Parallel computing for 2D/3D meshing manipulation

Lyon 1

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Context

- 2D / 3D Mesh refinement (Region Of Interest)
- Real time simulation

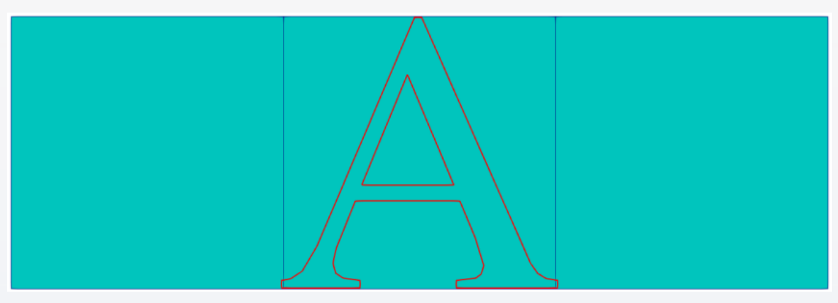
Objective

- Analyze the existing library
- Find data structure to optimize parallelization
- Speed up the meshing process

Mesh construction

1. Compute the Bounding Box

(i.e. create the minimal number of initial quadrants that contains the input surface)

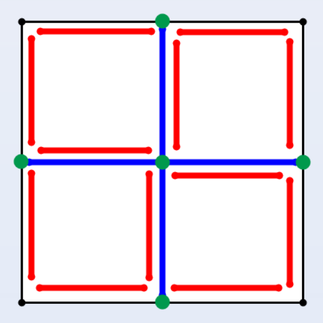


2. Generate Quadrants

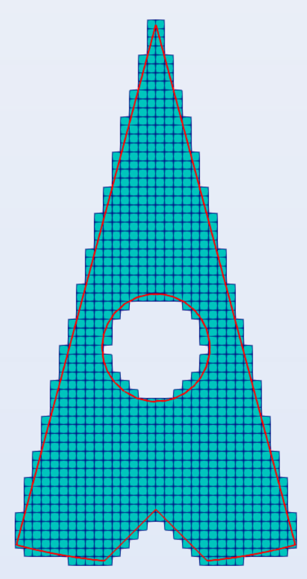
Process :

```
Repeat until desired Refinement Level
    For each Quadrant :
        If the quadrant intersects the chosen region
            Split the quadrant into 4 new identical quadrants.
        Remove those which are outside.
```

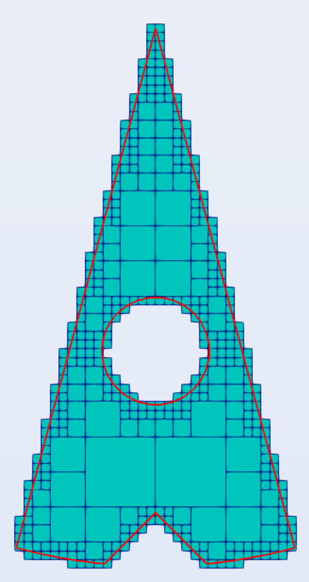
Splitting process :
in red and blue new edges
in green new points

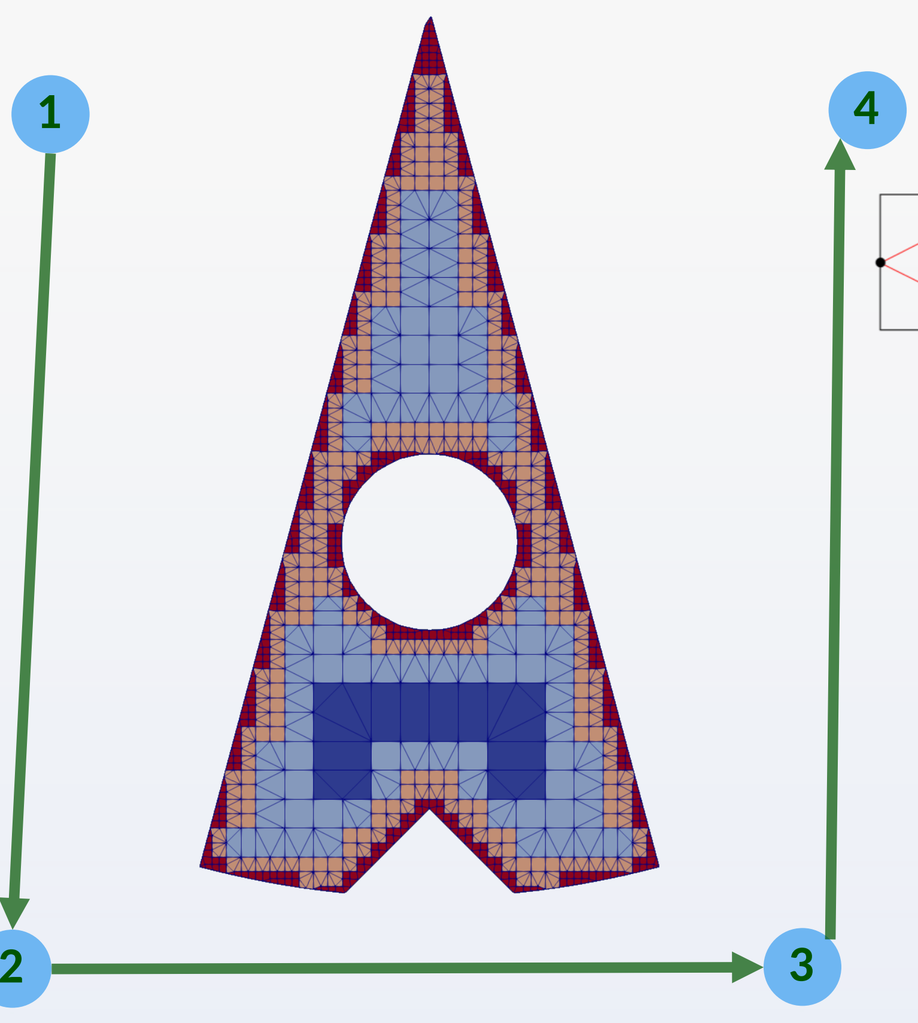


Split all region



Split surface region

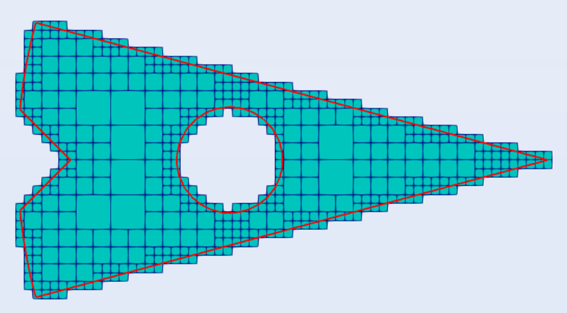




3. Create a balanced structure

(i.e. at most 1 subdivision level between two adjacent quadrants)

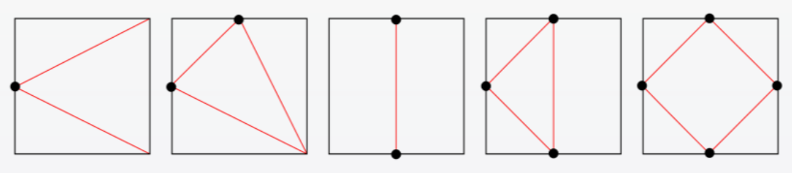
```
For each Quadrant :
    if the quadrant has a subdivided edge (midpoint != 0)
    check if the subdivided edge are subdivided
```



Balanced with surface region

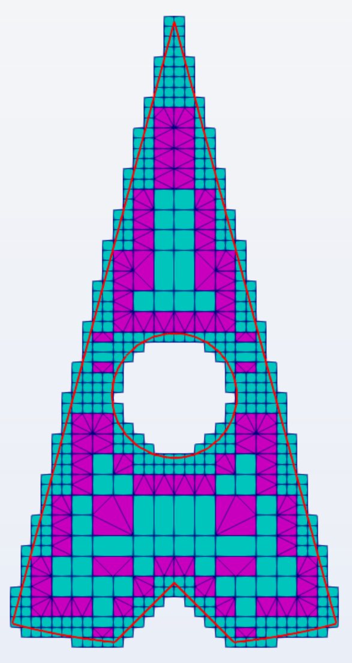
4. Apply the transition patterns

(i.e. to produce a conformal mesh)



The transition patterns

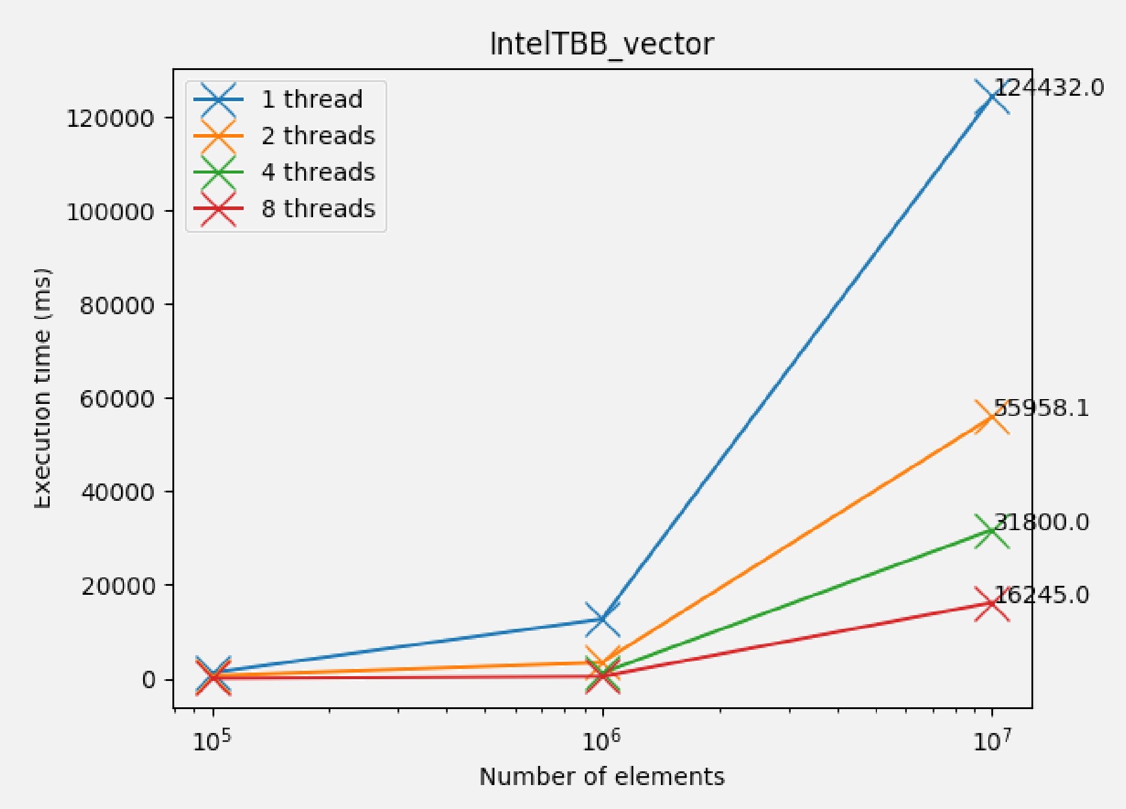
Transition patterns applied on output of the meshing on surface region



Libraries for C++ parallelism

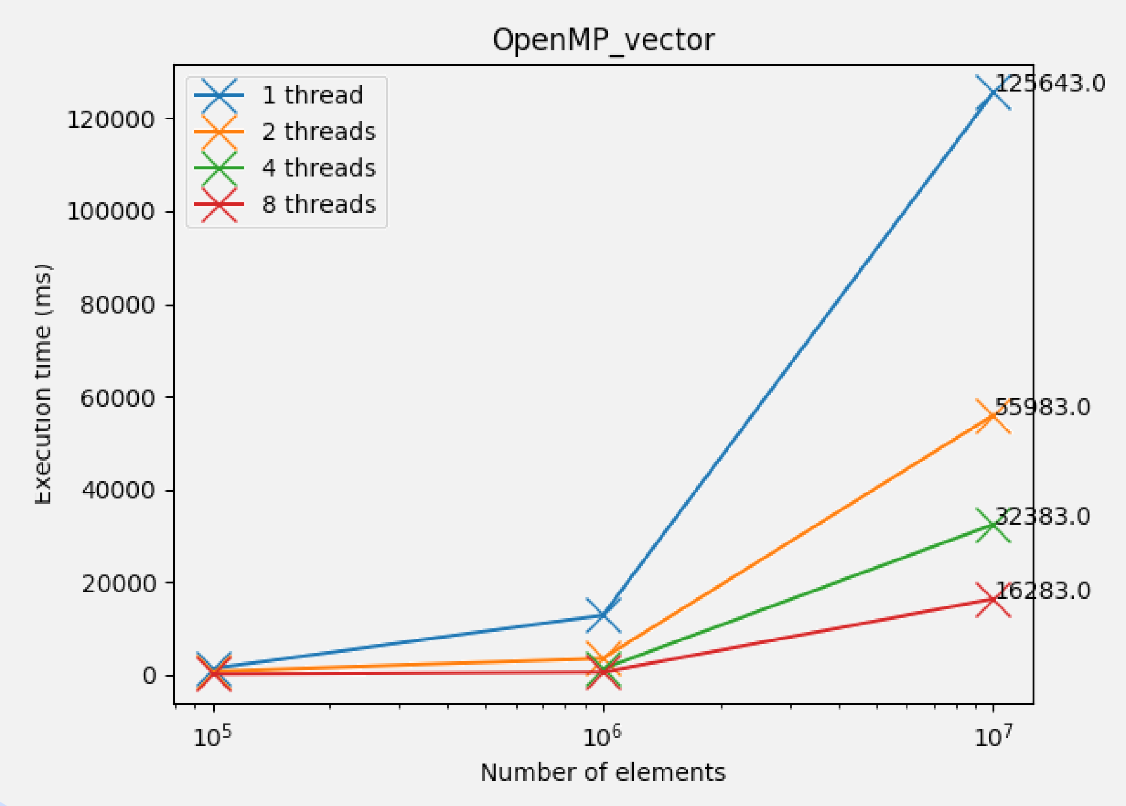
- IntelTBB

+ Thread-safe containers
- Only few examples



- OpenMP

+ Pre-processing directives



Parallelize the mesh construction

Mutex version

- Protect the critical regions with different mutex.
- Use of concurrent data structures, such as tbb::concurrent_unordered_set to replace the set of QuadEdges.

Critical regions

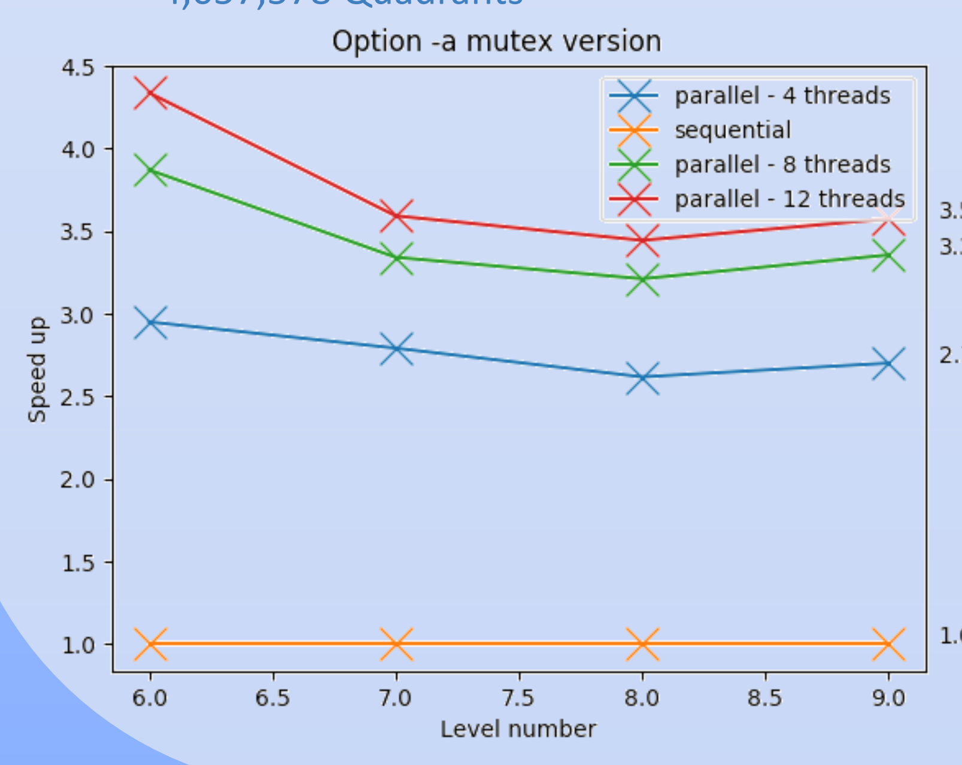
- read/write in concurrency in the set of quadedge = one edge could be split twice
- Write new points and new quadrants

Problems

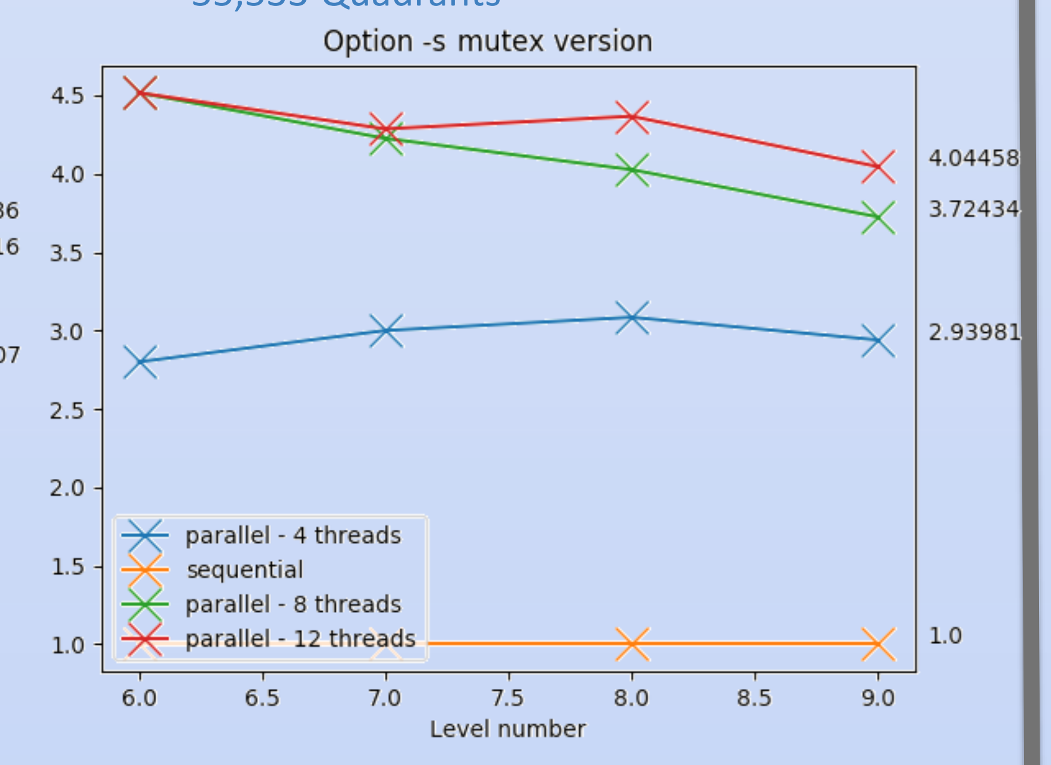
- It is not possible to modify an element in a set (eg. In the set of QuadEdges) because of the hashtable used to sort elements. However, it is possible to modify a mutable attribute of an element if it's not used for sorting.

Results

Refinement applied on ALL Quadrants
At the end :
4,095,572 points, 13,653,086 QuadEdges and 4,057,578 Quadrants



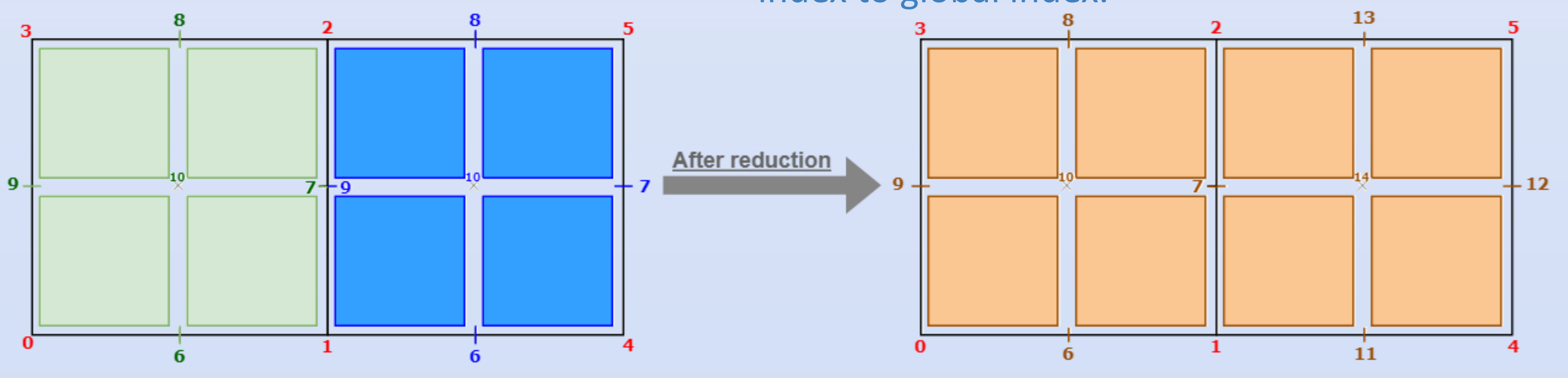
Refinement applied on SURFACE Quadrants
At the end :
106,819 points, 320,520 QuadEdges and 55,533 Quadrants



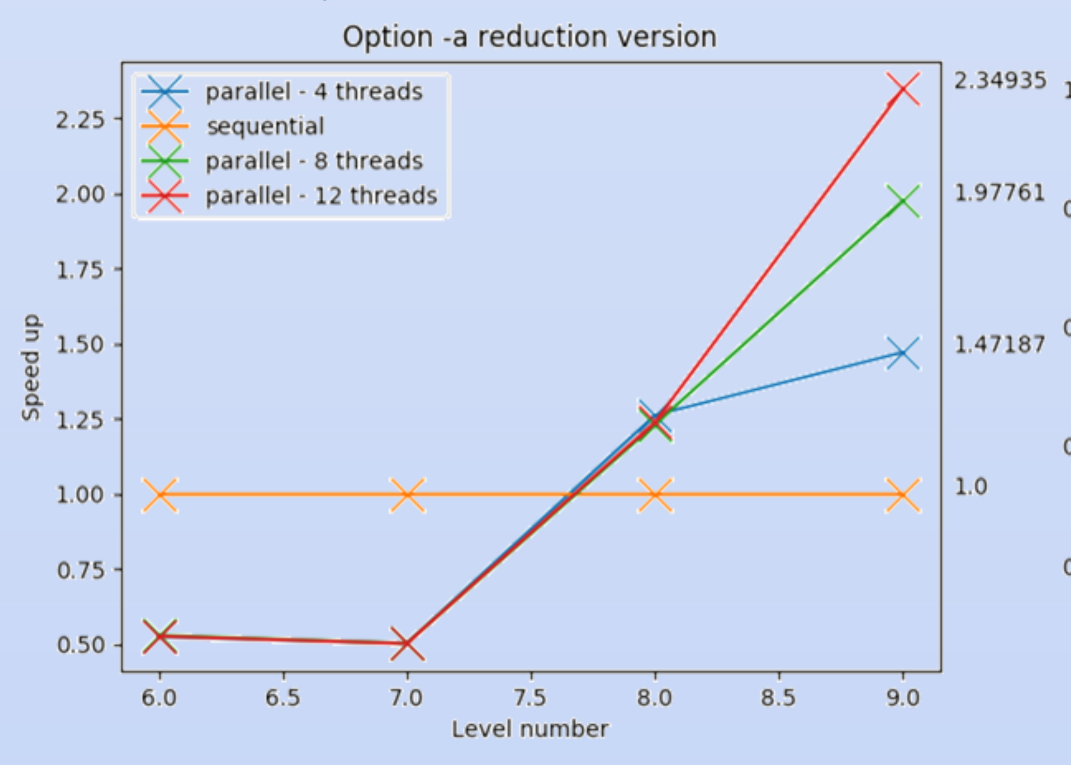
```
for (int rl=0; rl<desiredLevel; ++rl) {
    #pragma omp parallel
    {
        int tn = omp_get_thread_num();
        accumulation(newPts[tn], newEdges[tn], newQuad[tn]);
    }
    //Single thread
    reduction(newPts, newEdges, newQuad);
}
```

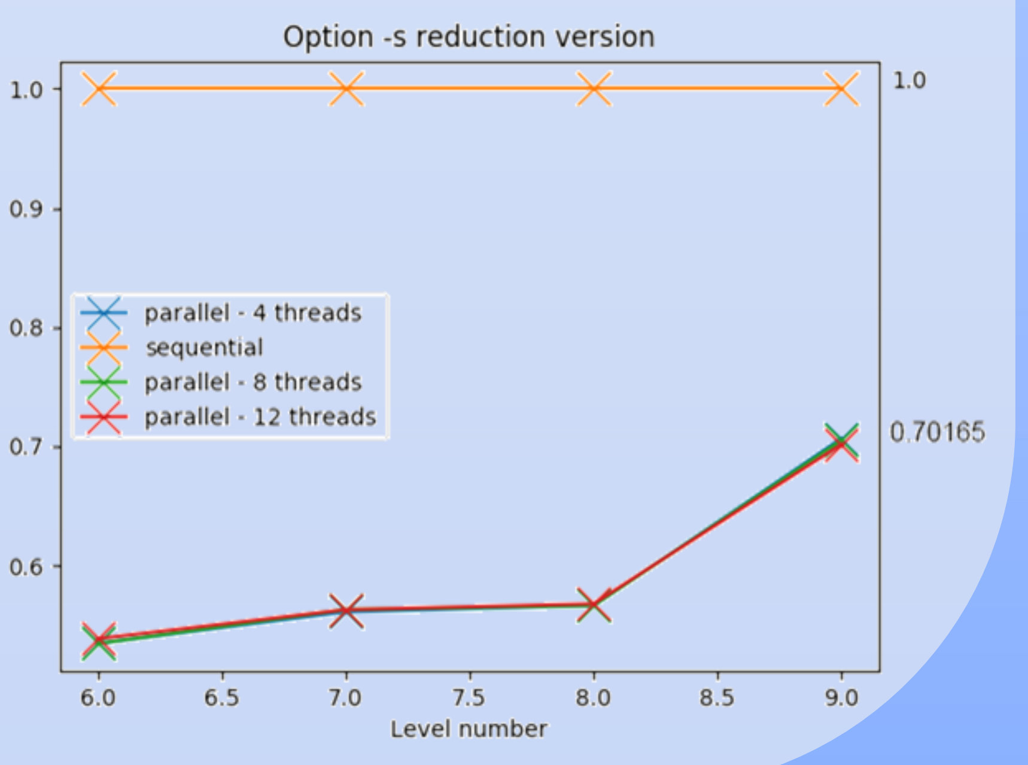
Reduction version

- No more critical regions.
- All threads have their own copy of Edges, Points and Quadrants filled in the accumulation part.
- The reduction part is done by a single thread and creates the final Edges, Points and Quadrants.
- Detection of identical points and update the local index to global index.



Before/after the reduction process. In red points before the accumulation done by green and blue threads. Notice that they start creating points at index 6 (the number of points before the accumulation)





Conclusion

- **The mutex version is more performant than the reduction, even for high number of quadrants (> 10^9). The reduction part is done sequentially and should need optimizations**
- **Implementations avoiding critical sections produce a lot of new code, and it makes the whole project less maintainable**
- **Parallelism is not easy !**

Perspectives

- **Build a quadtree structure to represent all the Quadrants**
- **Speed up the reduction part of the version with reduction with a better algorithm and/or the use of parallelism**
- **Make the reduction process only when the desired refinement level is reached**