Evaluation of an HPC Component Model on Jacobi and 3D FFT Kernels

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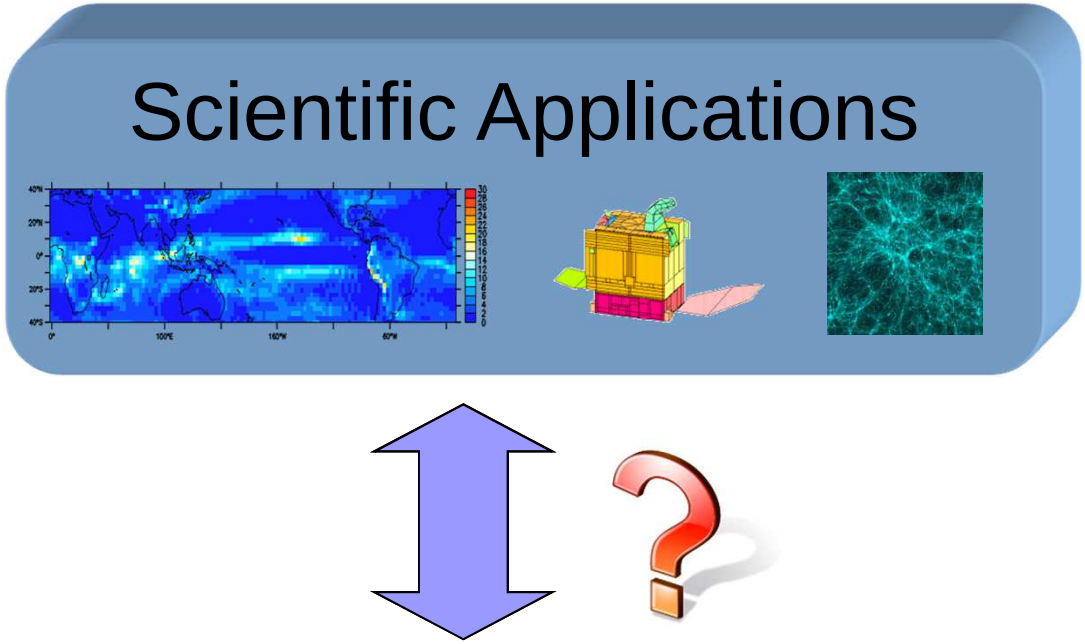
Context


Scientific Applications
Cluster
(GPU/MC/…)
Grids
(EGEE)
Super-
computer
(Exascale)
IaaS
(Cloud)

Parallel Programming

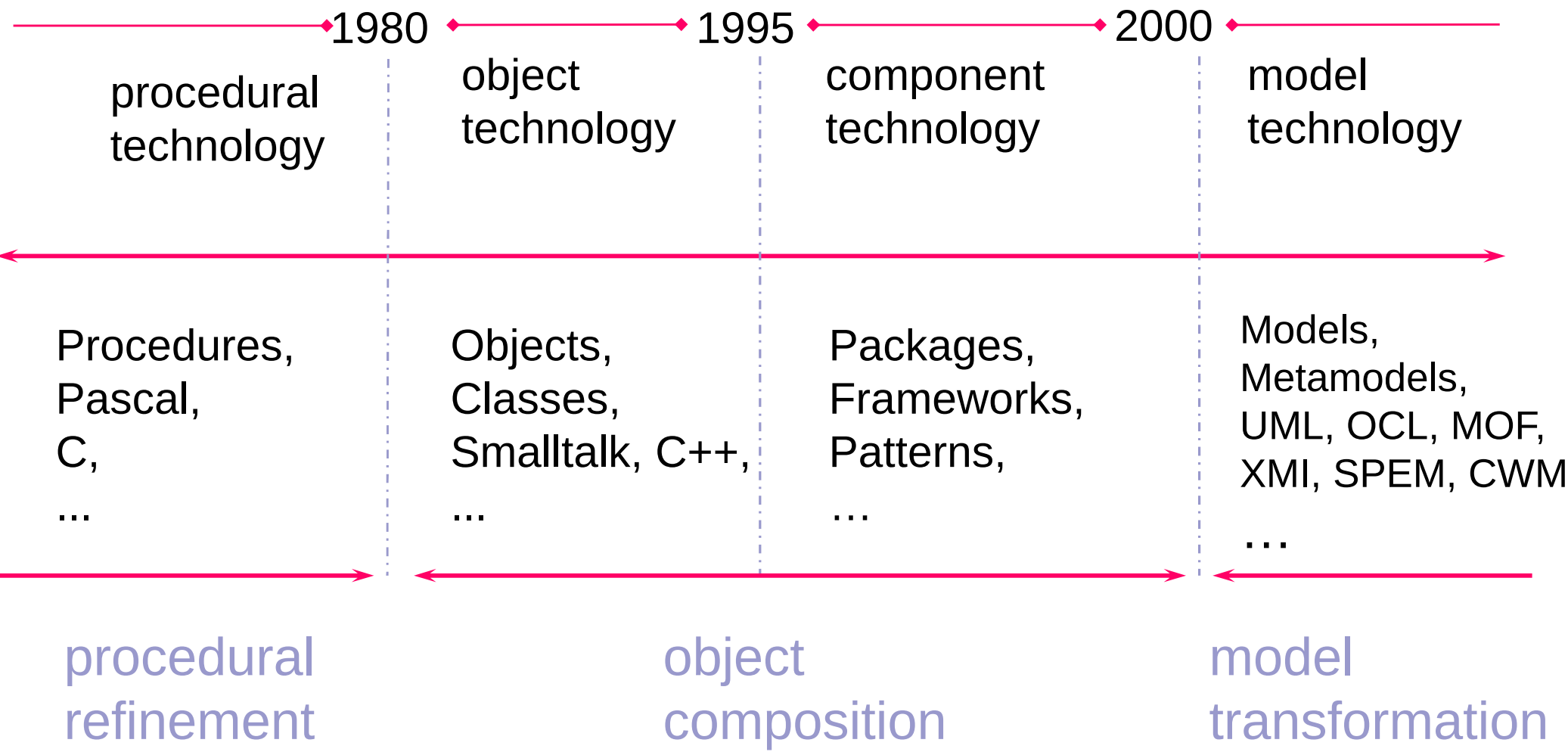
- (High level) parallel languages
  - PGAS, …
    - Not (yet) mature
- Platform oriented models
  - Multi-core ⇔ Threads, OpenMP
  - GPU ⇔ Cuda, OpenCL, OpenAPP
  - Multi-node ⇔ MPI
    - Many versions of the same code
    - Difficult to maintain all versions synchronized
    - Difficult to keep specific machine optimizations
    - Low code reuse

Proposed Approach Overview

- Separation of concerns
  - Machine specific code from re-usable code
    - Different algorithms!
- Make explicit points of configuration
  - Need a configurable representation of an application
- Generate machine specific version
  - Need a process

- Component model as an application description model to adapt to a particular machine

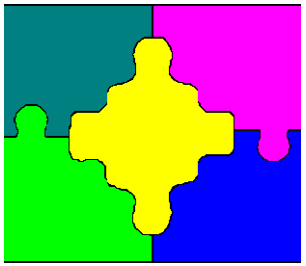
A global view of software engineering evolution



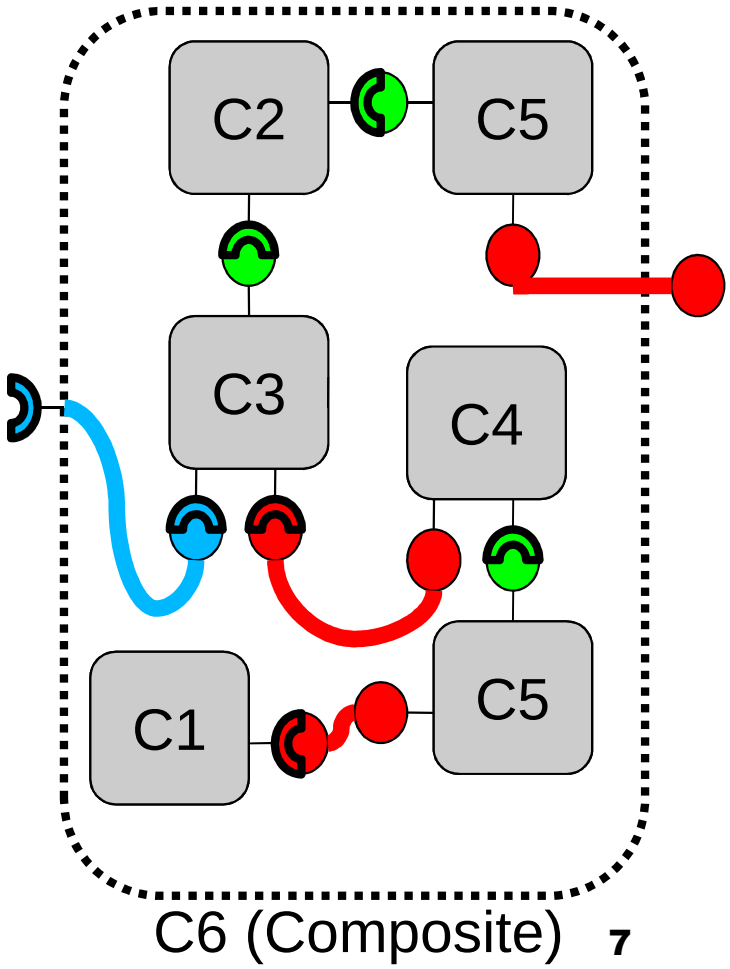
From Jean Bézivin presentation, ATLAS group (Inria & LINA), Nantes, France

OVEREVIEW OF COMPONENT MODELS

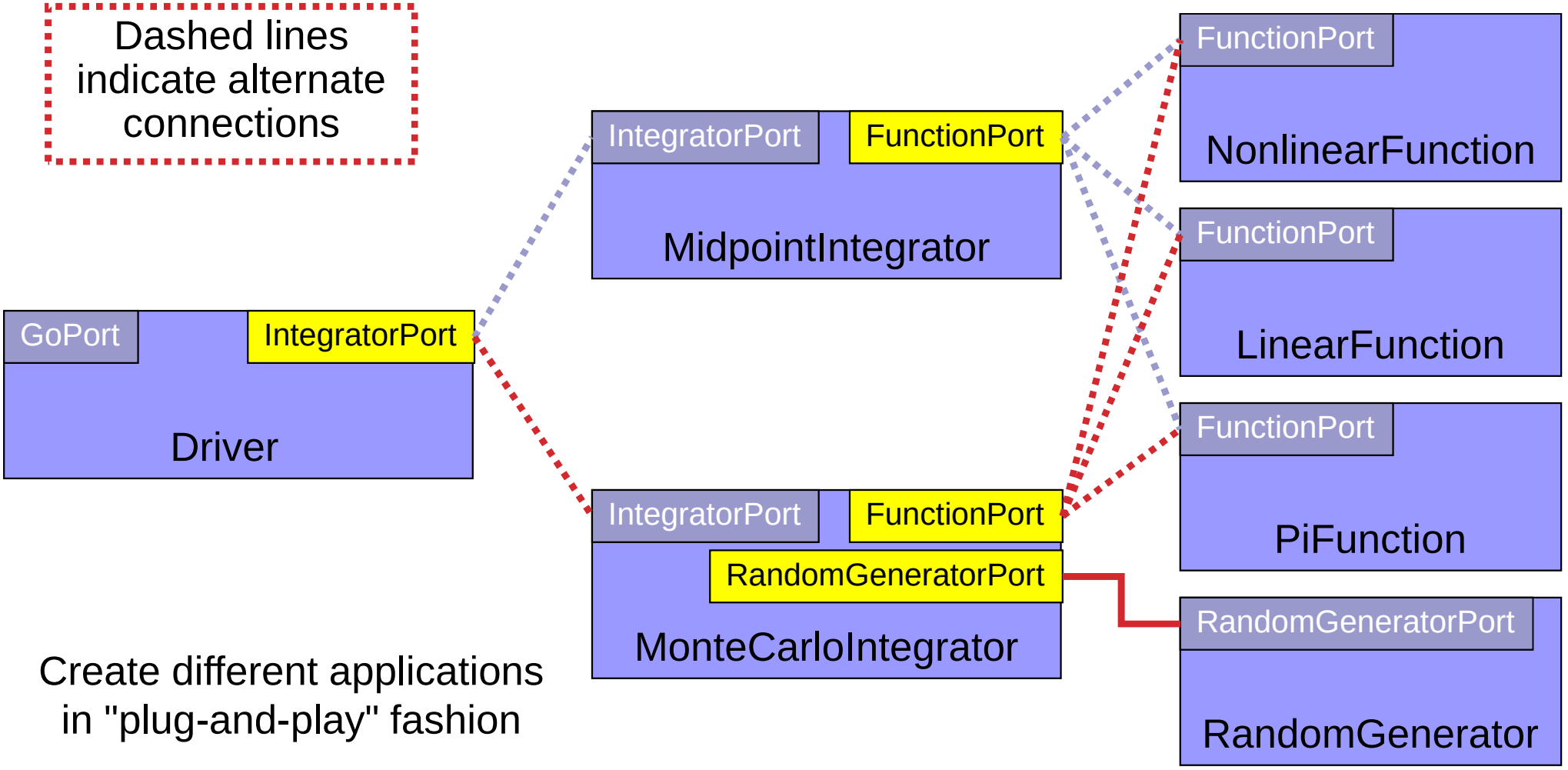
Software Component



- Technology that advocates for composition
  - Old idea (late 60's)
  - *Assembling* rather than *developing*
- Many types of composition operator
  - Spatial, temporal, ….
- Assembly of component
  - Primitive & composite components
- Many models (but in HPC)
  - CCA, Salome, CCM, Fractal, GCM, OGSi, SCA, …



Common Component Architecture (CCA) Example



Create different applications in "plug-and-play" fashion

From CCA Tutorial, http://www.cca-forum.org/tutorials/

Component in Parallel Computing

- Memory sharing between components
  - CCA & CCM Extensions
- Parallel components
  - CCA, SCIRun2, GridCCM
- Collective communications
  - CCM Extension
- Parallel method calls
  - SCIRun2, GridCCM
- Master / worker support
  - CCA & CCM Extensions
- Some algorithmic skeletons in assemblies
  - STKM

- Two type of features
  - Component **implementations**
    - ≈ skeletons
  - Component **interactions**

Limitation of Existing HPC Component Model

- Pre-defined set of interactions
  - Usually function/method invocation oriented
  - How to incorporate other interactions, eg MPI?
- Provide communication abstractions
  - Language interoperability (~IDL)
  - Network transparency
  - Potential overhead when not needed
  - Limited data types systems
    - Babel SIDL, OMG IDL, …
- Programming model vs execution model

Programming model vs Execution model

- L2C: Execution model
  - Performance oriented
  - Close to hardware
  - Not so easy to make use
- HLCM: « Programming » model
  - Assembly oriented
  - Abstract hardware
  - Shall be “easy” to make use

This talk

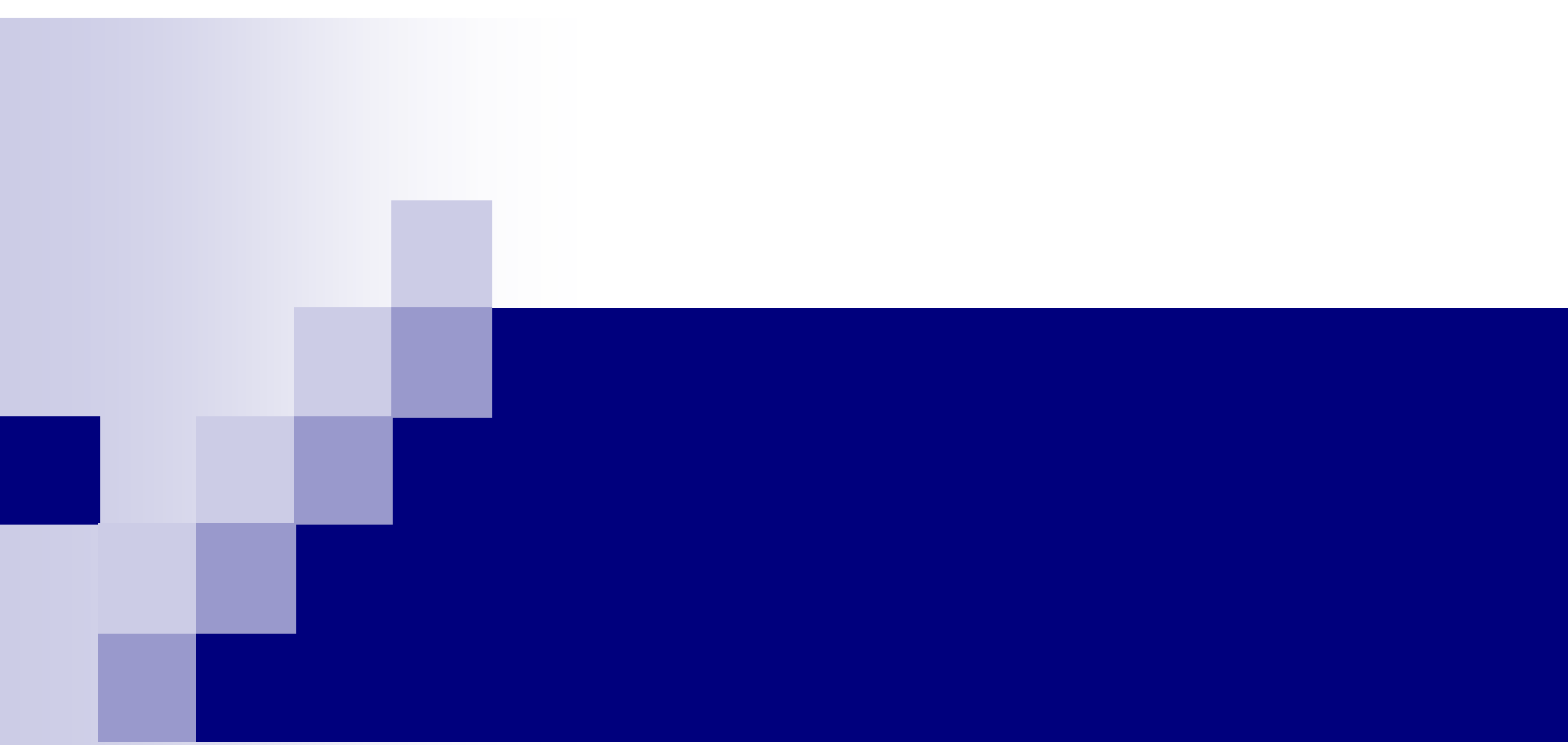
OVERVIEW OF L2C
LOW LEVEL COMPONENT

Low Level Component Model

- A minimalist component model for HPC
  - Component creation/deletion, configuration, and connection
  - An (optional) launcher
- No L2C code between components @ runtime
- Support native interactions
  - C++, MPI, CORBA, FORTRAN (2008)
- Extensible
- LGPL, available at *hlcm.gforge.inria.fr*

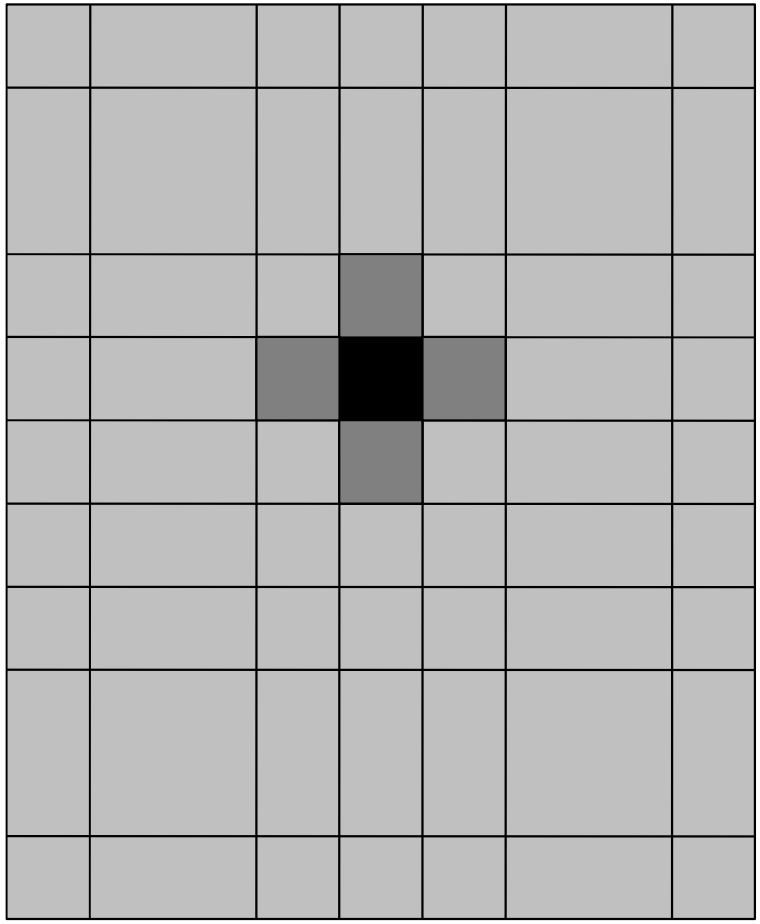
L2C: Connector Overview

- C++/FORTRAN Interactions
  - Use/Provide relationships
  - No language interoperability
    - Outside L2C goals
- MPI Interactions
  - Connector ~ communicator

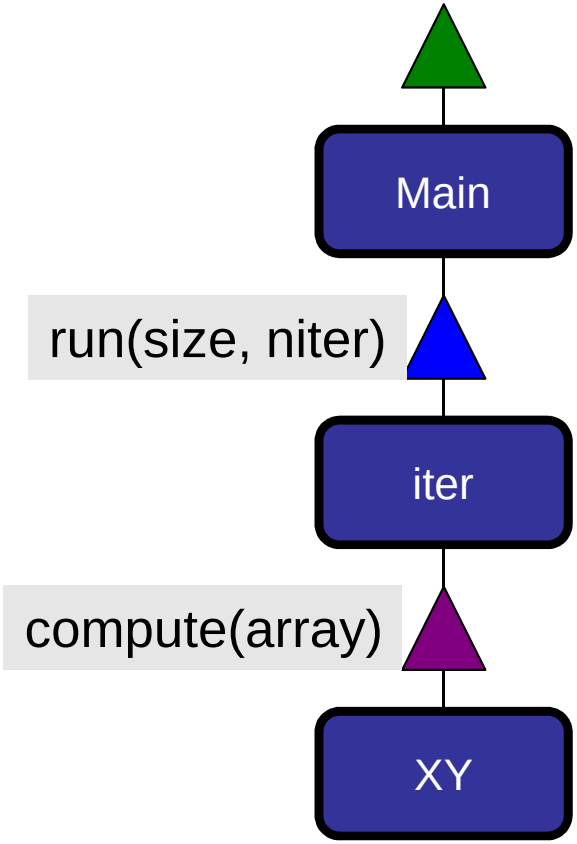


L2C AND JACOBI

Jacobi Sequential Computation



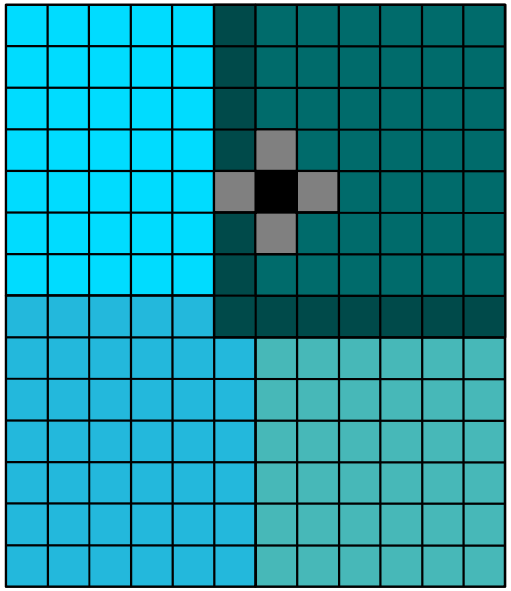
Iter = N



- For iter = 0 to Niter
  - For y = 0 to ymax
    - For x = 0 to xmax
      - tab[iter][x][y] = ...

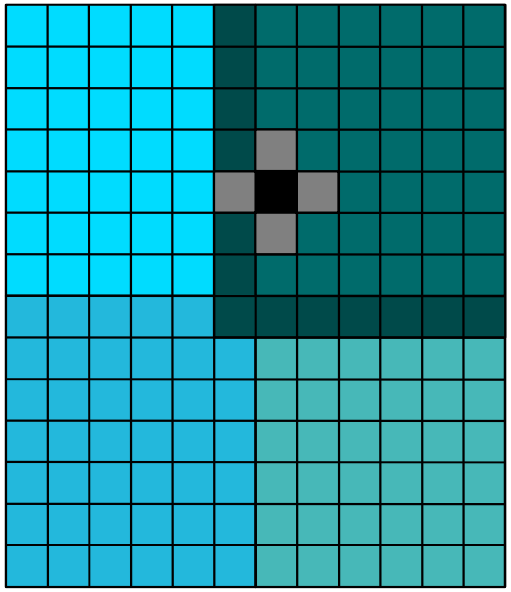
Thread Jacobi Parallelization

- 1 shared array
- Barrier after each iteration



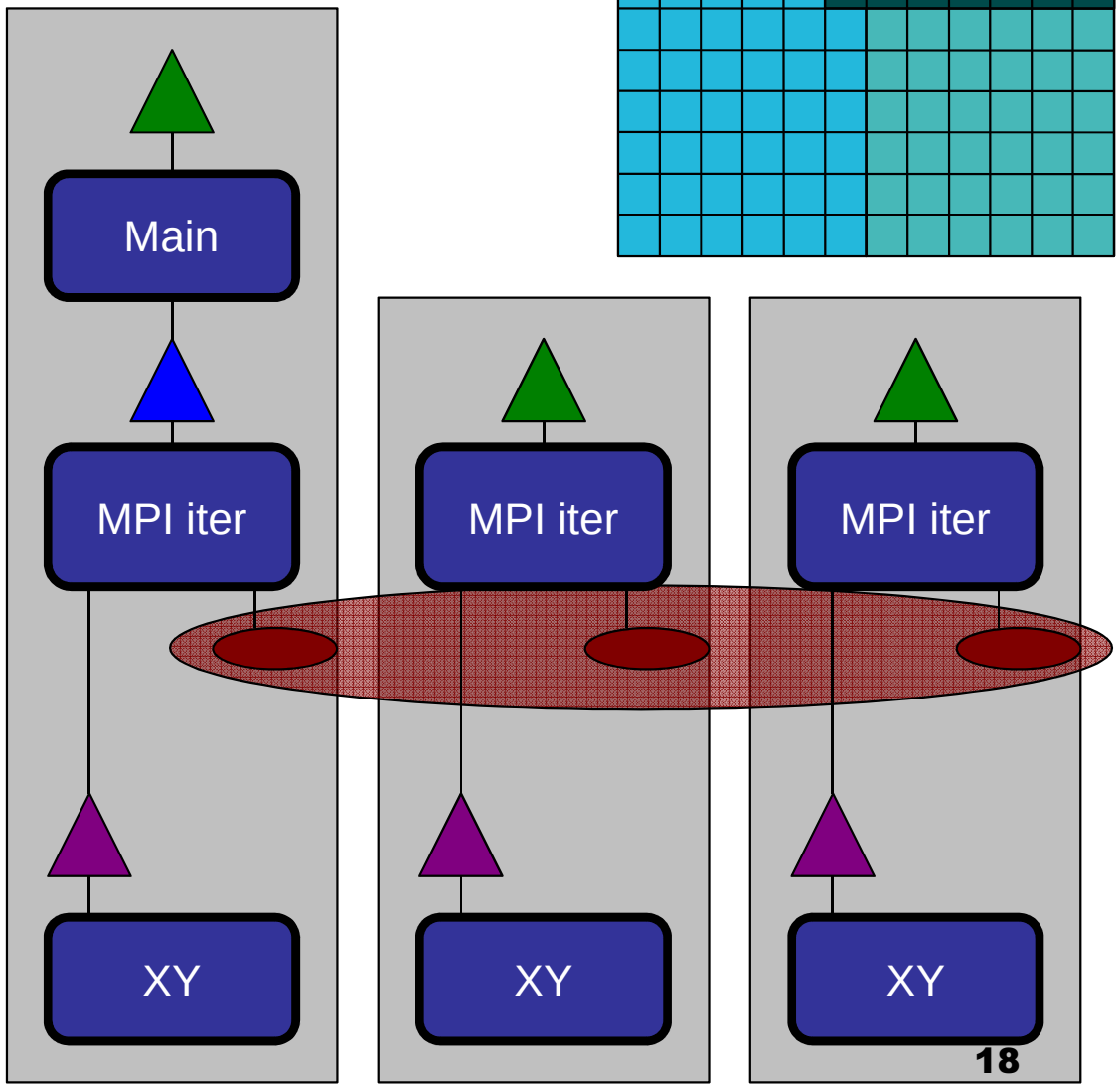
- For iter = 0 to Niter
  - For y = 0 to ymax
    - For x = 0 to xmax
      - tab[iter][x][y] = …
  - Barrier

MPI Jacobi Parallelization



- 1 local array per thread
- Send/receive at each iter

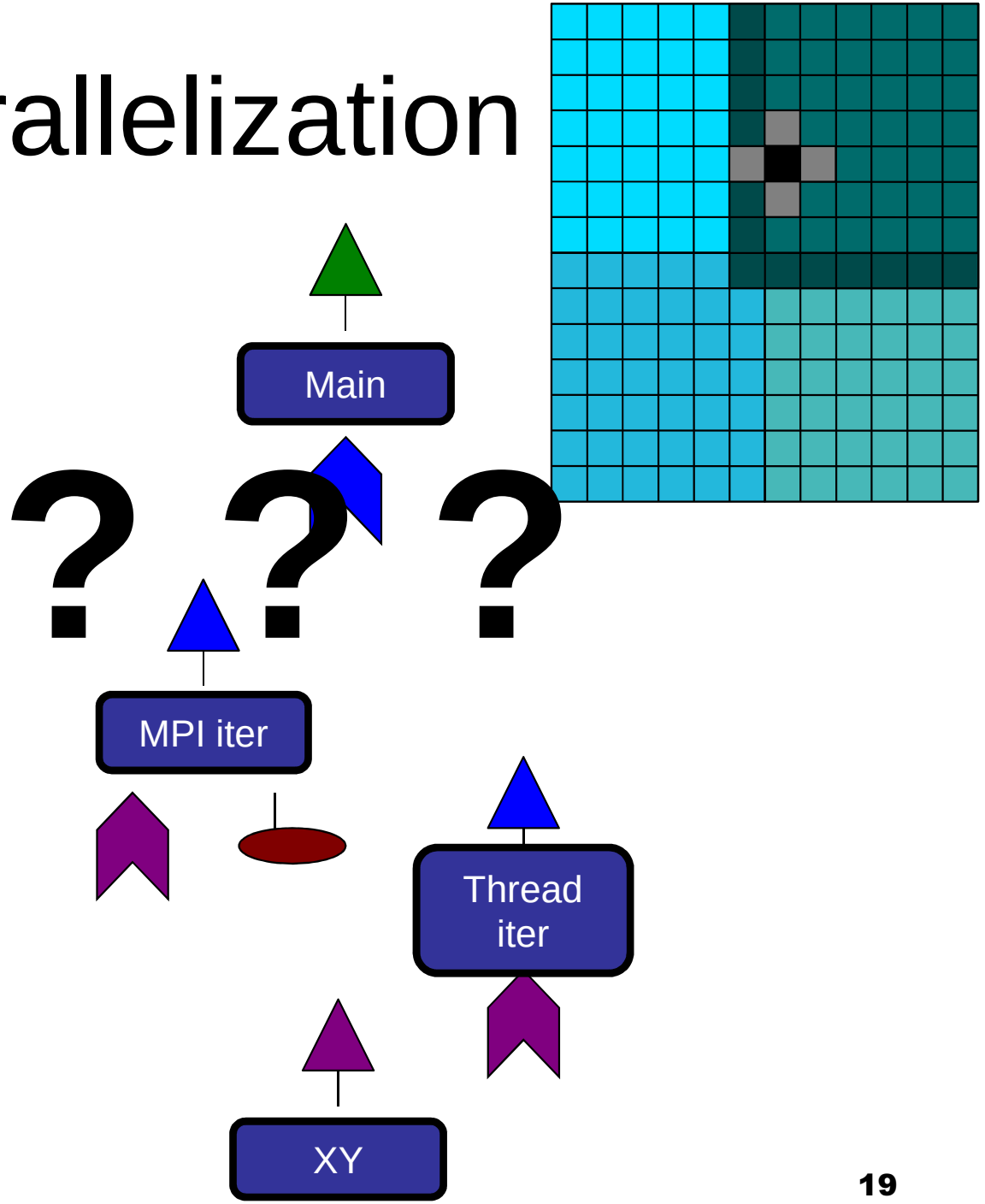
- For iter = 0 to Niter
  - For y = 0 to ymax
    - For x = 0 to xmax
      - tab[iter][x][y] = …
  - SendReceive



Hierarchic Parallelization

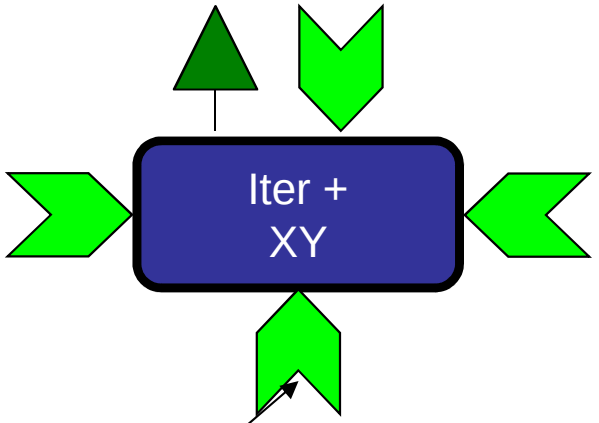
- Multi nodes
  - MPI
- Multi core
  - Threads

- For iter = 0 to Niter
  - For y = 0 to ymax
    - For x = 0 to xmax
      - tab[iter][x][y] = …
  - Local Barrier
  - SendReceive



The 4 connector way

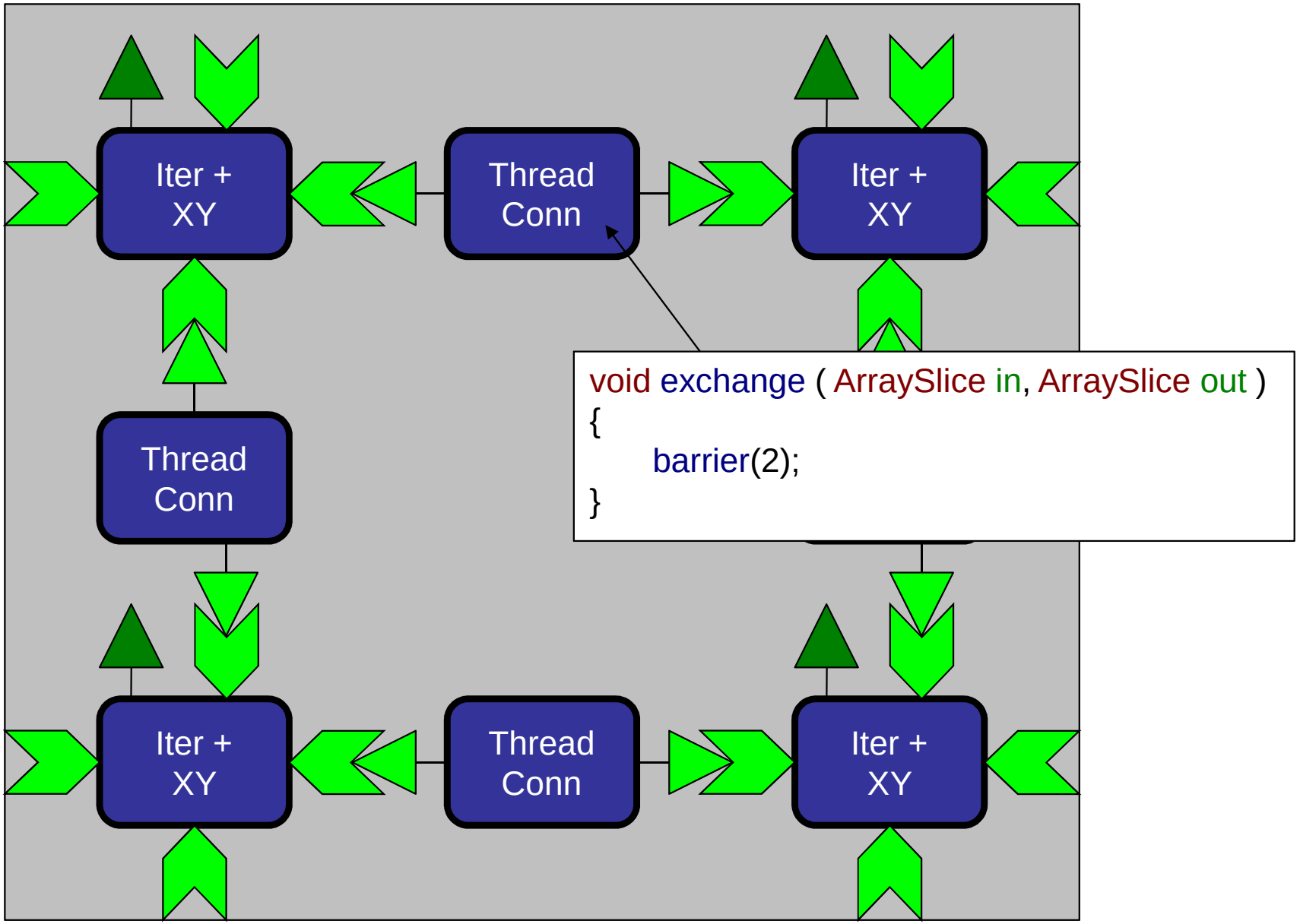
- 1 connector instance
  - 1 domain
- 1 DataExchange/side
  - Implementation agnostic interface



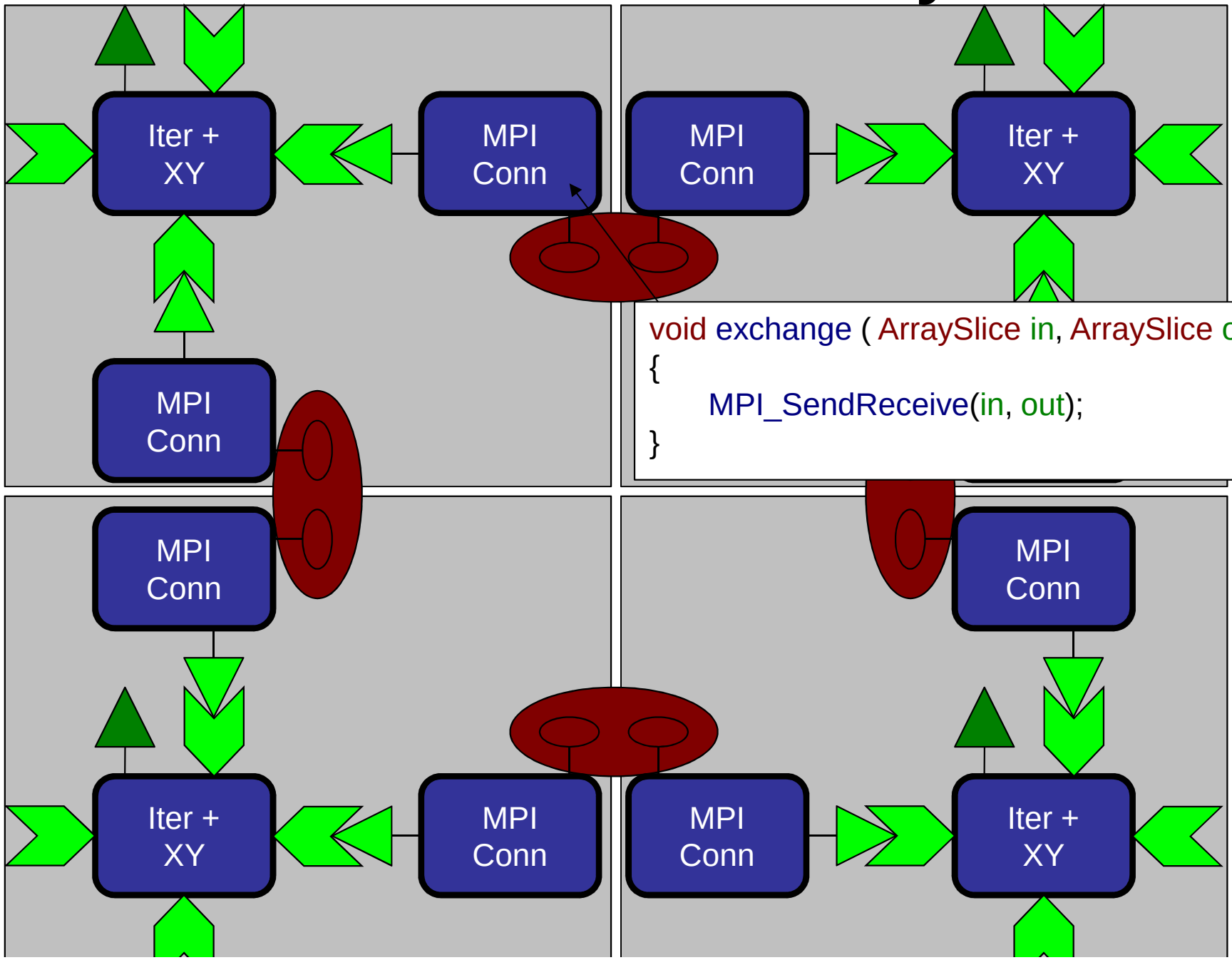
- For iter = 0 to Niter
  - Wait for frontier
  - For y = 0 to ymax
    - For x = 0 to xmax
      - tab[iter][x][y] = …
  - Data update T/B/L/R

```
class DataUpdate
{
public:
      virtual void exchange (
                  ArraySlice in,
                  ArraySlice out
      ) = 0;
};
```

The 4 Connector Way: Threads

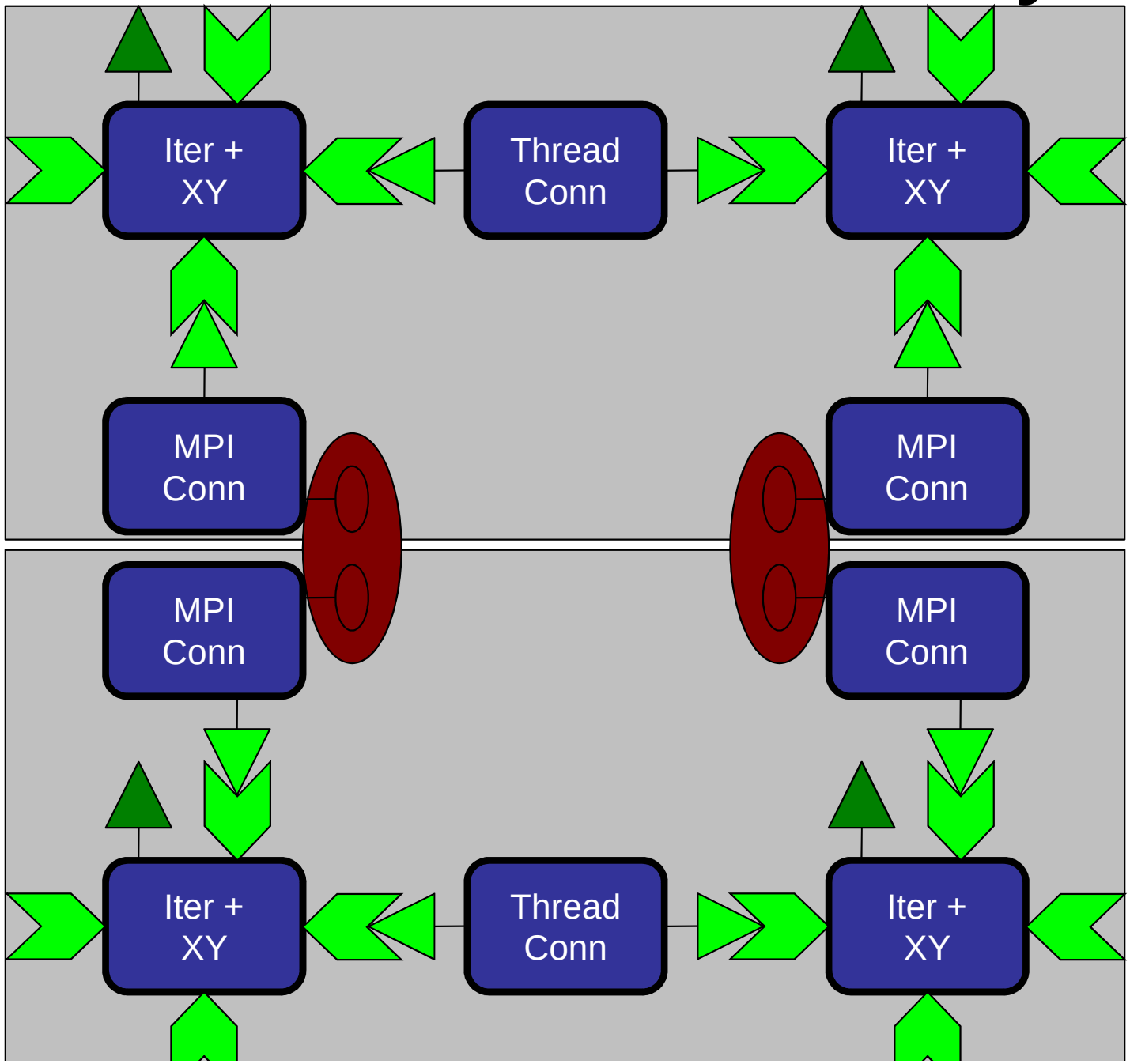


The 4 Connector Way: MPI



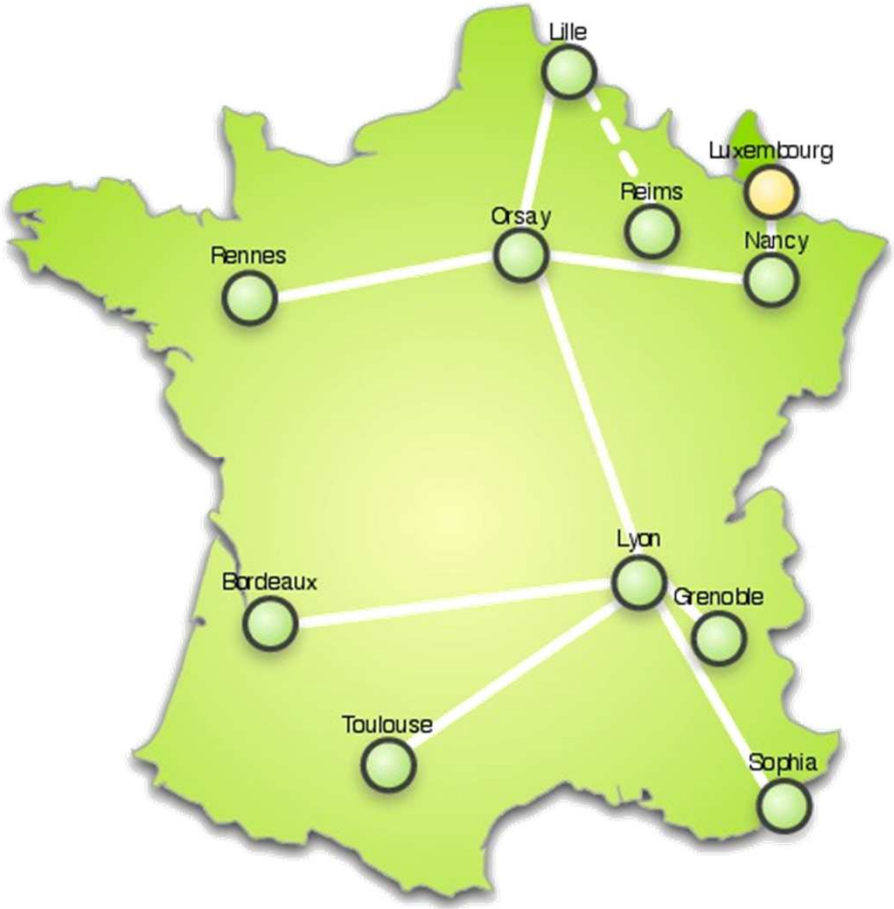

```
void exchange ( ArraySlice in, ArraySlice out )
{
      MPI_SendReceive(in, out);
}
```

The 4 Connector Way: Hierarchy

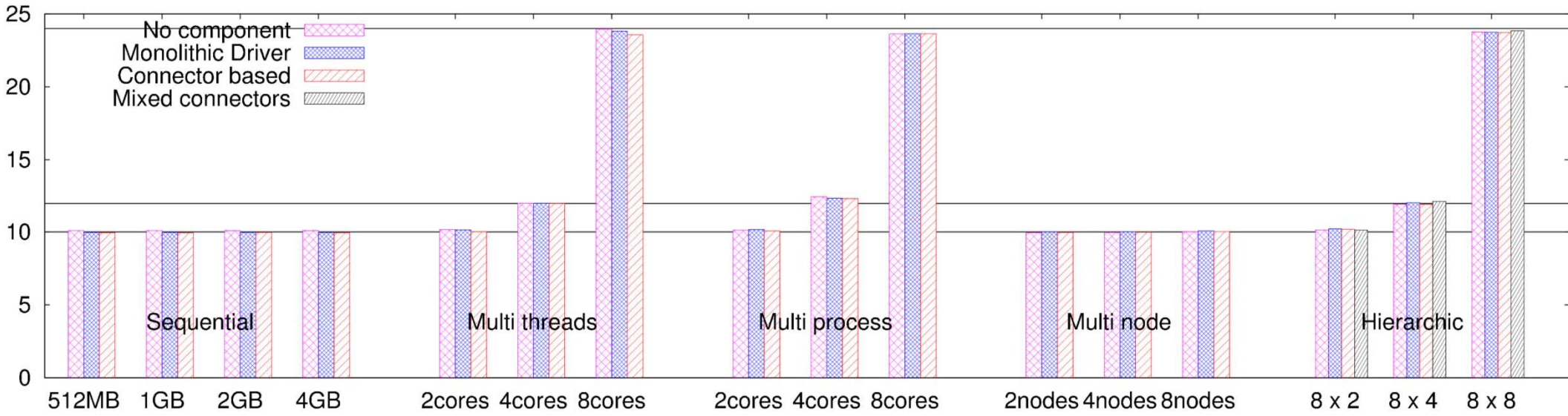


Experimental Platform: Grid'5000

- Griffon cluster
  - Intel Xeon L5420 2.5 GHz
    - 4 cores per CPU
    - 2 CPU per node
  - 92 nodes
  - 16 GB RAM
  - Infiniband-20G network



Iteration Time



Overhead coming from using too much threads on this machine!

- Limited memory bandwidth

Software Complexity

- Number of Lines

Jacobi Version	Native	Driver	Connector
Sequential	**161**	239	**388**
Multithreaded	**338**	386	**643**
MPI	**261**	285	**446**

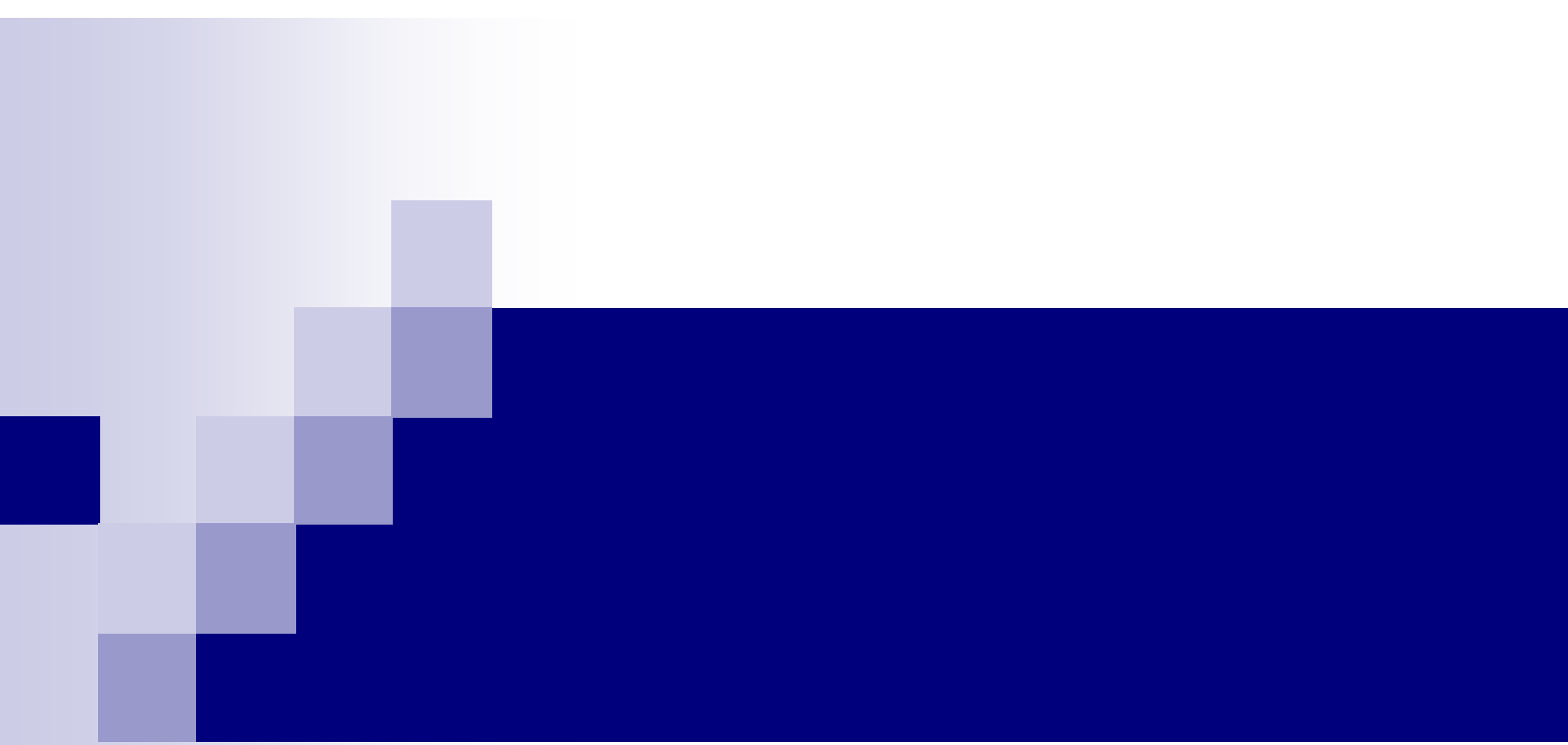
- Code Reuse

Code Reuse vs Seq (%)	**Driver**	**Connector**
Thread	26%	**31%**
MPI	32%	**87%**
MPI+Thread	-	**100%**

Software Complexity

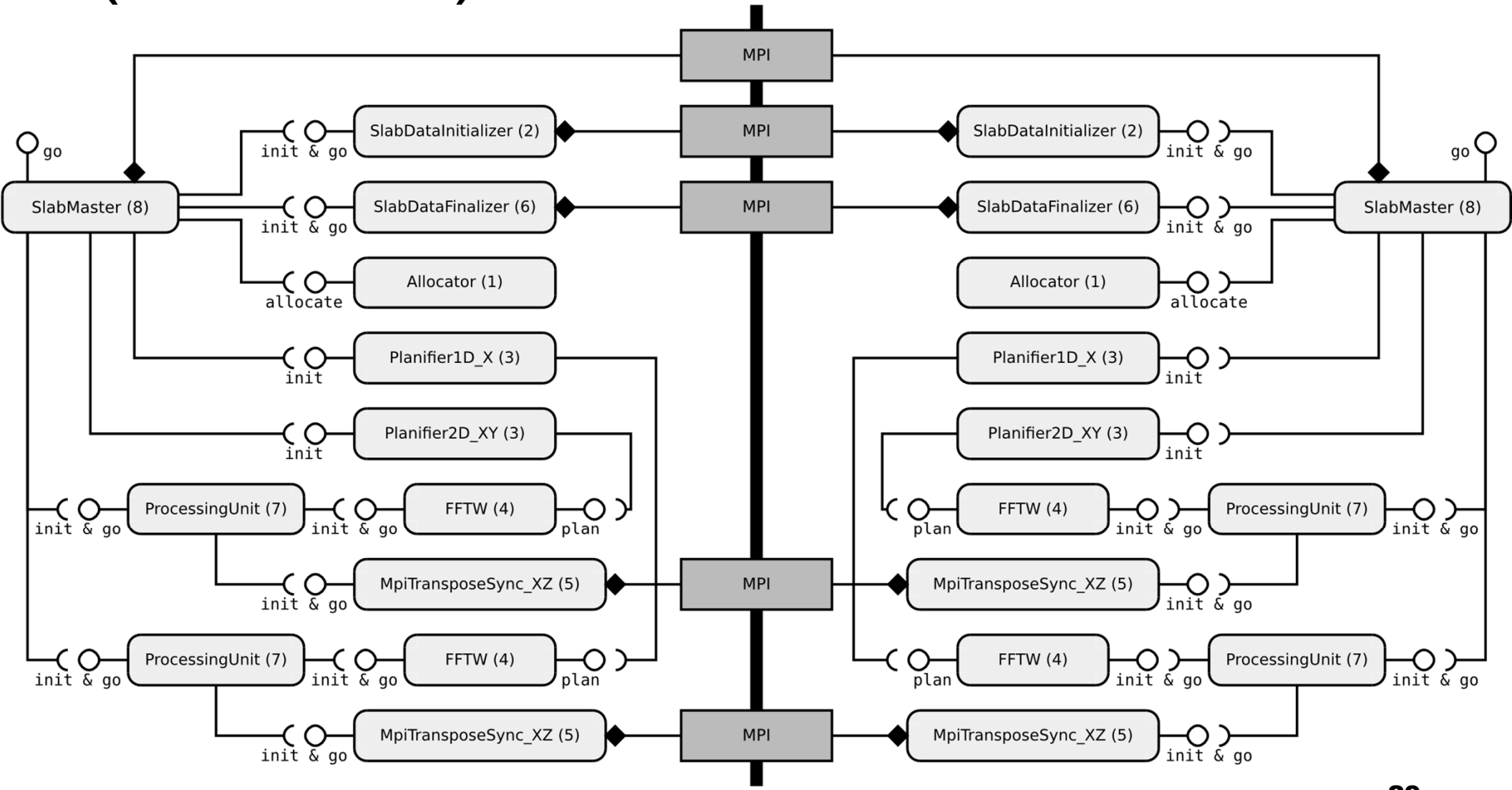
- Cyclomatic complexity
  - *It directly measures the number of linearly independent paths through a program's source code. Wikipedia*

Jacobi Version	Native	Driver	Connector
Sequential	**28**	**32**	**8**
Multithreaded	**76**	41	**26**
MPI	**55**	22	**13**

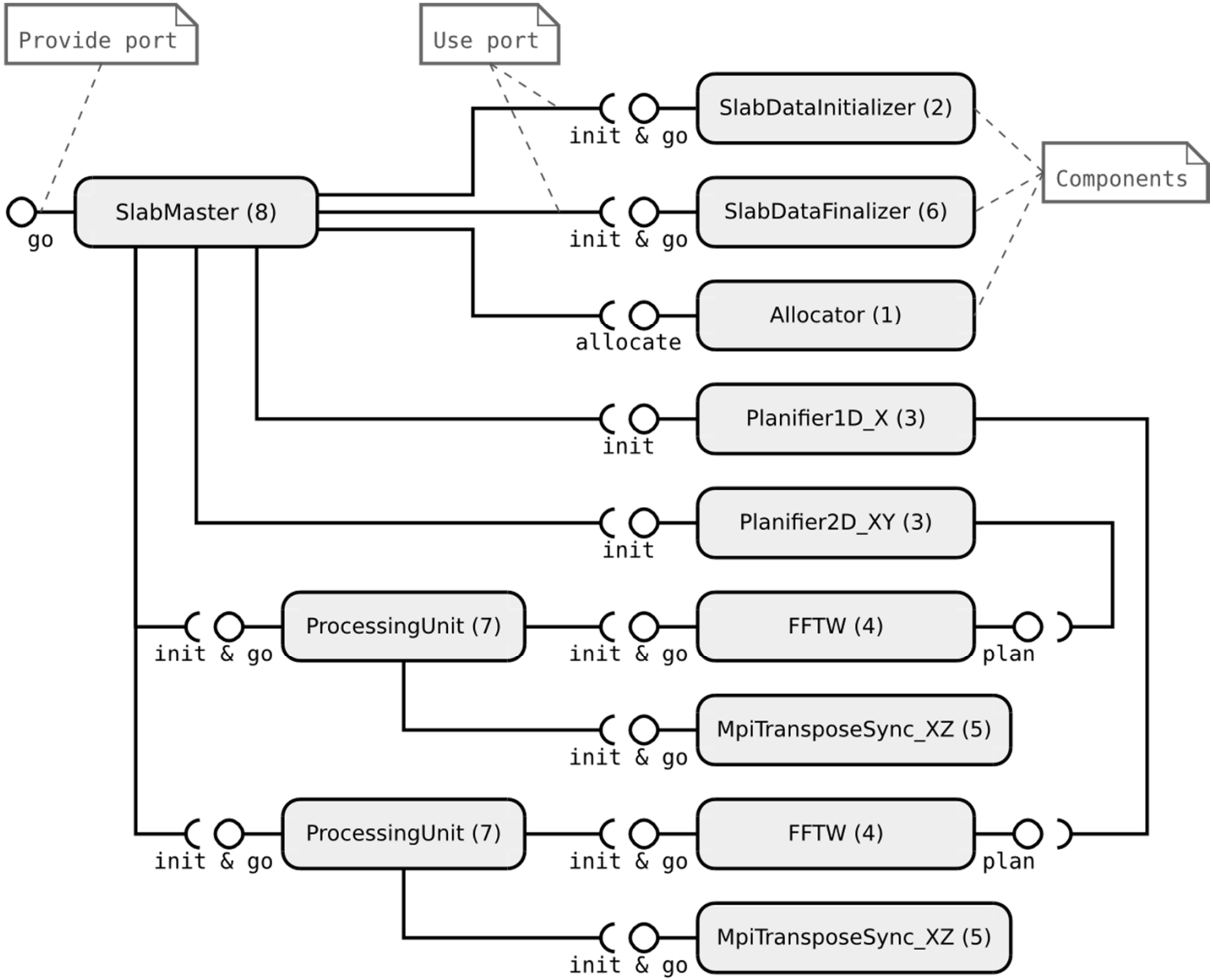


L2C AND 3D FFT

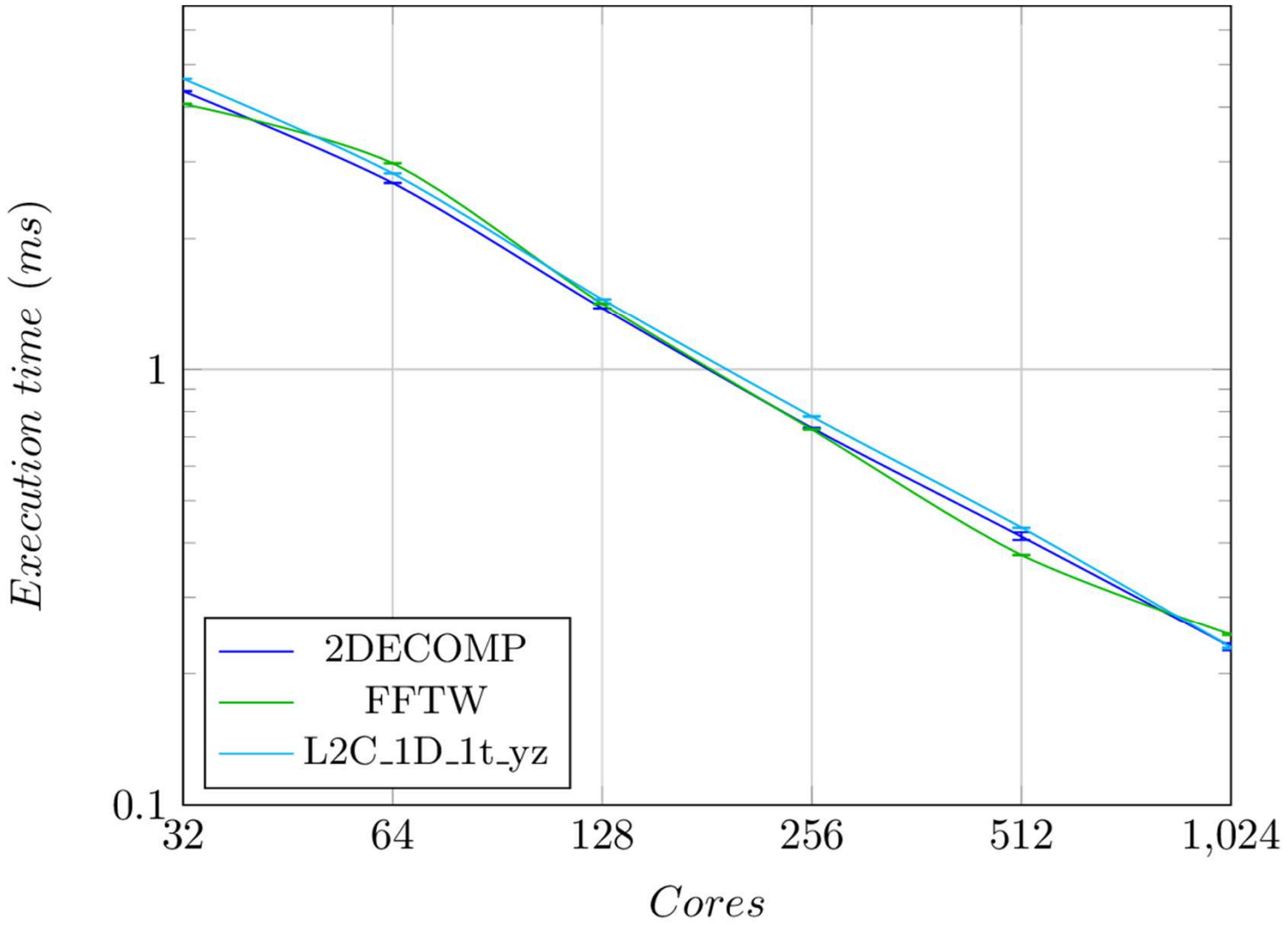
1D MPI 3D FFT Assembly (2 nodes)



1D MPI 3D FFT Assembly

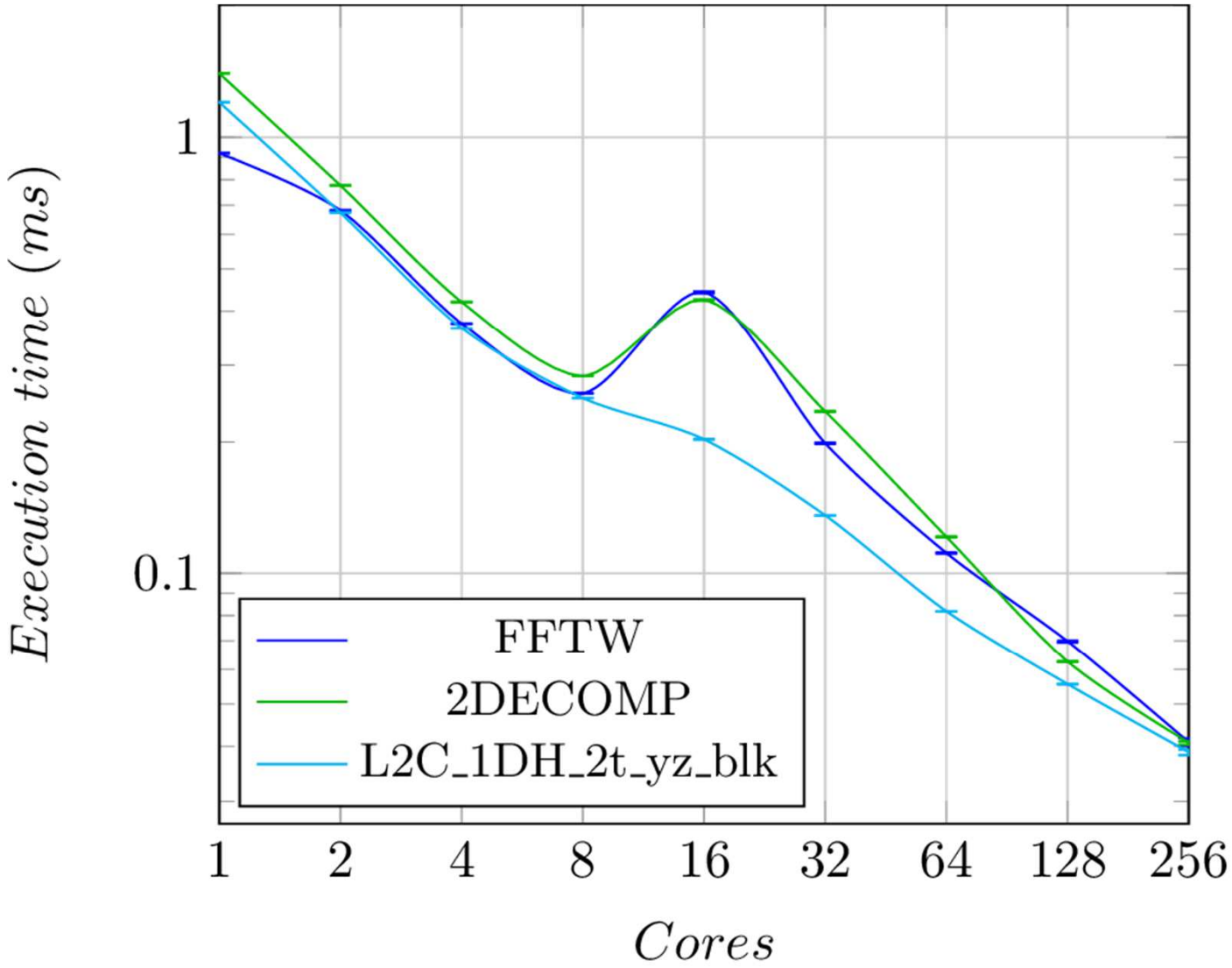


Homogeneous Experiments



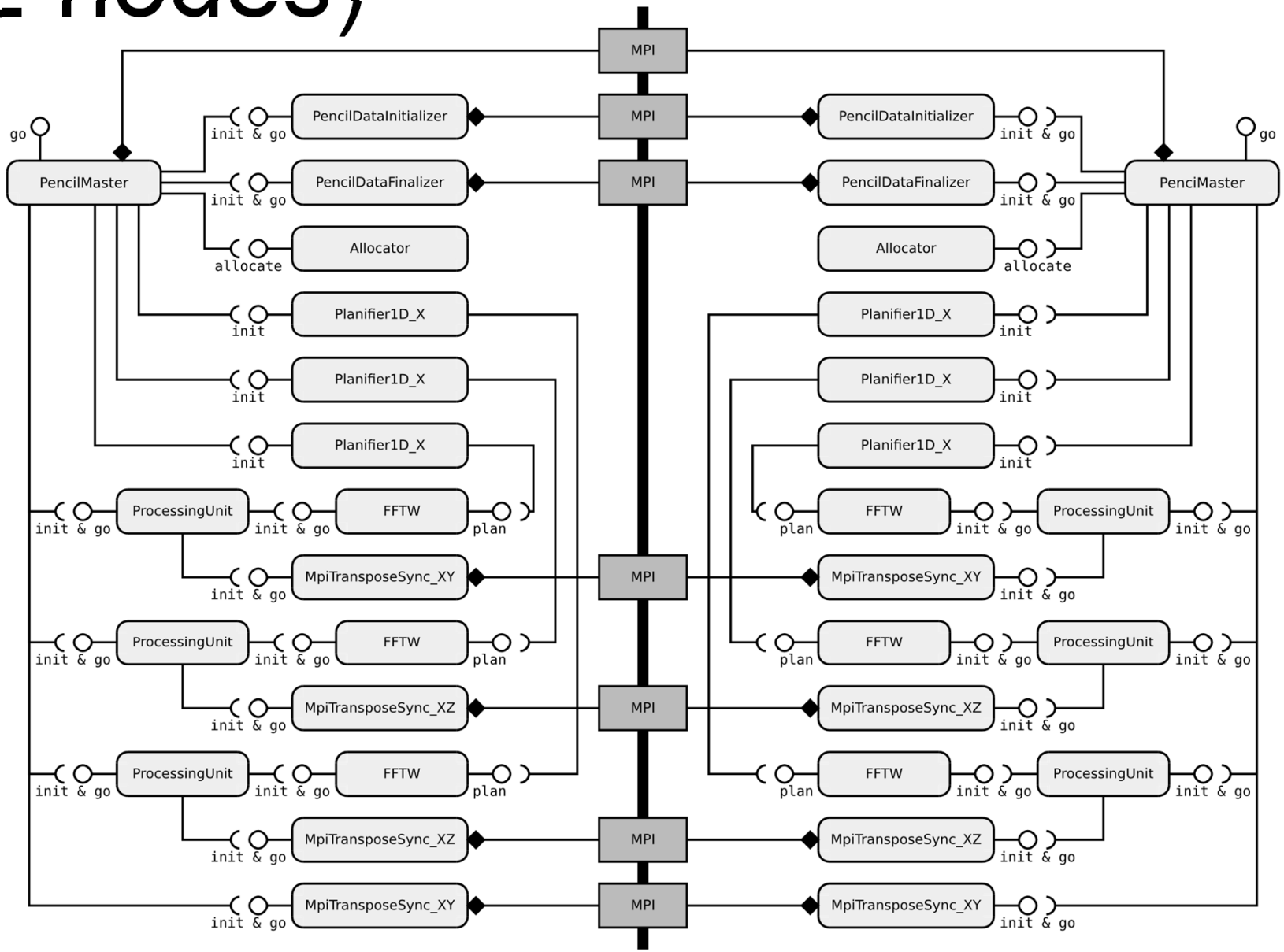
1024^3 3D FFT – 1D Decomposition – Curie (Thin node)

Heterogeneous Experiments

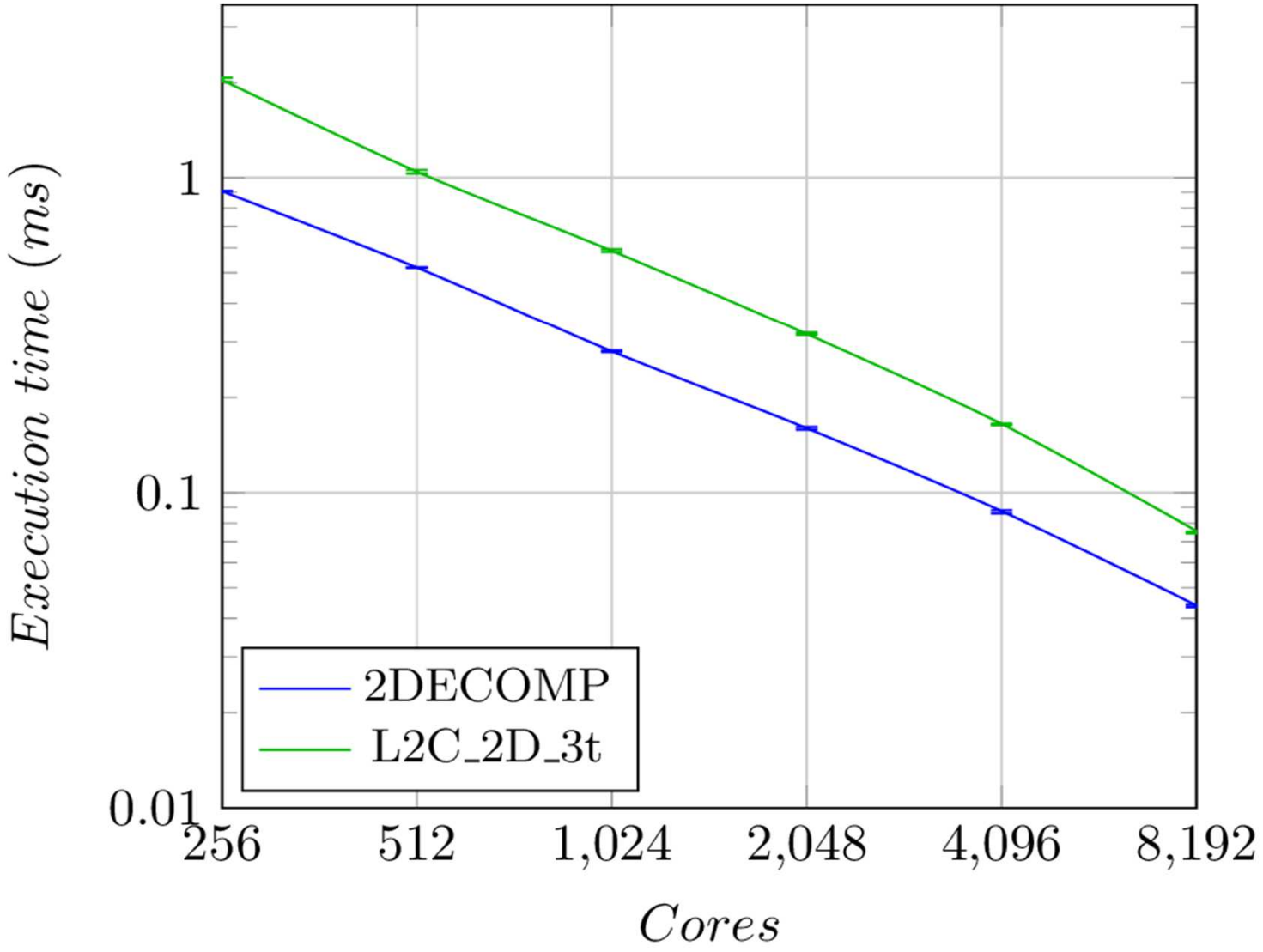


256^3 3D FFT – 1D Decomposition : Edel+Genepi Cluster (Grid'5000)

2D MPI 3D FFT Assembly (2 nodes)



Homogeneous Experiments



1024^3 3D FFT – 2D Decomposition – Curie (Thin node)

Number of Lines & Reusability

Version	C++ Lines of Code	% Reused Code
L2C 1D 2t xz	927	-
L2C 1D 1t xz	929	77%
L2C 1D 2t yz	929	100%
L2C 1D 2t yz blk	1035	69%
L2C 1DH 1t yz	983	80%
L2C 1DH 2t yz blk	1097	72%
L2C 2D 3t	1067	87%
L2C 2DH 3t	1146	69%

Conclusion & Perspectives

- Component model as a way to handle versions
  - Application adaptation => assembly modification
- L2C
  - A simple, efficient, and extensible model
- Towards component + task graph (L2C+StarPU)
- Efficient reconfiguration of component (on going)
- L2C assembly complex to write
  - Shall be generated by a higher model
  - HLCM: A high level component model
- Transformation algorithms from “HLCM” to “L2C”

Component and Task Graph

- Component
  - Good for describing application structure
- Task graph
  - Efficient to handle task dependencies
- Towards a Component+Task graph model
  - Runtime/Avalon/CEA PhD starting Nov 1.
  - Superseding L2C+StarPU
  - Gysela5D as a target application