Design of Data Management for Multi SPMD Workflow Programming Model

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Motivation

Multi SPMD for large scale computing

Why Multi SPMD

- Flat MPI reaches a limit
- Simulation code may consists in several parallel programs
- Each SPMD is an independant program $\rightarrow$ component approach,reusability

Programming environment

- Dominant execution model approach: MPI + X
- Coupling between models and apps involves I/O
- **Proposed approach for 2-level programming model**
  - Workflow programing with task dependencies
  - Single Program Multiple Data at the fine layer
  - Separation of data and computation
- **Programing environment YML-XMP**
  - XMP is a PGAS language`http://www.xcalablemp.org`
  - YML: graph of task, each task is described by a component, `http://www.yml.prism.uvsq.fr`

Multi SPMD model

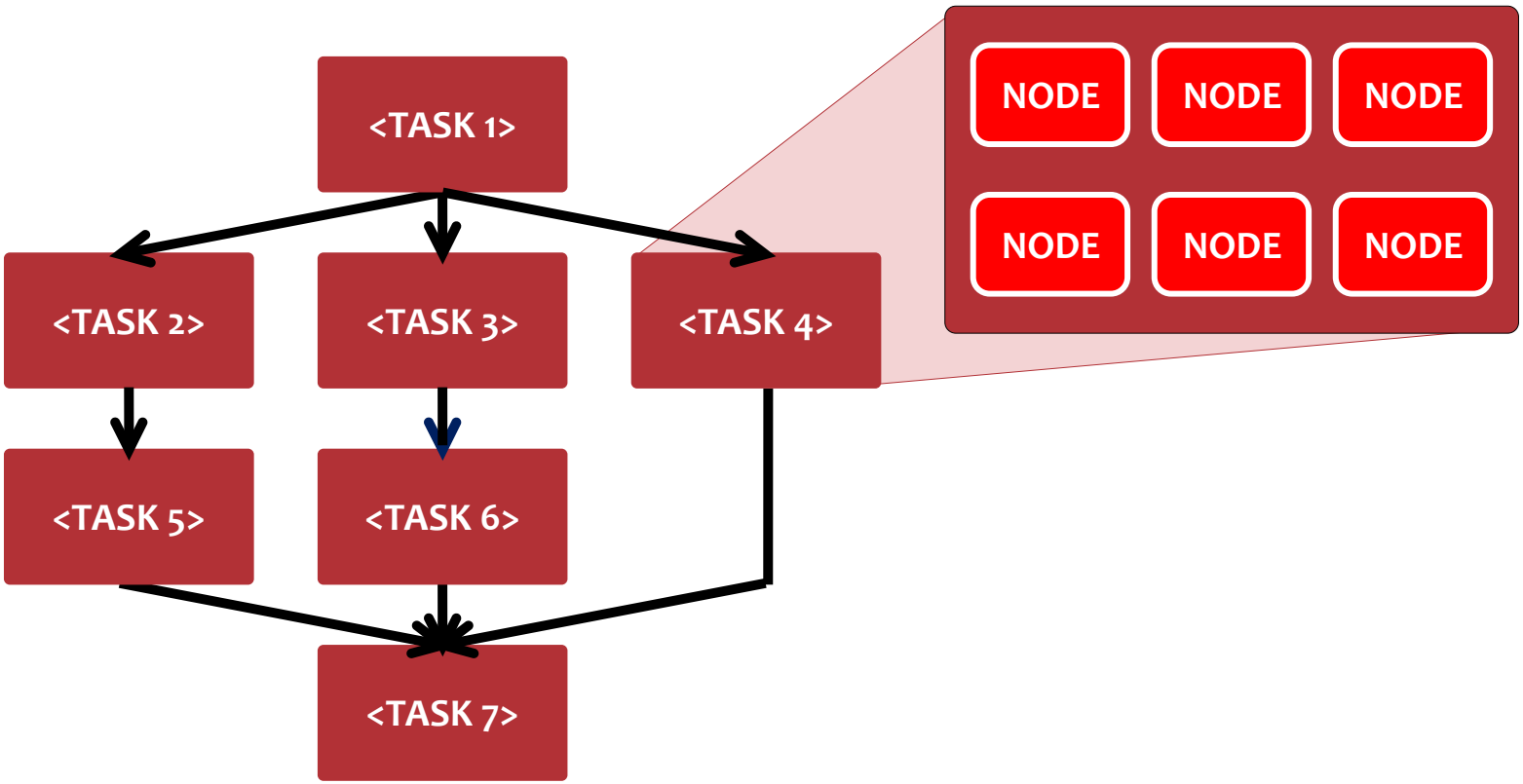


Figure: Multi SPMD - Graph of task (YML) task following SPMD model on distributed nodes (XMP)

I/O based data exchange

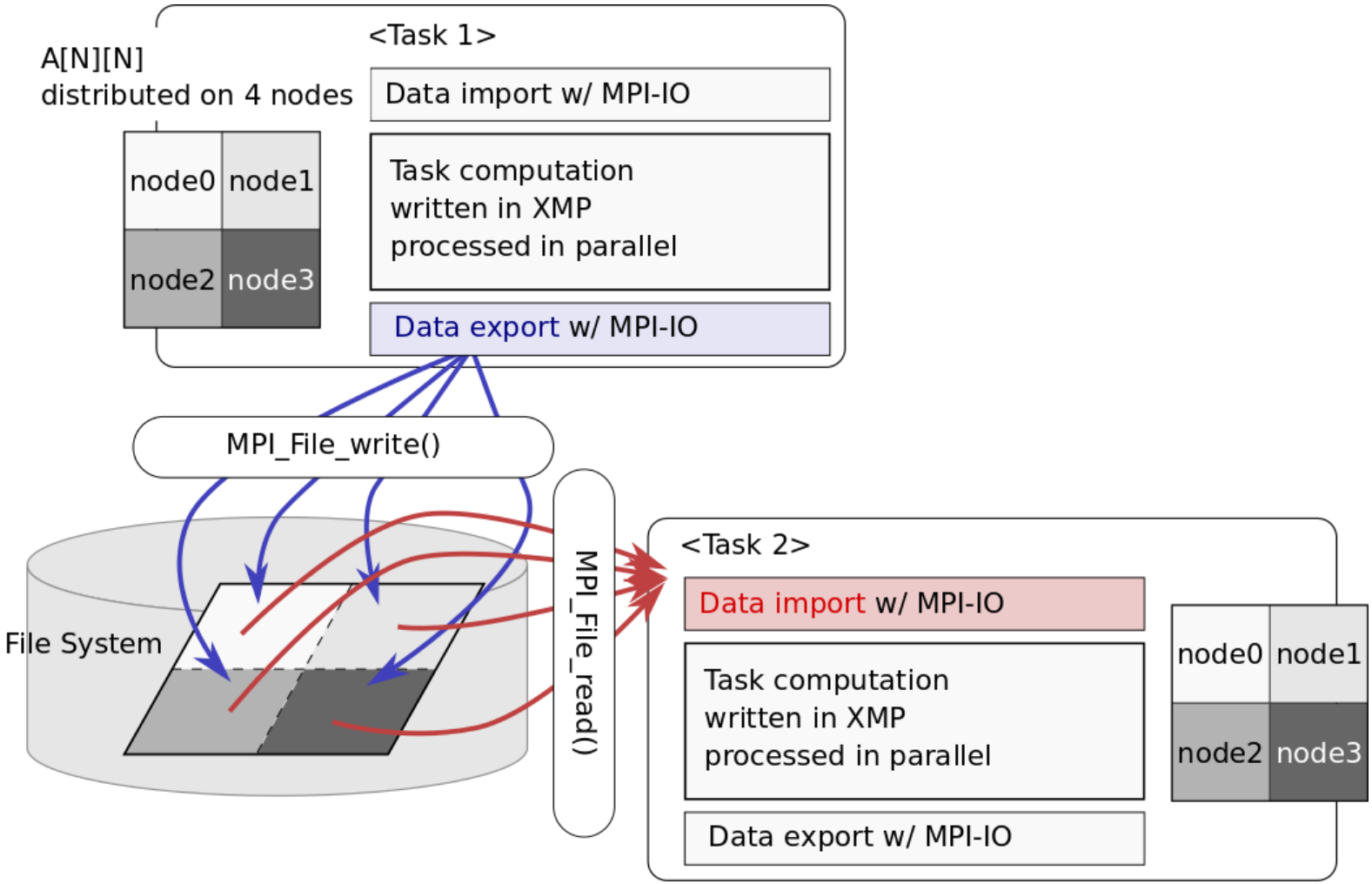


Figure: Import export based on I/O in YML-XMP

Data exchange issues and model

Data exchange for Multi SPMD

Context

- Parallel programming model on each level ?
- Separation of data and computation ?
- Data placement and dependencies ?
- Data persistency ?

Choices

- **Graph of tasks** on the higher level
- **SPMD** at the fine level
- Component approach at the higher level (large parallel tasks)
- Intensive data access and Persistency of certain data for fault tolerance

System quality

Assumption

- Data repository $\rightarrow$ store a global data, separate from computation
- High level $\rightarrow$ Global data (To be Imported/Exported)
- Low level $\rightarrow$ Group of local data
- Import/Export are synchronous

Quality

- High performance in case of intense computation
- Fault tolerance, persistency of important data

Key point of the system

Main design

- **Detection of data distribution** (Given by execution model)
- **Performance** of communication according to **data distribution**...
- ... and **architecture and middleware**
- adapt strategy at runtime(considering size of data and distribution)
- earn benefit of both dataflow and workflow knowledge (Drawing our inspiration from **M. Hugues *et. al.* ASIODS 2011**)
  - consider a **task scheduler and a data scheduler**
  - **interaction** between schedulers for optimization
  - $\Rightarrow$ **anticipate data migration, remapping of parallel data**

Remarks

- Component approach + ability to get information from interfaces
- $\Rightarrow$ enable integration of automatic decision tools

Target system

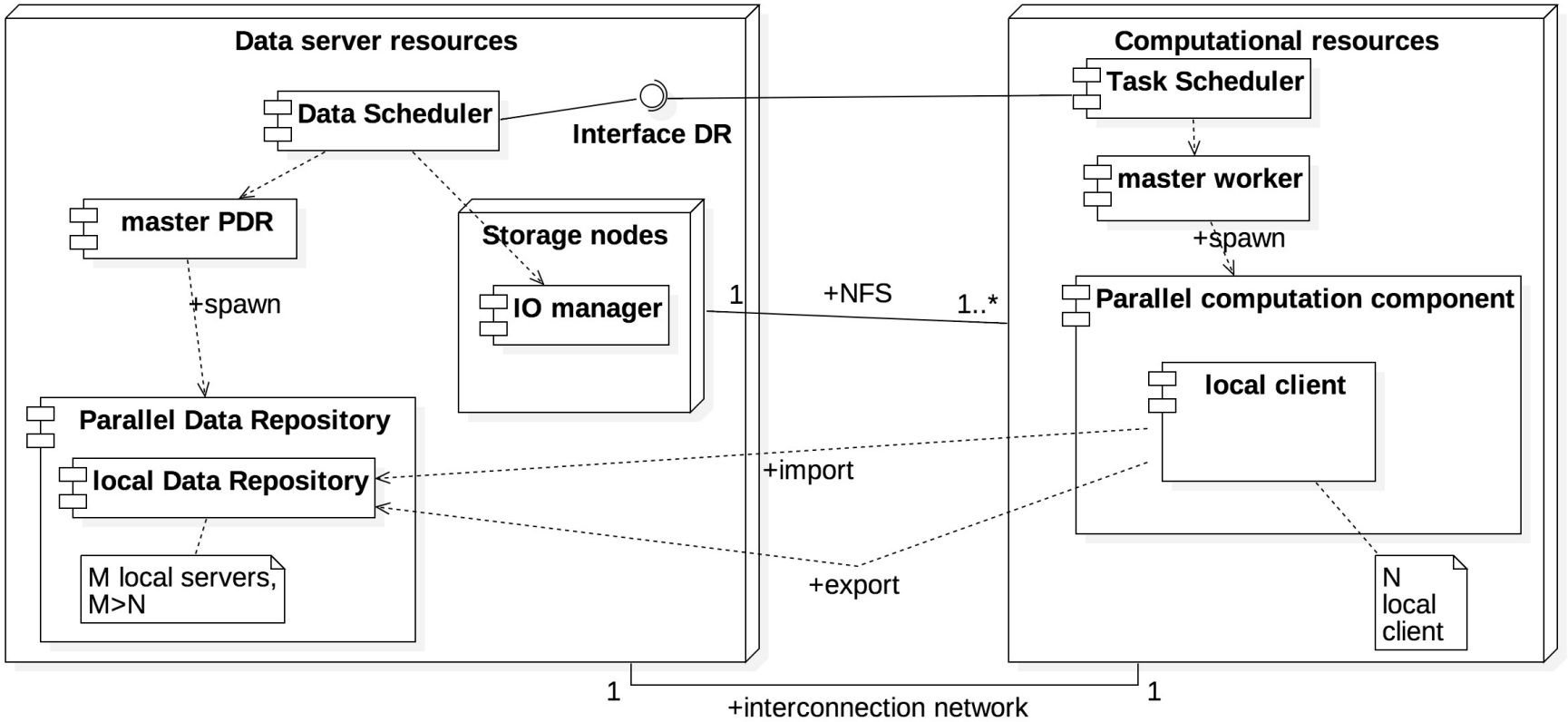


Figure: Target system

Implementation through YML user interface

First step implementation enable by YML front end

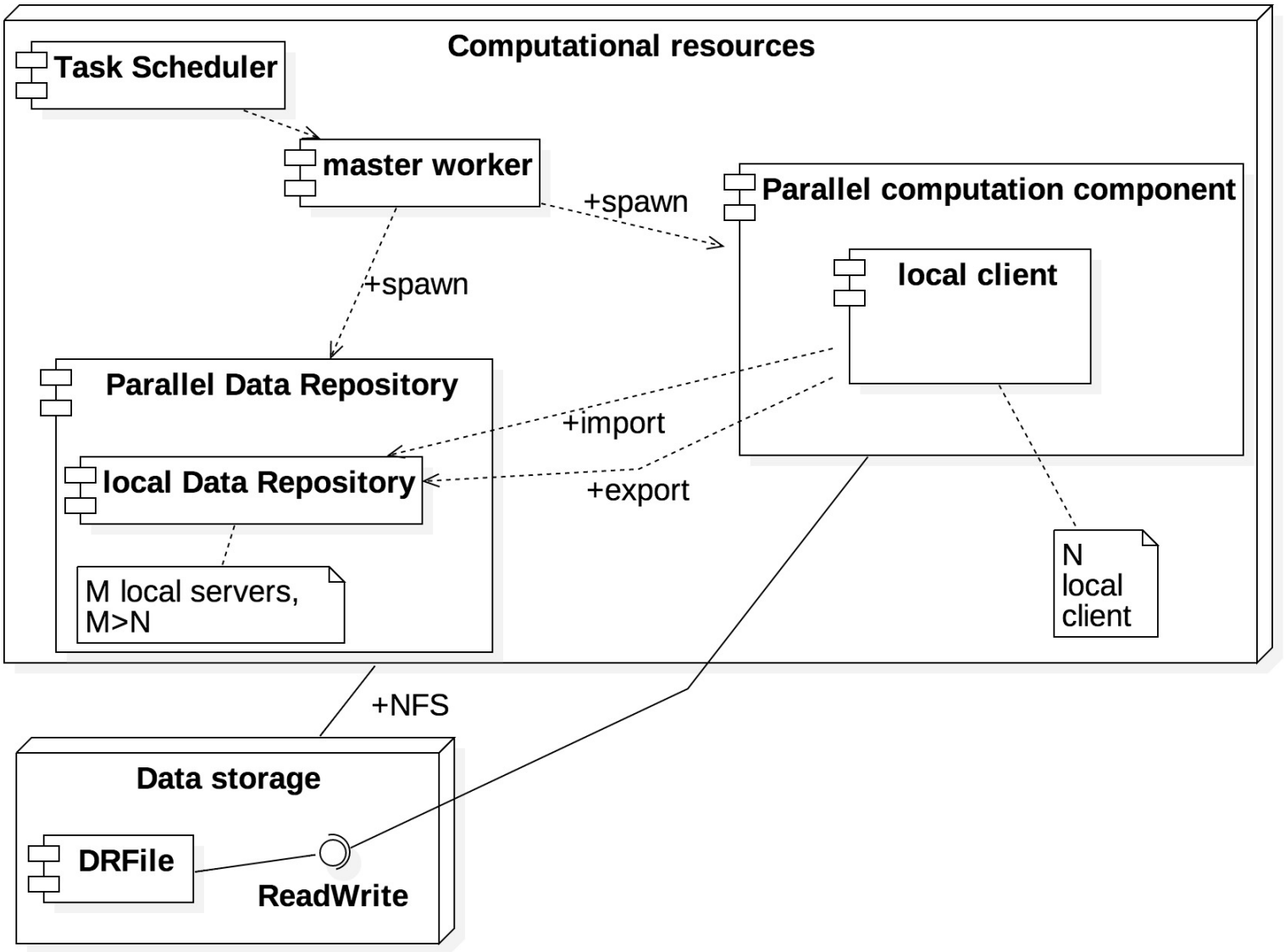


Figure: Integrate new data management through YML front end

I/O based data exchange

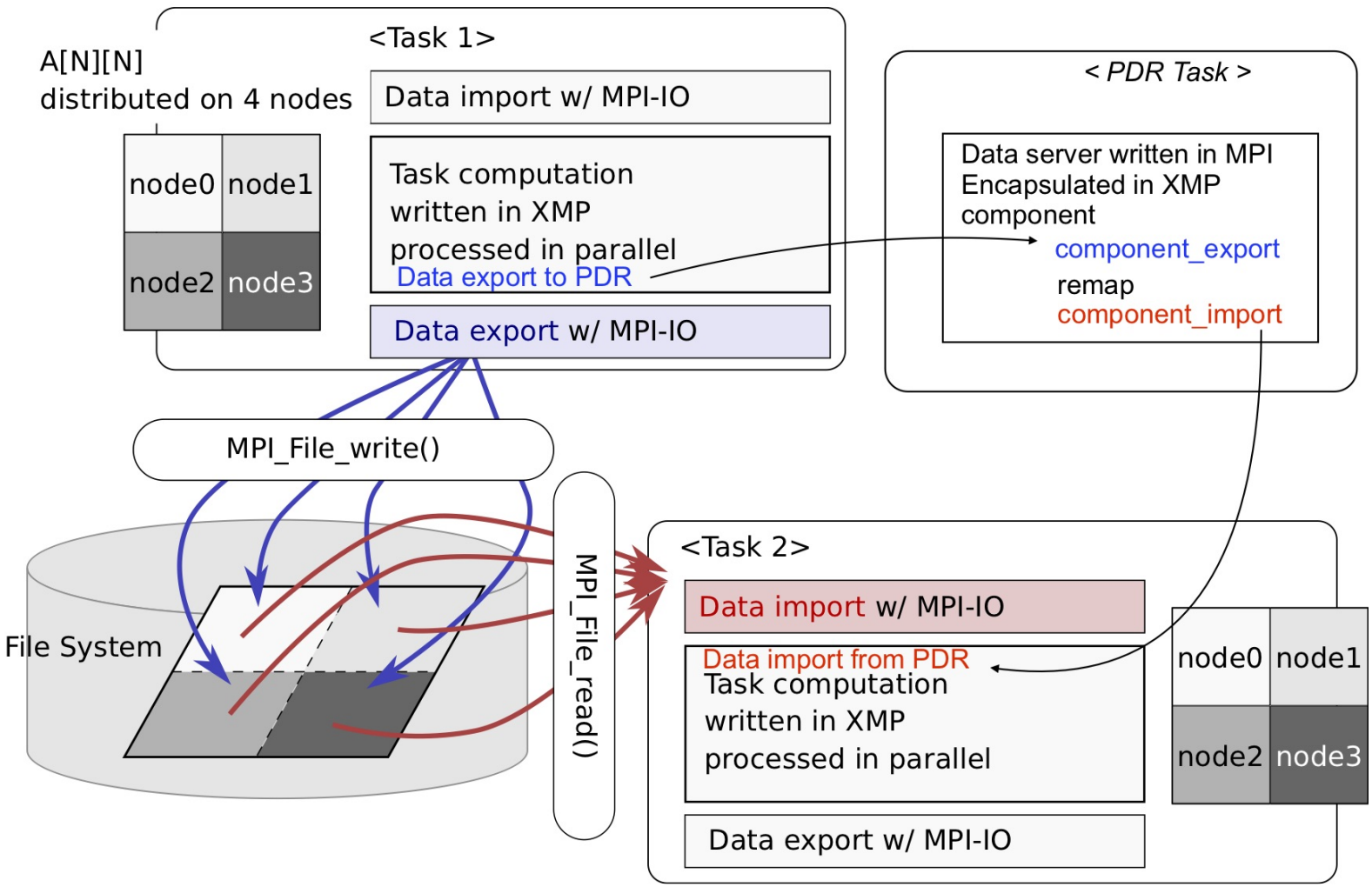


Figure: Import export with 2 strategies in YML-XMP

Integration of new PDR

```
par
  # ALLOCATE DATA IN PDR
  par(i:=0;blockcount-1)(j:=0;
       blockcount-1)
  do
    ij:=i*n+j; tidA[ij]:=0; tidB[ij]:
         =1;
    par
      compute allocateInPdr(ij,tidA[ij
           ],count);
    //
      compute allocateInPdr(ij,tidB[ij
           ],count);
    endpar
    notify(begin[ij]);
  enddo
//
  # RUN PARALLEL DATA REPOSITORY
  par(i:=0;blockcount-1)(j:=0;
       blockcount-1)
  do
    ij:=i*n+j; tidA[ij]:=0; tidB[ij]:
         =1;
    par
      compute pdr(ij,tidA[ij]);
    //
      compute pdr(ij,tidB[ij]);
    endpar
  enddo
//
  # ALGORITHM
  notify(end);
//
  # STOP PARALLEL DATA REPOSITORY
  wait(end);
  par(i:=0;blockcount-1)(j:=0;
       blockcount-1)
  do
    ij:=i*n+j;
    par
      compute stopPdr(ij,idA[ij]);
    //
      compute stopPdr(ij,idB[ij]);
    endpar
  enddo
endpar
```

Performance of our model implementation

Platform

- 92 nodes IBM cluster (iDataPlex dx360 M4 servers)
- 2 CPU Sandy Bridge E5-2670 (2.60GHz)
  - 8 cores per CPU / 16 cores per node
  - 32 GB RAM per node

Key points of evaluation

- (I) Import export by **one XMP task increasing load**
- (II) **Weak scaling** in case of one XMP task
- (III) **Multiple accesses** (N XMP tasks one PDR)

Performance of our model implementation I

Performance for Import/Export a real matrix

- $nt \times nt$ XMP matrix on 16 XMP nodes (**Fix number of MPI process**)
- D0: Current YML-XMP implementation using MPI-IO
- D3: No I/O, use MPI_Comm_connect (etc.) and MPI_Send / MPI_Recv
- 10 import/export

Local size	10×10	100×100	500×500	1000×1000
Design 0	0.10 s	0.18 s	0.87 s	2.98 s
Design 3	1.09 s	0.94 s	1.08 s	1.26 s

Table: 1 client of 16 XMP nodes : Time to perform 10 import/export, **Design 3 bounded by connection time**

Performance of our model implementation II

Weak scaling

- $nt \times nt$ XMP matrix
- D0: Current YML-XMP implementation using MPI-IO
- D3: No I/O, use MPI_Comm_connect (etc.) and MPI_Send / MPI_Recv
- **Increase XMP nodes**
- 100 import/export

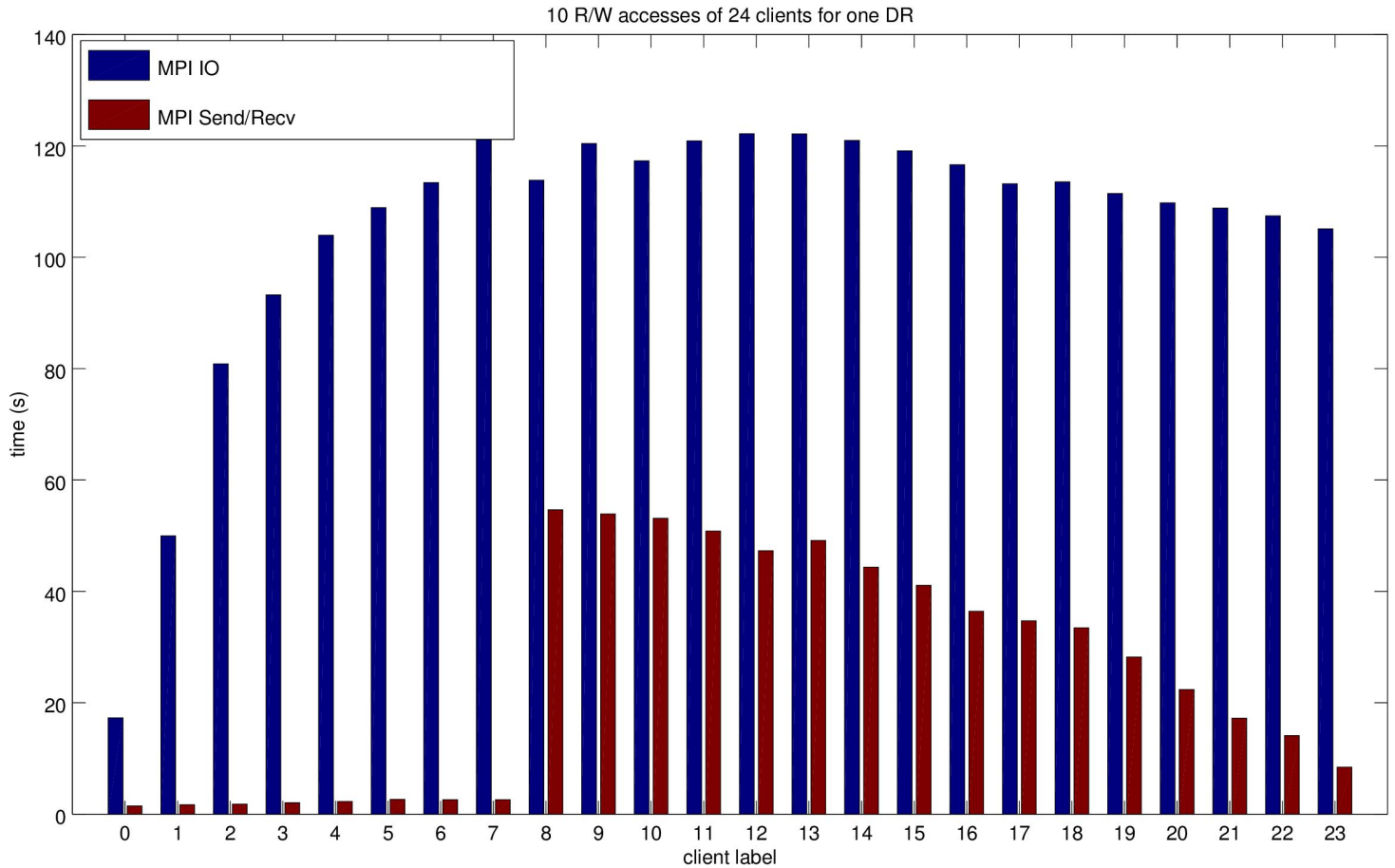
XMP grid size	4×4	5×5	6×6	7×7
Design 0	44.68 s	69.61 s	263.61 s	268.45 s
Design 3	17.8 s	21 s	20 s	22.3 s

Table: **Weak scaling**, increasing the grid size, with local array of size 1000×1000 : Time to perform 100 import/export

Performance of our model implementation III

Multiple accesses

- $nt \times nt$ XMP matrix on 16 XMP nodes
- **One Data Repository Multiple Task R/W**



Performance of our model implementation III (2)

Multiple accesses

- $nt \times nt$ XMP matrix on 16 XMP nodes
- **One Data Repository Multiple Task R/W**

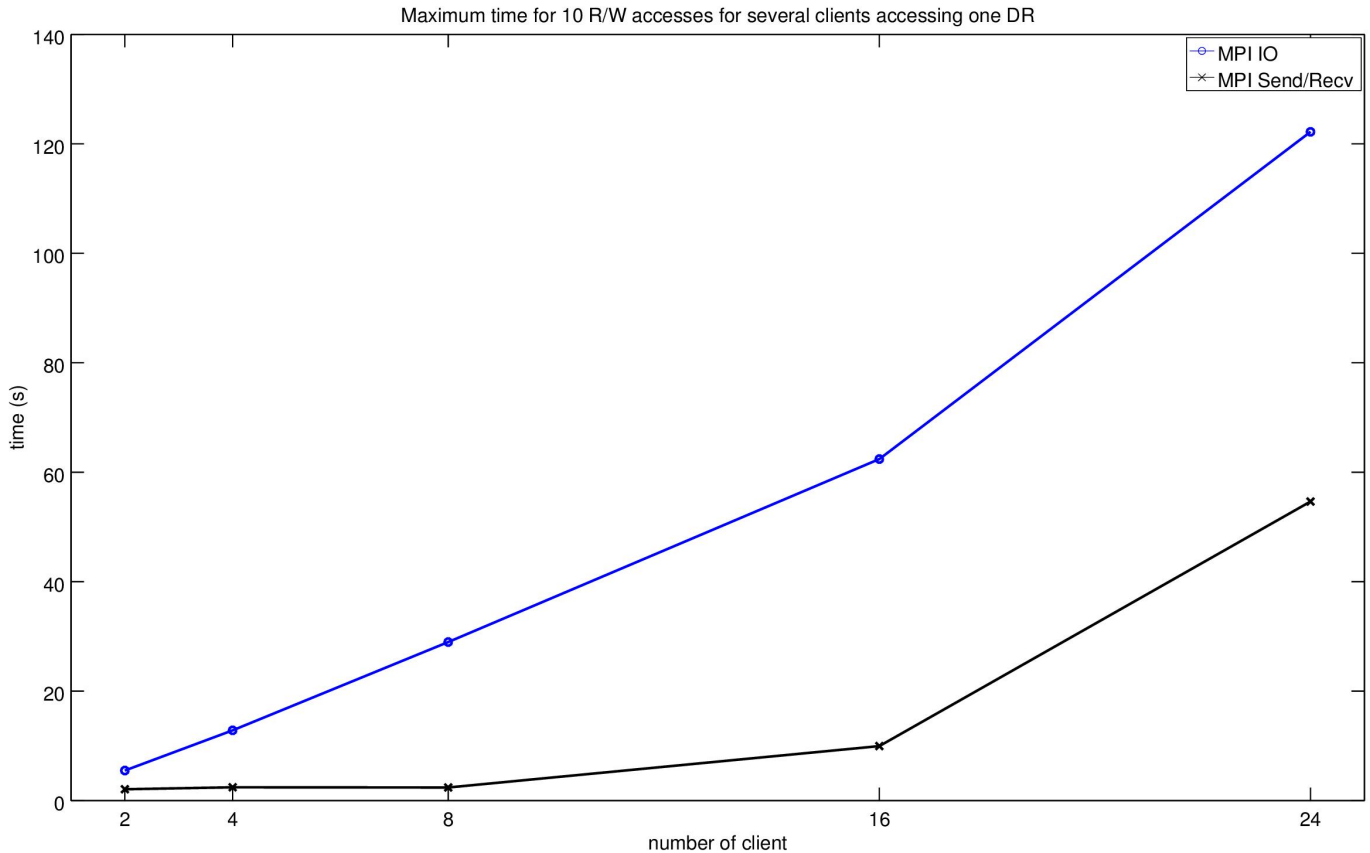


Figure: Maximum time in case **multiple accesses to one data repository.**

Development of Block Gauss-Jordan Algorithm

The Block Gauss Jordan Algorithm

Algorithm 1 The block-based Gauss-Jordan matrix inversion

Input: A (partitioned into $p \times p$ blocks)
Output: $B = A^{-1}$

For $k = 0$ to $p-1$
  1 $B_{kk} = A^{-1}{}_{kk}$
  For $i = k+1$ to $p-1$
    2 $A_{ki} = B_{kk} \times A_{ki}$
  End For
  For $i = 0$ to $p-1$
    If $(i \neq k)$
      2 $B_{ik} = -A_{ik} \times B_{kk}$
    End If
    If $(i < k)$
      2 $B_{ki} = B_{kk} \times B_{ki}$
    End If
  End For
  For $i = 0$ to $p-1$
    If $(i \neq k)$
      For $j = k+1$ to $p-1$
        3 $A_{ij} = A_{ij} - A_{ik} \times A_{kj}$
      End For
      For $j = 0$ to $k-1$
        3 $B_{ij} = B_{ij} - A_{ik} \times B_{kj}$
      End For
    End If
  End For
End For

```
par(k:=0;blockcount-1)
do
  par
    #inversion
    if (k neq 0) then
      wait(prodDiffA[k][k][k-1]);
    endif
1   compute XMP_inversion(A[k][k],B[k][k]);
    notify(bInversed[k][k]);
//
    if (k neq blockcount-1) then
      par (i:=k+1; blockcount-1)
      do
        wait(bInversed[k][k]);
2       compute XMP_prodMat(B[k][k],A[k][i]);
        notify(prodA[k][i]);
      enddo
    endif
//
    wait(bInversed[k][k]);
    par(i:=0;blockcount-1)
    do
      if(i neq k) then
        compute XMP_mProdMat(A[i][k],B[k][k],B[i][k]);
2       notify(mProdB[k][i][k]);
      endif
      if(k gt i) then
2       compute XMP_prodMat(B[k][k],B[k][i]);
        notify(prodB[k][i]);
      endif
    enddo
//
    par(i:= 0;blockcount-1)
    do
      if (i neq k) then
        if (k neq blockcount - 1) then
          par (j:=k + 1;blockcount - 1)
          do
            wait(prodA[k][j]);
            compute XMP_prodDiff(A[i][k],A[k][j],A[i][j]);
3           notify(prodDiffA[i][j][k]);
          enddo
        endif
        if (k neq 0) then
          par(j:=0;k - 1)
          do
            wait(prodB[k][j]);
3           compute XMP_prodDiff(A[i][k],B[k][j],B[i][j]);

          enddo
        endif
      endif
    enddo
endpar
enddo
```

Figure: "As you write" implementation: 1. **Pivot**, 2. **Update row and column**, 3. **Update A and B**
Algorithm from **M. Hugues, S. Petiton,** A Matrix Inversion Method with YML/OmniRPC on a Large Scale Platform, **VECPAR 2008**

Illustration of BGJ steps

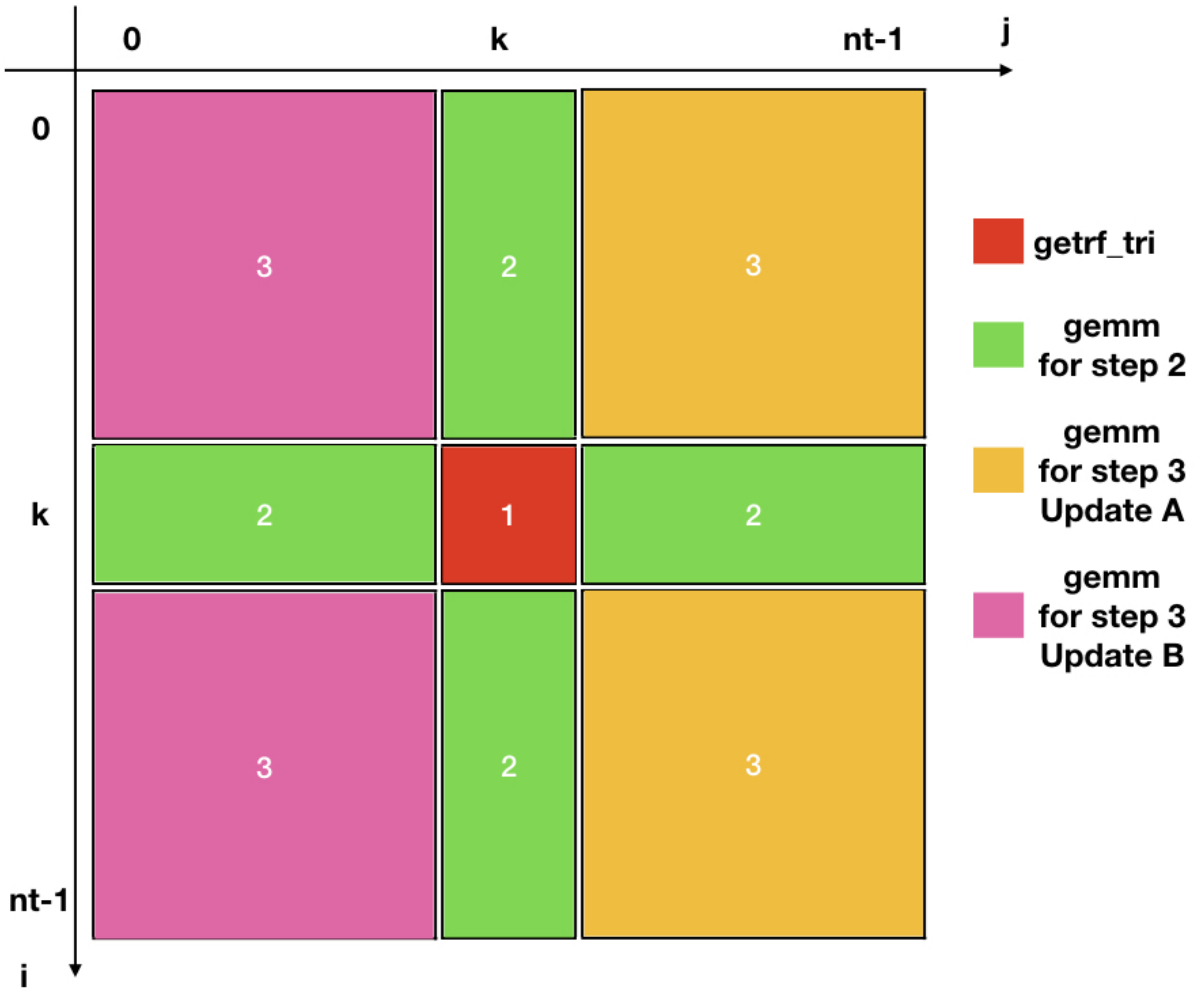


Figure: Illustration of one BGJ step

Large block size

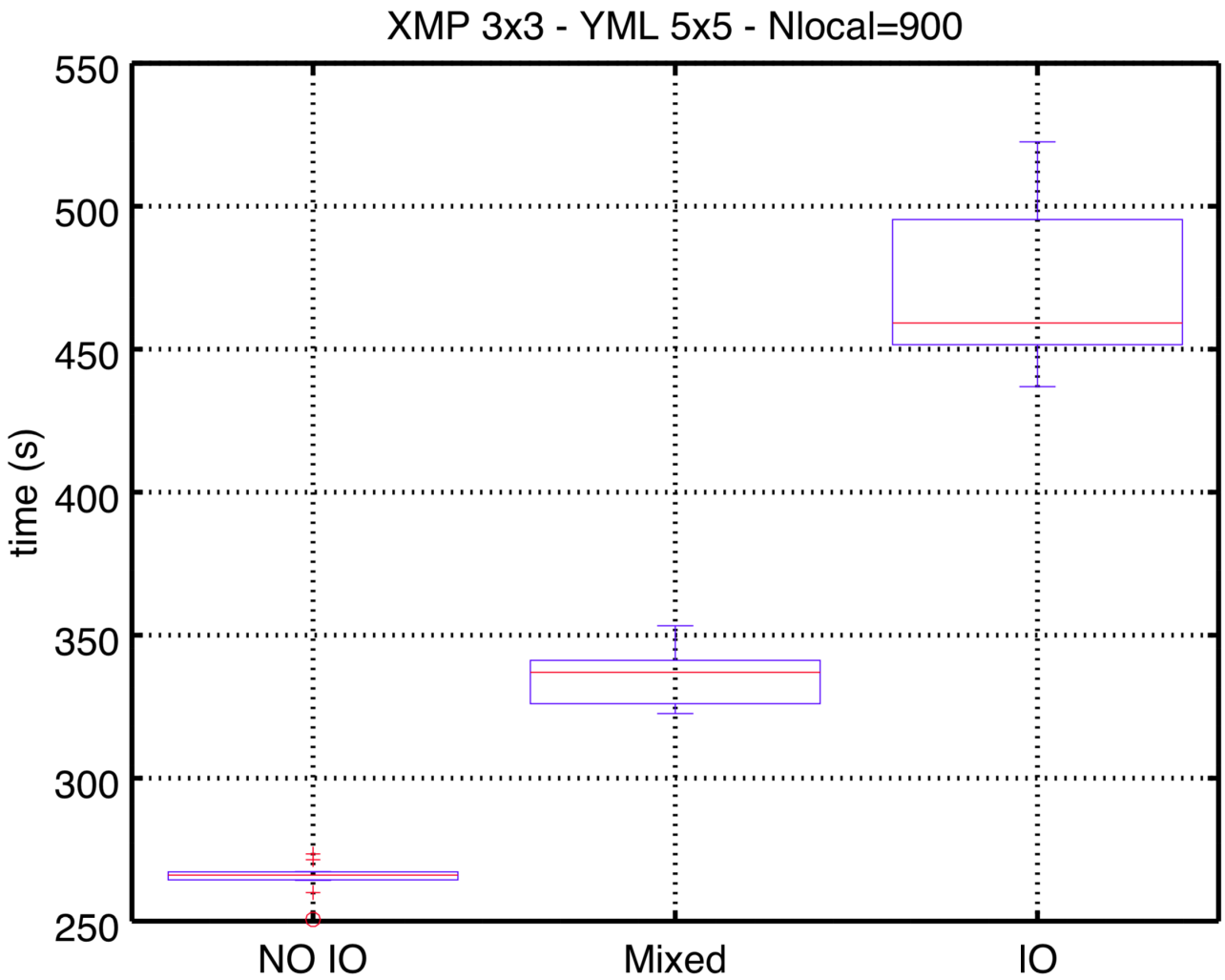


Figure: **NO I/O strategy = faster (1.73x speedup), more stable** / Mixed = compromise **1.36x**, checkpoint, stable

Small block size

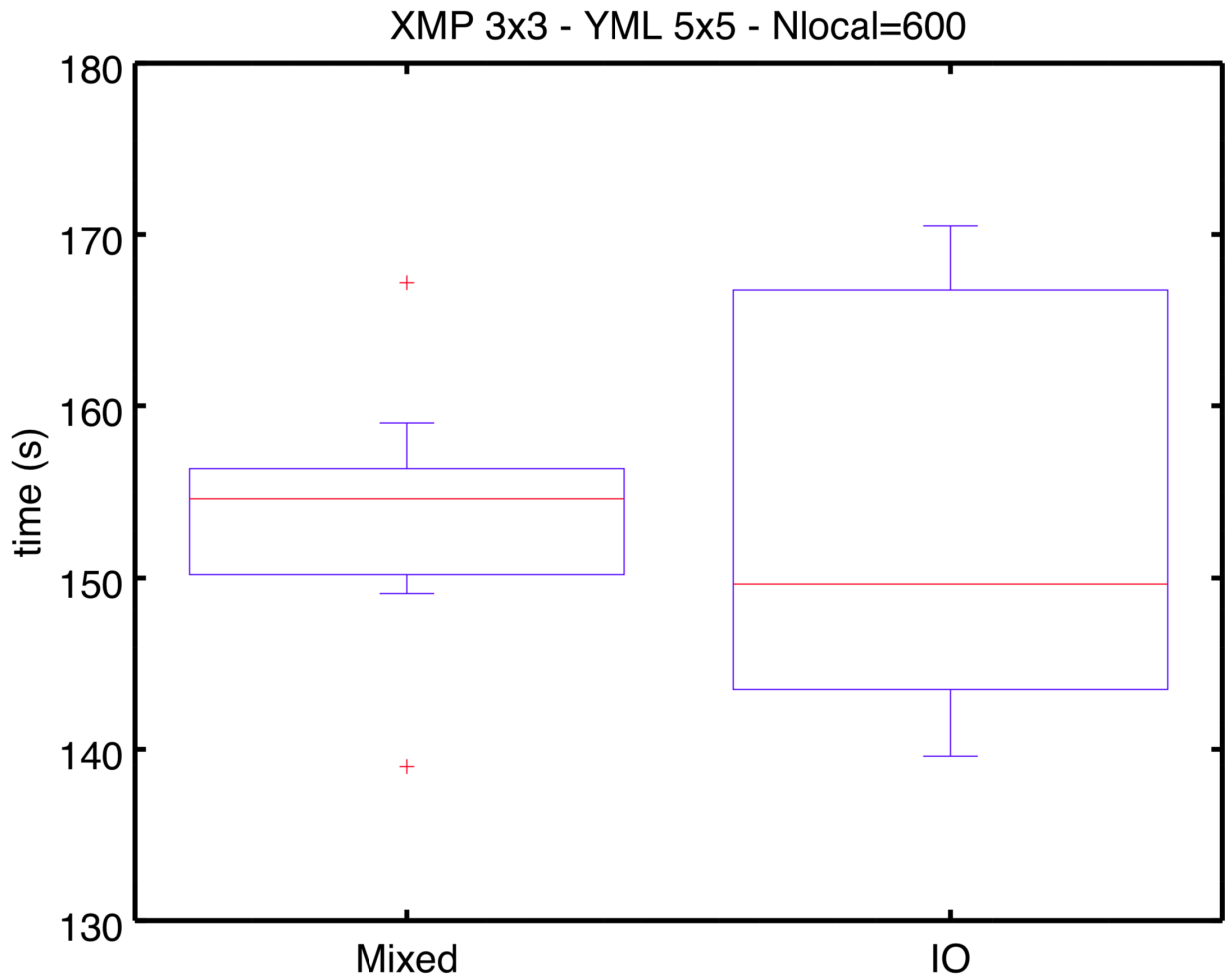


Figure: Mixed strategy **improve stability and limit loss of performance**

Conclusion

Design

- Design of data exchange for Multi SPMD
- **Grap of tasks + PGAS**
- **Design enables to extract and use information**
  - parallel programing model
  - execution model
  - architecture

Toward implementation

- YML-XMP and exchange through a data repository
- Task scheduler
- YML interface can be used
- **Choices: MPI-IO or MPI server (No I/O) or mix**
- **Speedup up to 2x for benchmark application (BGJ)**

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