Thesis Proposal

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Outline

- Scalable overlay operations over DCEL polygons layers
- Towards parallel detection of movement patterns in large trajectory databases

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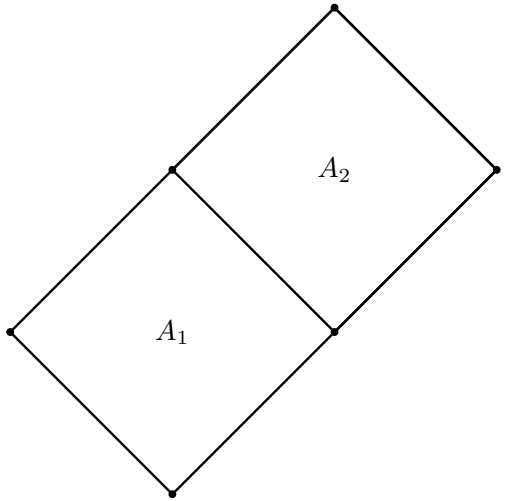
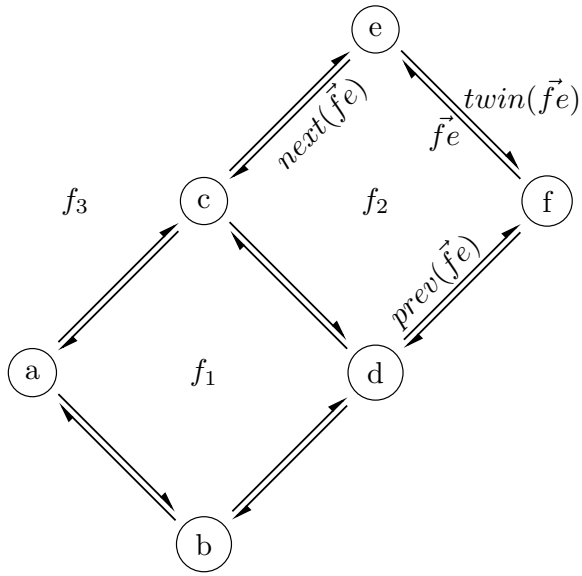
- **Scalable overlay operations over DCEL polygons layers (SSTD'23)**
- Towards parallel detection of movement patterns in large trajectory databases

What is a DCEL?

- **Doubly Connected Edge List** - DCEL.
- A spatial data structure to **represent planar subdivisions** of surfaces.
- Represent topological and geometric information as vertices, edges, and faces.
- **Applications**: polygon overlays, polygon triangulation and their applications in surveillance, robot motion planing, circuit board printing, etc.



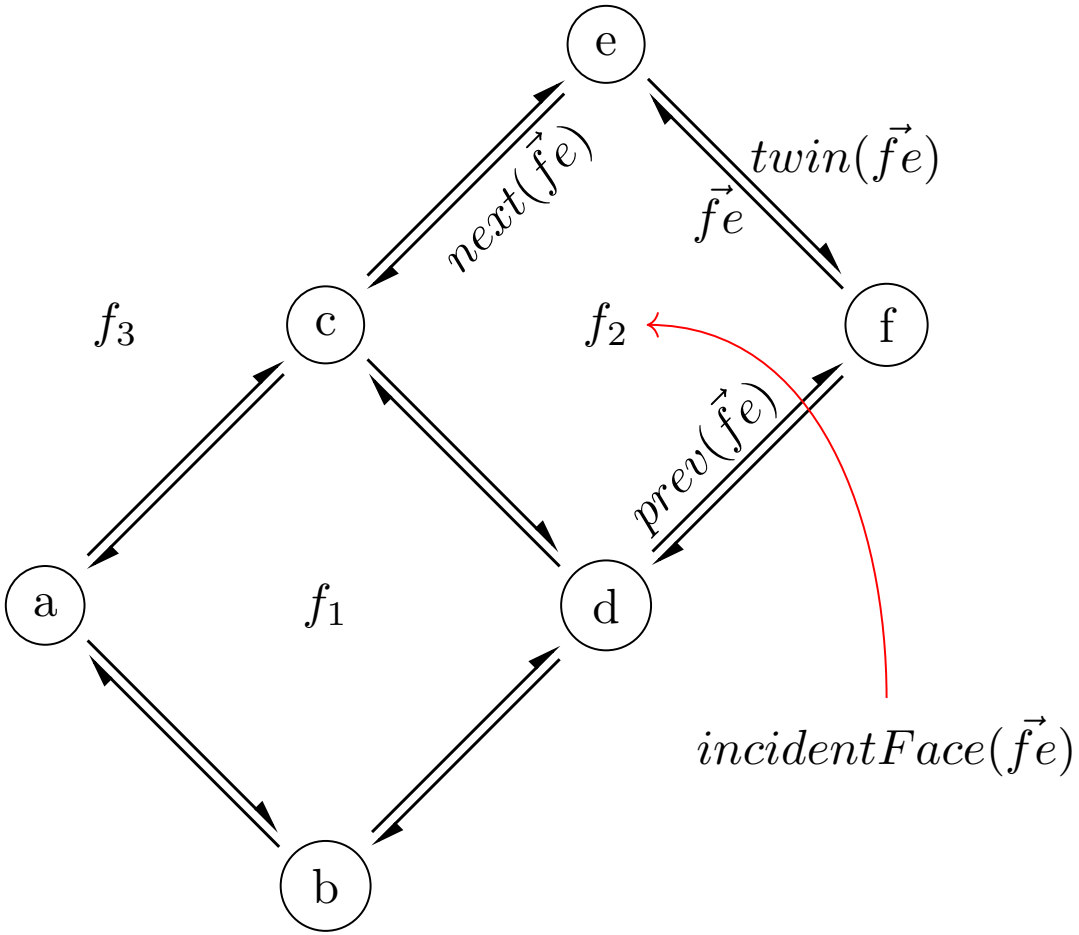
Planar subdivision



DCEL representation

DCEL description

- DCEL uses three tables: Vertices, Faces and Half-edges.



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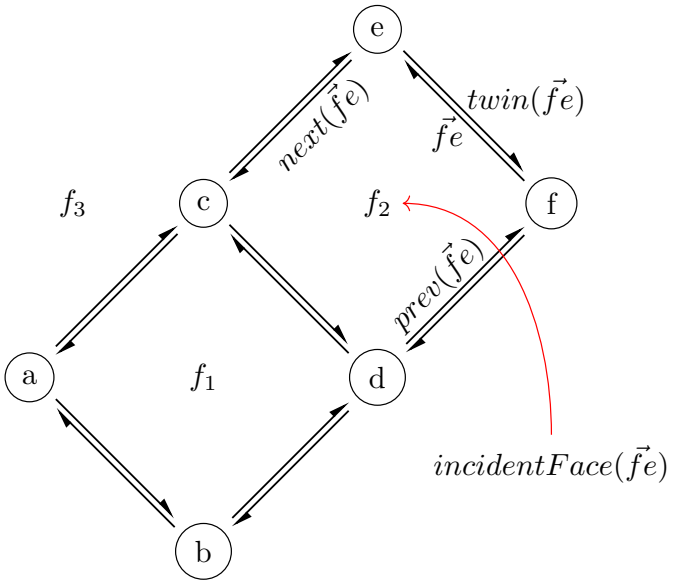


Table 1: **Vertex records.**

vertex	coordinates	incident edge
a	(0,2)	$\vec{ba}$
b	(2,0)	$\vec{db}$
⋮	⋮	⋮
e	(4,6)	$\vec{fe}$
f	(6,4)	$\vec{df}$
⋮	⋮	⋮

Table 2: **Face records.**

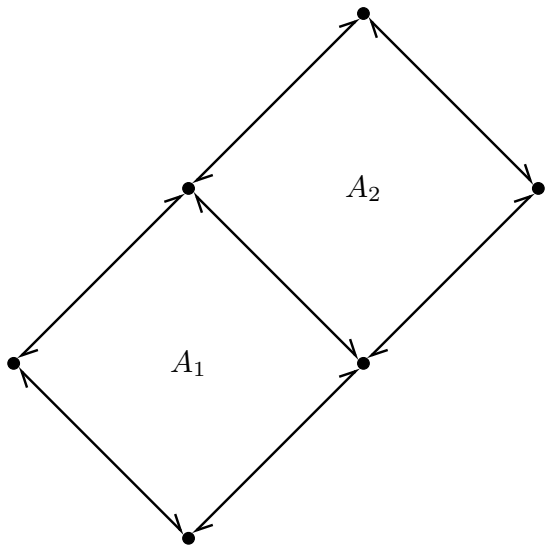
face	boundary edge	hole list
f_1	$\vec{ab}$	*nil*
f_2	$\vec{fe}$	*nil*
f_3	*nil*	*nil*

Table 3: **Half-edge records.**

half-edge	origin	face	twin	next	prev
$\vec{fe}$	f	f_2	$\vec{ef}$	$\vec{ec}$	$\vec{df}$
$\vec{ca}$	c	f_1	$\vec{ac}$	$\vec{ab}$	$\vec{dc}$
$\vec{db}$	d	f_3	$\vec{bd}$	$\vec{ba}$	$\vec{fd}$
⋮	⋮	⋮	⋮	⋮	⋮

DCEL Advantages

- **Efficiency**: very efficient for computation of *overlay operators*.
- **Re-usability**: allows multiple operations over the same DCEL.
- **Pipelining**: the output of a DCEL operator can be input to another DCEL operator.



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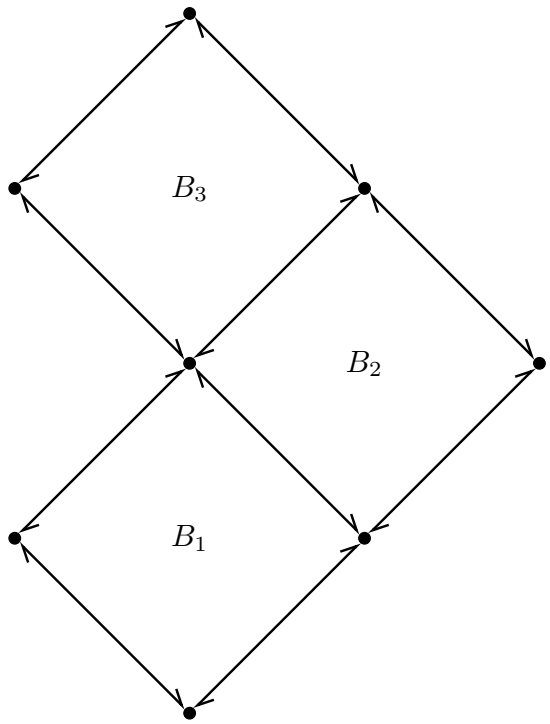

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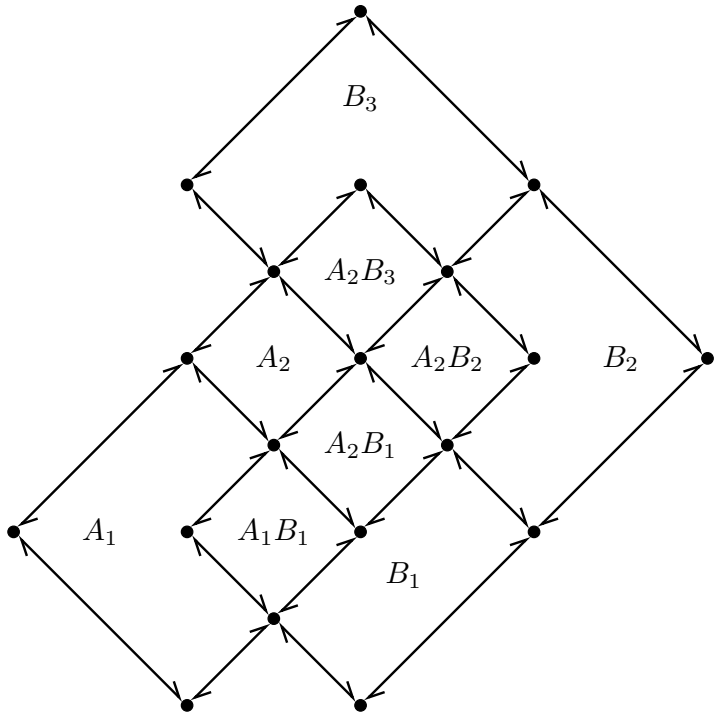

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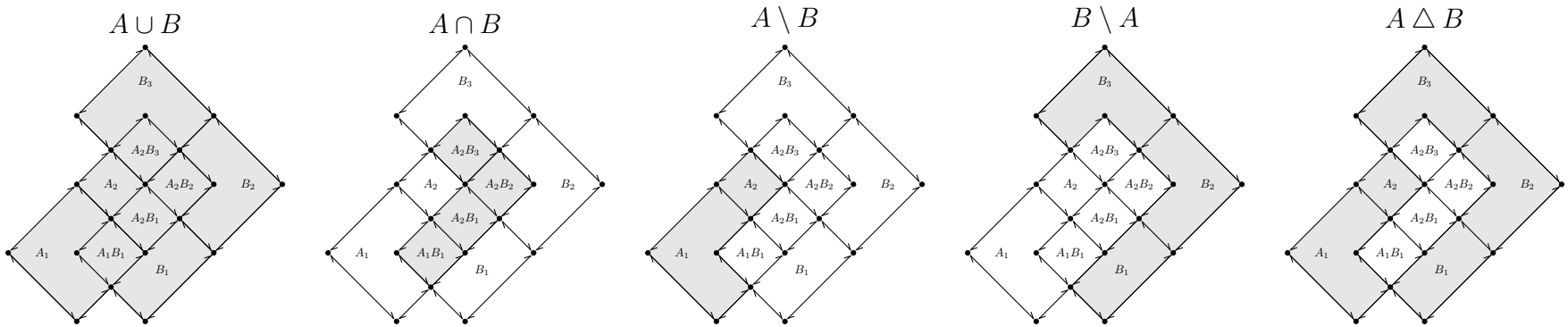
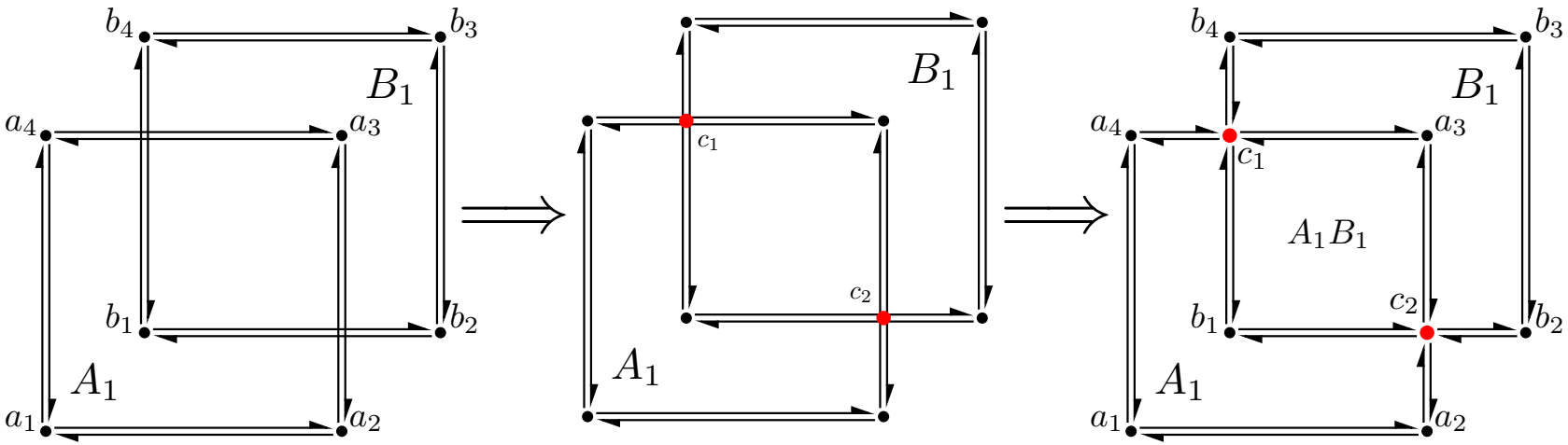


Challenges and Contributions

- Currently only sequential DCEL implementations exist.
- Unable to deal with large datasets (i.e. US Census tracks at national level).
- We propose a *scalable distributed* approach to compute the overlay of two polygon layers using DCELs.
- Distribution enables scalability, but introduces challenges: the ***orphan-cell*** problem and the ***orphan-hole*** problem.

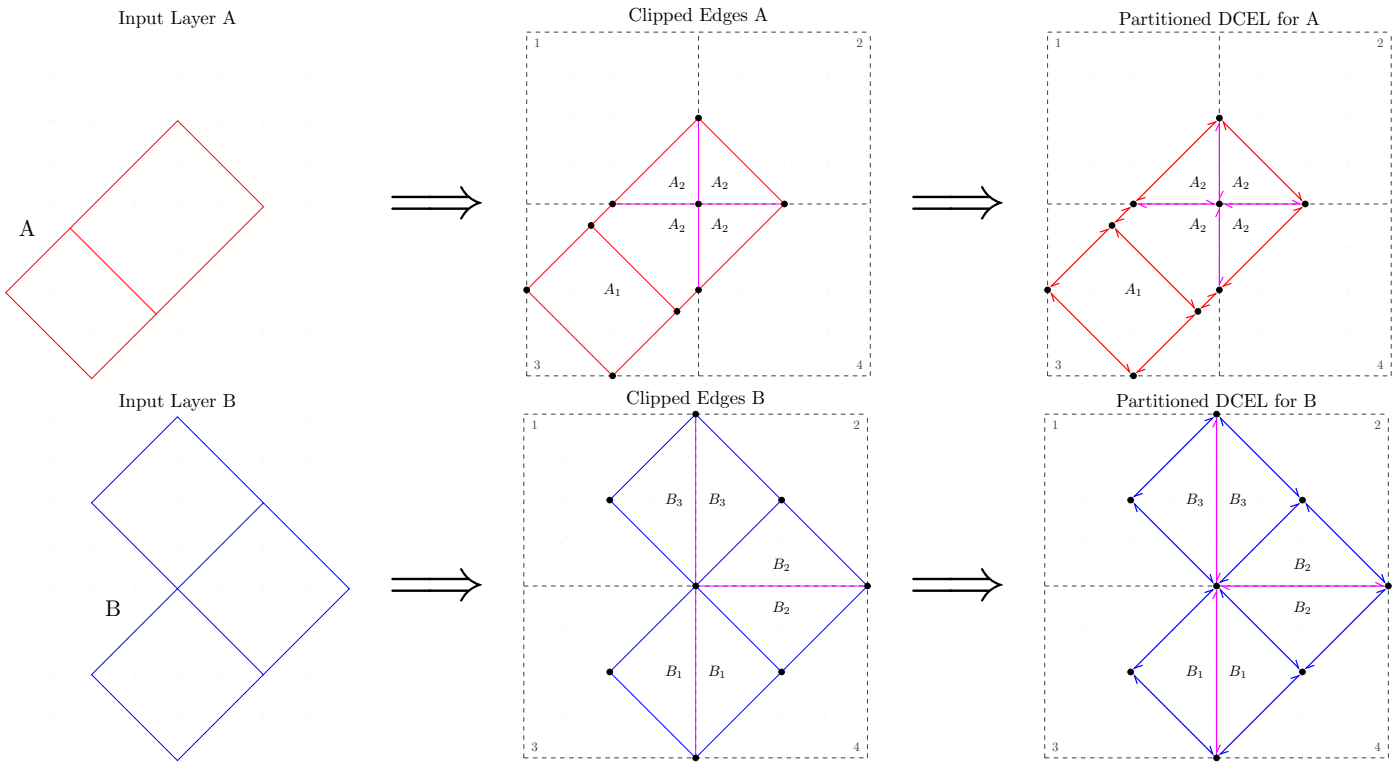
Sequential implementation

- Consider two (simple) input DCELs A_1 and B_1. The sequential algorithm first finds the intersections of half-edges.
- Then, new vertices (e.g. c_1, c_2) are created, half-edges are updated, new faces are added and labeled (e.g. A_1B_1).



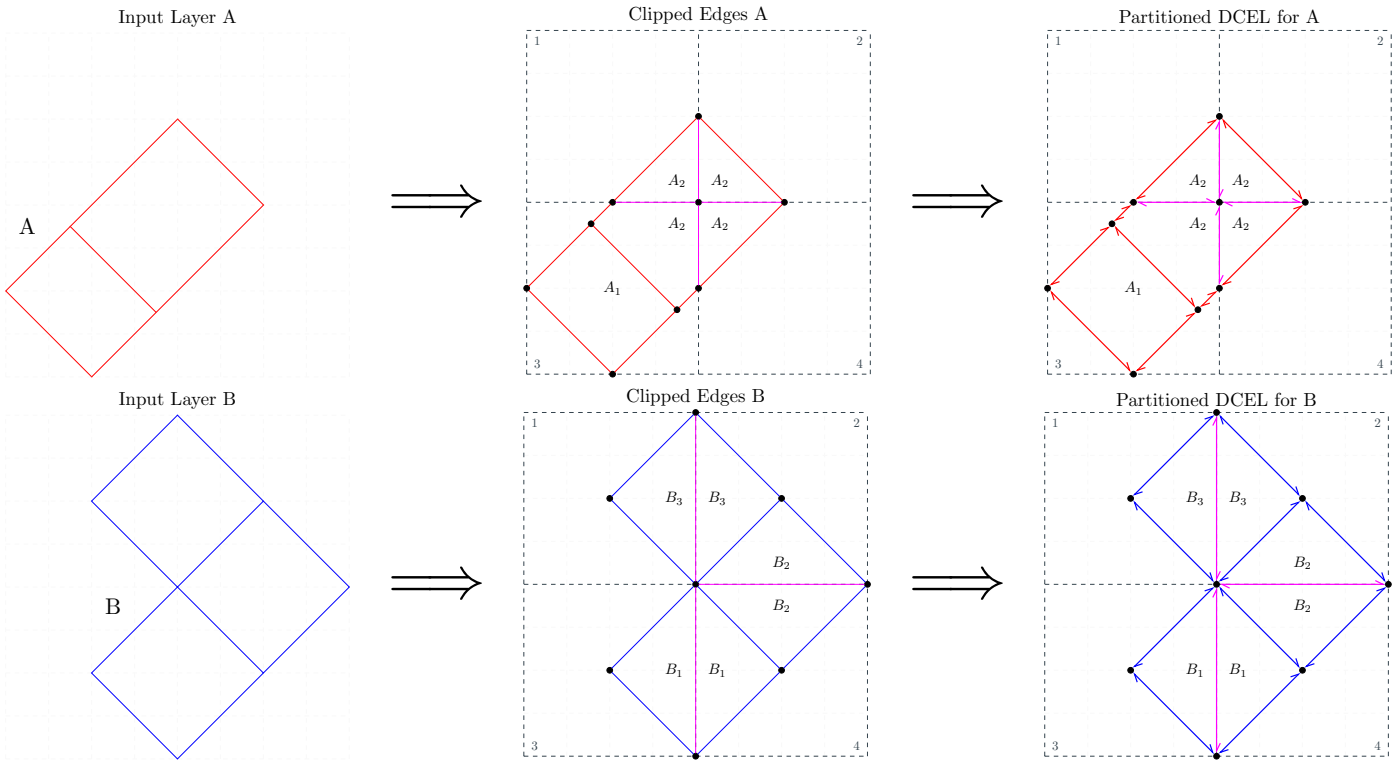
Scalable Implementation

- Two phases: (1) Distributed DCEL construction, and (2) Distributed overlay evaluation.
- Distribution is based on a spatial index (e.g. quadtree)
- Each input DCEL layer (e.g. A, B) is partitioned using the same index

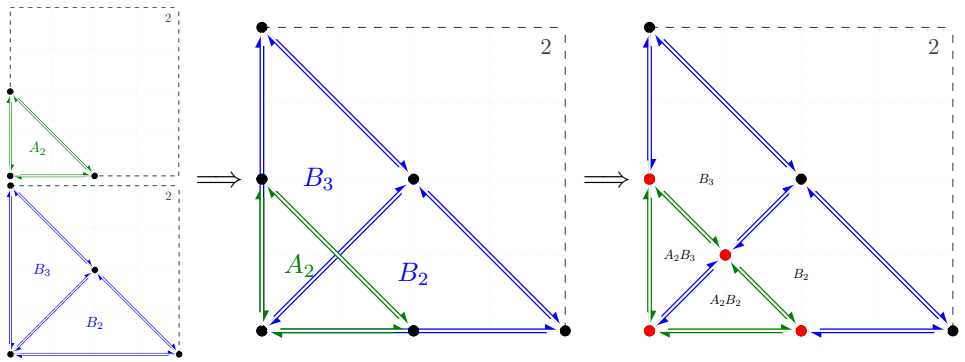


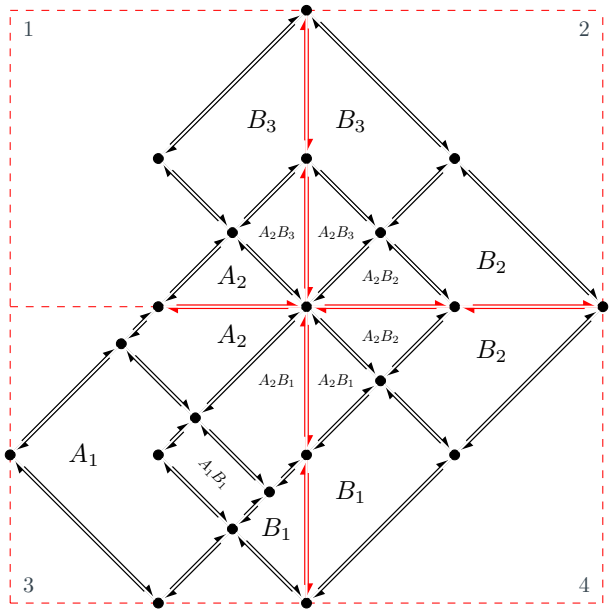
Scalable Implementation

- Each index cell should contain all information needed so that it can compute the overlay DCEL locally
- For each cell to be independent, we need to create "artificial" edges and vertices



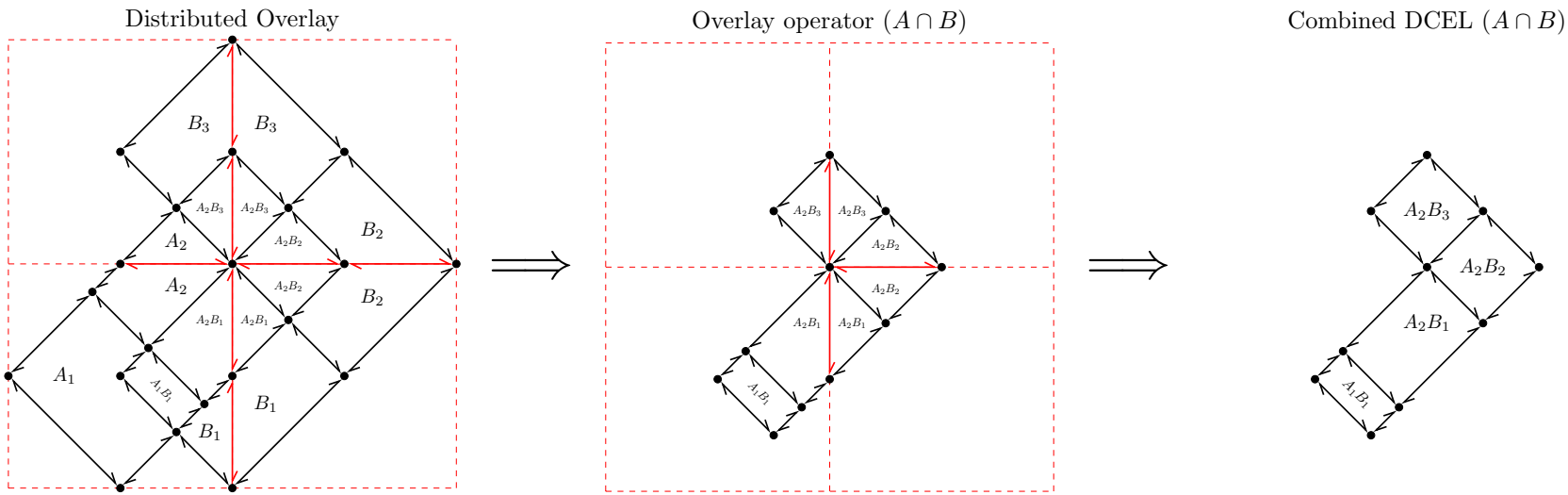
Distributed DCEL construction





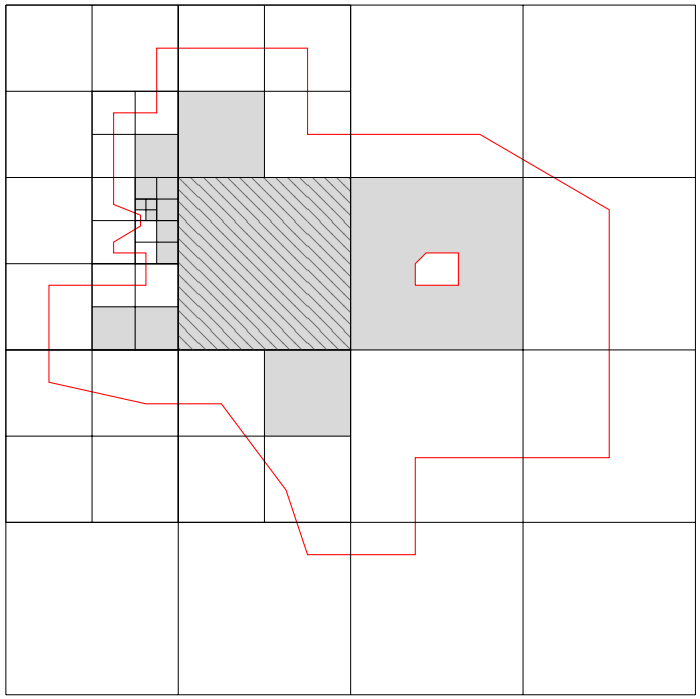
Overlay evaluation

- Answering global overlay queries...
  - To compute a particular overlay operator, we query local DCELs.
  - This work is done independently at each cell (node).
  - SDCEL then collects back all local DCEL answers and computes the final answer (by removing artificial edges and concatenating the resulting faces).



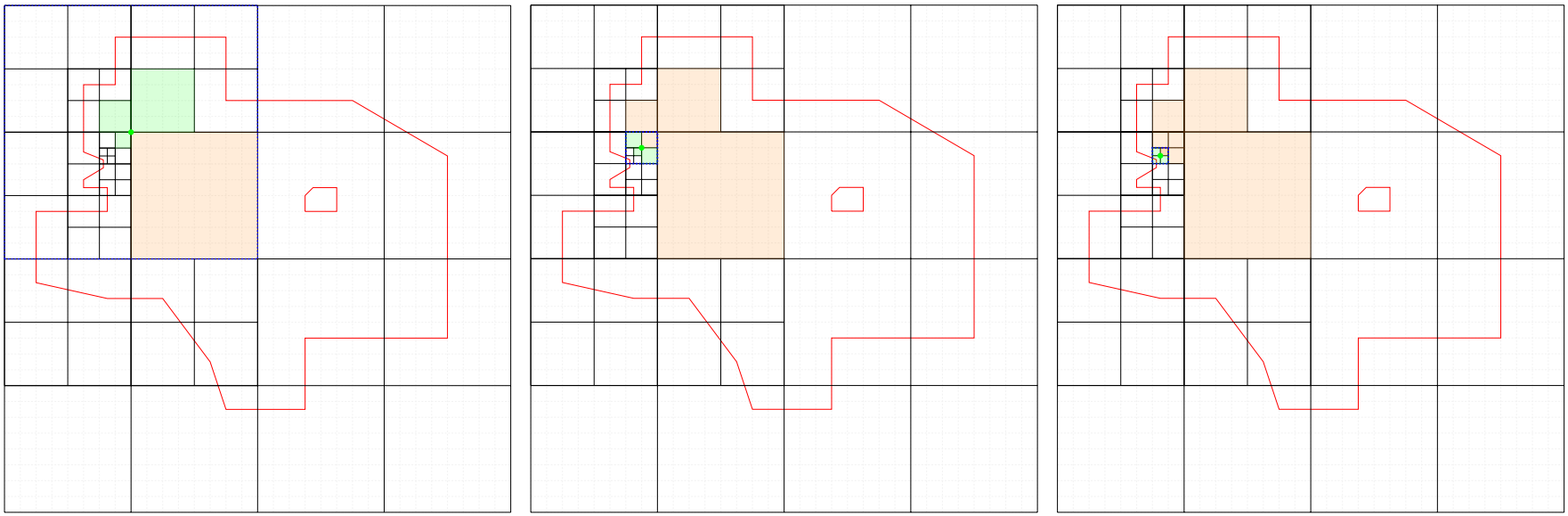
Labeling orphan cells and orphan holes

- We next discuss the **orphan cell** problem (orphan holes are handled similarly).
- A large face (e.g. the red polygon in the figure) can contain cells that do not intersect with any of the face's boundary edges (called *regular edges*).
- Such cells do not contain any label and thus we do not know which face they belong to.



Labeling orphan cells and orphan holes

- We provide an algorithm to efficiently solve the orphan cell problem.



Algorithm 1: getNextCellWithEdges algorithm

```
   Input: a quadtree Q and a list of cells M.
 1 function getNextCellWithEdges(Q,M):
 2     C ← orphan cells in M
 3     foreach orphanCell in C do
 4         initialize cellList with orphanCell
 5         nextCellWithEdges ← nil
 6         referenceCorner ← nil
 7         done ← false
 8         while ¬done do
 9             c ← last cell in cellList
10             cells, corner ← getCellsAtCorner(Q, c)
11             foreach cell in cells do
12                 nedges ← get edge count of cell in M
13                 if nedges > 0 then
14                     nextCellWithEdges ← cell
15                     referenceCorner ← corner
16                     done ← true
17                 else
18                     add cell to cellList
19                 end
20             end
21         end
22         foreach cell in cellList do
23             output(cell,nextCellWithEdges,
                 referenceCorner)
24             remove cell from C
25         end
26     end
27 end
```

Algorithm 2: getCellsAtCorner algorithm

```
   Input: a quadtree with cell envelopes Q and a cell c.
 1 function getCellsAtCorner(Q, c):
 2     region ← quadrant region of c in c.parent
 3     switch region do
 4         case 'SW' do
 5             corner ← left bottom corner of c.envelope
 6         case 'SE' do
 7             corner ← right bottom corner of c.envelope
 8         case 'NW' do
 9             corner ← left upper corner of c.envelope
10         case 'NE' do
11             corner ← right upper corner of c.envelope
12     end
13     cells ← cells which intersect corner in Q
14     cells ← cells − c
15     cells ← sort cells on basis of their depth
16     return (cells, corner)
17 end
```

Overlay optimizations

- Optimizing for faces overlapping many cells...
  - Naive approach sends all faces that overlap a cell to a master node (that will combine them).
  - We propose an intermediate reduce processing step.
    - The user provides a level in the quadtree structure and faces are evaluated at those intermediate reducers.
  - We also consider another approach that re-partitions such faces using their labels as the key.
    - It avoids the reduce phase but implies an additional shuffle.
    - However, as we show in the experiments this overhead is minimal.

Overlay optimizations

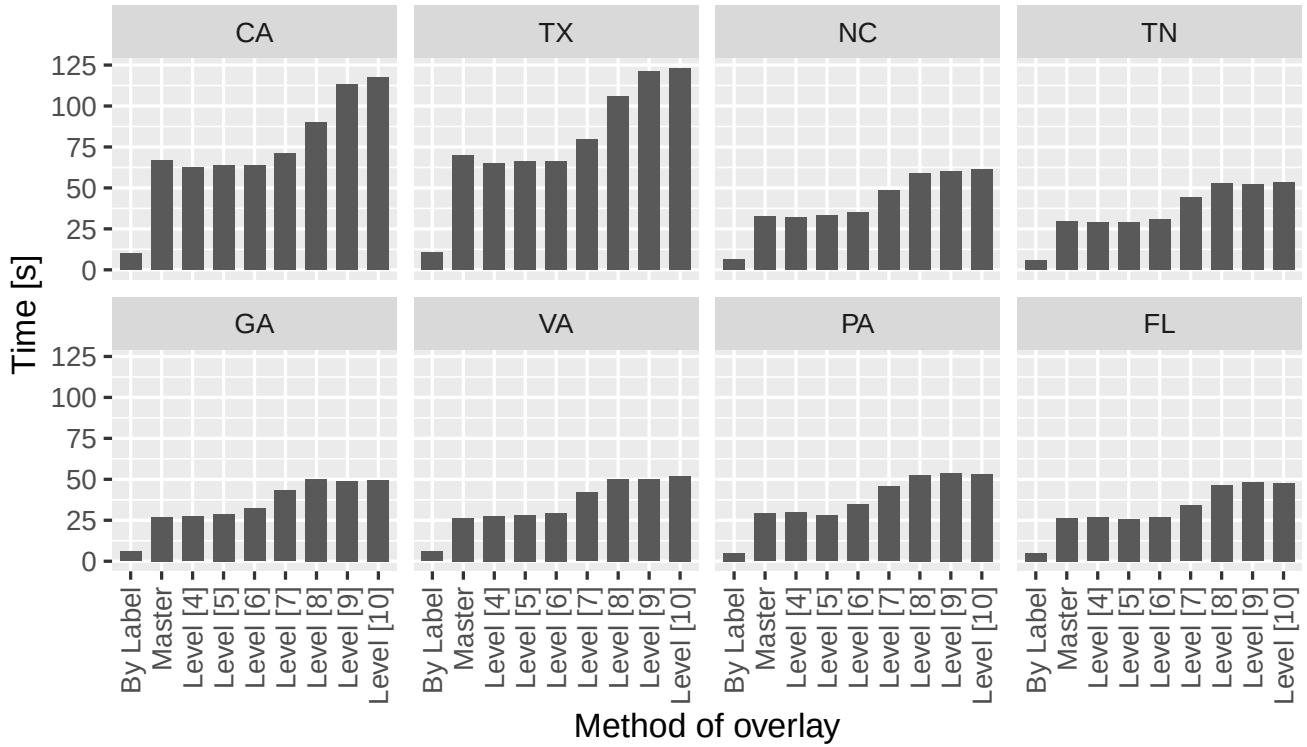
- Optimizing for unbalanced layers...
  - Finding intersections is the most critical part of the overlay computation.
  - However, in many cases one of the layers has much more half-edges than the other.
  - Sweep-line algorithms to detect intersections run over all the edges.
  - Instead we scan the larger dataset only for the x-intervals where there are half-edges from the smaller dataset.

- Datasets.

Dataset	Layer	Number of polygons	Number of edges
MainUS	Polygons for 2000	64983	35417146
	Polygons for 2010	72521	36764043
GADM	Polygons for Level 2	116995	32789444
	Polygons for Level 3	117891	37690256
CCT	Polygons for 2000	7028	2711639
	Polygons for 2010	8047	2917450

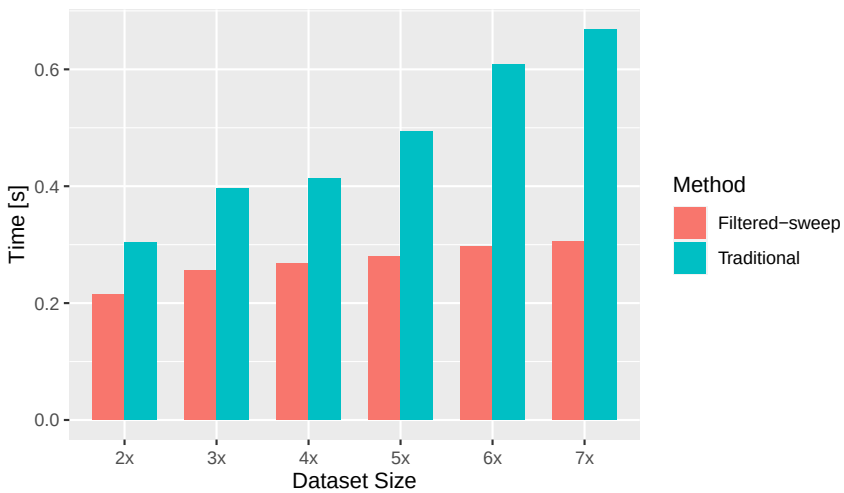
Experimental evaluation

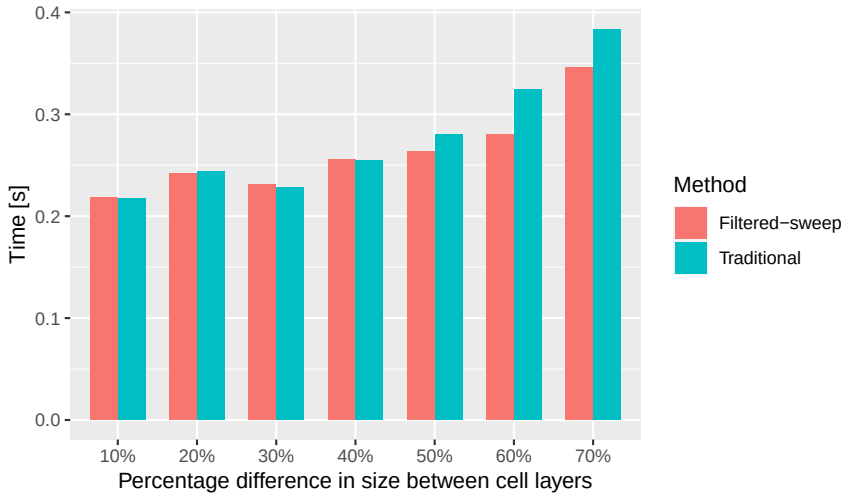
- Evaluation of the overlapping faces optimization.



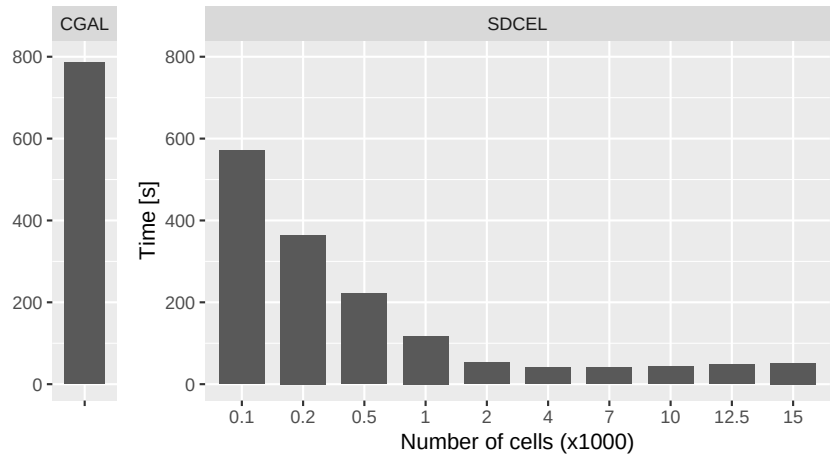
Experimental evaluation

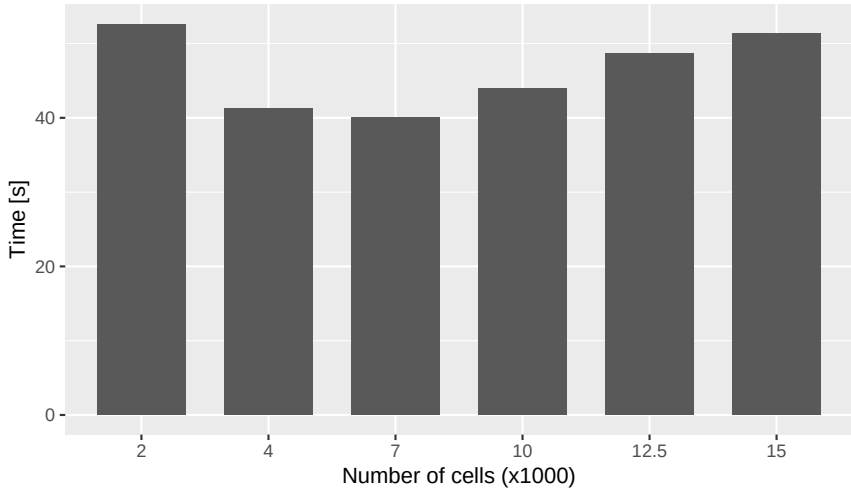
- Evaluation of the unbalanced layers optimization.





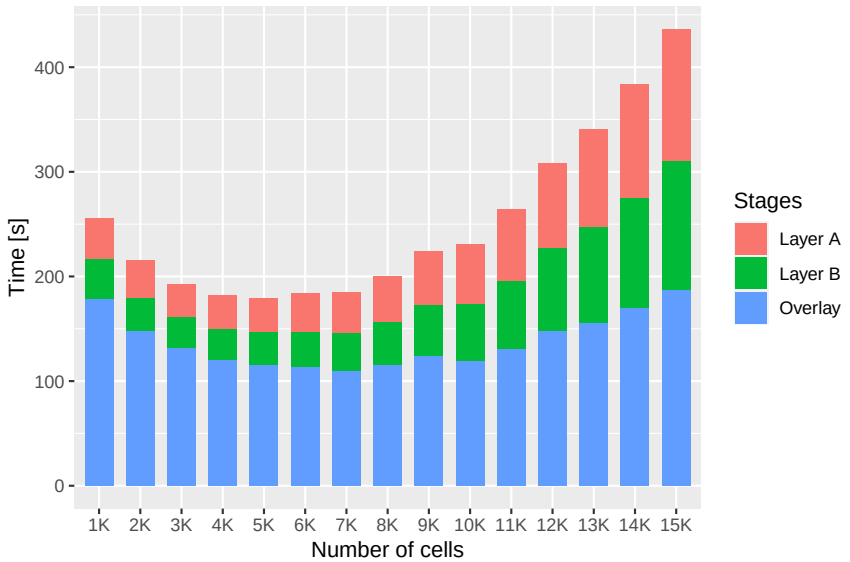
- Performance varying number of partition cells (CCT dataset).

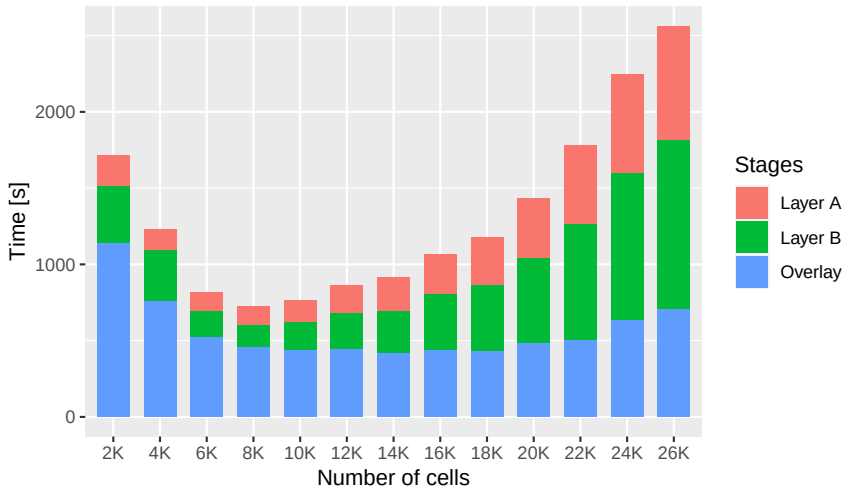




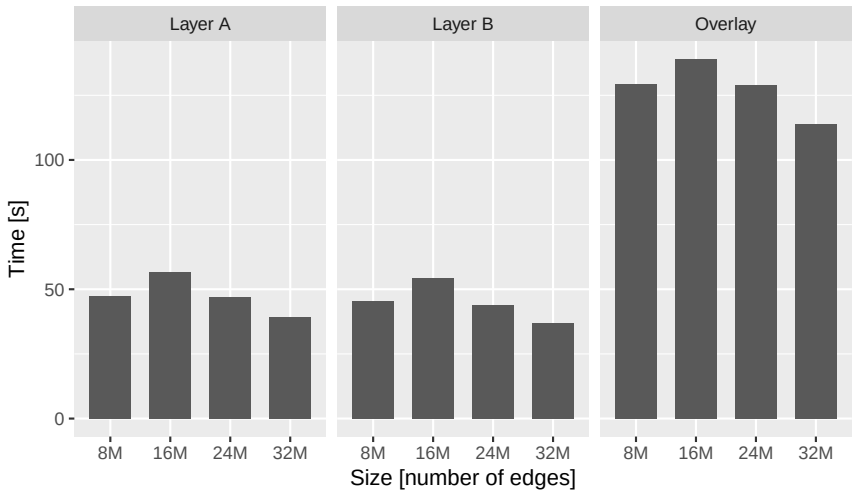
Experimental evaluation

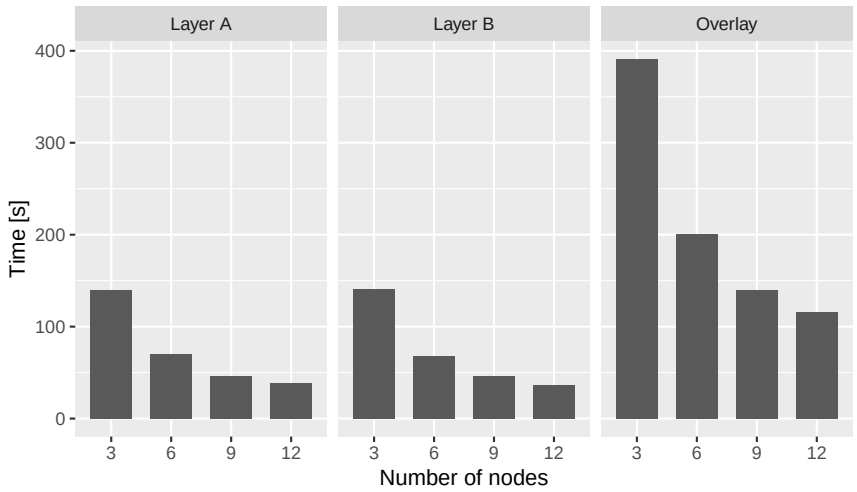
- Performance with MainUS and GADM datasets.





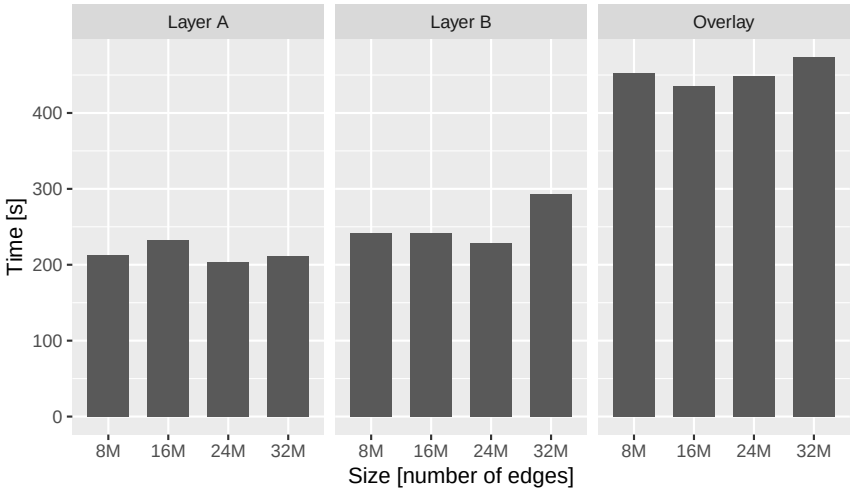
- MainUS scale-up and speed-up.

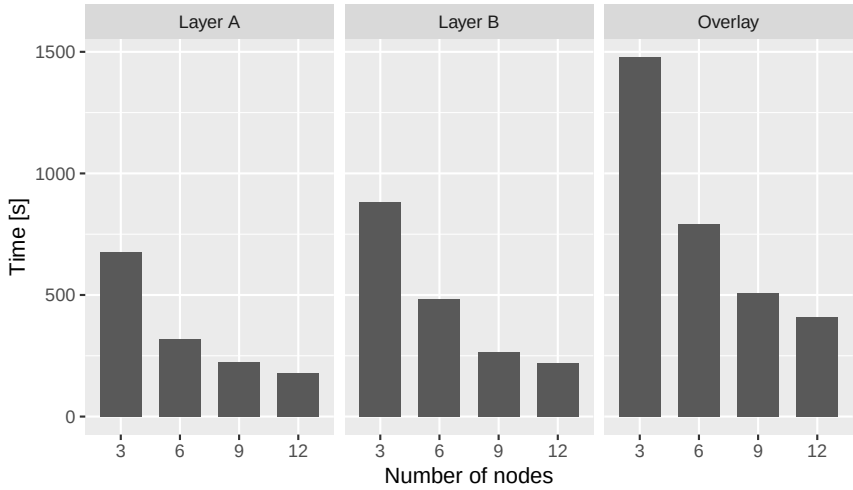




Experimental evaluation

- GADM scale-up and speed-up.





Conclusions

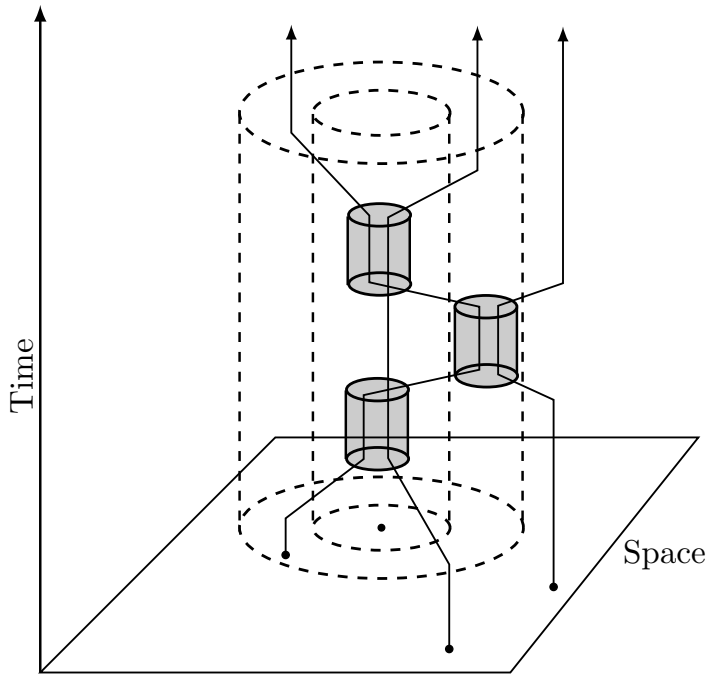
- We introduced SDCEL, a scalable approach to compute the overlay operation among two layers that represent polygons from a planar subdivision of a surface.
- We use a partition strategy which guarantees that each partition (cell) has the data needed to work independently.
- We also proposed several optimizations to improve performance.
- Our experiments using real datasets show very good performance; we are able to compute overlays over very large layers (each with >35M edges) in few minutes.

Outline

- Scalable overlay operations over DCEL polygons layers
- **Towards parallel detection of movement patterns in large trajectory databases**

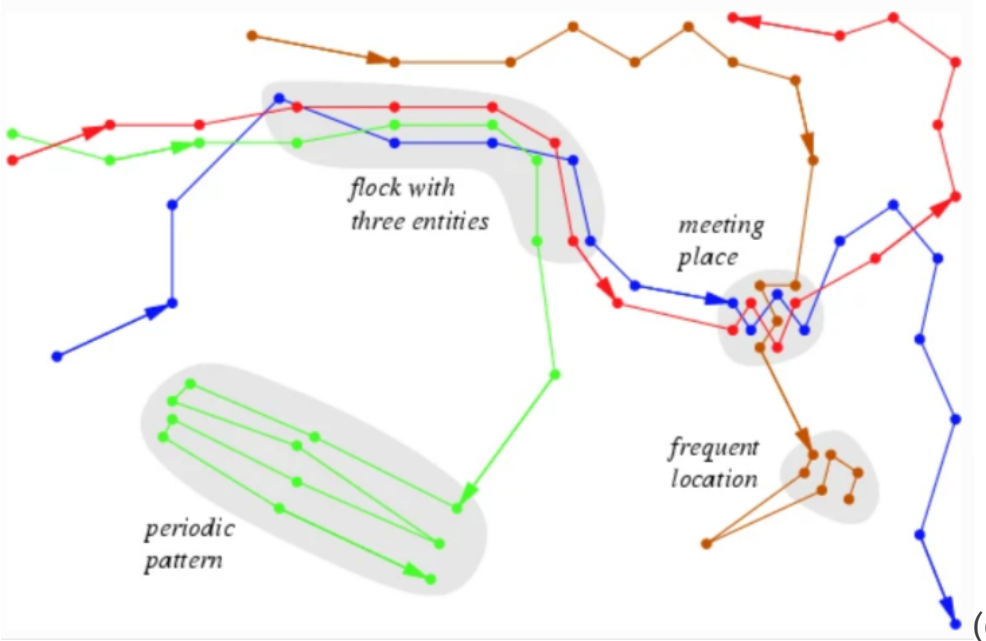
Large trajectory databases

- A spatial trajectory is a trace in time generated by a moving entity in a geographical space.
- i.e. $p_1 \rightarrow p_2 \rightarrow \cdots \rightarrow p_n$
- A trajectory is stored as a set of points, $p_i = (x, y, t)$ (spatial coordinate + time stamp).



(Shoval, 2017)

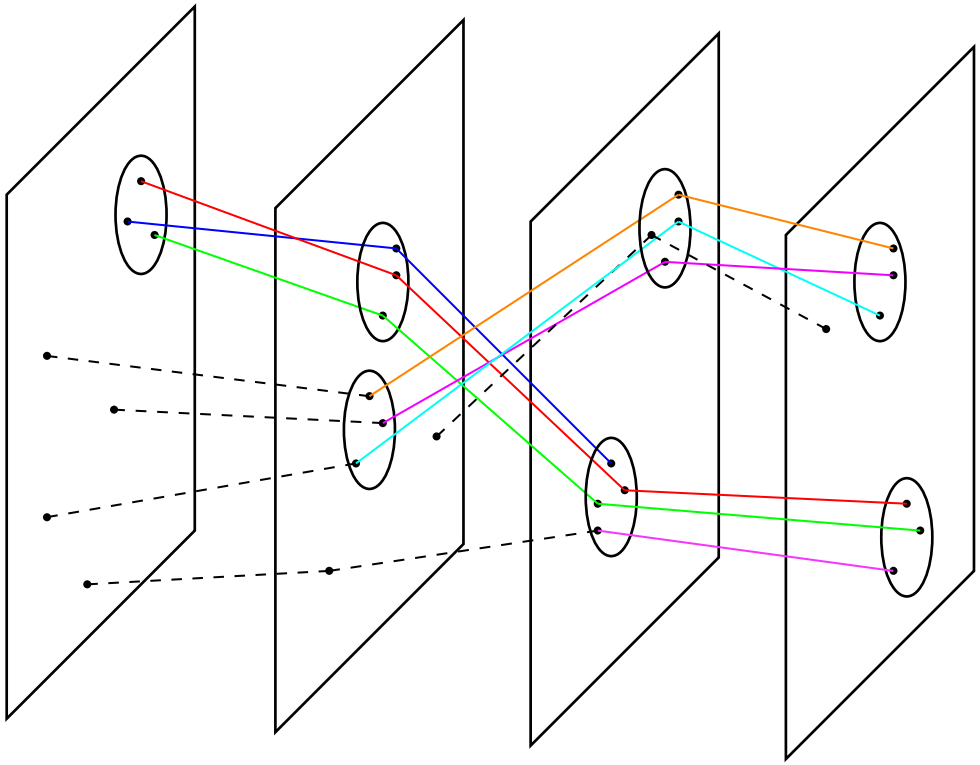
Movement patterns



(Gudmundsson, et al. 2008)

- i.e. convoys, moving clusters, swarms, gatherings, **flocks**, ...

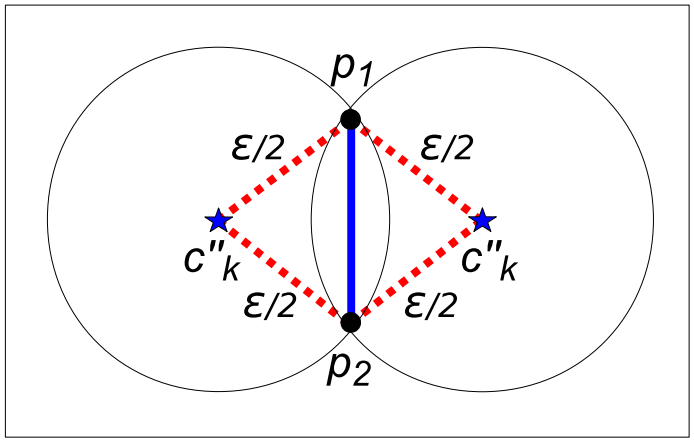
Flocks



- ε: Maximum distance between objects.
- μ: Minimum number of objects.
- δ: Minimum time the objects keep 'together'.

Basic Flock Evaluation algorithm

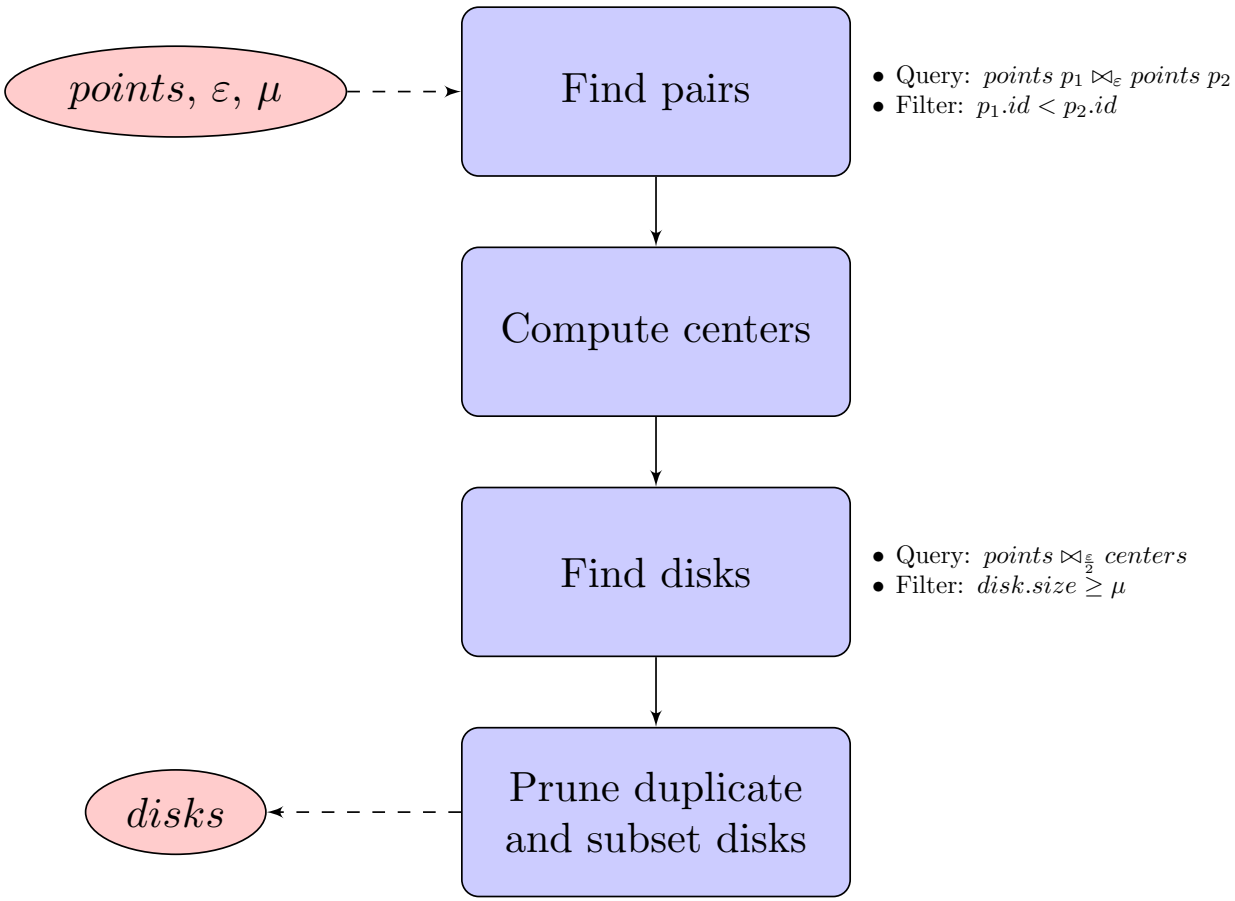
- Vieira, et al. 2009.
- First polynomial solution to location of the disks.
- Under fixed time duration it has polynomial time complexity $O(\delta|\tau|^{(2\delta)+1})$
- Two main parts:
  - In the spatial domain it finds maximal disks at each time stamp.
  - In the temporal domain it joins consecutive times to match set of maximal disks.



Challenges and contributions

- Due to high complexity it does not scale well.
- In databases with a large number of moving entities per time stamp it has a direct impact.
- Just sequential implementation yet.
- We propose a parallel solution in both domains.

- BFE overview...



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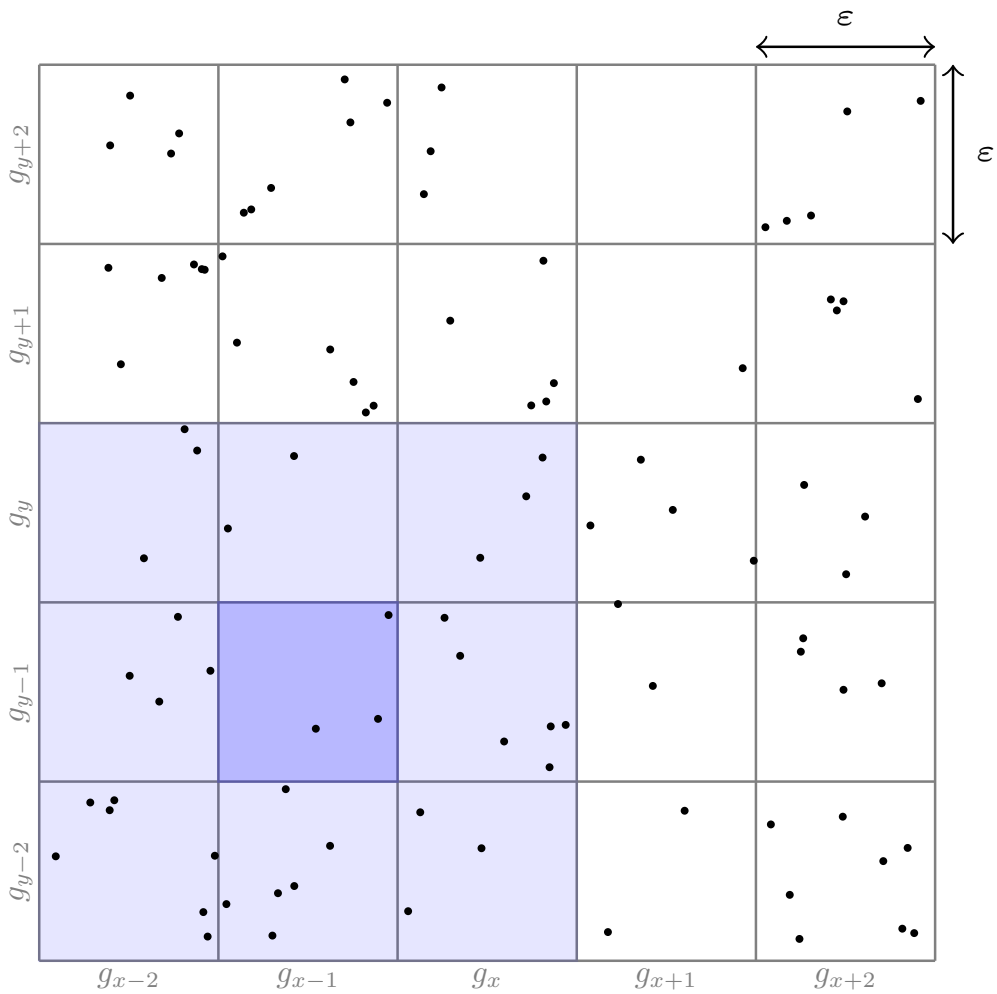

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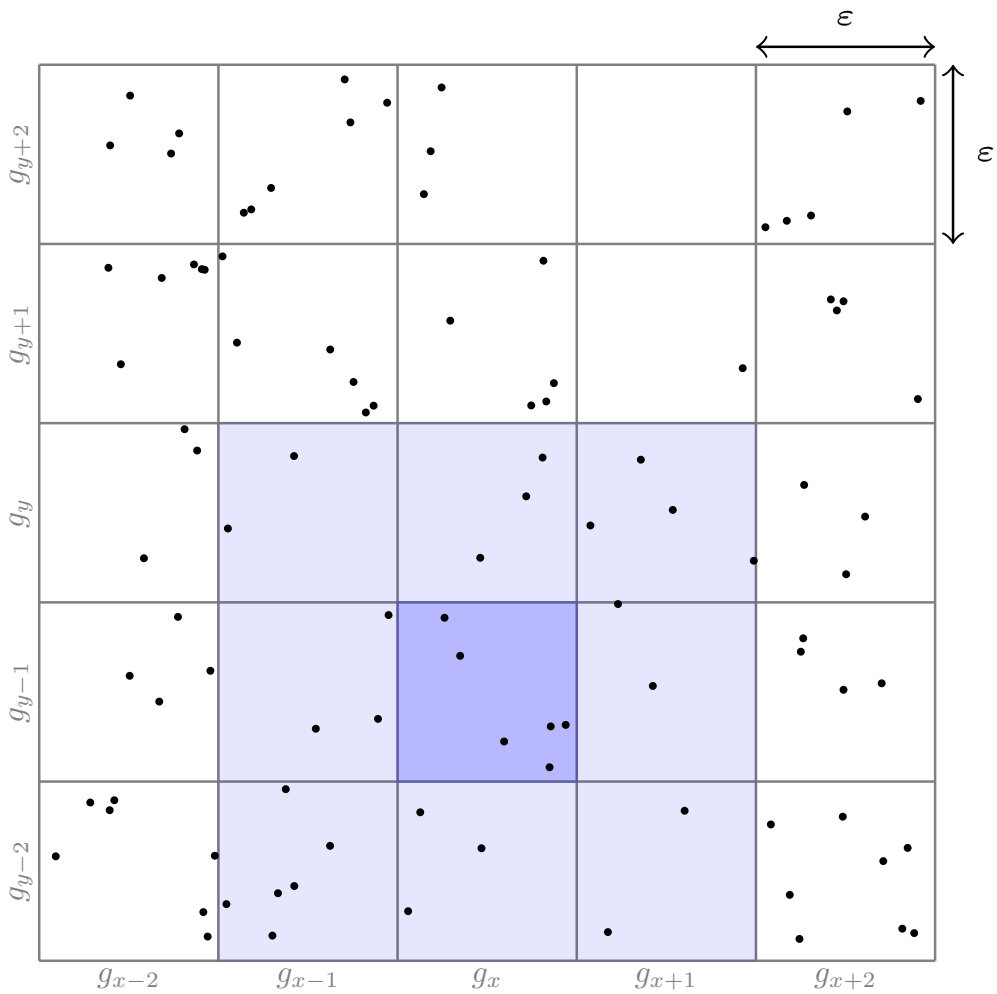

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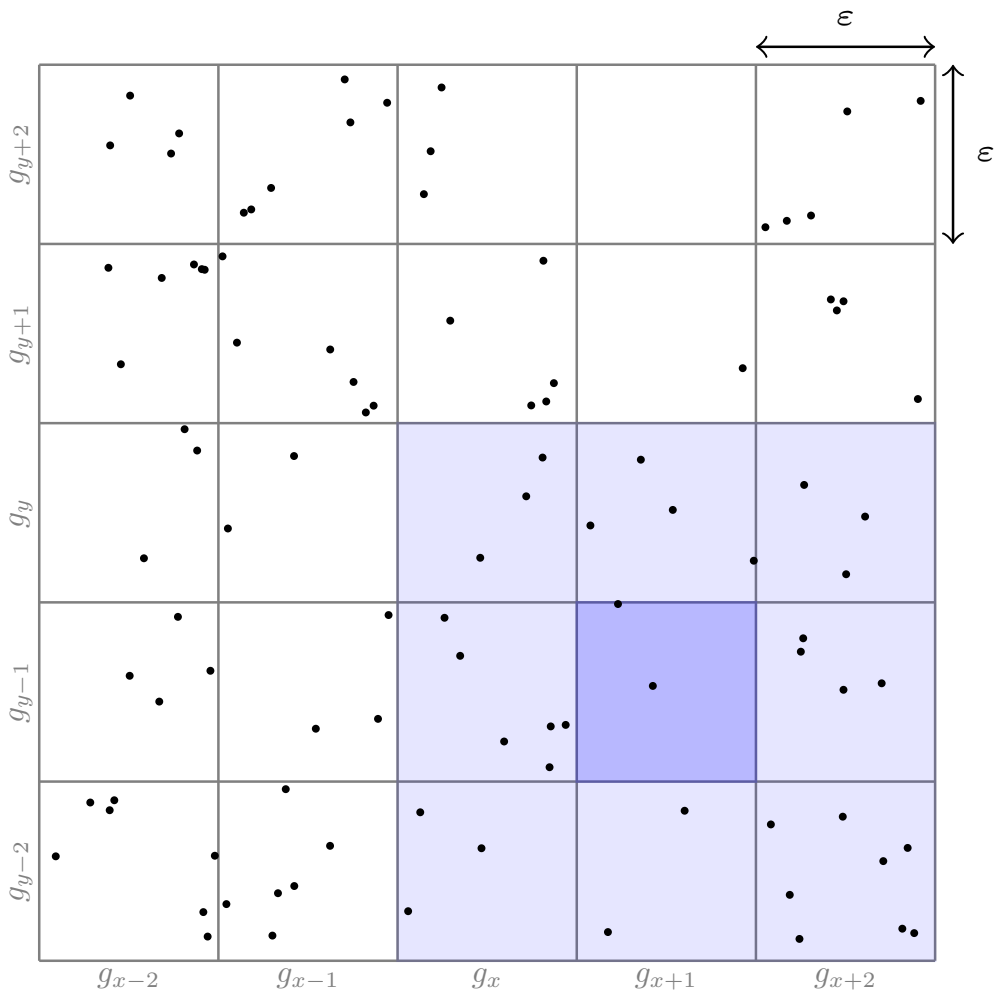

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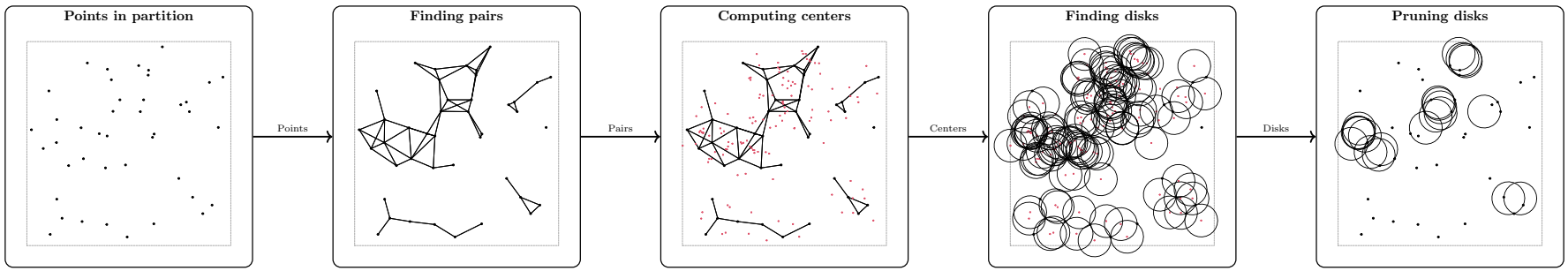
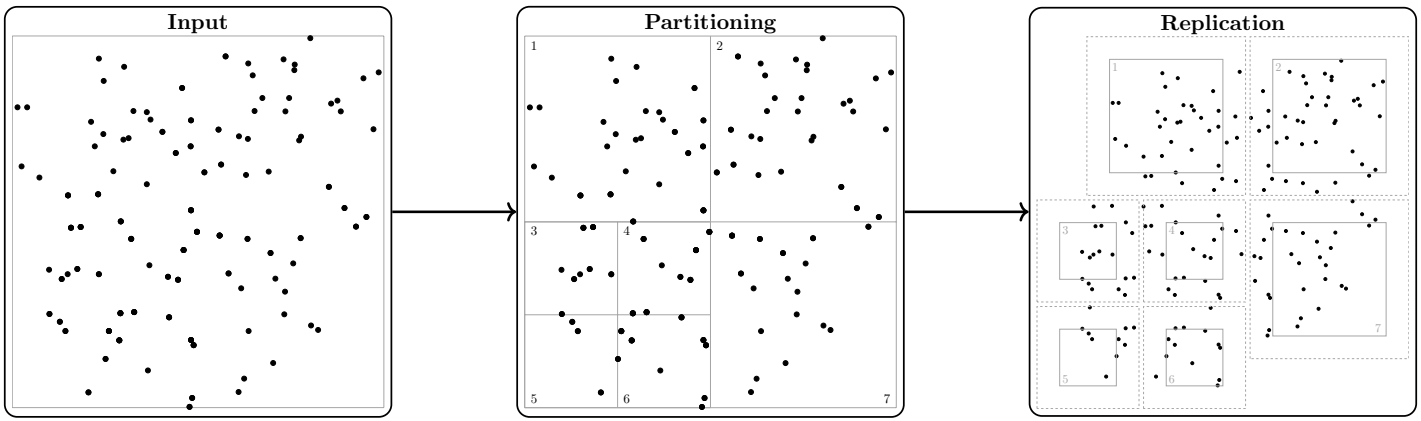
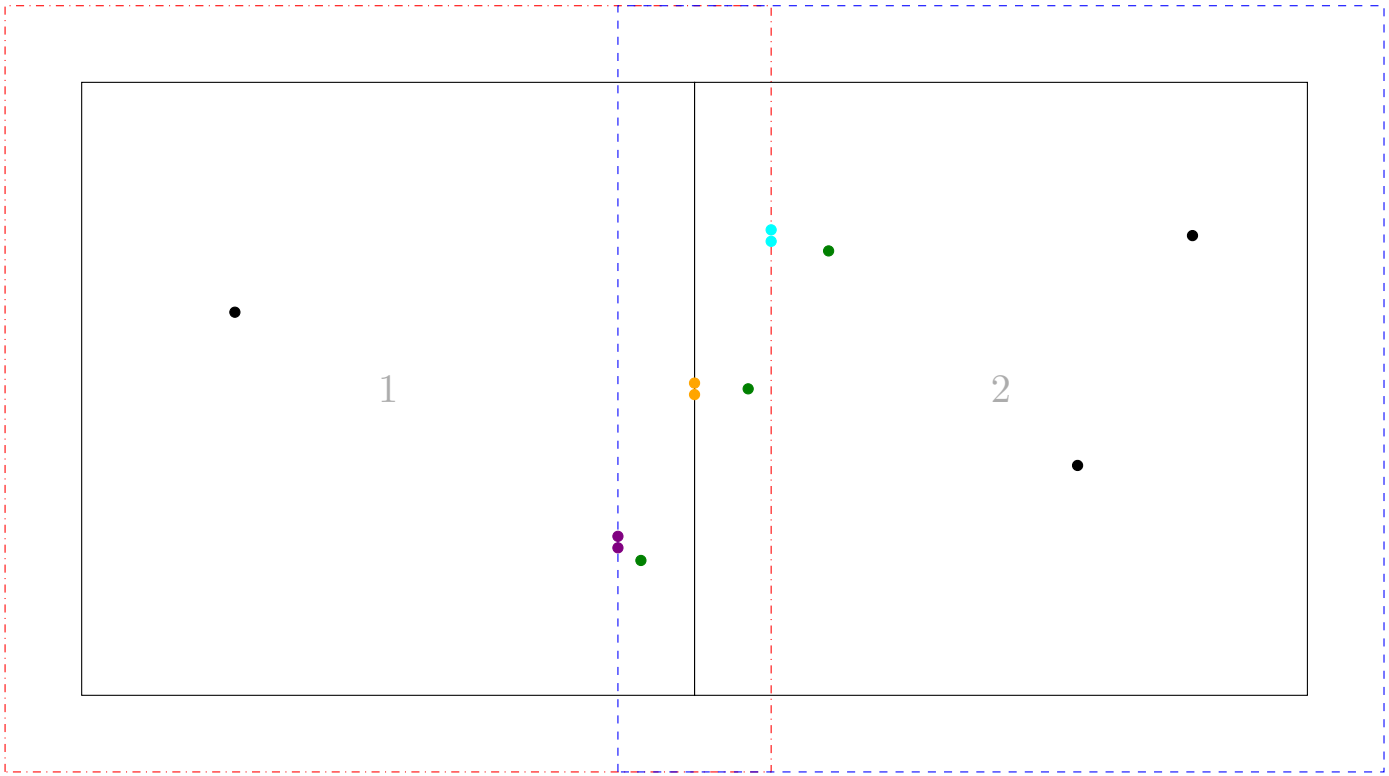


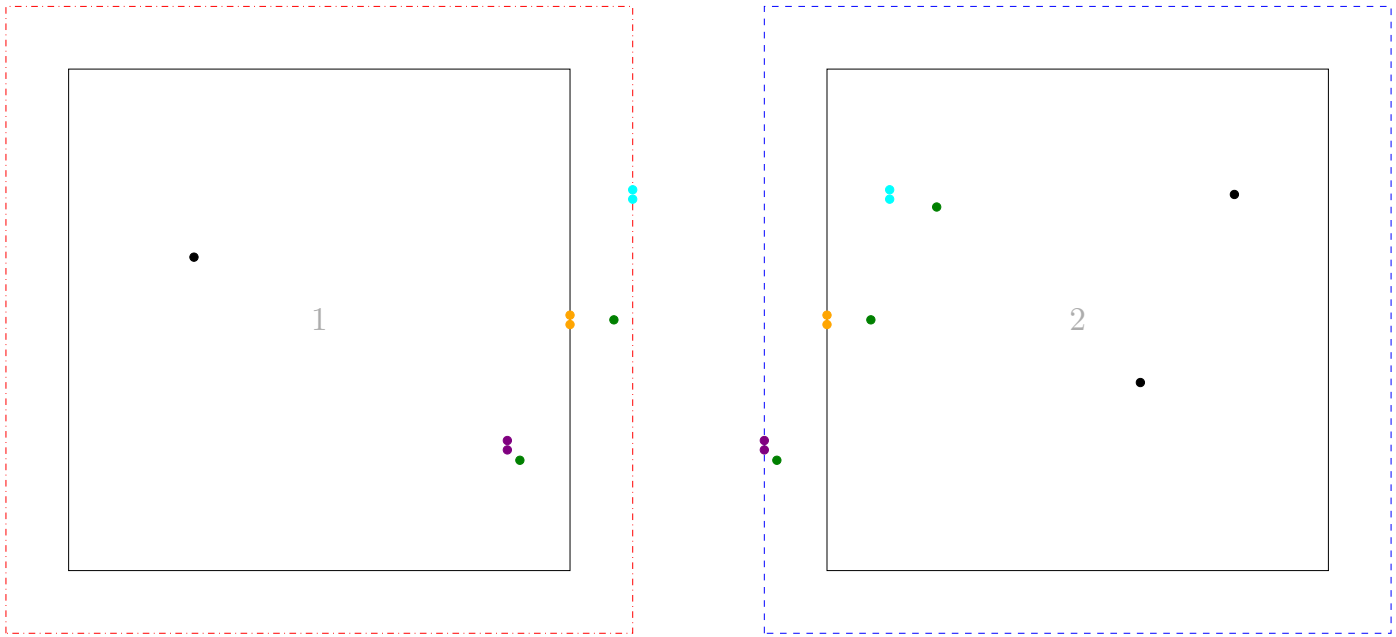
- Parallel overview...



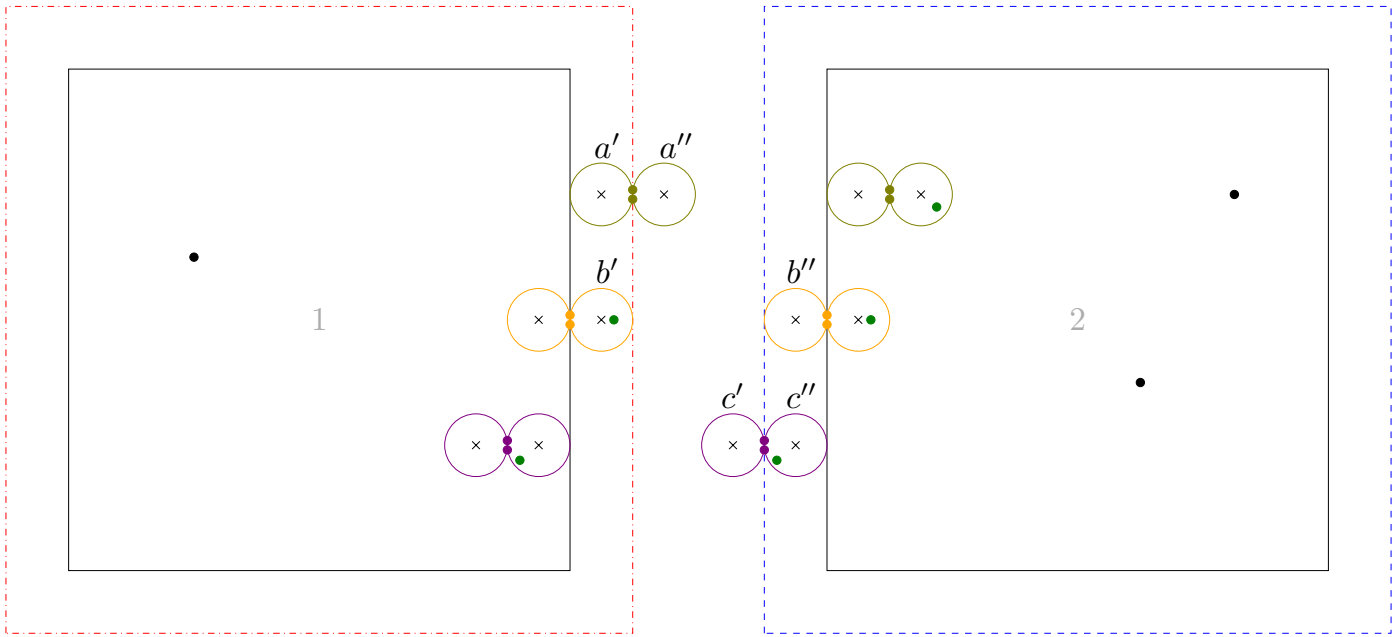
- Parallel overview...



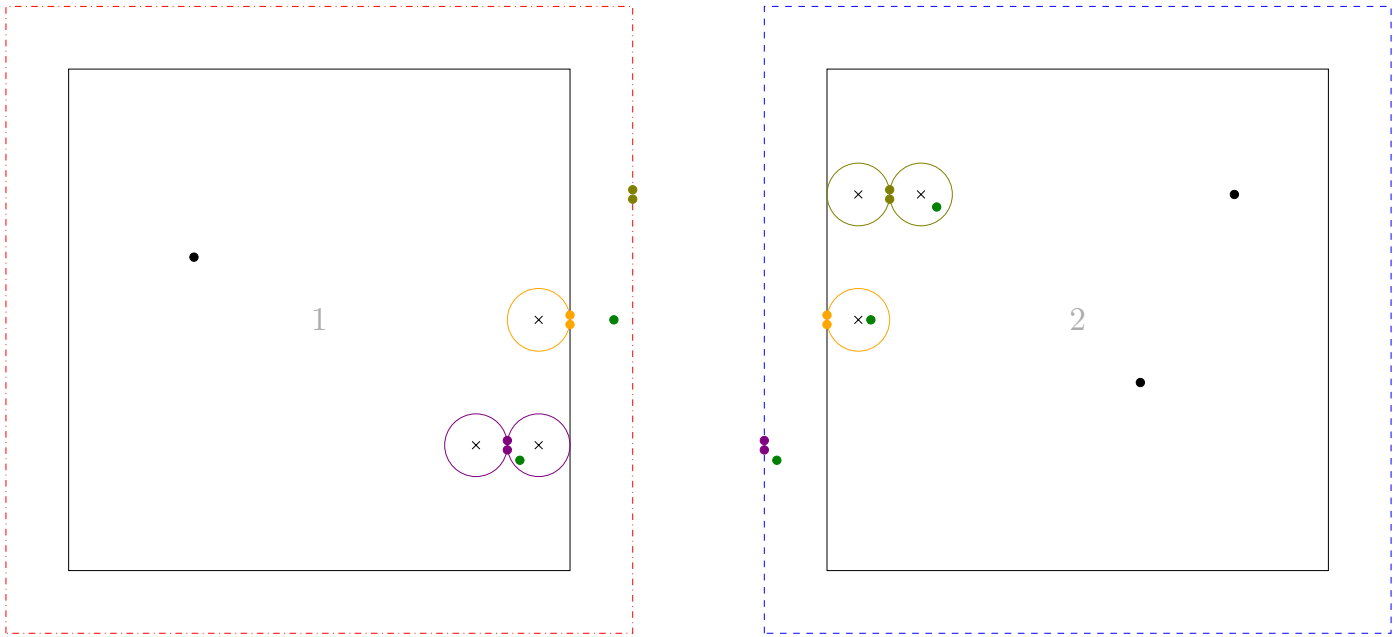
- Parallel overview...



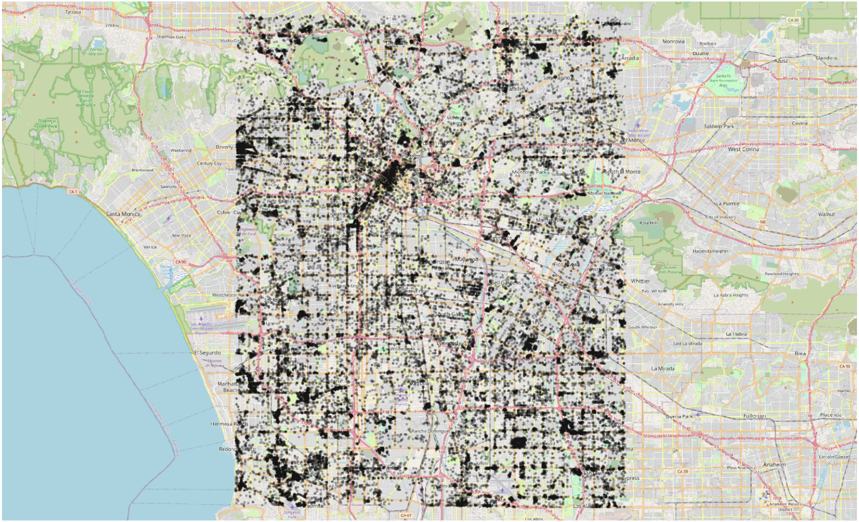
- Parallel overview...



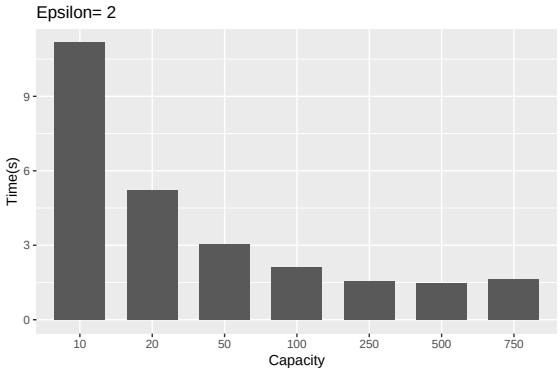
- Parallel overview...

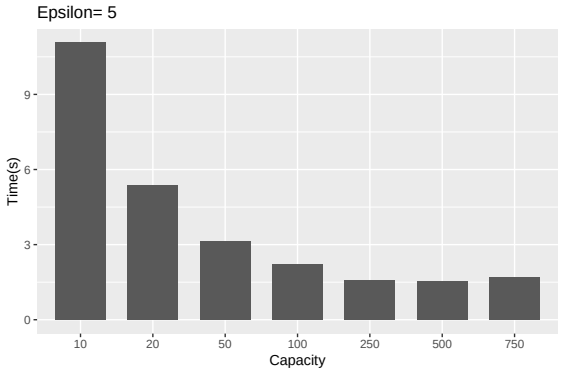


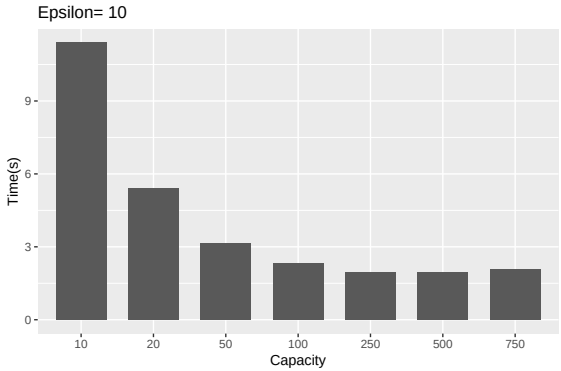
- Synthetic dataset [LA: 50K objects over 320 unit times]

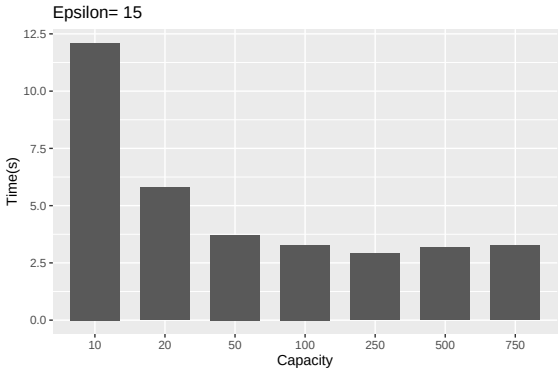


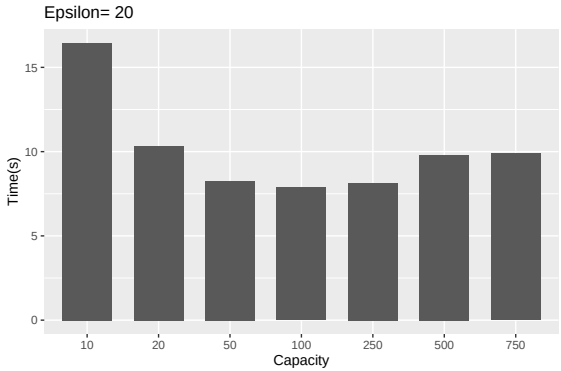
- Performance...



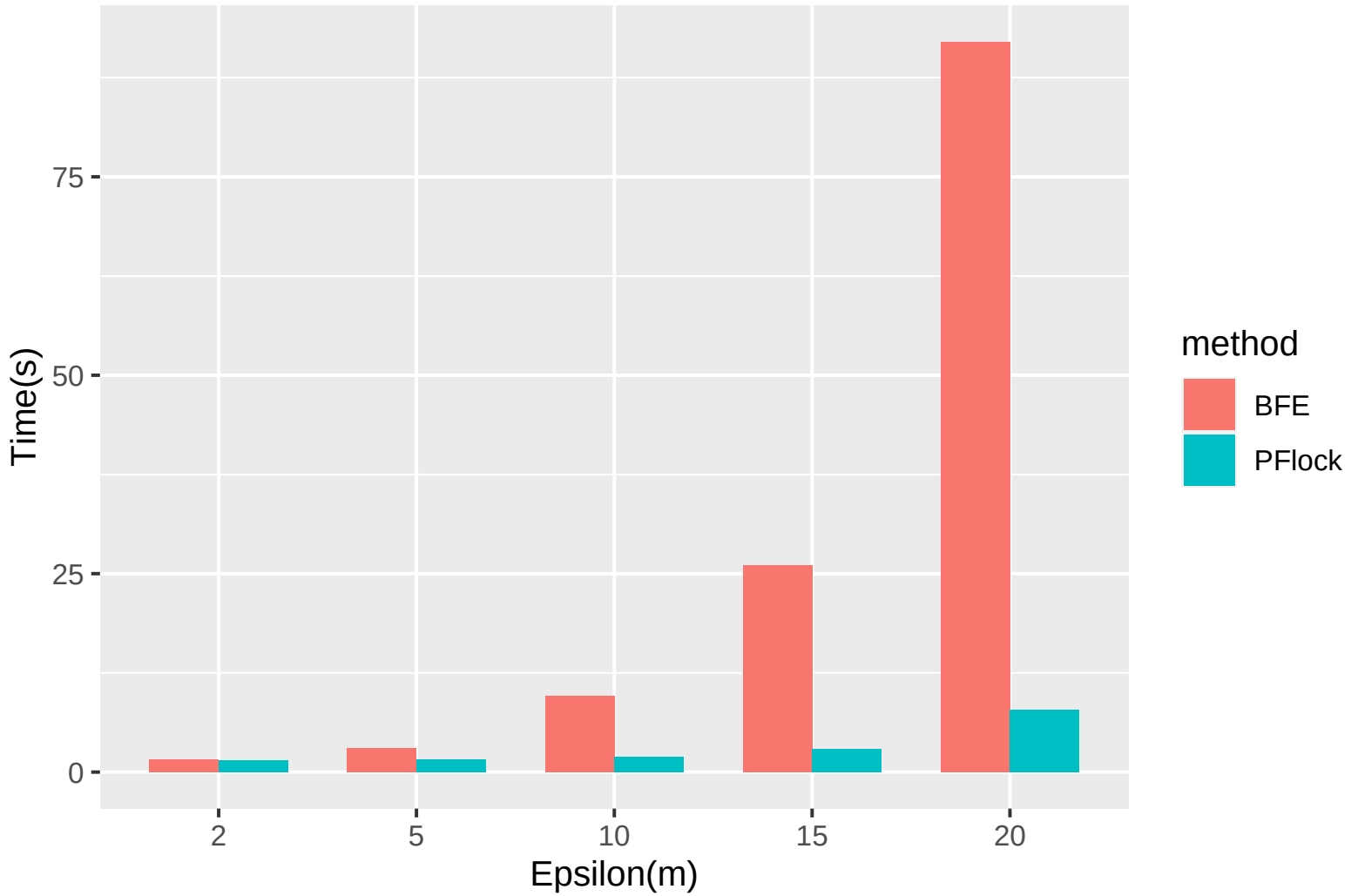








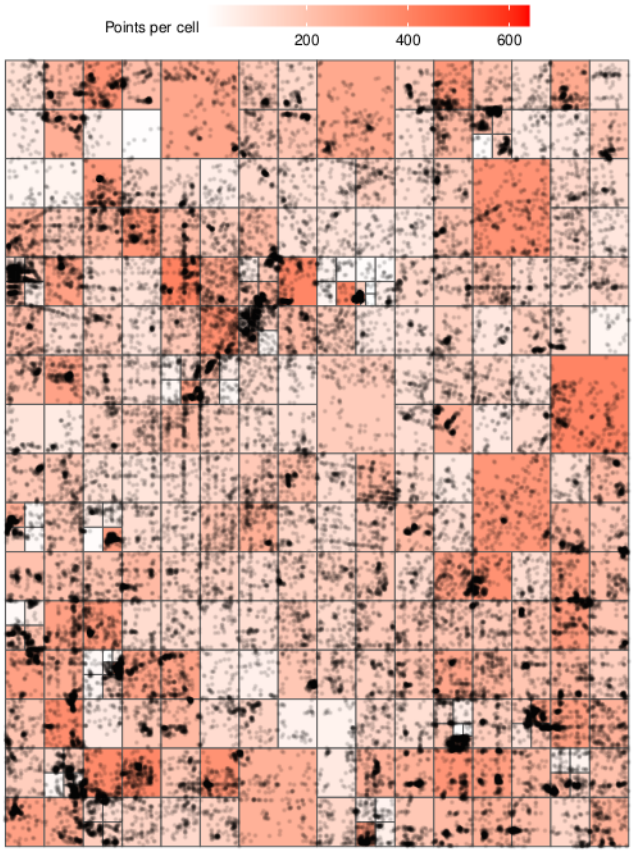
- Performance...



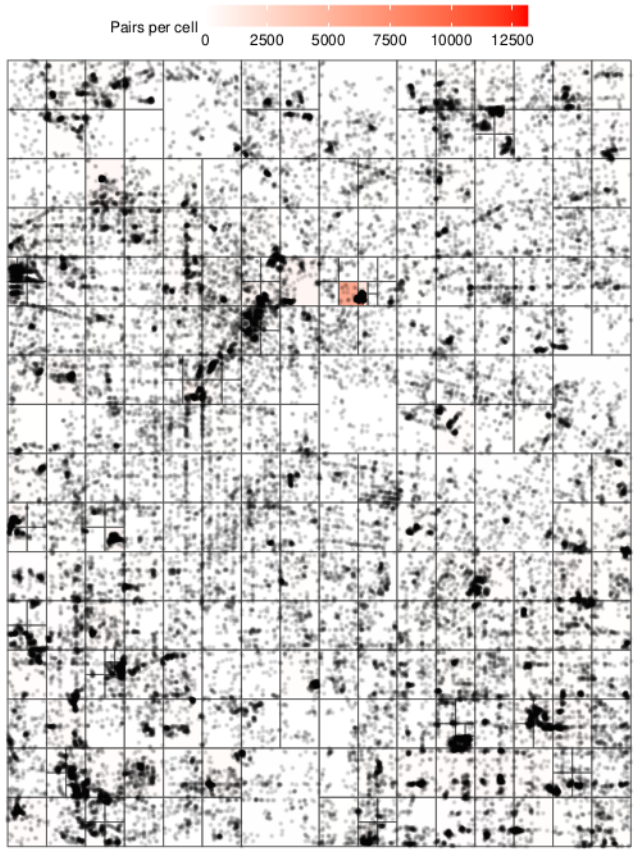
- Density issues...

Time instant : 320 (capacity=400, leafs=316, epsilon=20).

	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
stats	3.00	105.25	160.00	173.25	229.25	639.00



	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
stats	0.00	12.00	45.00	346.30	120.25	13123.00

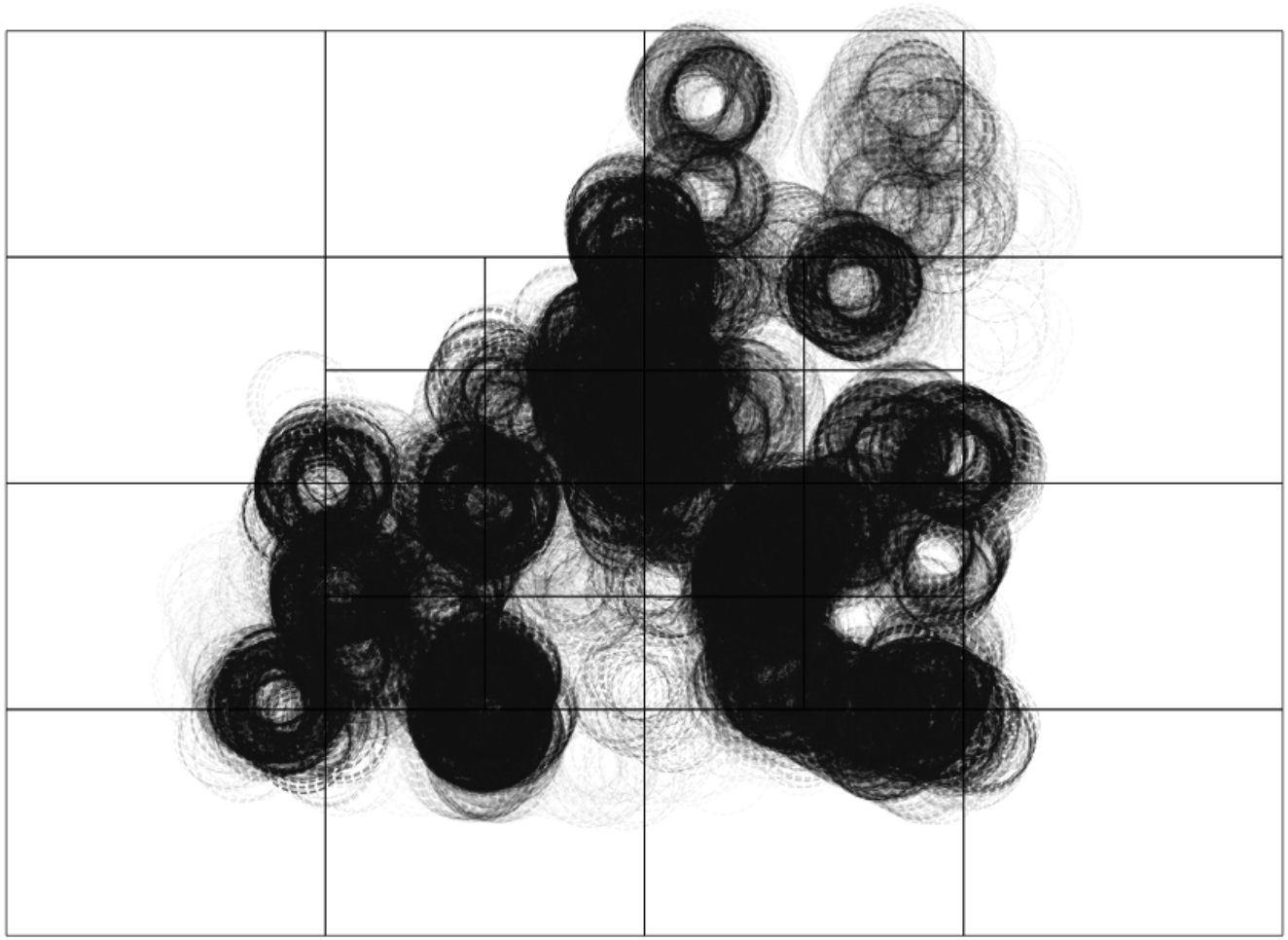


On the spatial domain

- Density issues...

On the spatial domain

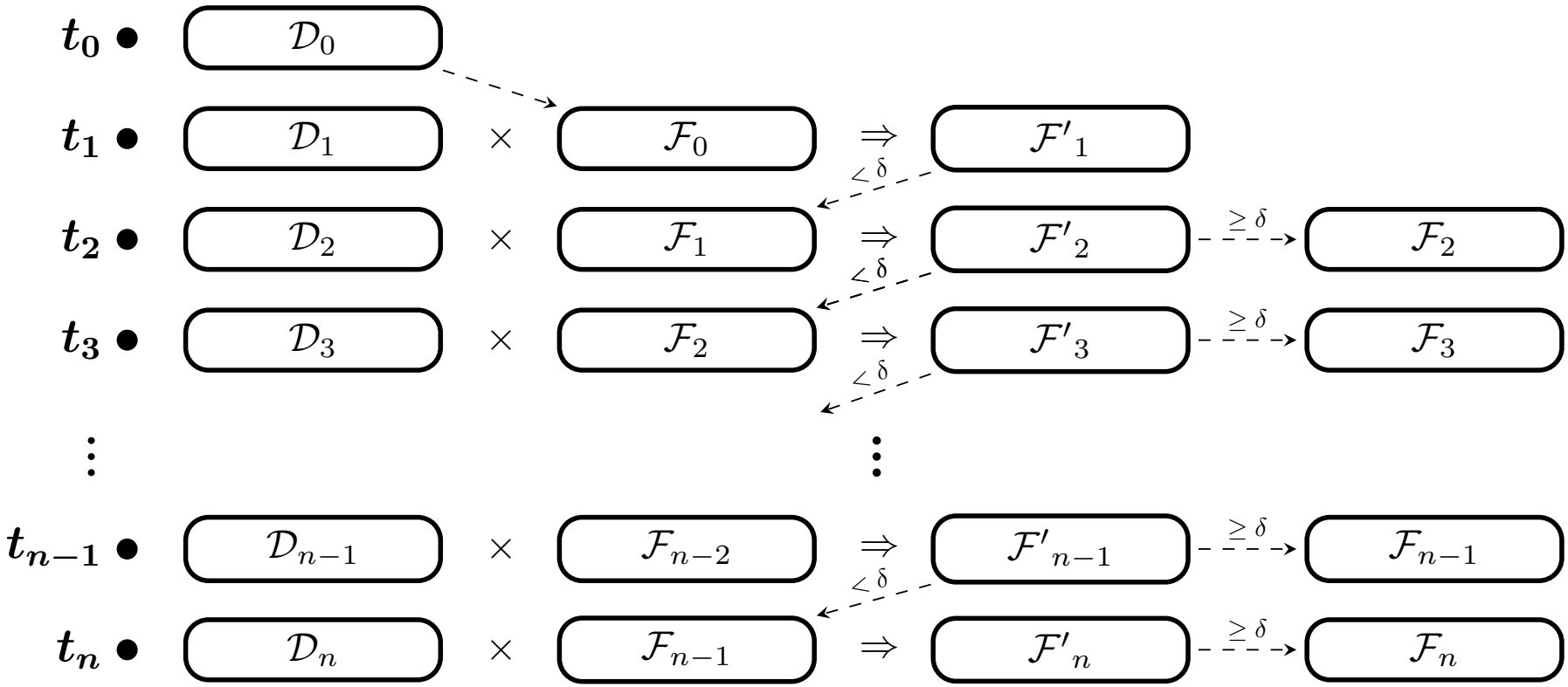
- Density issues...



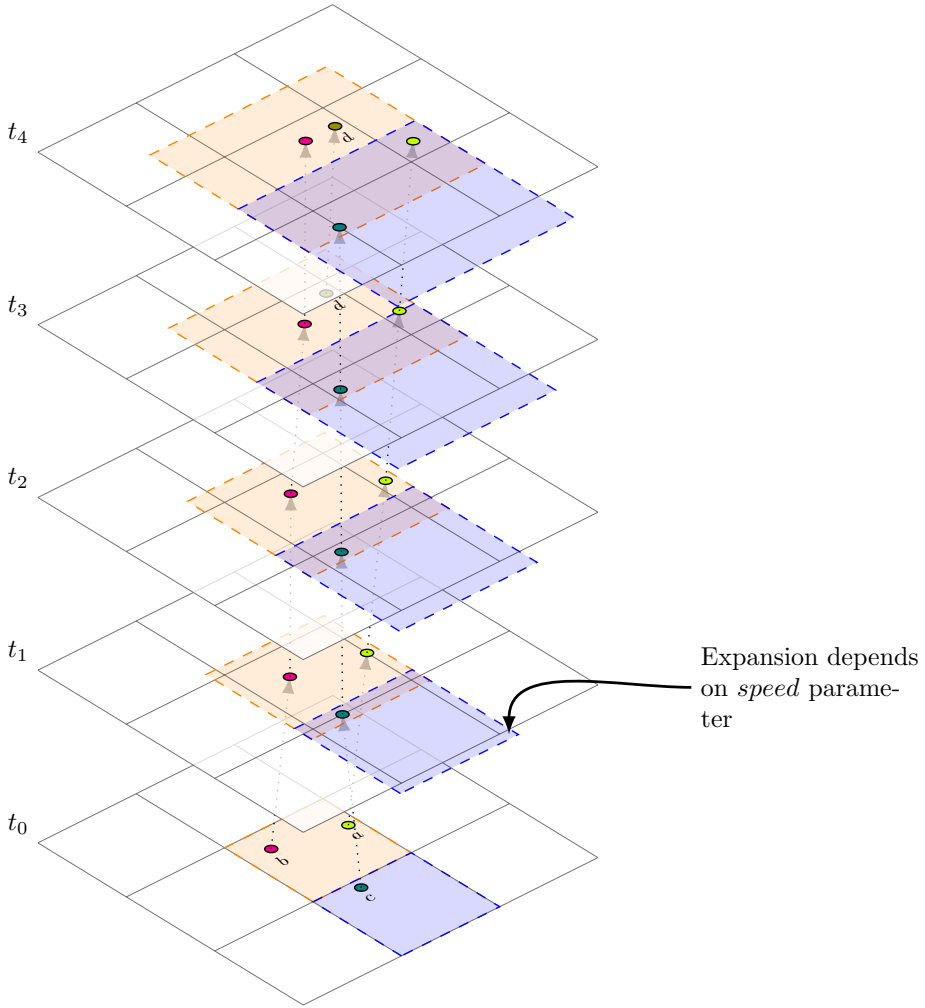
Work in progress...

- Have already try a couple of mitigation strategies (cliques, minimum bounding circles, dbscan, and now PSI (Tanaka, et al. 2016))
- Real trajectory datasets (NY taxis, SF taxis and NY bikes).
- Temporal domain implementation...

- BFE overview...



- Parallel alternative...



Thank you!