Graph partitioning techniques for load balancing of coupled simulations

Maria Predari, Aurélien Esnard

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Maria Predari & Aurélien Esnard (Inria, University of Bordeaux, France)

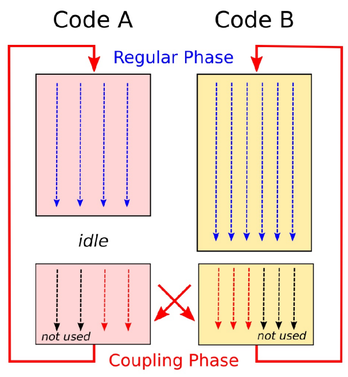
Introduction

Context – In the field of parallel computing, the load balancing is a crucial issue which determines the performance of parallel applications. A very common approach to solve the load-balancing problem is based on graph model. To equilibrate the load between k processors and minimize the communication cost, one performs a k-way *graph partitioning*, each part being assigned to a given processor.

Challenges – Multi-physics or multi-scales applications that emerge nowadays in real-life problems often have more complex structure and consist of numerous parallel codes, running concurrently and periodically coupled together.

Issue – The traditional load balancing strategy is not adequate. The naive partitioning of each code idependently will not balance the coupling phase, leading to bad inter-codes exchange.

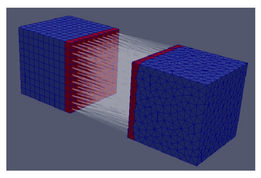
Our goal - Finding a *coupling-aware* partitioning that takes into account the coupling phase explicitly as a trade-off to the partitioning during the regular phase.



Model: A and B are running the regular phase on $K_A = 4$ and $K_B = 6$ processors, while less processors are involved in the coupling phase that acts as a synchronization phase.

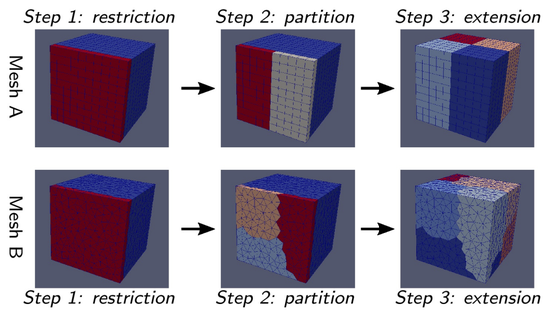
Copartitioning Algorithms

Given two coupled meshes A and B (or graphs G_A & G_B) and interedges I_{AB}, we propose two algorithms that compute the output partitions P_A and P_B in respectively K_A and K_B parts.

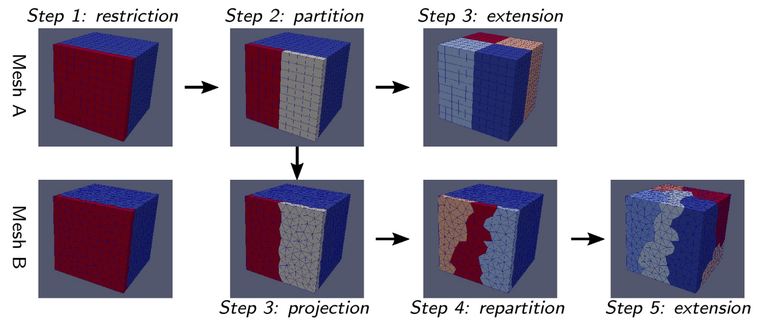


Meshes A & B with coupling interedges.

Aware: each code is aware of its coupling interface.



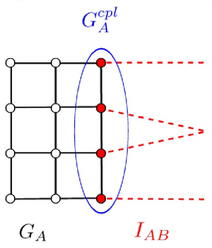
ProjRepart: each code is also aware of the other coupling interface.



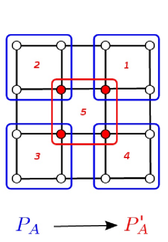
Graph Operators

Let consider, two graphs G_A and G_B coupled by interedges I_{AB}. Our copartitioning algorithms are described as a sequence of graph operators.

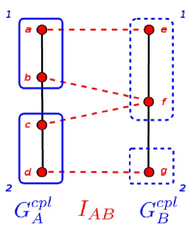
Restriction
find the subgraph in coupling interface



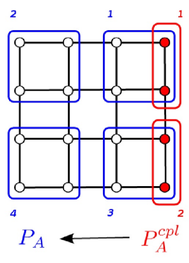
Repartition
change the number of parts in a partition



Projection
project a partition from one mesh to another



Extension
extend a partition to the rest of the graph



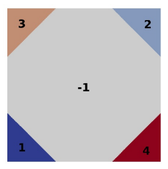
The implementation is based on biased graph partitioning with fixed vertices.

Graph Partitioning with Fixed Vertices

Motivation – Extension, Projection and Repartition operators need to handle vertices that must remain in place during the partitioning procedure (fixed vertices).

Issue – The state-of-the-art recursive bisection (RB) algorithms fail to handle properly the additionnal constraint of fixed vertices. So, we propose a different algorithm KGGGP (k-way Greedy Graph Growing Partitioning) to overcome this issue.

Limitation of Recursive Bisection – Given initial fixed vertices in the corners, comparison of KGGGP against RB (without multilevel framework) for a simple 2D grid, illustrating the inherent limitation of RB.

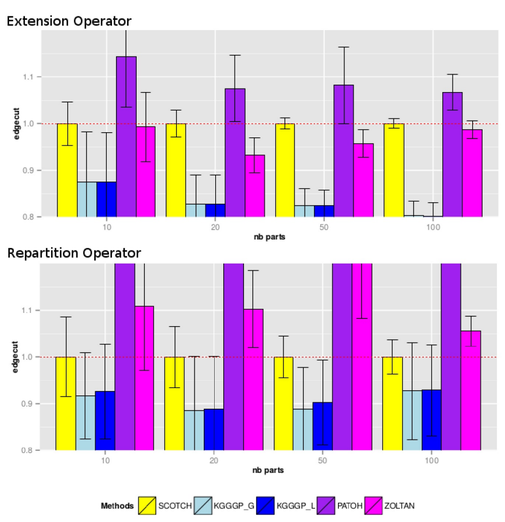


Fixed Vertices

RB

KGGGP

Experimental results – Evaluation of graph operators with different algorithms on the *Dimacs/Walshaw* graph collection.



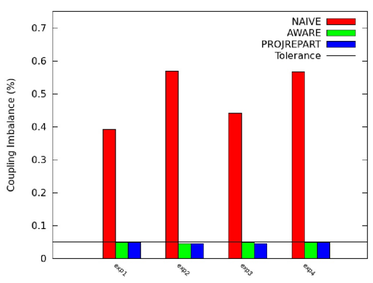
KGGGP achieves better partitioning quality as RB methods with similar performance.

Copartitioning Results

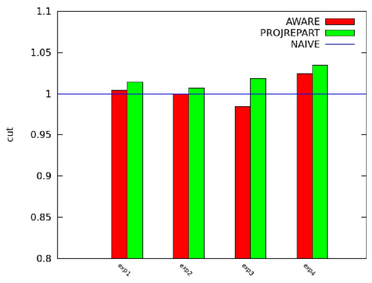
Experimental Setup – Surface coupling between two cubic meshes using different discretizations (hexahedron or tetrahedron elements). $K_A = 16$ and $K_B = 48$.

Exp.	Mesh A	Mesh B
exp1	hexa 25x25x25	hexa 100x100x100
exp2	hexa 25x25x25	hexa 70x70x70
exp3	tetra 40630	hexa 100x100x100
exp4	tetra 40630	tetra 486719

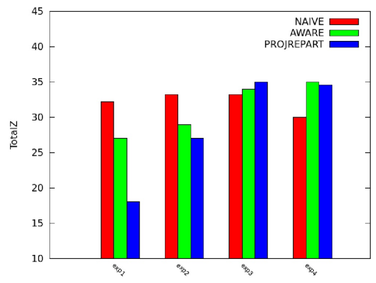
Results – Comparison of copartitioning algorithms (**Aware** and **ProjRepart**) (using KGGGP) against the **Naive** approach, where each graph is partitionned independently, ignoring the coupling phase.



load imbalance in coupling phase



total edgecut in regular phase



nb of messages exchanged in coupling phase

- Naive: highly imbalanced during coupling phase, best edgecut in the regular phase.
- Aware/ProjRepart: load balance respected in the coupling phase at a slight increase of edgecut.
- ProjRepart: the number of *major* messages exchanged in coupling phase is minimized (not shown).

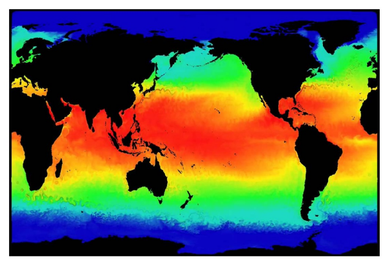
Conclusion

Our Contributions

- two new load-balancing algorithms, **Aware** and **ProjRepart**, for coupled simulations
- a new algorithm for graph partitioning **KGGGP**, that handles properly initial fixed vertices
- the code is publicly available in the **MetaPart** library at `metapart.gforge.inria.fr`

Future Work

- validate our copartitioning algorithms with real-life 3D coupled simulations with both surface and volume coupling
- implement a *multithread* version of KGGGP algorithm based on OpenMP



POP (Parallel Ocean Program) simulation coupling ocean and atmosphere models.

References

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