Master thesis

Master in Research and Innovation

Inferring programs structure from an execution trace

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Presentation outline I

1. Context
   - High Performance Computing
   - Performance Analysis tools
2. State of the Art
   - Syntactic structure
3. Proposal
   - Application structure by classification
   - Workflow
4. Further considerations
   - Data analysis
   - Proposal modifiations
5. Results
   - Specific capabilities
   - Real application
6. Conclusions

Outline for section 1

High Performance Computing

- Becomes the third support of science with mathematics and theory
- Tremendous improvement in all transformation hierarchy layers

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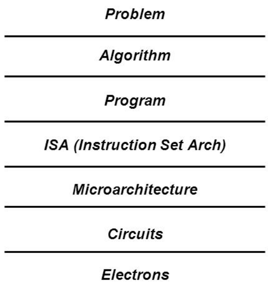

Figure: Transformation hierarchy

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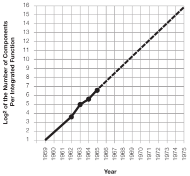

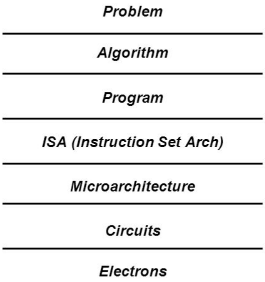

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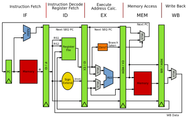

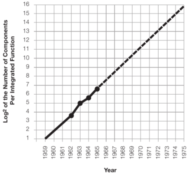

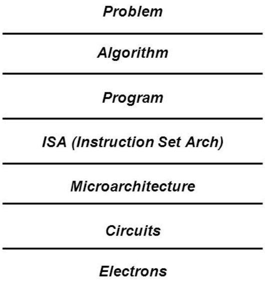

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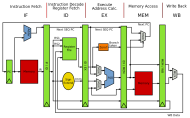

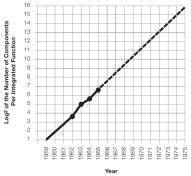

Problem

Algorithm

Program

ISA (Instruction Set Arch)

Microarchitecture

Circuits

Electrons

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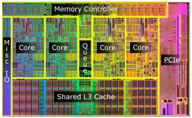

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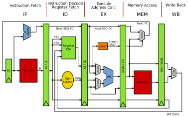

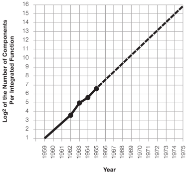

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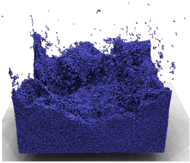

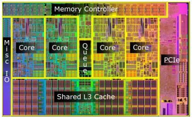

Performance Analysis tools (i)

- Focused on Program layer
- Aid to detect bottlenecks
- Is a cyclic process
    - Less iterations better
    - Depens on quality of hypothesis
    - That is strongly related with possibilities tools provides

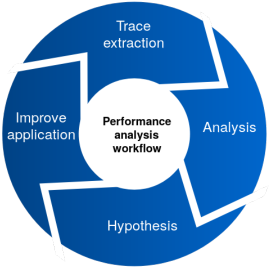

Figure: Performance analysis workflow

Performance Analysis tools (ii)

- Have been demonstrate to be valuable on detection of bottlenecks
- Demands high skilled analysts
- So developers use to delegate this work
  - **Analyst have to work with codes they are not familiar with**

Figure: Performance optimisation and Productivity project

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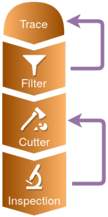
Figure: Performance optimisation and Productivity project

Motivation 1

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

Performance Analysis tools (iii)

- When dealing with big traces:
  - Visualizers responsiveness times **becomes prohibitive**
- Analysis phases is then break down into:
  1. Filter
  2. Cutter
  3. Inspection



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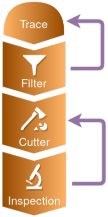

Motivation 2

Having the structure of the application will aid the process of identify regions of interest

Outline for section 2

State of the Art (i)

- On-line analysis
  - In [Noeth et al., 2009] propose structure derection for on-line trace compression
    - Rely on **detecting and aggregating patterns**
  - In [Aguilar et al., 2016] propose structure detection for on-line trace compression and visual performance analysis
    - Rely on **directed graph construction** and DFS-analysis for cycles hierarchical analysis.
- Off-line analysis
  - In [Safyallah and Sartipi, 2006] propose improving reverse engineering by structure detection analysis
    - Rely on **sequential pattern mining** techniques.
  - In [López-Cueva et al., 2012] propose to aid huge SoC traces
    - Rely on **frequent periodic pattern mining**.
  - In [Trahay et al., 2015] propose to select automatically the performance hotspots
    - Rely on **growing sequential pattern mining**.

State of the Art (ii)

- On-line analysis
  - [Noeth et al., 2009] By avoiding $O(n^2)$ they **limits pattern recognition**
  - In [Aguilar et al., 2016] **Loss temporality** when detecting hierarchical structure
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  - [Safyallah and Sartipi, 2006] [López-Cueva et al., 2012] [Trahay et al., 2015] relies on pattern mining techniques that presents **high complexity**.

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Motivation 3

Been scalable by finding out an alternative technique

Outline for section 3

Application structure by classification(i)

HPC applications idiosincracy

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

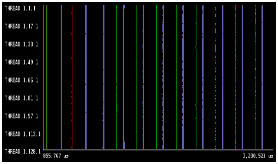
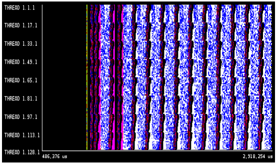


Figure: FT 128 ranks



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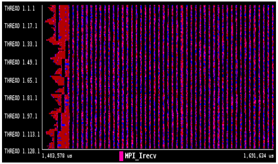

Figure: CG 128 ranks

Application structure by classification (ii)

- Instead of following the trend, different proposal
- Taking into account the characteristics of our target
- Loops can be discovered by monitoring the communications
- Stable executions implies same behaviour for all iterations in a given loop
- So...

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The key idea

Communications are used as proxies for the observation of iterations. Clustering them by its behaviour the applications structures can be betrayed.

Application structure by classification (iii)

Selected features must be able to

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

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As a starting point ...

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

Workflow

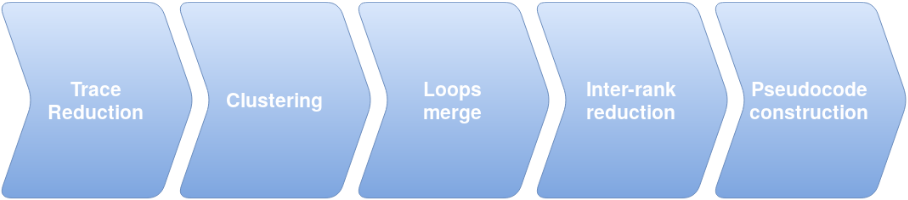

Figure: Structure detection workflow

Workflow

Trace reduction step (i)

Input Tracefile, i.e. Sequence of timestamped events ordered by time.

Output Set of unique MPI calls with attached information.

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- By **reduction** and **aggregation & derivation**
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- Every MPI call is identified by its **signature**
- Being the signature: Ordered sequence of pairs (*file*, *line*) that define the call path, i.e. The dynamic position

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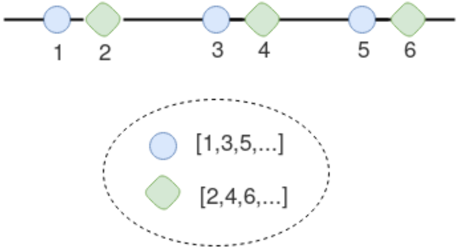


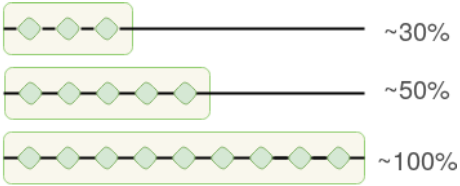
Workflow

Trace reduction step (ii)

Additionally **filter less representative MPI calls**.

- Allows to decrease even more the clustering complexity.
- Focus only on the important data.
- The criteria is whether a given threshold of “explained time” is surpased.

$$\delta(call) = \frac{it(call) * imt(call)}{T_{exe}} \tag{1}$$



Workflow

Trace reduction step (iii)

The stored information for every unique MPI call is:

- **Number of repetitions**
- **Mean time time between repetitions**
- Entire call path
- Previous burst performance information
- All timestamps
- Calculed delta

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Keynote

HPC applications are strongly repetitive over time so number of unique MPI calls will remain despite the increasing problem size.

Workflow

Clustering

Input Set of unique MPI calls with attached information.
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- In a bidimentional space defined by
  - Number of repetitions
  - Mean time between repetitions
- Resulting clusters **will be considered loops**.
  - Since MPI calls acts as proxies
  - Number of repetitions $\rightarrow$ Number of iterations.
  - Mean time between repetitions $\rightarrow$ Mean iterations time.

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Loops merge (i)

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

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- Isolated loops are just **pieces of the overall puzzle**.
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Some clues

- Outer loop will have **more iterations** then nested one.
- Outer loop will spend **more time** for per iteration.
- Outer loop will **explain the same amount of time** as inner loop.

Workflow

Loops merge (ii)

comment: Short initialization

for 1 to 10

$$\textbf{do} \begin{cases} \textbf{for } 1 \text{ to } 2 \\ \quad \textbf{do} \begin{cases} \textbf{for } 1 \text{ to } 2 \\ \quad \textbf{do} \left\{ someComms() \right. \\ \text{MPI\_Call} \end{cases} \\ \text{MPI\_Call} \end{cases}$$

comment: Body of execution

for 1 to 100

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    for 1 to 2
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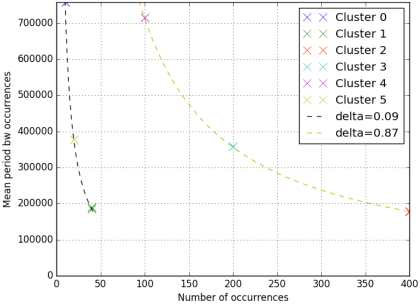

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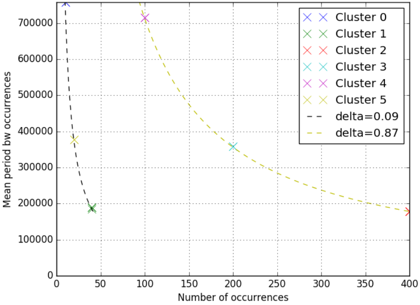

Keynote

Different phases can be detected by this way and used for the loops merging.

Workflow

Loops merge (iii)

$$\textbf{for } 1 \text{ to } 10 \\ \quad \textbf{do } \begin{cases} \textbf{for } 1 \text{ to } 5 \\ \quad \textbf{do } \left\{ someComms() \right. \\ \textbf{for } 1 \text{ to } 10 \\ \quad \textbf{do } \left\{ someComms() \right. \\ \text{MPI\_Call} \end{cases}$$

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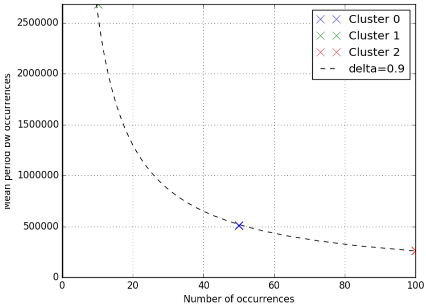

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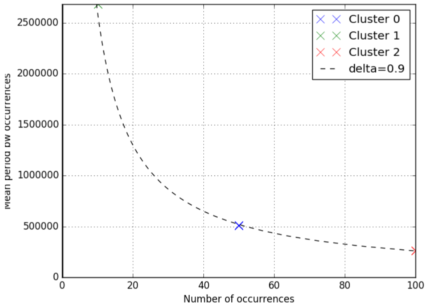

Warning

Not all loops that fulfills with nested loops conditions, are nested loops. Extra check is needed.

Workflow

Loops merge (iv)

- Classify MPI clusters/Loops ($\upsilon \in \Upsilon$) per "how much of execution represents" ($\delta \in \Delta$)[1].
- For every phase (δ) sort loops (υ) by number of iterations.
- Perform the loop merge **from high to low iterations count**.
- Before every merge, **check out** whether the hierarchical relationship is true.

$$
\begin{array}{l}
\Delta \leftarrow deltaClassification(\Upsilon) \\
\textbf{for all } \delta \in \Delta \\
\quad \textbf{do} \begin{cases}
\textbf{comment:} \text{ Sort by it}(\upsilon) \text{ desc} \\
sort(\upsilon \in \delta) \\
\textbf{for } i \in [0, |\delta| - 1) \\
\quad \textbf{do} \begin{cases}
\textbf{for } j \in [i+1, |\delta|) \\
\quad \textbf{do} \begin{cases}
\textbf{if } isSubloop(\upsilon_i, \upsilon j) \\
\quad \textbf{then } \upsilon_i \mapsto \upsilon_j
\end{cases}
\end{cases}
\end{cases}
\end{array}
$$

[1] Do not confuse with $\delta()$ function.

Workflow

Inter-rank reduction (i)

Input Set of top level loops.
Output Set of top level loops with rank conditional structures.

[2] Single Program Multiple Data

Workflow

Inter-rank reduction (i)

Input Set of top level loops.
Output Set of top level loops with rank conditional structures.

- Two calls with **same call paths still coexist** if belongs to different MPI ranks.
  - **Conservative** reduction step! If assuming SPMD[2] applications.
- Divergences between MPI ranks are understood as **conditional structures in code**.
- This step is about:
  1. MPI Calls/Subloops ordenation
  2. Reduction
  3. Arrangement in conditional blocks

[2] Single Program Multiple Data

Workflow

Inter-rank reduction (ii)

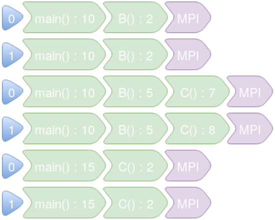

Figure: Ordenation

Workflow

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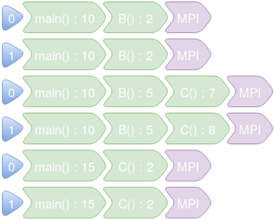

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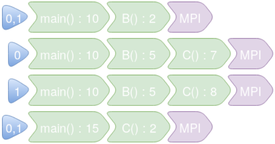

Figure: Reduction

Workflow

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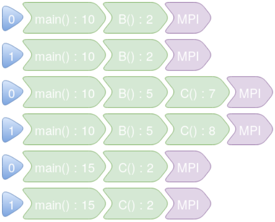

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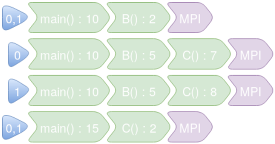

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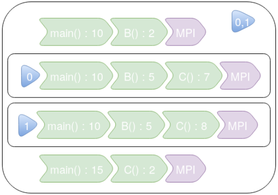

Figure: Conditional blocks

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Pseudocode construction (i)

Input Set of top level loops with rank conditional structures.
Output Pseudocode representing the actual application structure.

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- Straightforward construction
- For bettern understanding **repetitive information from call paths is removed**.
  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

$$\textbf{for } 1 \text{ to } N \quad \textbf{do} \begin{cases} a:1 \rightarrow b:1 \rightarrow mpi \\ a:1 \rightarrow b:1 \rightarrow mpi \\ a:1 \rightarrow b:2 \rightarrow mpi \\ a:1 \rightarrow b:2 \rightarrow mpi \end{cases}$$

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$$a:1 \to \quad \textbf{for } 1 \text{ to } N \quad \textbf{do} \begin{cases} b:1 \to mpi \\ b:1 \to mpi \\ b:2 \to mpi \\ b:2 \to mpi \end{cases}$$

Figure: After extract common call path

Workflow

Pseudocode construction (i)

Input Set of top level loops with rank conditional structures.

Output Pseudocode representing the actual application structure.

- Straightforward construction
- For bettern understanding **repetitive information from call paths is removed**.
  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

$$\textbf{for } 1 \text{ to } N \quad \textbf{do} \begin{cases} a:1 \rightarrow b:1 \rightarrow mpi \\ a:1 \rightarrow b:1 \rightarrow mpi \\ a:1 \rightarrow b:2 \rightarrow mpi \\ a:1 \rightarrow b:2 \rightarrow mpi \end{cases}$$

Figure: Raw pseudocode

$$a:1 \rightarrow \quad \textbf{for } 1 \text{ to } N \quad \textbf{do} \begin{cases} b:1 \rightarrow mpi \\ b:1 \rightarrow mpi \\ b:2 \rightarrow mpi \\ b:2 \rightarrow mpi \end{cases}$$

Figure: After extract common call path

$$\textbf{for } 1 \text{ to } N \quad \textbf{do} \begin{cases} b:1 \\ \rightarrow mpi \\ \rightarrow mpi \\ b:2 \\ \rightarrow mpi \\ \rightarrow mpi \end{cases}$$

Figure: After extract contiguous call path

Workflow

Pseudocode construction (ii)

FILE	LINE	PSEUDOCODE	E(TIME)	E(SIZE)	E(IPC)
	0	main()	-	-	-
		: FOR 1 TO 10 [id=2.0]	-	-	-
		: : FOR 1 TO 2.0 [id=0.0]	-	-	-
test-2.c	42	: : : CommSend()	-	-	-
		: : : : IF rank in [1]	-	-	-
test-2.c	14	: : : : : MPI_Send(1:0)	6.37us	4.0B	0.69
test-2.c	16	: : : : : MPI_Recv(1:1)	8.47us	4.0B	0.33
test-2.c	44	: : : CommRecv()	-	-	-
		: : : : IF rank in [0]	-	-	-
test-2.c	25	: : : : : MPI_Recv()	88.21us	-	0.7
test-2.c	26	: : : : : MPI_Send(0:1)	6.82us	4.0B	0.77
		: : END LOOP	-	-	-
		: : FOR 1 TO 5.0 [id=1.0]	-	-	-
test-2.c	49	: : : CommSend()	-	-	-
		: : : : IF rank in [1]	-	-	-
test-2.c	14	: : : : : MPI_Send(1:0)	6.08us	4.0B	0.82
test-2.c	16	: : : : : MPI_Recv(1:1)	8.54us	4.0B	0.3
test-2.c	51	: : : CommRecv()	-	-	-
		: : : : IF rank in [0]	-	-	-
test-2.c	25	: : : : : MPI_Recv()	168.88us	-	0.86
test-2.c	26	: : : : : MPI_Send(0:1)	6.27us	4.0B	0.79
		: : END LOOP	-	-	-
test-2.c	53	: : MPI_Barrier(CommId:1.0)	97.72us	-	0.44
		: END LOOP	-	-	-

Figure: Example console output

Workflow

Pseudocode construction (ii)

FILE	LINE	PSEUDOCODE	E(TIME)	E(SIZE)	E(IPC)
	0	main()	-	-	-
		: FOR 1 TO 10 [id=2.0]	-	-	-
		: : FOR 1 TO 2.0 [id=0.0]	-	-	-
test-2.c	42	: : : CommSend()	-	-	-
		: : : : IF rank in [1]	-	-	-
test-2.c	14	: : : : : MPI_Send(1:0)	6.37us	4.0B	0.69
test-2.c	16	: : : : : MPI_Recv(1:1)	8.47us	4.0B	0.33
test-2.c	44	: : : CommRecv()	-	-	-
		: : : : IF rank in [0]	-	-	-
test-2.c	25	: : : : : MPI_Recv()	88.21us	-	0.7
test-2.c	26	: : : : : MPI_Send(0:1)	6.82us	4.0B	0.77
		: : END LOOP	-	-	-
		: : FOR 1 TO 5.0 [id=1.0]	-	-	-
test-2.c	49	: : : CommSend()	-	-	-
		: : : : IF rank in [1]	-	-	-
test-2.c	14	: : : : : MPI_Send(1:0)	6.08us	4.0B	0.82
test-2.c	16	: : : : : MPI_Recv(1:1)	8.54us	4.0B	0.3
test-2.c	51	: : : CommRecv()	-	-	-
		: : : : IF rank in [0]	-	-	-
test-2.c	25	: : : : : MPI_Recv()	168.88us	-	0.86
test-2.c	26	: : : : : MPI_Send(0:1)	6.27us	4.0B	0.79
		: : END LOOP	-	-	-
test-2.c	53	: : MPI_Barrier(CommId:1.0)	97.72us	-	0.44
		: END LOOP	-	-	-

Figure: Example console output

- Additionally an **interactive shell** is provided to the user allowing...
  1. Show cpu burst metrics over a given thresshold.
  2. Filter by MPI rank.
  3. Show clustering plot.
  4. ...

Outline for section 4

Further considerations

Until now were not aware **the problems can arise from clustering step**. But there are some:

1. **Cluster aliasing** when two different loops behaves similarly enough over our defined space
2. **Cluster split** when MPI calls belonging to the same loop behaves in a different way.

Further considerations

Until now were not aware **the problems can arise from clustering step**. But there are some:

1. **Cluster aliasing** when two different loops behaves similarly enough over our defined space
2. **Cluster split** when MPI calls belonging to the same loop behaves in a different way.

$$\textbf{for } 1 \text{ to } 2 \quad \textbf{do} \begin{cases} \textbf{for } 1 \text{ to } 2 \\ \quad \textbf{do} \begin{cases} MPI\_A() \\ MPI\_B() \end{cases} \\ \textbf{for } 1 \text{ to } 2 \\ \quad \textbf{do} \begin{cases} MPI\_C() \\ MPI\_D() \end{cases} \end{cases}$$

Figure: Cluster aliasing example

$$\textbf{for } i = 1 \text{ to } 10 \quad \textbf{do} \begin{cases} \textbf{if } isPair(i) \\ \quad \textbf{then } MPI\_A() \\ MPI\_B() \\ MPI\_C() \end{cases}$$

Figure: Cluster split example

Outline for section 5

Hola manola

Hola manola

Outline for section 6

Hola manola

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