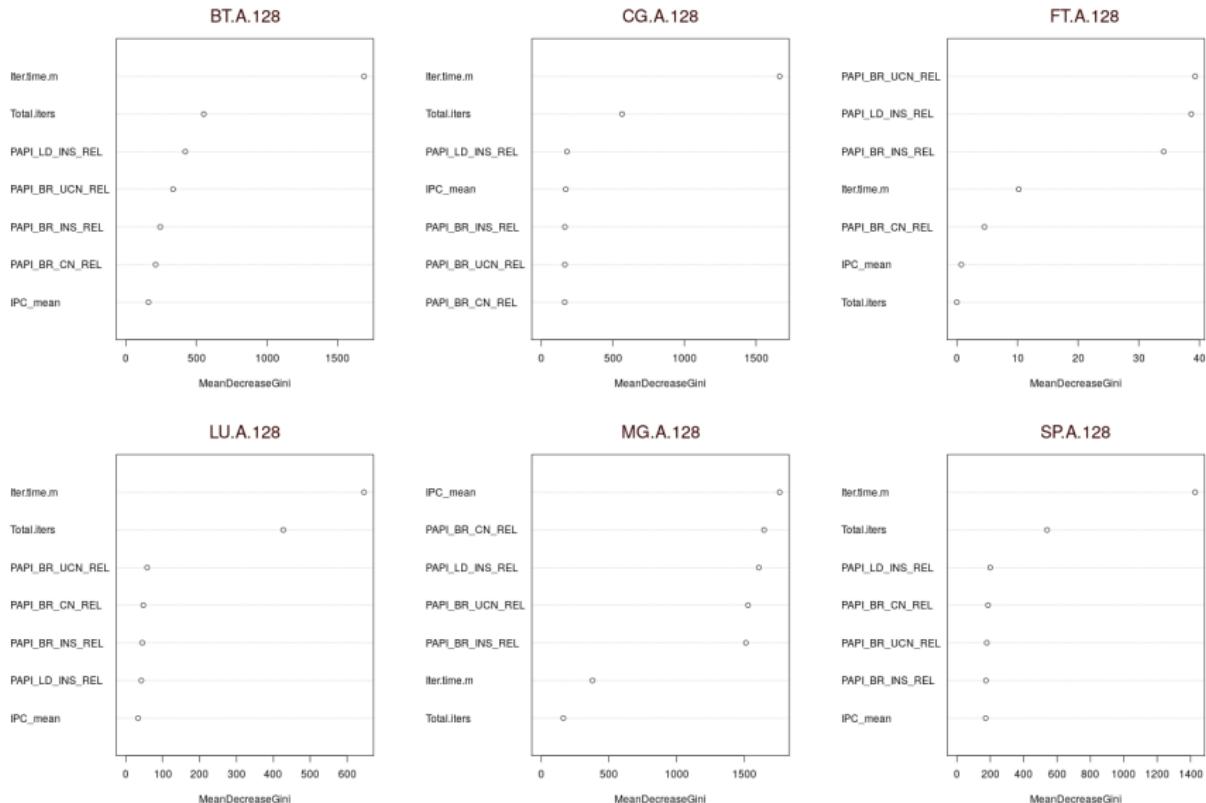
Data acquisition:

- Used tracing library (Extrace) is monitoring calls to shared libraries
- Loops monitors injection by **Mercurium**

¹Strictly limited by available hardware

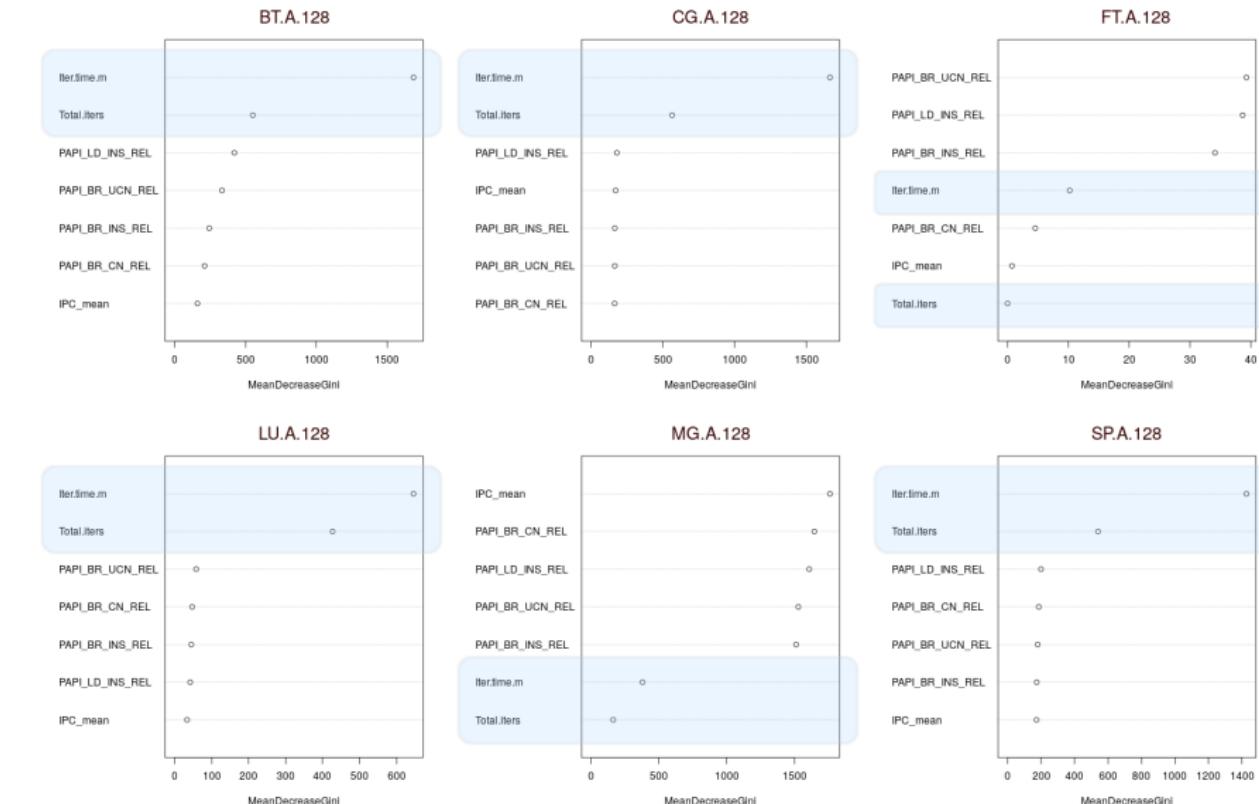
Best features analysis

Analysis of results: Variable Importance



Best features analysis

Analysis of results: Variable Importance



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Lulesh 2.0

Execution:

- 6014 code lines (C++) (142 MPI calls)
- 125 parallel processes
- $\approx 160MB$ tracefile

Analysis:

- Filter all *loops* $< 10\%$
- CPU burst *time* $> 6ms$

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Results:

- 30 iterations loop

FILE	LINB	PSEUDOCODE	E(ETIME)	E(SIZE)	E(BIG)
lullesh.cc	1	main()	[=	[=	[=
lullesh.cc	1	: FOR 1 TO 30 [id=0.0]	[=	[=	[=
lullesh.cc	1	: : TimeIncrement()	[=	[=	[=
lullesh.cc	11627	: : : : CallToFunction(Rule0)	[=	[=	[=
lullesh.cc	11371	: : : : CommRecv()	[=	[=	[=
lullesh.cc	11371	: : : : : MPI_Irecv(...,rank,0)	10.27us	[=	10.29
lullesh.cc	11391	: : : : : MPI_Irecv(0;23)	10.51us	[=	9.55
lullesh.cc	1371	: : : : : MPI_Irecv(0;1)	18.67us	[=	0.96
lullesh.cc	1371	: : : : : MPI_Irecv(0;1)	18.67us	[=	0.96
lullesh.cc	1921	: : : : : MPI_Irecv(0;6)	8.9us	[=	1.08
lullesh.cc	2011	: : : : : MPI_Irecv(0;30)	18.54us	[=	0.25
lullesh.cc	2011	: : : : : MPI_Irecv(0;30)	18.54us	[=	0.25
lullesh.cc	3451	: : : : : MPI_Irecv(0;31)	19.32us	[=	0.9
lullesh.cc	11581	: : : : : CommRecv()	[=	[=	[=
lullesh.cc	4011	: : : : : : - computation -	[=	85.2us	[=
lullesh.cc	4011	: : : : : : MPI_Comp_rank(0)	10.08us	[=	11.59
lullesh.cc	4361	: : : : : : MPI_Comp_rank(0;25)	14.95us	[=	3.15
lullesh.cc	4361	: : : : : : MPI_Comp_rank(0;25)	14.95us	[=	3.15
lullesh.cc	5181	: : : : : : MPI_Iwait(0;1)	11.5us	[=	22.528B
lullesh.cc	8891	: : : : : : MPI_Iwait(0;1)	14.79us	[=	14.4B
lullesh.cc	8891	: : : : : : MPI_Iwait(0;1)	14.79us	[=	14.4B
lullesh.cc	6231	: : : : : : MPI_Iwait(0;26)	13.13us	[=	7.04B
lullesh.cc	8431	: : : : : : MPI_Iwait(0;1)	14.1us	[=	14.4B
lullesh.cc	11611	: : : : : : CommSend()	[=	141.3us	[=
lullesh.cc	11611	: : : : : : MPI_Comp_rank(0;1)	10.33us	[=	10.49
lullesh.cc	9111	: : : : : : MPI_Iwait(0;1)	9.25us	[=	0.6
lullesh.cc	9451	: : : : : : MPI_Iwait(0;1)	8.6us	[=	2.48
lullesh.cc	9451	: : : : : : MPI_Iwait(0;1)	8.6us	[=	2.48
lullesh.cc	10391	: : : : : : MPI_Iwait(0;2)	8.41us	[=	1.72
lullesh.cc	10553	: : : : : : MPI_Iwait(0;2)	8.19us	[=	1.64
lullesh.cc	10553	: : : : : : MPI_Iwait(0;2)	8.19us	[=	1.64
lullesh.cc	12551	: : : : : : MPI_Iwait(0;2)	58.99us	[=	3.44
lullesh.cc	12671	: : : : : : CommSend()	[=	1.01us	[=
lullesh.cc	11911	: : : : : : MPI_Comp_rank(0;1)	7.77us	[=	10.73
lullesh.cc	11911	: : : : : : MPI_Irecv(0;25)	9.03us	[=	145.05B
lullesh.cc	13521	: : : : : : MPI_Irecv(0;5)	7.37us	[=	14.05B
lullesh.cc	13521	: : : : : : MPI_Irecv(0;5)	7.37us	[=	14.05B
lullesh.cc	19211	: : : : : : MPI_Irecv(0;16)	7.6us	[=	14.45B
lullesh.cc	20211	: : : : : : MPI_Irecv(0;19)	7.51us	[=	14.45B
lullesh.cc	21011	: : : : : : MPI_Irecv(0;19)	7.51us	[=	14.45B
lullesh.cc	3451	: : : : : : MPI_Irecv(0;31)	7.7us	[=	0.95
lullesh.cc	4011	: : : : : : - computation -	[=	16.15us	[=
lullesh.cc	4011	: : : : : : MPI_Comp_rank(0;1)	11.58us	[=	13.63
lullesh.cc	4361	: : : : : : MPI_Comp_rank(0;1)	10.26us	[=	10.35
lullesh.cc	12921	: : : : : : CommSyncVal(1)	[=	1.35us	[=
lullesh.cc	13310	: : : : : : MPI_Comp_rank(0;1)	12.14us	[=	0.73
lullesh.cc	13310	: : : : : : MPI_Comp_rank(0;1)	12.14us	[=	0.73
lullesh.cc	13661	: : : : : : MPI_Iwait(0;1)	73.95us	[=	2.46
lullesh.cc	14021	: : : : : : MPI_Iwait(0;1)	23.24us	[=	2.2
lullesh.cc	14021	: : : : : : MPI_Iwait(0;1)	23.24us	[=	2.2
lullesh.cc	14751	: : : : : : MPI_Iwait(0;1)	7.83us	[=	1.83
lullesh.cc	14891	: : : : : : MPI_Iwait(0;1)	7.75us	[=	2.08
lullesh.cc	14891	: : : : : : MPI_Iwait(0;1)	7.75us	[=	2.08
lullesh.cc	126561	: : : : : : LagrangeElements()	[=	333.67us	[=
lullesh.cc	124611	: : : : : : CallForElement()	[=	1.01us	[=
lullesh.cc	124611	: : : : : : CallForElement()	[=	1.01us	[=
lullesh.cc	10111	: : : : : : - computation -	[=	29.32us	[=
lullesh.cc	10111	: : : : : : MPI_Comp_rank(0;1)	18.11us	[=	3.53
lullesh.cc	13511	: : : : : : MPI_Irecv(0;5)	11.61us	[=	21.09B
lullesh.cc	13711	: : : : : : MPI_Irecv(0;5)	19.23us	[=	21.09B
lullesh.cc	13711	: : : : : : MPI_Irecv(0;5)	19.23us	[=	21.09B
lullesh.cc	20101	: : : : : : CommSyncVal(1)	[=	18.79us	[=
lullesh.cc	4011	: : : : : : - computation -	[=	15.35us	[=
lullesh.cc	4011	: : : : : : MPI_Comp_rank(0;1)	13.01us	[=	1.52
lullesh.cc	4361	: : : : : : MPI_Irecv(0;25)	13.14us	[=	21.09B
lullesh.cc	4771	: : : : : : MPI_Irecv(0;5)	10.28us	[=	21.09B
lullesh.cc	5001	: : : : : : MPI_Irecv(0;5)	11.61us	[=	21.09B
lullesh.cc	8431	: : : : : : MPI_Iwait(0;1)	291.68us	[=	0.45
lullesh.cc	20141	: : : : : : CommSyncVal(1)	[=	9.51us	[=
lullesh.cc	13751	: : : : : : MPI_Comp_rank(0;1)	8.98us	[=	0.81
lullesh.cc	17911	: : : : : : MPI_Iwait(0;1)	8.78us	[=	2.04
lullesh.cc	18241	: : : : : : MPI_Iwait(0;1)	8.53us	[=	12.13
lullesh.cc	18241	: : : : : : END_LOOP	[=	1.01us	[=

Validation

Lulesh 2.0

Execution:

- 6014 code lines (C++) (142 MPI calls)
 - 125 parallel processes
 - $\approx 160MB$ tracefile

Analysis:

- Filter all *loops* < 10%
 - CPU burst *time* > 6ms

Results:

- 30 iterations loop
 - 5 long CPU burst

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FILE	ILINE	PSEUDOCODE	E(TIME)	E(RISE)	E(IPC)
lulesh.cc	11	Domain()	[~]	[~]	[~]
lulesh.cc	11	TimeIncrement()	[~]	[~]	[~]
lulesh.cc	11	: [~ computation ~]	[~]	[~]	[~]
lulesh.cc	11	: 96.6% => MPI_Allreduce(CommId:1)	[~]	[~]	[~]
lulesh.cc	11	LagrangeLeapFrog()	[~]	[~]	[~]
lulesh-comm.cc	1191	MPIL_Recv(0 25)	10.51us	122.53KB	0.55
lulesh-comm.cc	1371	MPIL_Irecv(0 5)	18.67us	122.52KB	0.96
lulesh-comm.cc	1381	MPIL_Irecv(0 1)	18.49us	122.52KB	1.08
lulesh-comm.cc	1391	MPIL_Irecv(0 3)	18.49us	1744.0B	1.18
lulesh-comm.cc	1201	MPIL_Irecv(0 30)	18.51us	1744.0B	1.25
lulesh-comm.cc	2210	MPIL_Irecv(0 26)	18.29us	1744.0B	1.25
lulesh-comm.cc	1391	MPIL_Irecv(0 1)	18.49us	1744.0B	1.25
lulesh-comm.cc	11581	CommSend()	[~]	[~]	[~]
lulesh-comm.cc	4011	MPIL_Isend(0 31) : [~ computation ~]	185.2us	[~]	12.48
lulesh-comm.cc	4011	MPIL_Wait(0 1)	18.0us	[~]	1.59
lulesh-comm.cc	4361	MPIL_Isend(0 25)	14.95us	122.52KB	1.9
lulesh-comm.cc	4361	MPIL_Wait(0 1)	14.07us	122.52KB	1.65
lulesh-comm.cc	1181	MPIL_Irecv(0 1)	18.49us	122.52KB	1.25
lulesh-comm.cc	5891	MPIL_Isend(0 16)	14.79us	1744.0B	1.68
lulesh-comm.cc	6061	MPIL_Irecv(0 30)	12.45us	1744.0B	1.86
lulesh-comm.cc	1201	MPIL_Irecv(0 1)	18.49us	1744.0B	1.46
lulesh-comm.cc	8371	MPIL_Isend(0 31)	18.48us	124.0B	0.84
lulesh-comm.cc	8431	MPIL_Waitall(0 1)	541.3us	[~]	0.43
lulesh-comm.cc	1101	ConnSync()	[~]	[~]	[~]
lulesh-comm.cc	8891	MPIL_Comm_rank(0 1)	9.32us	[~]	0.49
lulesh-comm.cc	9111	MPIL_Wait(0 1)	9.25us	[~]	0.4
lulesh-comm.cc	9111	MPIL_Wait(0 1)	9.25us	[~]	1.48
lulesh-comm.cc	9801	MPIL_Wait(0 1)	8.52us	[~]	2.35
lulesh-comm.cc	10391	MPIL_Wait(0 1)	8.41us	[~]	1.72
lulesh-comm.cc	10391	MPIL_Wait(0 1)	8.41us	[~]	1.64
lulesh-comm.cc	10671	MPIL_Wait(0 1)	8.31us	[~]	1.98
lulesh-comm.cc	12551	MPIL_Wait(0 1)	58.99us	[~]	1.44
lulesh-comm.cc	12551	MPIL_Wait(0 1)	58.99us	[~]	1.44
lulesh-comm.cc	1011	MPIL_Comm_rank(0 1)	7.77us	[~]	0.73
lulesh-comm.cc	1191	MPIL_Irecv(0 23)	9.03us	14.03KB	0.78
lulesh-comm.cc	1201	MPIL_Irecv(0 1)	12.8us	14.03KB	1.25
lulesh-comm.cc	1551	MPIL_Irecv(0 11)	7.34us	14.03KB	0.95
lulesh-comm.cc	1921	MPIL_Irecv(0 4)	7.46us	14.49KB	1.17
lulesh-comm.cc	1921	MPIL_Irecv(0 1)	7.46us	14.49KB	1.33
lulesh-comm.cc	2101	MPIL_Irecv(0 24)	7.42us	14.49KB	1.13
lulesh-comm.cc	2451	MPIL_Irecv(0 31)	7.5us	14.08B	0.95
lulesh-comm.cc	12551	MPIL_Wait(0 1)	[~]	[~]	[~]
lulesh-comm.cc	1011	MPIL_Comm_rank(0 1)	7.77us	[~]	0.73
lulesh-comm.cc	4011	MPIL_Comm_rank(0 1)	14.58us	[~]	1.62
lulesh-comm.cc	4011	MPIL_Wait(0 1)	14.58us	[~]	1.25
lulesh.cc	12921	ConnSyncForVal()	[~]	[~]	[~]
lulesh-comm.cc	13101	MPIL_Comm_rank(0 1)	132.14us	[~]	0.73
lulesh-comm.cc	13201	MPIL_Wait(0 1)	132.14us	[~]	0.79
lulesh-comm.cc	13361	MPIL_Wait(0 1)	73.95us	[~]	2.46
lulesh-comm.cc	14021	MPIL_Wait(0 1)	23.24us	[~]	2.3
lulesh-comm.cc	14021	MPIL_Wait(0 1)	19.89us	[~]	1.79
lulesh-comm.cc	14751	MPIL_Wait(0 1)	7.83us	[~]	1.83
lulesh-comm.cc	14891	MPIL_Wait(0 1)	7.75us	[~]	2.08
lulesh-comm.cc	16011	MPIL_Wait(0 1)	333.07us	[~]	1.73
lulesh-comm.cc	12651	LagrangeElements()	[~]	[~]	[~]
lulesh.cc	12461	CalQForElement()	[~]	[~]	[~]
lulesh.cc	12461	ConnSync()	[~]	[~]	[~]
lulesh-comm.cc	10111	MPIL_Comm_rank(0 1)	10.32us	[~]	2.25
lulesh-comm.cc	10111	MPIL_Comm_rank(0 1)	18.76us	[~]	1.39
lulesh-comm.cc	10111	MPIL_Wait(0 1)	18.76us	123.09KB	1.0
lulesh-comm.cc	13711	MPIL_Irecv(0 5)	9.23us	123.09KB	1.03
lulesh-comm.cc	15511	MPIL_Irecv(0 1)	8.79us	123.09KB	1.17
lulesh-comm.cc	40111	MPIL_Comm_rank(0 1)	15.35us	[~]	1.91
lulesh-comm.cc	40111	MPIL_Wait(0 1)	15.24us	[~]	1.52
lulesh-comm.cc	40111	ConnSync()	[~]	[~]	[~]
lulesh-comm.cc	4771	MPIL_Isend(0 15)	10.28us	123.09KB	1.89
lulesh-comm.cc	5181	MPIL_Isend(0 1)	10.57us	123.09KB	1.26
lulesh-comm.cc	12011	MPIL_Irecv(0 11)	13.91us	104.0B	0.43
lulesh.cc	12014	ConnSync()	[~]	[~]	[~]
lulesh-comm.cc	13724	MPIL_Comm_rank(0 1)	9.51us	[~]	0.45
lulesh-comm.cc	13724	MPIL_Wait(0 1)	9.49us	[~]	0.41
lulesh-comm.cc	17911	MPIL_Wait(0 1)	8.78us	[~]	2.04
lulesh-comm.cc	18241	1 SIMD LOOP	8.53us	[~]	2.13

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- CPU burst time $> 6ms$

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- 5 long CPU burst
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- 56 no conditioned MPI

FILE	LINE	PSEUDOCODE	E(TIME)	E(EISE)	E(IPCI)
lulesh.cc	12773	: FOR 1 TO 30 [id=0..0]	-	-	-
lulesh.cc	12774	: computation ->	-	-	-
lulesh.cc	12774	: LagrangeLapPrcGpu	-	-	-
lulesh.cc	12774	: LagrangeAll	-	-	-
lulesh.cc	12863	: MPI_ScatterNodes()	-	-	-
lulesh.cc	12371	: ConnRecv()	-	-	-
lulesh-comm.cc	1100	: MPI_Irecv(0x100)	10.27ms	10.08/8.08	1.25
lulesh-comm.cc	1138	: MPI_Irecv(0x123)	10.51us	-	1.57
lulesh-comm.cc	1371	: MPI_Irecv(0x15)	10.67us	12.52KB	0.96
lulesh-comm.cc	1389	: MPI_Irecv(0x11)	10.49us	5.52KB	1.18
lulesh-comm.cc	1592	: MPI_Irecv(0x10)	10.74us	174.0B	1.08
lulesh-comm.cc	2011	: MPI_Irecv(0x130)	8.51us	1744.0B	1.25
lulesh-comm.cc	2110	: MPI_Irecv(0x246)	8.29us	1744.0B	1.25
lulesh-comm.cc	2110	: MPI_Irecv(0x131)	8.30us	1744.0B	0.9
lulesh-comm.cc	11581	: ConnSend()	-	-	-
lulesh-comm.cc	4011	: computation ->	-	-	2.48
lulesh-comm.cc	4011	: MPI_Wait(0x10)	10.59us	-	1.59
lulesh-comm.cc	4361	: MPI_Isend(0x25)	14.95us	12.52KB	1.9
lulesh-comm.cc	4361	: MPI_Irecv(0x19)	10.47us	12.52KB	1.65
lulesh-comm.cc	1138	: MPI_Irecv(0x123)	10.51us	12.52KB	0.96
lulesh-comm.cc	5891	: MPI_Isend(0x16)	14.79us	1744.0B	1.68
lulesh-comm.cc	6061	: MPI_Irecv(0x245)	12.45us	1744.0B	1.86
lulesh-comm.cc	1020	: MPI_Irecv(0x130)	11.81us	1744.0B	1.46
lulesh-comm.cc	8371	: MPI_Irecv(0x31)	9.48us	124.0B	0.84
lulesh-comm.cc	8452	: MPI_WaitAll(0x1)	541.3us	-	0.43
lulesh-comm.cc	1100	: ConnRecv()	-	-	-
lulesh-comm.cc	8891	: MPI_Comm_rank(0)	9.32us	-	0.49
lulesh-comm.cc	9111	: MPI_Irecv(0x100)	9.25us	-	0.6
lulesh-comm.cc	9111	: MPI_Irecv(0x123)	9.25us	-	1.28
lulesh-comm.cc	9801	: MPI_Wait(0x1)	8.53us	-	2.35
lulesh-comm.cc	10391	: MPI_Wait(0x1)	8.41us	-	1.72
lulesh-comm.cc	10391	: MPI_Wait(0x1)	8.41us	-	1.46
lulesh-comm.cc	10671	: MPI_Wait(0x1)	8.31us	-	1.98
lulesh-comm.cc	12551	: MPI_Wait(0x1)	58.99us	-	1.44
lulesh-comm.cc	12551	: MPI_Wait(0x1)	1.12us	-	1.44
lulesh-comm.cc	1011	: MPI_Comm_rank(0)	7.77us	-	0.73
lulesh-comm.cc	1191	: MPI_Irecv(0x25)	9.03us	14.05KB	0.78
lulesh-comm.cc	1191	: MPI_Irecv(0x123)	9.03us	14.05KB	1.02
lulesh-comm.cc	1551	: MPI_Irecv(0x11)	7.34us	14.05KB	0.95
lulesh-comm.cc	1921	: MPI_Irecv(0x16)	7.46us	14.45KB	1.15
lulesh-comm.cc	2001	: MPI_Irecv(0x246)	7.46us	14.45KB	1.33
lulesh-comm.cc	2110	: MPI_Irecv(0x241)	7.42us	14.45KB	1.13
lulesh-comm.cc	3451	: MPI_Irecv(0x31)	7.3us	14.05KB	0.95
lulesh-comm.cc	14011	: computation ->	-	-	2.0
lulesh-comm.cc	4011	: MPI_Comm_rank(0)	14.58us	-	1.63
lulesh-comm.cc	4011	: MPI_Wait(0x1)	10.89us	-	0.95
lulesh-comm.cc	12921	: ConnSyncFoxVal()	-	-	-
lulesh-comm.cc	13210	: MPI_Comm_rank(0)	23.14us	-	0.73
lulesh-comm.cc	13210	: MPI_Wait(0x1)	12.7us	-	0.79
lulesh-comm.cc	13661	: MPI_Wait(0x1)	72.95us	-	2.46
lulesh-comm.cc	14021	: MPI_Wait(0x1)	23.34us	-	2.3
lulesh-comm.cc	14021	: MPI_Wait(0x1)	19.84us	-	1.79
lulesh-comm.cc	14751	: MPI_Wait(0x1)	7.83us	-	1.83
lulesh-comm.cc	14891	: MPI_Wait(0x1)	7.75us	-	2.08
lulesh-comm.cc	16111	: MPI_Wait(0x1)	333.07us	-	11.73
lulesh-comm.cc	28561	: LagrangeElements()	-	-	-
lulesh-comm.cc	24611	: CalcForlent()	-	-	-
lulesh-comm.cc	24611	: MPI_Wait(0x1)	1.2us	-	1
lulesh-comm.cc	10111	: computation ->	29.32us	-	2.25
lulesh-comm.cc	10111	: MPI_Comm_rank(0)	18.76us	-	1.39
lulesh-comm.cc	10111	: MPI_Wait(0x1)	12.21us	21.09KB	0.9
lulesh-comm.cc	13711	: MPI_Irecv(0x15)	9.31us	21.09KB	1.01
lulesh-comm.cc	15511	: MPI_Irecv(0x11)	8.79us	21.09KB	1.17
lulesh-comm.cc	40111	: computation ->	15.35us	-	1.91
lulesh-comm.cc	40111	: MPI_Comm_rank(0)	15.24us	-	1.52
lulesh-comm.cc	40111	: MPI_Wait(0x1)	13.81us	-	1.39
lulesh-comm.cc	47711	: MPI_Isend(0x15)	10.28us	21.09KB	1.89
lulesh-comm.cc	51811	: MPI_Irecv(0x11)	10.57us	21.09KB	1.26
lulesh-comm.cc	10211	: MPI_Irecv(0x10)	10.54us	21.09KB	1.43
lulesh-comm.cc	20141	: ConnMonQ()	-	-	-
lulesh-comm.cc	13734	: MPI_Comm_rank(0)	9.51us	-	0.45
lulesh-comm.cc	13734	: MPI_Wait(0x1)	8.81us	-	0.9
lulesh-comm.cc	17931	: MPI_Wait(0x1)	8.78us	-	2.04
lulesh-comm.cc	18241	: MPI_Wait(0x1)	8.53us	-	2.13
	1	END LOOP	-	-	-

Validation

Lulesh 2.0

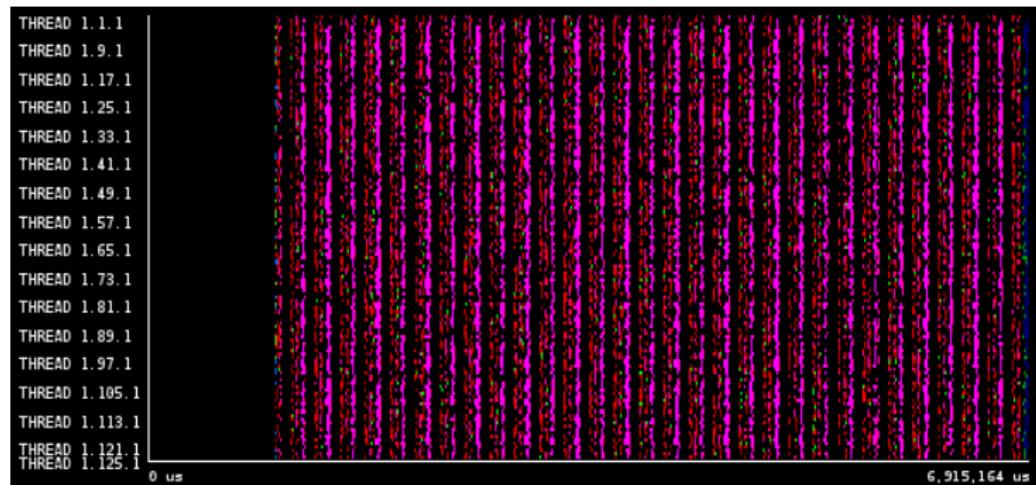


Figure: Lulesh 2.0 125 MPI ranks – 30 iterations

Validation

Lulesh 2.0

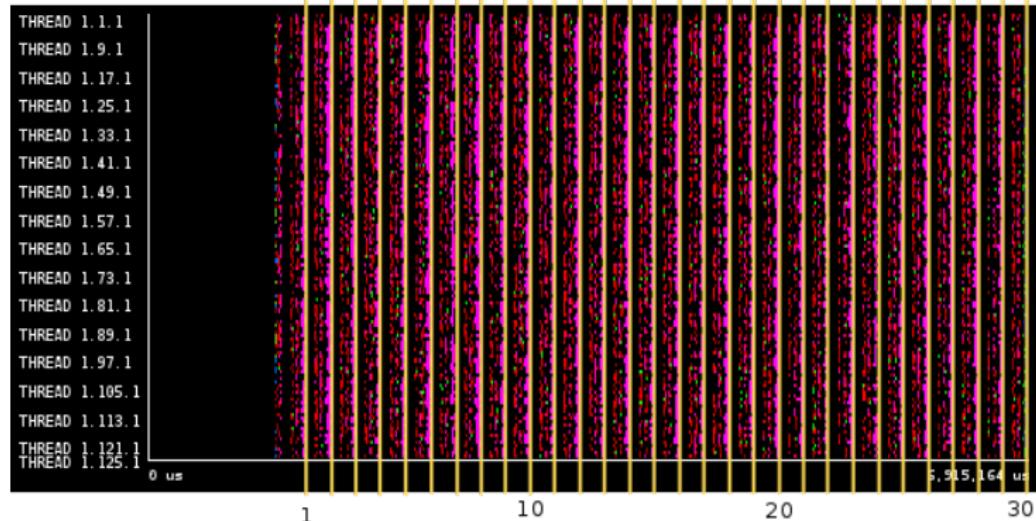
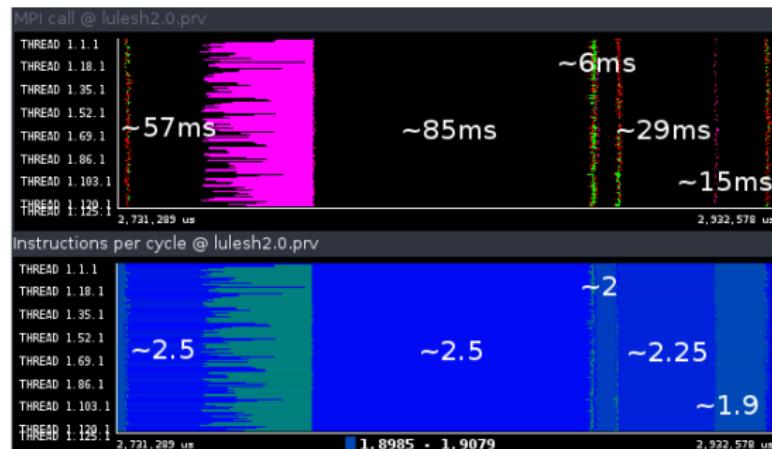


Figure: Lulesh 2.0 125 MPI ranks – 30 iterations

Validation

Lulesh 2.0

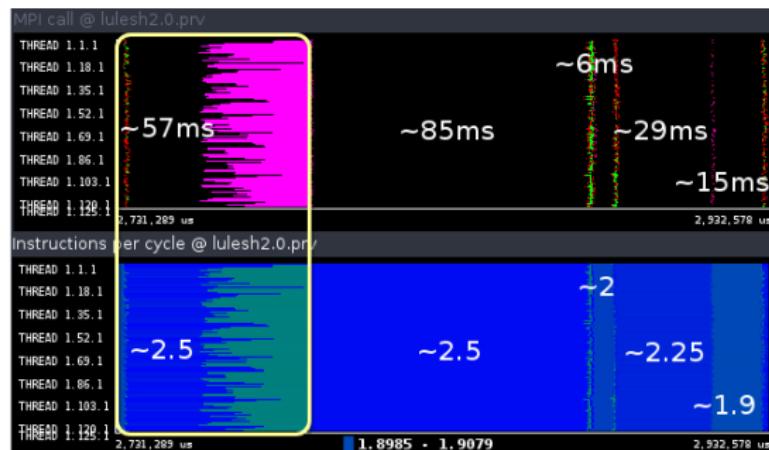
FILE	LINE	PSEUDOCODE	E(TIME)	E(SIZE)	E(IPC)
lulesh.cc	2773 : : TimeIncrement()	-	-	-	-
lulesh.cc	214 : : : [~ computation ~]	56.63ms	-	2.56	-
lulesh.cc	214 : : : 96.6% => MPI_Allreduce(CommId:1)	35.32us	8.0B/8.0B	1.57	-
lulesh.cc	1158 : : : : CommSend()	-	-	-	-
lulesh-comm.cc	401 : : : : : [~ computation ~]	85.2ms	-	2.48	-
lulesh-comm.cc	401 : : : : MPI_Comm_rank(0:)	20.08us	-	1.59	-
lulesh.cc	1289 : : : : CommSend()	-	-	-	-
lulesh-comm.cc	401 : : : : : [~ computation ~]	6.15ms	-	2.0	-
lulesh-comm.cc	401 : : : : MPI_Comm_rank(0:)	14.58us	-	1.63	-
lulesh.cc	1992 : : : : CommRecv()	-	-	-	-
lulesh-comm.cc	101 : : : : : [~ computation ~]	29.32ms	-	2.25	-
lulesh-comm.cc	101 : : : : MPI_Comm_rank(0:)	18.76us	-	1.39	-
lulesh.cc	2010 : : : : CommSend()	-	-	-	-
lulesh-comm.cc	401 : : : : : [~ computation ~]	15.35ms	-	1.91	-
lulesh-comm.cc	401 : : : : MPI_Comm_rank(0:)	15.24us	-	1.52	-



Validation

Lulesh 2.0

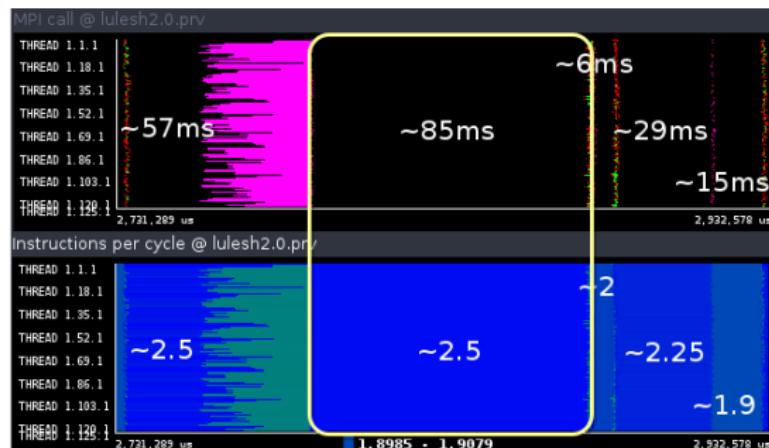
FILE	LINE	PSEUDOCODE	E(TIME)	E(SIZE)	E(IPC)
lulesh.cc	2773 : : TimeIncrement()	-	-	-	-
lulesh.cc	214 : : : [~ computation ~]	56.63ms	-	2.56	-
lulesh.cc	214 : : : 96.6% => MPI_Allreduce(CommId:1)	35.32us	8.0B/8.0B	1.57	-
lulesh.cc	1158 : : : : CommSend()	-	-	-	-
lulesh-comm.cc	401 : : : : : [~ computation ~]	85.2ms	-	2.48	-
lulesh-comm.cc	401 : : : : : MPI_Comm_rank(0:)	20.08us	-	1.59	-
lulesh.cc	1289 : : : : CommSend()	-	-	-	-
lulesh-comm.cc	401 : : : : : [~ computation ~]	6.15ms	-	2.0	-
lulesh-comm.cc	401 : : : : : MPI_Comm_rank(0:)	14.58us	-	1.63	-
lulesh.cc	1992 : : : : CommRecv()	-	-	-	-
lulesh-comm.cc	101 : : : : : [~ computation ~]	29.32ms	-	2.25	-
lulesh-comm.cc	101 : : : : : MPI_Comm_rank(0:)	18.76us	-	1.39	-
lulesh.cc	2010 : : : : CommSend()	-	-	-	-
lulesh-comm.cc	401 : : : : : [~ computation ~]	15.35ms	-	1.91	-
lulesh-comm.cc	401 : : : : : MPI_Comm_rank(0:)	15.24us	-	1.52	-



Validation

Lulesh 2.0

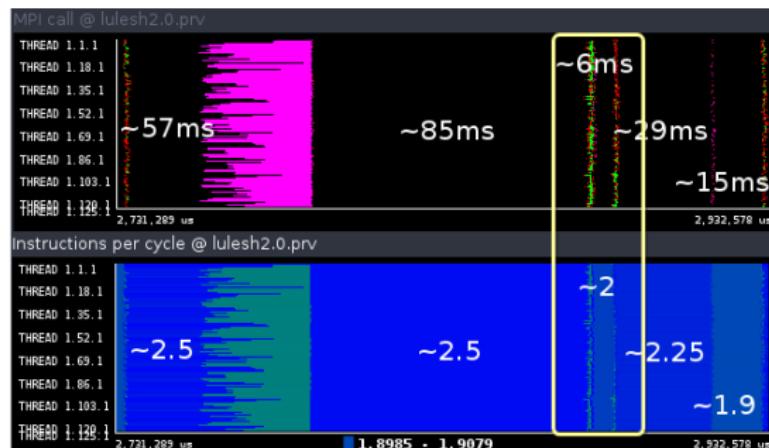
FILE	LINE	PSEUDOCODE	E(TIME)	E(SIZE)	E(IPC)
lulesh.cc	2773 : TimeIncrement()	-	-	-	-
lulesh.cc	214 : : : [~ computation ~]	56.63ms	-	2.56	-
lulesh.cc	214 : : : 96.6% => MPI_Allreduce(CommId:1)	35.32us	8.0B/8.0B	1.57	-
lulesh.cc	1158 : : : : CommSend()	-	-	-	-
lulesh-comm.cc	401 : : : : : [~ computation ~]	85.2ms	-	2.48	-
lulesh-comm.cc	401 : : : : : MPI_Comm_rank(0:)	20.08us	-	1.59	-
lulesh.cc	1289 : : : : CommSend()	-	-	-	-
lulesh-comm.cc	401 : : : : : [~ computation ~]	6.15ms	-	2.0	-
lulesh-comm.cc	401 : : : : : MPI_Comm_rank(0:)	14.58us	-	1.63	-
lulesh.cc	1992 : : : : CommRecv()	-	-	-	-
lulesh-comm.cc	101 : : : : : [~ computation ~]	29.32ms	-	2.25	-
lulesh-comm.cc	101 : : : : : MPI_Comm_rank(0:)	18.76us	-	1.39	-
lulesh.cc	2010 : : : : CommSend()	-	-	-	-
lulesh-comm.cc	401 : : : : : [~ computation ~]	15.35ms	-	1.91	-
lulesh-comm.cc	401 : : : : : MPI_Comm_rank(0:)	15.24us	-	1.52	-



Validation

Lulesh 2.0

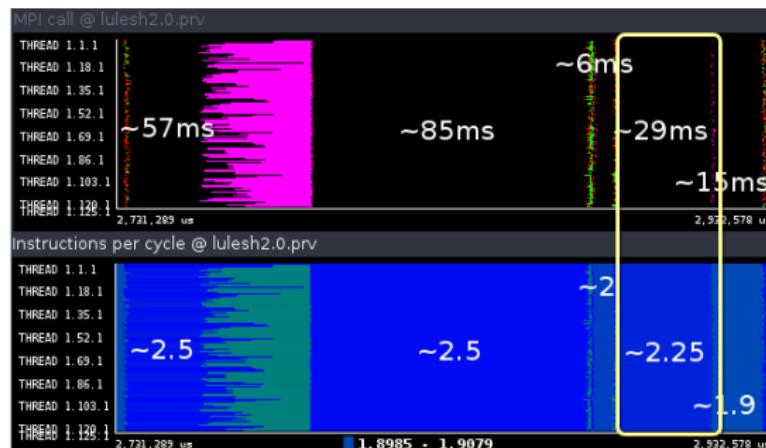
FILE	LINE	PSEUDOCODE	E(TIME)	E(SIZE)	E(IPC)
lulesh.cc	2773 : : TimeIncrement()	-	-	-	-
lulesh.cc	214 : : : [~ computation ~]	56.63ms	-	2.56	-
lulesh.cc	214 : : : 96.6% => MPI_Allreduce(CommId:1)	35.32us	8.0B/8.0B	1.57	-
lulesh.cc	1158 : : : : CommSend()	-	-	-	-
lulesh-comm.cc	401 : : : : : [~ computation ~]	85.2ms	-	2.48	-
lulesh-comm.cc	401 : : : : : MPI_Comm_rank(0:)	20.08us	-	1.59	-
lulesh.cc	1289 : : : : CommSend()	-	-	-	-
lulesh-comm.cc	401 : : : : : [~ computation ~]	6.15ms	-	2.0	-
lulesh-comm.cc	401 : : : : : MPI_Comm_rank(0:)	14.58us	-	1.63	-
lulesh.cc	1992 : : : : CommRecv()	-	-	-	-
lulesh-comm.cc	101 : : : : : [~ computation ~]	29.32ms	-	2.25	-
lulesh-comm.cc	101 : : : : : MPI_Comm_rank(0:)	18.76us	-	1.39	-
lulesh.cc	2010 : : : : CommSend()	-	-	-	-
lulesh-comm.cc	401 : : : : : [~ computation ~]	15.35ms	-	1.91	-
lulesh-comm.cc	401 : : : : : MPI_Comm_rank(0:)	15.24us	-	1.52	-



Validation

Lulesh 2.0

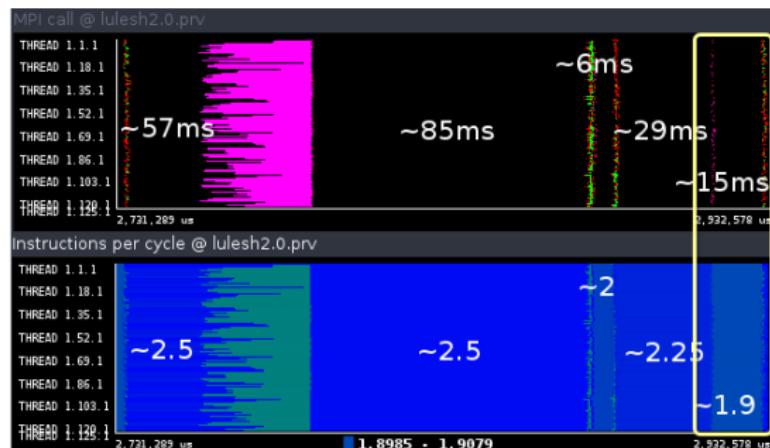
FILE	LINE	PSEUDOCODE	E(TIME)	E(SIZE)	E(IPC)
lulesh.cc	2773 : : TimeIncrement()	-	-	-	-
lulesh.cc	214 : : : [~ computation ~]	56.63ms	-	2.56	-
lulesh.cc	214 : : : 96.6% => MPI_Allreduce(CommId:1)	35.32us	8.0B/8.0B	1.57	-
lulesh.cc	1158 : : : : CommSend()	-	-	-	-
lulesh-comm.cc	401 : : : : : [~ computation ~]	85.2ms	-	2.48	-
lulesh-comm.cc	401 : : : : : MPI_Comm_rank(0:)	20.08us	-	1.59	-
lulesh.cc	1289 : : : : CommSend()	-	-	-	-
lulesh-comm.cc	401 : : : : : [~ computation ~]	6.15ms	-	2.0	-
lulesh-comm.cc	401 : : : : : MPI_Comm_rank(0:)	14.58us	-	1.63	-
lulesh.cc	1992 : : : : CommRecv()	-	-	-	-
lulesh-comm.cc	101 : : : : : [~ computation ~]	29.32ms	-	2.25	-
lulesh-comm.cc	101 : : : : : MPI_Comm_rank(0:)	18.76us	-	1.39	-
lulesh.cc	2010 : : : : CommSend()	-	-	-	-
lulesh-comm.cc	401 : : : : : [~ computation ~]	15.35ms	-	1.91	-
lulesh-comm.cc	401 : : : : : MPI_Comm_rank(0:)	15.24us	-	1.52	-



Validation

Lulesh 2.0

FILE	LINE	PSEUDOCODE	E(TIME)	E(SIZE)	E(IPC)
lulesh.cc	2773 : : TimeIncrement()	-	-	-	-
lulesh.cc	214 : : : [~ computation ~]	56.63ms	-	2.56	-
lulesh.cc	214 : : : 96.6% => MPI_Allreduce(CommId:1)	35.32us	8.0B/8.0B	1.57	-
lulesh.cc	1158 : : : : CommSend()	-	-	-	-
lulesh-comm.cc	401 : : : : : [~ computation ~]	85.2ms	-	2.48	-
lulesh-comm.cc	401 : : : : : MPI_Comm_rank(0:)	20.08us	-	1.59	-
lulesh.cc	1289 : : : : CommSend()	-	-	-	-
lulesh-comm.cc	401 : : : : : [~ computation ~]	6.15ms	-	2.0	-
lulesh-comm.cc	401 : : : : : MPI_Comm_rank(0:)	14.58us	-	1.63	-
lulesh.cc	1992 : : : : CommRecv()	-	-	-	-
lulesh-comm.cc	101 : : : : : [~ computation ~]	29.32ms	-	2.25	-
lulesh-comm.cc	101 : : : : : MPI_Comm_rank(0:)	18.76us	-	1.39	-
lulesh.cc	2010 : : : : CommSend()	-	-	-	-
lulesh-comm.cc	401 : : : : : [~ computation ~]	15.35ms	-	1.91	-
lulesh-comm.cc	401 : : : : : MPI_Comm_rank(0:)	15.24us	-	1.52	-



Validation

CG Class A

Execution:

- ≈ 2000 code lines (Fortran)
(40 MPI calls)
- 32 parallel processes
- $\approx 150MB$ tracefile

Analysis:

- Filter all *loops* $< 10\%$
- CPU burst *time* $> 100\mu s$

Validation

CG Class A

Execution:

- ≈ 2000 code lines (Fortran)
(40 MPI calls)
- 32 parallel processes
- $\approx 150MB$ tracefile

Analysis:

- Filter all *loops* $< 10\%$
- CPU burst *time* $> 100\mu s$

Results:

- 15 iterations loop

	0 MAIN_()	-	-	-	-
cg.f	475 : FOR 1 TO 15	-	-	-	-
cg.f	475 : : config_grid()	-	-	-	-
cg.f	1089 : : : FOR 1 TO 3.0	-	-	-	-
cg.E	1096 : : : MPI_Irecv(0:1,2,4)	7.23us	8.0B	1.76	
cg.E	1096 : : : MPI_Send(0:1,2,4)	6.81us	8.0B	1.34	
cg.F	1097 : : : MPI_Wait(0:)	46.79us	-	1.32	
cg.F	1097 : : : END LOOP	-	-	-	
cg.F	1097 : : : FOR 1 TO 25.0	-	-	-	
cg.F	1097 : : : : FOR 1 TO 3.0	-	-	-	
cg.F	1137 : : : : [- computation -]	115.51us	-	-	2.32
cg.F	1137 : : : : MPI_Irecv(0:1,2,4)	7.31us	13.67KB	1.27	
cg.F	1144 : : : : MPI_Send(0:1,2,4)	10.52us	13.67KB	1.42	
cg.F	1145 : : : : MPI_Wait(0:)	12.07us	-	1.3	
cg.F	1145 : : : : END LOOP	-	-	-	
cg.F	1163 : : : : MPI_Irecv(0:0)	6.7us	13.67KB	2.48	
cg.F	1171 : : : : MPI_Send(0:0)	7.04us	13.67KB	1.45	
cg.F	1172 : : : : MPI_Wait(0:)	6.45us	-	1.28	
cg.F	1172 : : : : FOR 1 TO 3.0	-	-	-	
cg.F	1207 : : : : MPI_Irecv(0:1,2,4)	6.55us	8.0B	1.83	
cg.F	1214 : : : : MPI_Send(0:1,2,4)	6.98us	8.0B	1.52	
cg.F	1216 : : : : MPI_Wait(0:)	13.15us	-	1.4	
cg.F	1216 : : : : END LOOP	-	-	-	
cg.F	1216 : : : : FOR 1 TO 3.0	-	-	-	
cg.F	1262 : : : MPI_Irecv(0:1,2,4)	-	8.0B	2.75	
cg.F	1269 : : : MPI_Send(0:1,2,4)	-	8.0B	1.51	
cg.F	1270 : : : MPI_Wait(0:)	-	-	1.39	
cg.F	1270 : : : END LOOP	-	-	-	
cg.F	1270 : : : END LOOP	-	-	-	
cg.F	1270 : : : FOR 1 TO 3.0	-	-	-	
cg.F	1320 : : : [- computation -]	115.65us	-	-	2.31
cg.F	1320 : : : MPI_Irecv(0:1,2,4)	6.94us	13.67KB	1.13	
cg.F	1327 : : : MPI_Send(0:1,2,4)	10.55us	13.67KB	1.43	
cg.F	1328 : : : MPI_Wait(0:)	9.14us	-	1.25	
cg.F	1328 : : : END LOOP	-	-	-	
cg.F	1347 : : : MPI_Irecv(0:0)	6.76us	13.67KB	2.47	
cg.F	1355 : : : MPI_Send(0:0)	7.13us	13.67KB	1.44	
cg.F	1356 : : : MPI_Wait(0:)	6.59us	-	1.19	
cg.F	1356 : : : FOR 1 TO 3.0	-	-	-	
cg.F	1384 : : : MPI_Irecv(0:1,2,4)	6.57us	8.0B	2.37	
cg.F	1391 : : : MPI_Send(0:1,2,4)	6.63us	8.0B	1.51	
cg.F	1392 : : : MPI_Wait(0:)	25.38us	-	1.38	
cg.F	1392 : : : END LOOP	-	-	-	
cg.F	1392 : : : FOR 1 TO 3.0	-	-	-	
cg.F	1499 : : : MPI_Irecv(0:1,2,4)	6.03us	16.0B	3.09	
cg.F	506 : : : MPI_Send(0:1,2,4)	6.1us	16.0B	1.53	
cg.F	507 : : : MPI_Wait(0:)	6.48us	-	1.35	
cg.F	507 : : : END LOOP	-	-	-	
cg.F	507 : : : END LOOP	-	-	-	

15x

Validation

CG Class A

Execution:

- \approx 2000 code lines (Fortran)
(40 MPI calls)
 - 32 parallel processes
 - \approx 150MB tracefile

Analysis:

- Filter all *loops* $< 10\%$
 - CPU burst *time* $> 100\mu s$

Results:

- 15 iterations loop
 - 25 iterations subloop

	MAIN__()			
	: FOR 1 TO 15	-	-	-
cg.f	475 : : : coni_grad()	-	-	-
	: : : FOR 1 TO 3.0	-	-	-
cg.f	1089 : : : MPI_Recv(0:1,2,4)	8.0B	1.76	
cg.f	1096 : : : MPI_Send(0:1,2,4)	8.0B	1.34	
cg.f	1097 : : : MPI_Wait(0:)		1.32	
	: : : END LOOP	-	-	-
	: : : FOR 1 TO 25.0	-	-	-
	: : : FOR 1 TO 3.0	-	-	-
cg.f	[1137 : : : [computation ~]	115.51us	2.32	
cg.f	1137 : : : MPI_Recv(0:1,2,4)	7.31us	13.67KB	1.27
cg.f	1144 : : : MPI_Send(0:1,2,4)	10.52us	13.67KB	1.42
cg.f	1145 : : : MPI_Wait(0:)	12.07us	-	1.3
	: : : END LOOP	-	-	-
cg.f	1163 : : : MPI_Recv(0:0)	6.7us	13.67KB	2.48
cg.f	1171 : : : MPI_Send(0:0)	7.04us	13.67KB	1.45
cg.f	1172 : : : MPI_Wait(0:)		1.28	
	: : : FOR 1 TO 3.0	-	-	-
cg.f	[1207 : : : [computation ~]	13.15us	1.83	
cg.f	1214 : : : MPI_Recv(0:1,2,4)	8.0B	1.83	
cg.f	1216 : : : MPI_Wait(0:)		1.52	
	: : : END LOOP	-	-	-
	: : : FOR 1 TO 3.0	-	-	-
cg.f	[1262 : : : MPI_Recv(0:1,2,4)	6.58us	8.0B	2.75
cg.f	1269 : : : MPI_Send(0:1,2,4)	6.62us	8.0B	1.51
cg.f	1270 : : : MPI_Wait(0:)	9.8us	-	1.39
	: : : END LOOP	-	-	-
	: : : END LOOP	-	-	-
	: : : FOR 1 TO 3.0	-	-	-
cg.f	[1320 : : : [computation ~]	13.67KB	2.31	
cg.f	1320 : : : MPI_Recv(0:1,2,4)		13.67KB	1.13
cg.f	1327 : : : MPI_Send(0:1,2,4)		13.67KB	1.43
cg.f	1328 : : : MPI_Wait(0:)		1.25	
	: : : END LOOP	-	-	-
cg.f	1347 : : : MPI_Recv(0:0)	6.76us	13.67KB	2.47
cg.f	1355 : : : MPI_Send(0:0)	7.13us	13.67KB	1.44
cg.f	1356 : : : MPI_Wait(0:)	6.59us	-	1.19
	: : : FOR 1 TO 3.0	-	-	-
cg.f	1384 : : : MPI_Recv(0:1,2,4)	8.0B	2.37	
cg.f	1391 : : : MPI_Send(0:1,2,4)	8.0B	1.51	
cg.f	1392 : : : MPI_Wait(0:)		1.38	
	: : : END LOOP	-	-	-
	: : : FOR 1 TO 3.0	-	-	-
cg.f	199 : : : MPI_Recv(0:1,2,4)	16.0B	3.09	
cg.f	506 : : : MPI_Send(0:1,2,4)	16.0B	1.53	
cg.f	507 : : : MPI_Wait(0:)		1.35	
	: : : END LOOP	-	-	-
	: : : END LOOP	-	-	-

Validation

CG Class A

Execution:

- ≈ 2000 code lines (Fortran)
(40 MPI calls)
- 32 parallel processes
- $\approx 150MB$ tracefile

Analysis:

- Filter all *loops* $< 10\%$
- CPU burst *time* $> 100\mu s$

Results:

- 15 iterations loop
- 25 iterations subloop
- Other 3 iterations subloops

	0 MAIN__()	-	-	-	-
cg.f	475 : FOR 1 TO 15	-	-	-	-
cg.f	475 : : : : : config_grid()	-	-	-	-
cg.f	1089 : : : : : FOR 1 TO 3.0	-	-	-	-
cg.E	1096 : : : : : MPI_Irecv(0:1,2,4)	7.23us	8.0B	1.76	
cg.E	1096 : : : : : MPI_Send(0:1,2,4)	6.81us	8.0B	1.34	
cg.F	1097 : : : : : MPI_Wait(0:)	16.79us	-	1.32	
cg.F	1097 : : : : : END LOOP	-	-	-	-
cg.F	1097 : : : : : FOR 1 TO 25.0	-	-	-	-
cg.F	1097 : : : : : : FOR 1 TO 3.0	-	-	-	-
cg.F	1137 : : : : : : : [- computation -]	-	-	-	-
cg.F	1137 : : : : : : : MPI_Irecv(0:1,2,4)	13.67KB	-	2.32	
cg.F	1144 : : : : : : : MPI_Send(0:1,2,4)	13.67KB	-	1.42	
cg.F	1145 : : : : : : : MPI_Wait(0:)	-	-	1.3	
cg.F	1163 : : : : : : : END LOOP	-	-	-	-
cg.F	1163 : : : : : : : MPI_Irecv(0:0)	16.7us	13.67KB	2.48	
cg.E	1171 : : : : : : : MPI_Send(0:0)	17.04us	13.67KB	1.45	
cg.E	1172 : : : : : : : MPI_Wait(0:)	6.45us	-	1.28	
cg.F	1172 : : : : : : : FOR 1 TO 3.0	-	-	-	-
cg.F	1207 : : : : : : : MPI_Irecv(0:1,2,4)	8.0B	-	1.83	
cg.F	1214 : : : : : : : MPI_Send(0:1,2,4)	8.0B	-	1.52	
cg.F	1216 : : : : : : : MPI_Wait(0:)	-	-	1.4	
cg.F	1216 : : : : : : : END LOOP	-	-	-	-
cg.F	1216 : : : : : : : FOR 1 TO 3.0	-	-	-	-
cg.F	1262 : : : : : : : MPI_Irecv(0:1,2,4)	8.0B	-	2.75	
cg.F	1269 : : : : : : : MPI_Send(0:1,2,4)	8.0B	-	1.51	
cg.F	1270 : : : : : : : MPI_Wait(0:)	-	-	1.39	
cg.F	1270 : : : : : : : END LOOP	-	-	-	-
cg.F	1270 : : : : : : : FOR 1 TO 3.0	-	-	-	-
cg.F	1320 : : : : : : : [- computation -]	115.65us	-	2.31	
cg.F	1320 : : : : : : : MPI_Irecv(0:1,2,4)	6.94us	13.67KB	1.13	
cg.F	1327 : : : : : : : MPI_Send(0:1,2,4)	10.55us	13.67KB	1.43	
cg.F	1328 : : : : : : : MPI_Wait(0:)	9.14us	-	1.25	
cg.F	1328 : : : : : : : END LOOP	-	-	-	-
cg.E	1347 : : : : : : : MPI_Irecv(0:0)	6.76us	13.67KB	2.47	
cg.E	1355 : : : : : : : MPI_Send(0:0)	7.13us	13.67KB	1.44	
cg.E	1356 : : : : : : : MPI_Wait(0:)	6.59us	-	1.19	
cg.E	1356 : : : : : : : FOR 1 TO 3.0	-	-	-	-
cg.E	1384 : : : : : : : MPI_Irecv(0:1,2,4)	6.57us	8.0B	2.37	
cg.E	1391 : : : : : : : MPI_Send(0:1,2,4)	6.63us	8.0B	1.51	
cg.E	1392 : : : : : : : MPI_Wait(0:)	25.38us	-	1.38	
cg.E	1392 : : : : : : : END LOOP	-	-	-	-
cg.E	1392 : : : : : : : FOR 1 TO 3.0	-	-	-	-
cg.E	499 : : : : : : : MPI_Irecv(0:1,2,4)	6.03us	16.0B	3.09	
cg.E	506 : : : : : : : MPI_Send(0:1,2,4)	6.1us	16.0B	1.53	
cg.E	507 : : : : : : : MPI_Wait(0:)	6.48us	-	1.35	
cg.E	507 : : : : : : : END LOOP	-	-	-	-
cg.E	507 : : : : : : : END LOOP	-	-	-	-

Validation

CG Class A

Execution:

- ≈ 2000 code lines (Fortran)
(40 MPI calls)
- 32 parallel processes
- $\approx 150MB$ tracefile

Analysis:

- Filter all *loops* $< 10\%$
- CPU burst *time* $> 100\mu s$

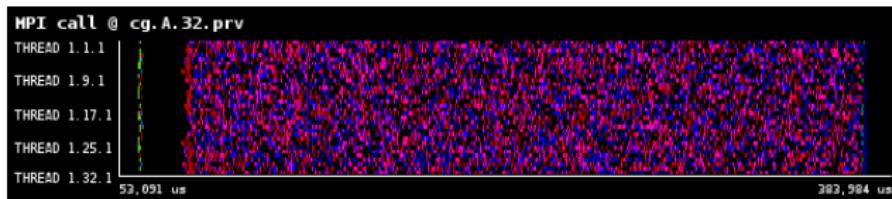
Results:

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- 25 iterations subloop
- Other 3 iterations subloops
- 2 long CPU burst above
100 μs

	0 MAIN_(-	-	-	-
cg.f	475: : FOR 1 TO 15	-	-	-	-
cg.f	475: : : : : conjgrad()	-	-	-	-
cg.f	475: : : : : FOR 1 TO 15	-	-	-	-
cg.f	1089: : : : : MPI_Irecv(0:1,2,4)	7.23us	8.0B	1.76	
cg.f	1096: : : : : MPI_Send(0:1,2,4)	6.81us	8.0B	1.34	
cg.f	1097: : : : : MPI_Wait(0:)	146.79us	-	1.32	
cg.f	1097: : : : : END LOOP	-	-	-	
cg.f	1097: : : : : FOR 1 TO 25.0	-	-	-	-
cg.f	1097: : : : : : : : FOR 1 TO 3.0	-	-	-	-
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cg.f	1145: : : : : : : : MPI_Wait(0:)	12.07us	-	1.3	
cg.f	1145: : : : : : : : END LOOP	-	-	-	
cg.f	1163: : : : : : : : MPI_Irecv(0:0)	6.7us	13.67KB	2.48	
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cg.f	1172: : : : : : : : MPI_Wait(0:)	6.45us	-	1.28	
cg.f	1172: : : : : : : : FOR 1 TO 3.0	-	-	-	-
cg.f	1207: : : : : : : : MPI_Irecv(0:1,2,4)	6.55us	8.0B	1.83	
cg.f	1214: : : : : : : : MPI_Send(0:1,2,4)	6.98us	8.0B	1.52	
cg.f	1216: : : : : : : : MPI_Wait(0:)	13.15us	-	1.4	
cg.f	1216: : : : : : : : END LOOP	-	-	-	
cg.f	1216: : : : : : : : FOR 1 TO 3.0	-	-	-	-
cg.f	1262: : : : : : : : MPI_Irecv(0:1,2,4)	6.58us	8.0B	2.75	
cg.f	1269: : : : : : : : MPI_Send(0:1,2,4)	6.62us	8.0B	1.51	
cg.f	1270: : : : : : : : MPI_Wait(0:)	9.8us	-	1.39	
cg.f	1270: : : : : : : : END LOOP	-	-	-	
cg.f	1270: : : : : : : : END LOOP	-	-	-	
cg.f	1270: : : : : : : : FOR 1 TO 3.0	-	-	-	-
cg.f	1320: : : : : : : : [- computation -]	115.65us	-	2.31	
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cg.f	1328: : : : : : : : END LOOP	-	-	-	
cg.f	1347: : : : : : : : MPI_Irecv(0:0)	6.76us	13.67KB	2.47	
cg.f	1355: : : : : : : : MPI_Send(0:0)	7.13us	13.67KB	1.44	
cg.f	1356: : : : : : : : MPI_Wait(0:)	6.59us	-	1.19	
cg.f	1356: : : : : : : : FOR 1 TO 3.0	-	-	-	-
cg.f	1384: : : : : : : : MPI_Irecv(0:1,2,4)	6.57us	8.0B	2.37	
cg.f	1391: : : : : : : : MPI_Send(0:1,2,4)	6.63us	8.0B	1.51	
cg.f	1392: : : : : : : : MPI_Wait(0:)	25.38us	-	1.38	
cg.f	1392: : : : : : : : END LOOP	-	-	-	
cg.f	1392: : : : : : : : FOR 1 TO 3.0	-	-	-	-
cg.f	1499: : : : : : : : MPI_Irecv(0:1,2,4)	6.03us	16.0B	3.09	
cg.f	506: : : : : : : : MPI_Send(0:1,2,4)	6.1us	16.0B	1.53	
cg.f	507: : : : : : : : MPI_Wait(0:)	6.48us	-	1.35	
cg.f	507: : : : : : : : END LOOP	-	-	-	
cg.f	507: : : : : : : : END LOOP	-	-	-	

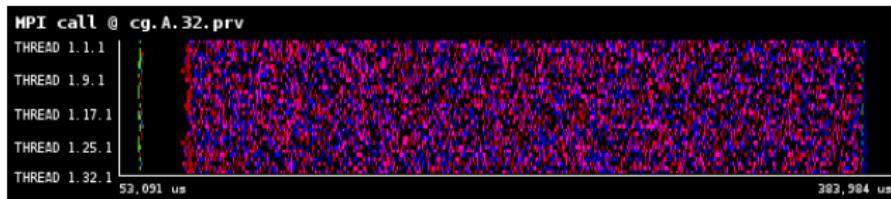
Validation

CG Class A

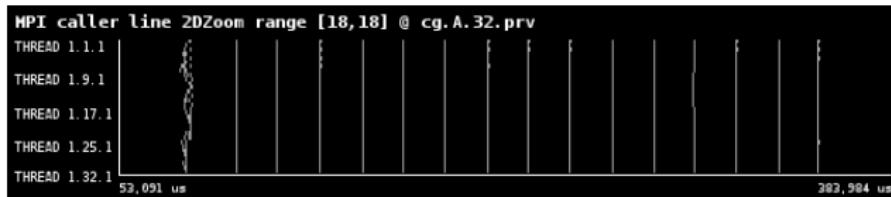


Validation

CG Class A

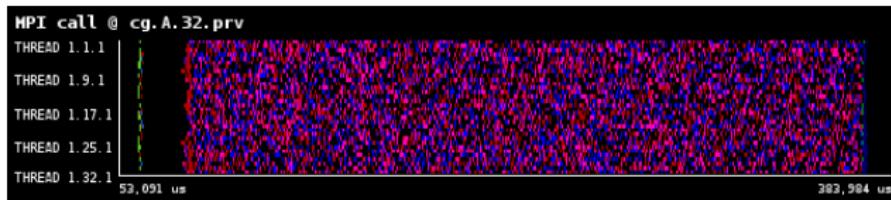


Showing just **MPI_Irecv** on **cg.f** : 1089

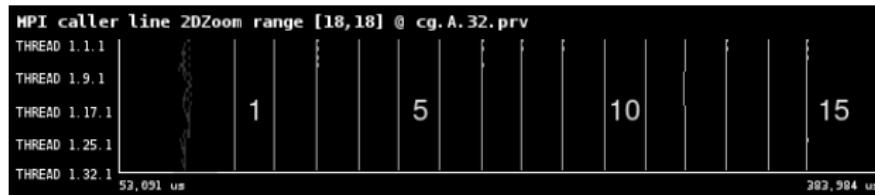


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CG Class A

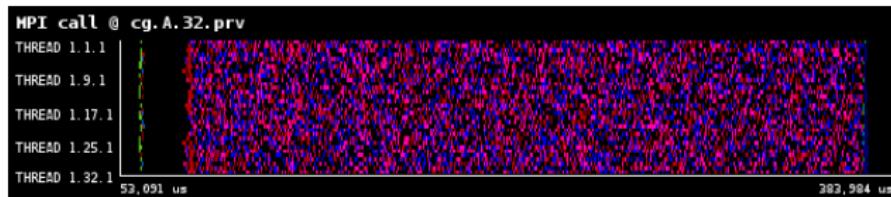


Showing just **MPI_Irecv** on **cg.f** : 1089

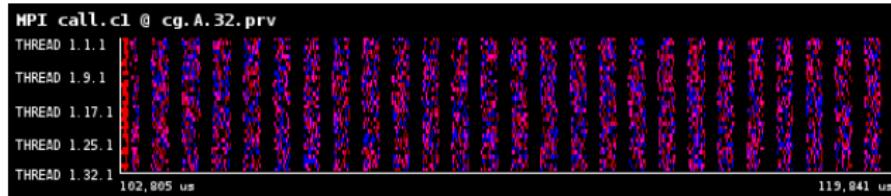


Validation

CG Class A

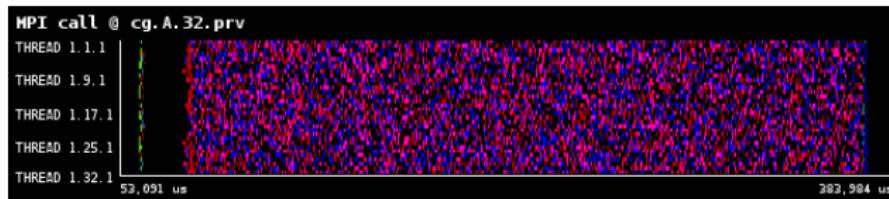


Showing just MPI_Irecv on cg.f : 1089

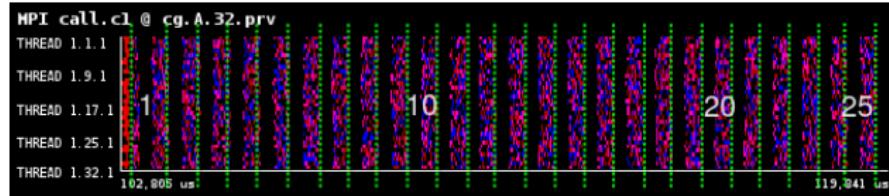


Validation

CG Class A



Showing just MPI_Irecv on cg.f : 1089



Outline

1 Introduction

- Context
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2 Proposal

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- Implementation
- Refinement

3 Best features analysis

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- CG

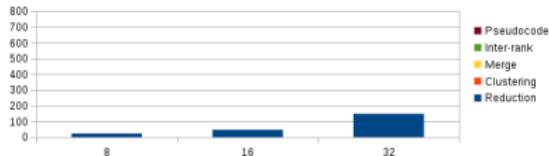
5 Scalability

6 Conclusions

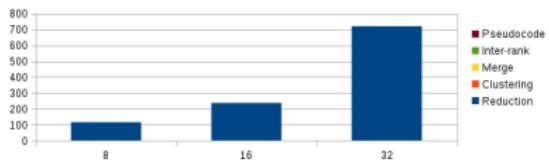
7 Future work

Scalability

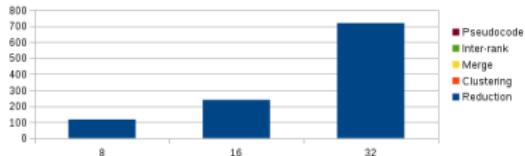
CG (A) phases breakdown



CG (B) phases breakdown

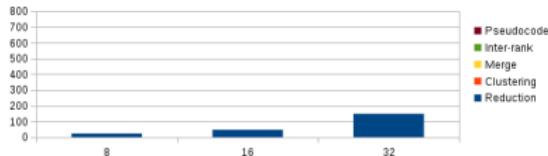


CG (C) phases breakdown

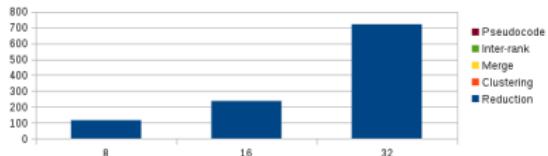


Scalability

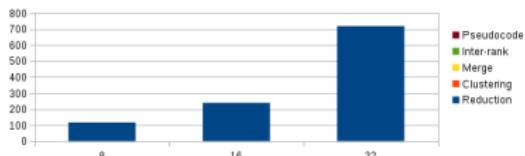
CG (A) phases breakdown



CG (B) phases breakdown



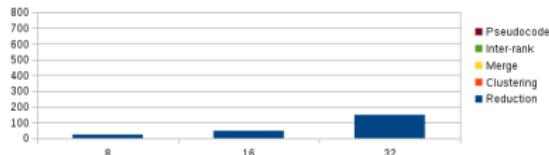
CG (C) phases breakdown



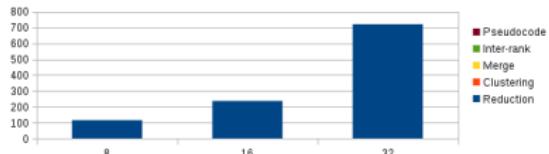
Reduction step is clearly dominating the execution time.

Scalability

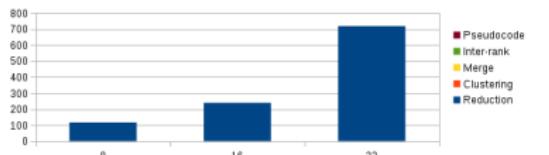
CG (A) phases breakdown



CG (B) phases breakdown

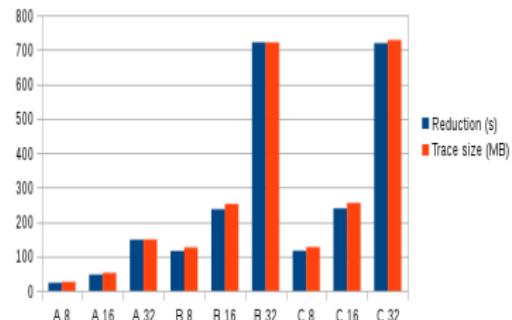


CG (C) phases breakdown



Reduction step is clearly dominating the execution time.

CG Reduction time and Trace size



Reduction step time is highly correlated with trace size.

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- New approach for application structure detection has been explored.

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Conclusions

- New approach for application structure detection has been explored.
- Have demonstrated that it works well with HPC applications.
- Number of iterations and iterations mean time has been identified as valuable features for loops classification.
- Execution time is clearly dominated by Reduction step that presents linear complexity with the trace size.

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- Improve memory usage by timestamps compression.

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Future work

- Improve memory usage by timestamps compression.
- Improve Reduce phase times by parallelizing the reduction using for example well-known infrastructures like Hadoop.
- Explore the possibility to use sampling techniques to get more detailed structure of an application.

Master thesis
Master in Research and Innovation

**Inferring programs structure from
an execution trace**

Author

Juan Francisco Martínez Vera

Supervisor

Jesús Labarta Mancho

Facultat d'Informàtica de Barcelona (FIB)
Universitat Politècnica de Catalunya (UPC)



Refinement

Even if it **works pretty well** in general.

Some problems **have been identified**.

- ① **Cluster aliasing** when two different loops behaves similarly enough over our defined space
- ② **Hidden superloop** when not detected superloop prevents from a good structure detection.
- ③ **Cluster split** when MPI calls belonging to the same loop behaves in a different way.

All three **have been solved by looking to timestamps**.

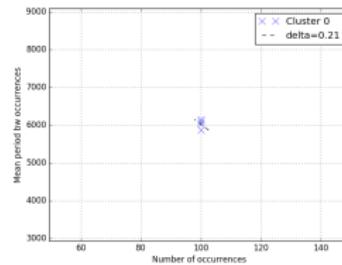
Proposal modifications

Cluster aliasing

Keynote

Aliasing can be detected and solved **looking at timestamps**.

```
for 1to100
  do {MPI_A()
       MPI_B()}
for 1to100
  do {MPI_C()
       MPI_D()}
```



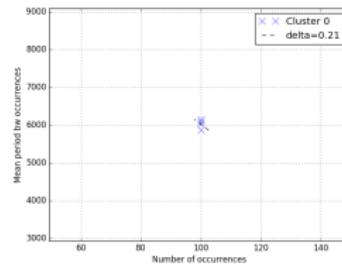
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```



MPI_A	1	3
MPI_B	2	4
MPI_C	5	7
MPI_D	6	8

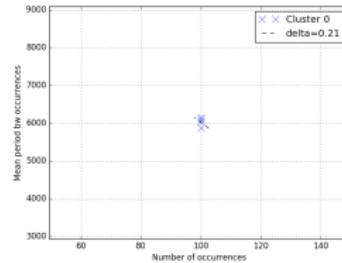
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MPI_D		6 8

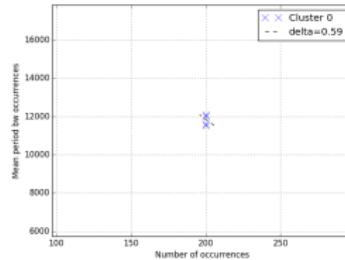
Proposal modifications

Hidden superloop

Keynote

Similarly than with aliasing, **looking at timestamps**.

```
for 1to100
    do { for 1to2
        do { MPI_A()
            for 1to2
                do { MPI_B()
```



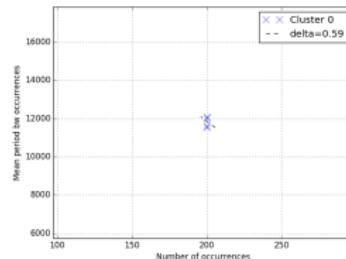
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```
for 1to100
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        do {MPI_A()
            for 1to2
                do {MPI_B()}
```



MPI_A	1	2	5	6
MPI_B	3	4	7	8

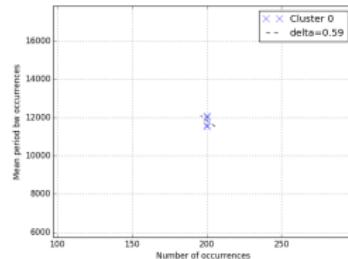
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Hidden superloop

Keynote

Similarly than with aliasing, **looking at timestamps**.

```
for 1to100
    do {for 1to2
        do {MPI_A()
            for 1to2
                do {MPI_B()}
```



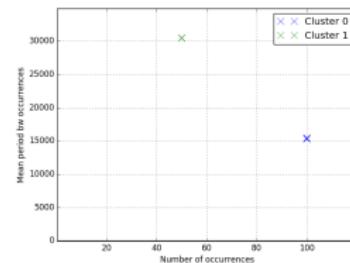
MPI_A	1	2	5	6
MPI_B	3	4	7	8

	MPI_A	1	2	5	6
MPI_B		3	4	7	8

Proposal modifications

Cluster split

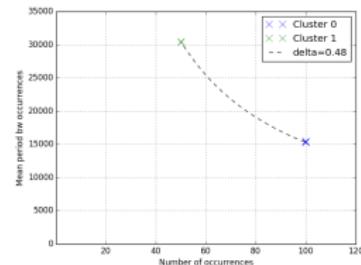
```
for i = 1 to 10
    do {MPI_B()
        if odd(i)
            then MPI_A()
        MPI_B()}
```



Proposal modifications

Cluster split

```
for i = 1 to 10
    do { MPI_B()
          if odd(i)
              then MPI_A()
          MPI_B()}
```



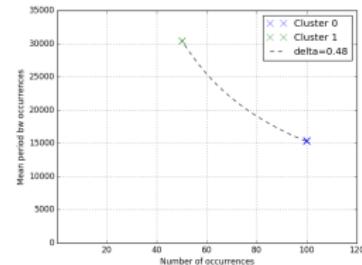
Whether MPI call is conditioned

- #repetitions and mean time bw. reps. change (in same proportion).

Proposal modifications

Cluster split

```
for i = 1 to 10
    do {MPI_B()
        if odd(i)
            then MPI_A()
        MPI_B()}
```



Whether MPI call is conditioned

- #repetitions and mean time bw. reps. change (in same proportion).

By “reverse loop merging” and times checking

FILE	LINE	PSEUDOCODE	E(TIME)	E(SIZE)	E(IPC)
test-9.c	0	main()	-	-	-
	: FOR 1 TO 100		-	-	-
	: : IF rank in [1]		-	-	-
	20	: : : MPI_Send(1:0)	5.01us	4.0B	1.1
	: : : IF rank in [0]		-	-	-
	22	: : : MPI_Recv()	5.3us	-	1.03
test-9.c	24	: 50.0% => MPI_Barrier(CommId:1)	5.99us	-	0.97
	: : IF rank in [1]		-	-	-
test-9.c	26	: : MPI_Send(1:0)	4.9us	4.0B	1.14
	: : IF rank in [0]		-	-	-
test-9.c	28	: : MPI_Recv()	5.23us	-	1.1
	: END LOOP		-	-	-

Data analysis

Data acquisition

Desired data...

- PCA²: Set of observations with set of features, i.e. Set of loops with **iteration-level aggregated features**.
- Variable Importance Same data as in production traces but labeled, i.e. textbf{With} information to what loop every MPI call belongs to.

How to obtain it

- ① The needed information is not in trace so ...
- ② **Manually inject monitors** to the source code
 - Very tough and error prone for huge source codes
- ③ Alternatively use source-to-source compiler to **do it automatically**
 - Mercurium

²Principal component analysis

Data analysis

Data acquisition

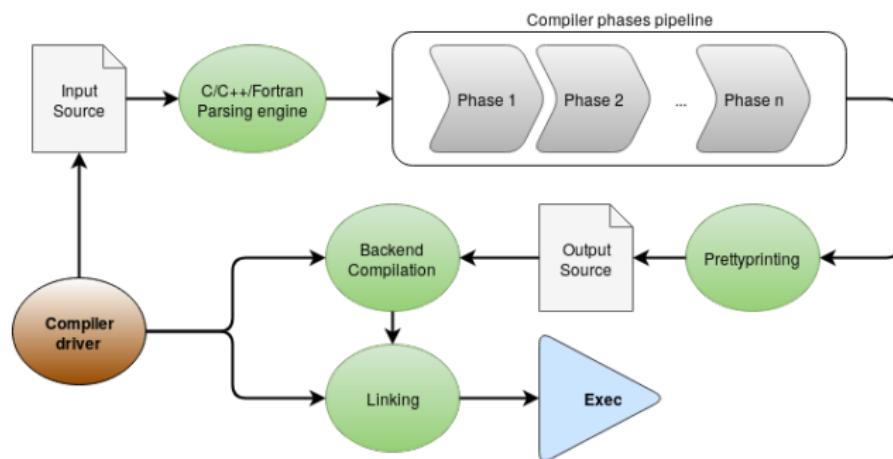


Figure: Mercurium internals overview

Data analysis

Data acquisition

Algorithm 7.1: PCA()

```
MLoopInit(loopline, loopfile)
```

```
for i ∈ I
```

```
do {  
    MIterInit(chance)  
    ...  
    MIterFini()  
}
```

```
MLoopFini()
```

- MLoopInit and MLoopFini fire loops boundaries
- MIterInit and MiterFini fire iteration boundaries with hwc information o trace

Data analysis

Data acquisition

Algorithm 7.3: PCA()

```
MLoopInit( $loop_{line}$ ,  $loop_{file}$ )
for  $i \in I$ 
    do {  $MIterInit(chance)$ 
          ...
           $MIterFini()$ 
      } MLoopFini()
```

Algorithm 7.4: VARIMP()

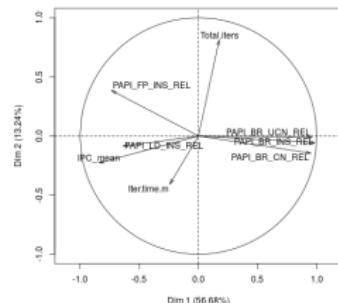
```
MLoopInit( $loop_{line}$ ,  $loop_{file}$ )
for  $i \in I$ 
    do { ...
           $MBefCall()$ 
           $MPI\_Call()$ 
           $MPIAftCall()$ 
          ...
      } MLoopFini()
```

- MLoopInit and MLoopFini fire loops boundaries
- MIterInit and MiterFini fire iteration boundaries with hwc information o trace

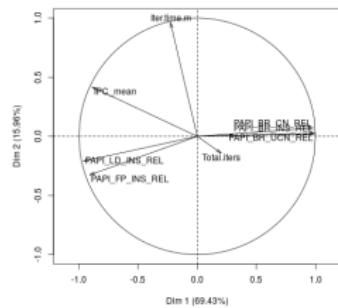
- MLoopInit and MLoopFini keep track entry/exit loops
- MPIBefCall and MPIAftCall fire loop id

Data analysis

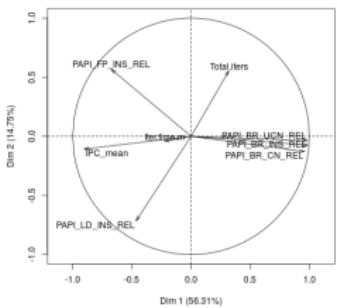
Analysis of results: PCA



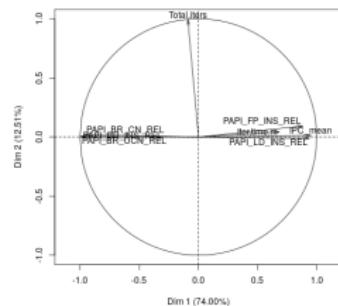
BT



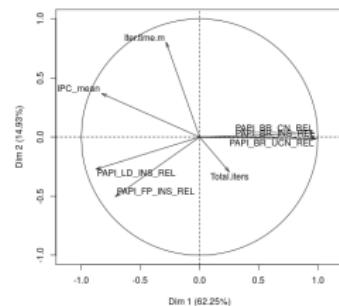
MG



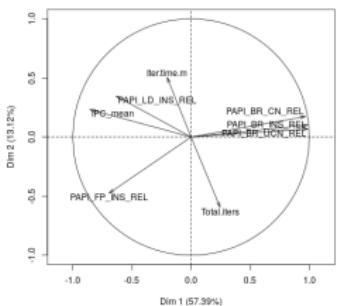
SP



CG



FT



LU

Validation

Lulesh 2.0

File	Line	Function	Time	Size	Count
lulesh.cc	214	: : : [~ computation ~]	56.63ms	-	12.56
lulesh.cc	214	: : : 96.6% -> MPI_Allreduce(CommId:1)	35.32us	8.0B/8.0B	1.57
lulesh.cc	2774	: : : LagrangeLeapFrog()	-	-	-
lulesh.cc	2648	: : : LagrangeNodal()	-	-	-
lulesh.cc	1263	: : : CalcForceForNodes()	-	-	-
lulesh.cc	1137	: : : CommRecv()	-	-	-
lulesh-comm.cc	101	: : : : MPI_Comm_rank(0:)	10.27us	-	10.28
lulesh-comm.cc	119	: : : : MPI_Irecv(0:25)	10.51us	22.52KB	10.55
lulesh-comm.cc	137	: : : : MPI_Irecv(0:5)	8.67us	22.52KB	10.96
lulesh-comm.cc	155	: : : : MPI_Irecv(0:1)	8.43us	22.52KB	11.08
lulesh-comm.cc	192	: : : : MPI_Irecv(0:6)	8.8us	744.0B	11.08
lulesh-comm.cc	201	: : : : MPI_Irecv(0:30)	8.54us	744.0B	11.25
lulesh-comm.cc	210	: : : : MPI_Irecv(0:26)	8.29us	744.0B	11.25
lulesh-comm.cc	345	: : : : MPI_Irecv(0:31)	8.32us	24.0B	0.9
lulesh.cc	1158	: : : : CommSend()	-	-	-
lulesh-comm.cc	401	: : : : [~ computation ~]	85.2ms	-	12.48
lulesh-comm.cc	401	: : : : MPI_Comm_rank(0:)	120.08us	-	11.59

Table: Total MPI calls

	MPI_Isend	MPI_Irecv	MPI_Wait	MPI_Waitall	MPI_Allreduce	MPI_Comm_rank
Rank 0	300	510	510	90	29	270

Table: MPI calls counts by communication phases

	MPI_Isend	MPI_Irecv	MPI_Wait	MPI_Waitall	MPI_Allreduce	MPI_Comm_rank
Comm phase 1	0	7	0	0	1	1
Comm phase 2	7	7	1	0	0	3
Comm phase 3	0	0	7	1	0	2
Comm phase 4	0	3	0	0	0	1
Comm phase 5	3	0	3	1	0	2

Validation

Lulesh 2.0

Lulesh-conn.cc						
440	: : :	[- computation -]	~	85.2ns	~	12.48
403	: : :	MPI_Isend(0:1)	~	12.5us	~	11.9
403	: : :	MPI_Irecv(0:1)	~	12.5us	~	11.9
436	: : :	MPI_Isend(0:25)	14.95us	22.52KB	1.9	
477	: : :	MPI_Isend(0:51)	10.07us	22.52KB	1.65	
232	: : :	MPI_Isend(0:1)	12.5us	22.52KB	1.23	
589	: : :	MPI_Isend(0:6)	14.79us	1744.0B	1.68	
606	: : :	MPI_Isend(0:30)	12.45us	1744.0B	1.86	
623	: : :	MPI_Isend(0:1)	12.5us	1744.0B	1.56	
837	: : :	MPI_Isend(0:31)	9.48us	124.0B	0.84	
843	: : :	MPI_Waitall(0:1)	541.3us	~	0.43	
132	: : :	MPI_Wait(0:1)	~	~	~	
889	: : :	MPI_Comm_rank(0:1)	9.32us	~	0.49	
913	: : :	MPI_Wait(0:1)	9.32us	~	0.6	
940	: : :	MPI_Wait(0:1)	9.32us	~	0.58	
980	: : :	MPI_Wait(0:1)	9.32us	~	2.35	
1039	: : :	MPI_Wait(0:1)	8.41us	~	11.73	
1204	: : :	MPI_Wait(0:1)	9.32us	~	1.44	
1307	: : :	MPI_Wait(0:1)	9.32us	~	1.98	
1325	: : :	MPI_Wait(0:1)	58.99us	~	11.44	
1325	: : :	MPI_Wait(0:1)	~	~	~	
101	: : :	MPI_Comm_rank(0:1)	17.77us	~	0.73	
119	: : :	MPI_Irecv(0:25)	19.53us	45.05KB	0.79	
120	: : :	MPI_Irecv(0:25)	17.77us	45.05KB	1.12	
155	: : :	MPI_Irecv(0:11)	17.74us	45.05KB	0.95	
192	: : :	MPI_Irecv(0:6)	17.6us	11.45KB	11.12	
200	: : :	MPI_Irecv(0:25)	17.74us	11.45KB	1.13	
210	: : :	MPI_Irecv(0:25)	17.42us	11.45KB	1.13	
345	: : :	MPI_Irecv(0:31)	17.36us	148.0B	0.95	
345	: : :	MPI_Irecv(0:31)	~	~	~	
403	: : :	[- computation -]	16.15us	~	2.0	
403	: : :	MPI_Comm_rank(0:1)	14.58us	~	1.63	

Table: Total MPI calls

	MPI_Isend	MPI_Irecv	MPI_Wait	MPI_Waitall	MPI_Allreduce	MPI_Comm_rank
Rank 0	300	510	510	90	29	270

Table: MPI calls counts by communication phases

	MPI_Isend	MPI_Irecv	MPI_Wait	MPI_Waitall	MPI_Allreduce	MPI_Comm_rank
Comm phase 1	0	7	0	0	1	1
Comm phase 2	2	7	7	1	0	3
Comm phase 3	0	0	7	1	0	2
Comm phase 4	0	3	0	0	0	1
Comm phase 5	3	0	3	1	0	2

Validation

Lulesh 2.0

lulesh-comm.cc	401 : : : : [~ computation ~]	6.15ms	-	2.0
lulesh-comm.cc	401 : : : : MPI_Comm_rank(0:)	14.58us	-	1.63
lulesh-comm.cc	843 : : : : MPI_Waitall(0:)	10.26us	-	0.35
lulesh.cc	1292 : : : CommSyncPosVel()	-	-	-
lulesh-comm.cc	1310 : : : : MPI_Comm_rank(0:)	22.14us	-	0.73
lulesh-comm.cc	1332 : : : : MPI_Wait(0:)	274.73us	-	0.79
lulesh-comm.cc	1366 : : : : MPI_Wait(0:)	72.95us	-	2.46
lulesh-comm.cc	1402 : : : : MPI_Wait(0:)	23.24us	-	2.3
lulesh-comm.cc	1461 : : : : MPI_Wait(0:)	198.36us	-	1.79
lulesh-comm.cc	1475 : : : : MPI_Wait(0:)	7.83us	-	1.83
lulesh-comm.cc	1489 : : : : MPI_Wait(0:)	7.75us	-	2.08
lulesh-comm.cc	1674 : : : : MPI_Wait(0:)	333.07us	-	1.73
lulesh.cc	2656 : : : LagrangeElements()	-	-	-
lulesh.cc	2461 : : : CalcQForElems()	-	-	-
lulesh.cc	1992 : : : : CommRecv()	-	-	-
lulesh-comm.cc	101 : : : : [~ computation ~]	29.32ms	-	2.25
lulesh-comm.cc	101 : : : : MPI_Comm_rank(0:)	140.76us	-	2.25

Table: Total MPI calls

	MPI_Isend	MPI_Irecv	MPI_Wait	MPI_Waitall	MPI_Allreduce	MPI_Comm_rank
Rank 0	300	510	510	90	29	270

Table: MPI calls counts by communication phases

	MPI_Isend	MPI_Irecv	MPI_Wait	MPI_Waitall	MPI_Allreduce	MPI_Comm_rank
Comm phase 1	0	7	0	0	1	1
Comm phase 2	2	7	7	1	0	3
Comm phase 3	0	0	7	1	0	2
Comm phase 4	0	3	0	0	0	1
Comm phase 5	3	0	3	1	0	2

Validation

Lulesh 2.0

lulesh-comm.cc	101 : : : : : [~ computation ~]	29.32ms	-	2.25				
lulesh-comm.cc	101 : : : : : MPI_Comm_rank(0:)	18.76us	-	1.39				
lulesh-comm.cc	119 : : : : : MPI_Irecv(0:25)	12.61us	21.09KB	0.43				
lulesh-comm.cc	137 : : : : : MPI_Irecv(0:5)	9.23us	21.09KB	1.01				
lulesh-comm.cc	155 : : : : : MPI_Irecv(0:1)	8.79us	21.09KB	1.17				
lulesh.cc	2010 : : : : : CommSend()	-	-	-				
lulesh-comm.cc	401 : : : : : [- computation ~]	15.35ms	-	1.91				
lulesh-comm.cc	401 : : : : : MPI_Comm_rank(0:)	15.24us	-	1.52				
lulesh-comm.cc	436 : : : : : MPI_Isend(0:25)	13.14us	21.09KB	1.9				
lulesh-comm.cc	477 : : : : : MPI_Isend(0:5)	10.28us	21.09KB	1.89				
lulesh-comm.cc	518 : : : : : MPI_Isend(0:1)	10.57us	21.09KB	1.26				
lulesh-comm.cc	843 : : : : : MPI_Waitall(0:)	291.68us	-	0.45				
lulesh.cc	2014 : : : : : CommMonoQ()	-	-	-				
lulesh-comm.cc	1734 : : : : : MPI_Comm_rank(0:)	9.51us	-	0.45				
lulesh-comm.cc	1757 : : : : : MPI_Wait(0:)	8.88us	-	0.81				
lulesh-comm.cc	1793 : : : : : MPI_Wait(0:)	8.78us	-	2.04				
lulesh-comm.cc	1824 : : : : : MPI_Wait(0:)	8.53us	-	2.13				
	: END LOOP	-	-	-				

Table: Total MPI calls

	MPI_Isend	MPI_Irecv	MPI_Wait	MPI_Waitall	MPI_Allreduce	MPI_Comm_rank
Rank 0	300	510	510	90	29	270

Table: MPI calls counts by communication phases

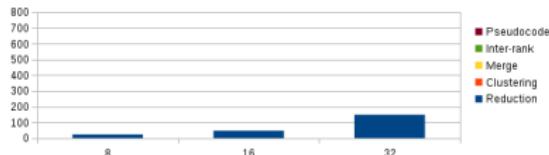
	MPI_Isend	MPI_Irecv	MPI_Wait	MPI_Waitall	MPI_Allreduce	MPI_Comm_rank
Comm phase 1	0	7	0	0	1	1
Comm phase 2	7	7	1	0	0	3
Comm phase 3	0	0	1	0	0	2
Comm phase 4	0	3	0	0	0	1
Comm phase 5	3	0	3	1	0	2

Outline

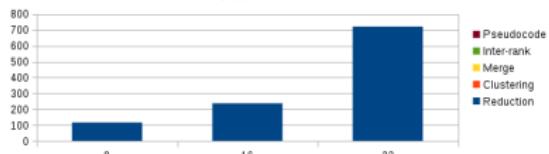
⑧ Scalability

Scalability

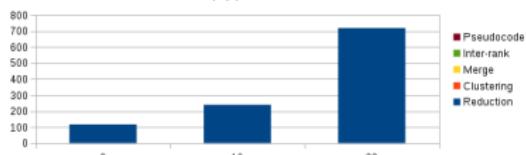
CG (A) phases breakdown



CG (B) phases breakdown

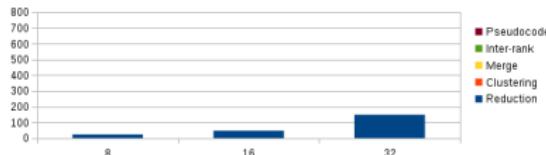


CG (C) phases breakdown

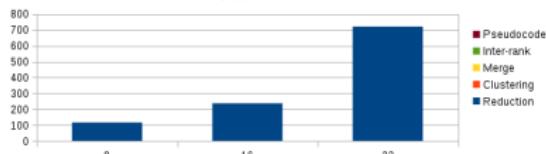


Scalability

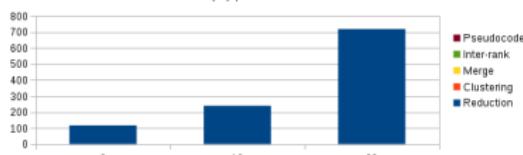
CG (A) phases breakdown



CG (B) phases breakdown



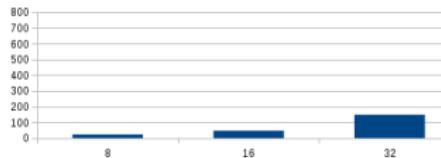
CG (C) phases breakdown



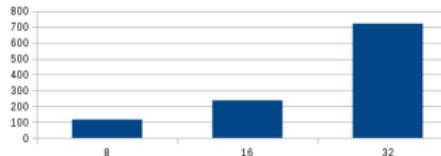
Reduction step is clearly dominating the execution time.

Scalability

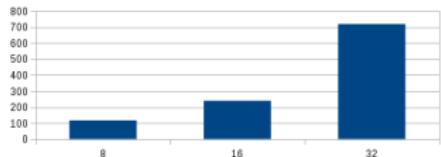
CG (A) phases breakdown



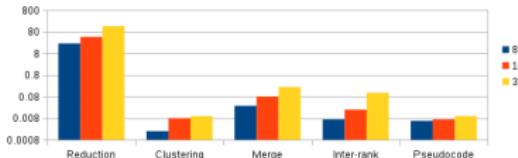
CG (B) phases breakdown



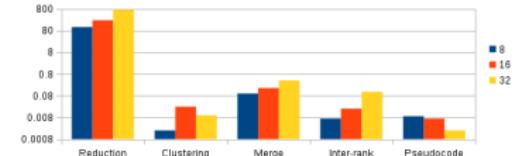
CG (C) phases breakdown



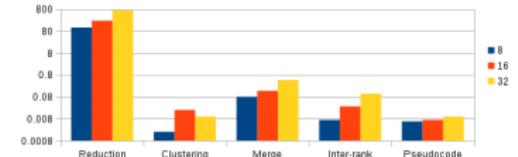
CG problem size A



CG problem size B



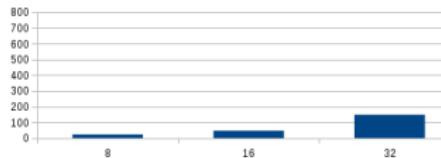
CG problem size C



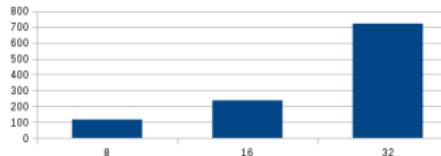
Reduction step is clearly dominating the execution time.

Scalability

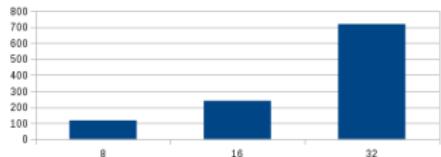
CG (A) phases breakdown



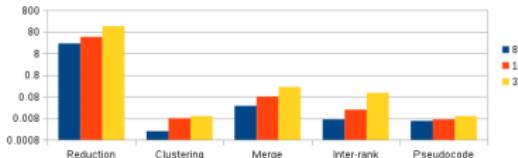
CG (B) phases breakdown



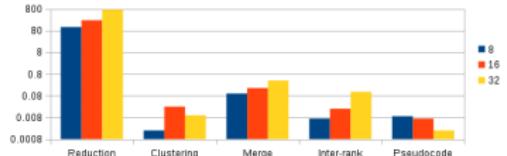
CG (C) phases breakdown



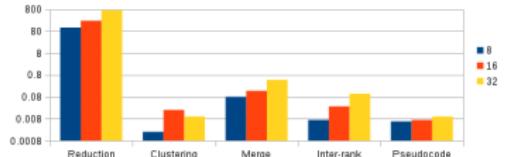
CG problem size A



CG problem size B



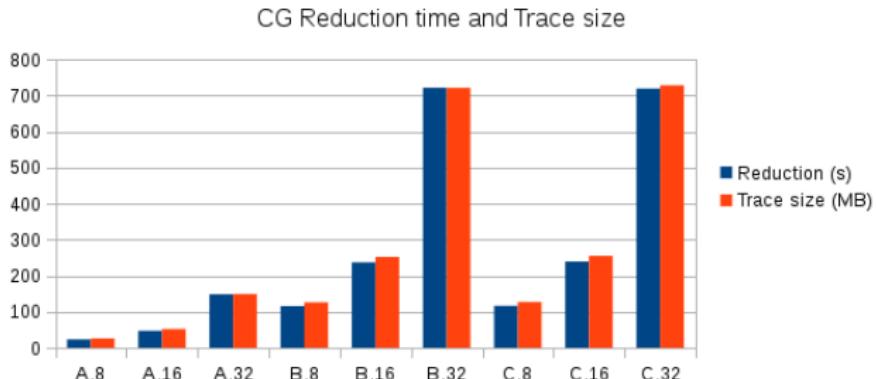
CG problem size C



Reduction step is clearly dominating the execution time.

The rest maintains its time even if increasing problem size.

Scalability



Keynote

Reduction time is highly correlated with trace size