A Parallel Data Distribution Management Algorithm

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joint work with:

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Distributed **S**imulation and **R**eal **T**ime Applications (**DS-RT**), 2013

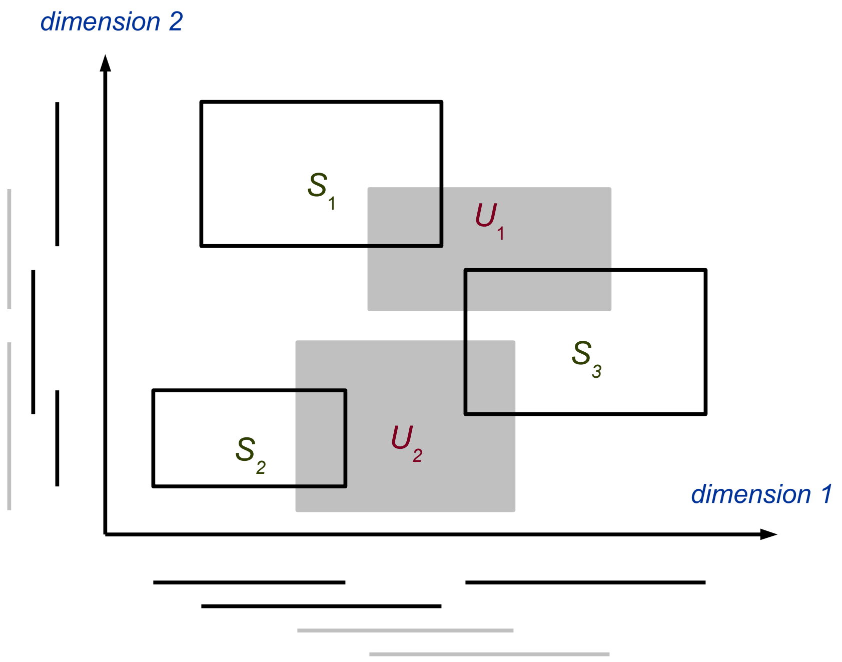
Presentation **outline**

- **D**ata **D**istribution **M**anagement (**DDM**)
- **DDM** algorithms
- **Parallel** Data Distribution Management
- Parallel Matching Algorithms
- **I**nterval **T**ree **M**atching (**ITM**)
- Experimental Evaluation
- **Conclusions**

Data **D**istribution **M**anagement (**DDM**)

- **DDM** services are part of the **IEEE 1516** "*High Level Architecture*" (HLA) specification
- **DDM** is about forwarding events generated on ***update* regions** to a set of ***subscription* regions**
- A **region** is a *d*-dimensional rectangle (*d*-rectangle) in a *d*-dimensional routing space
- The goal is to find all the couples of update and subscription regions **that overlap**
- We assume that each **region** corresponds to a single **extent**

DDM: simple example in **2 dimensions**



- The problem of identifying whether two *d*-rectangles intersect can be reduced to ***d*** independent intersection problems among one-dimensional segments

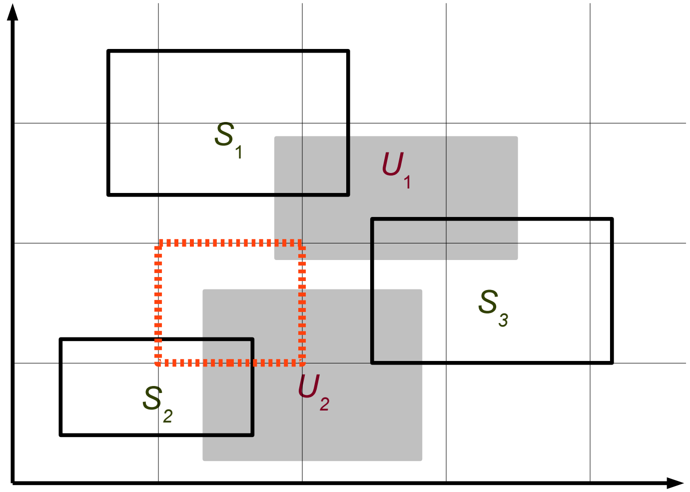
- Two d-rectangles intersect **if and only if** they **intersect among all their projections**

DDM algorithms: from simple to complex

- **No DDM**: all updates are broadcasted, the filtering is on receivers. **CONS:** communication inefficiency

- **Region-based matching** (**Brute Force**, **BF**): it tests all the subscription-update pairs. **CONS:** computational inefficiency

- **Grid-based matching**: it partitions the routing space into a grid of *d*-dimensional cells and finds matches



CONS:

- false positives
- which cell size is the best?

DDM algorithms: from simple to complex

- **Sort-Based Matching** (**SBM**): before matching, the extents are sorted. In this way, the overlaps can be found efficiently. In many cases **SBM** does better than **grid-based** [Raczy et al. 2005]. **CONS:** are there drawbacks?

- **Binary partition-based**: recursive binary partitioning of the extents. **CONS:** (more than) quadratic worst case cost

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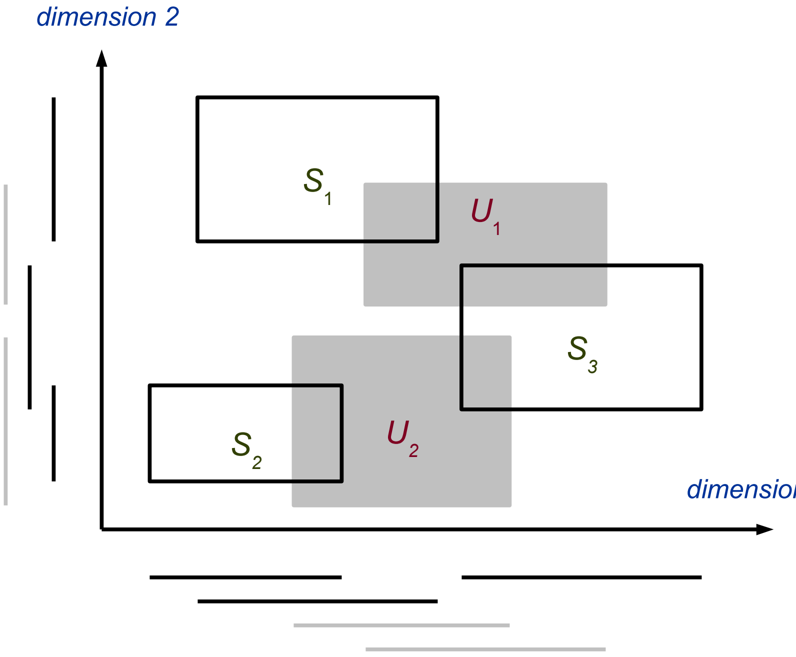
- … and so, **what's the problem?**

- Even smartphones are **multi-core** and we're still dealing with **sequential algorithms**

- The future of computing is very likely to be **many-core**

Parallel Data Distribution Management

- **Easy solution**: each core (or CPU) is responsible of a specific dimension. The "master" core computes the final result



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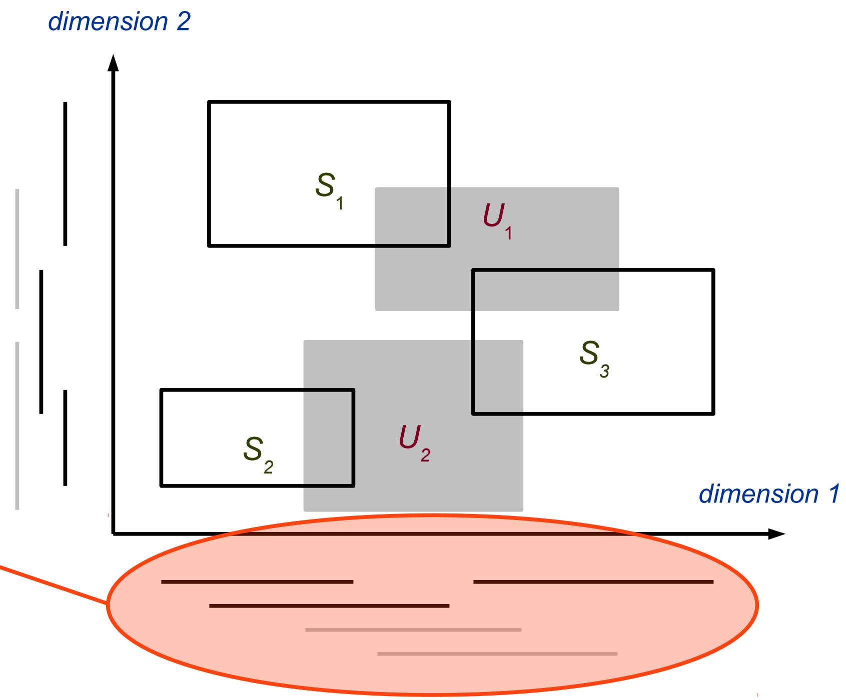
core 1 → $\boxed{\texttt{result 1}}$



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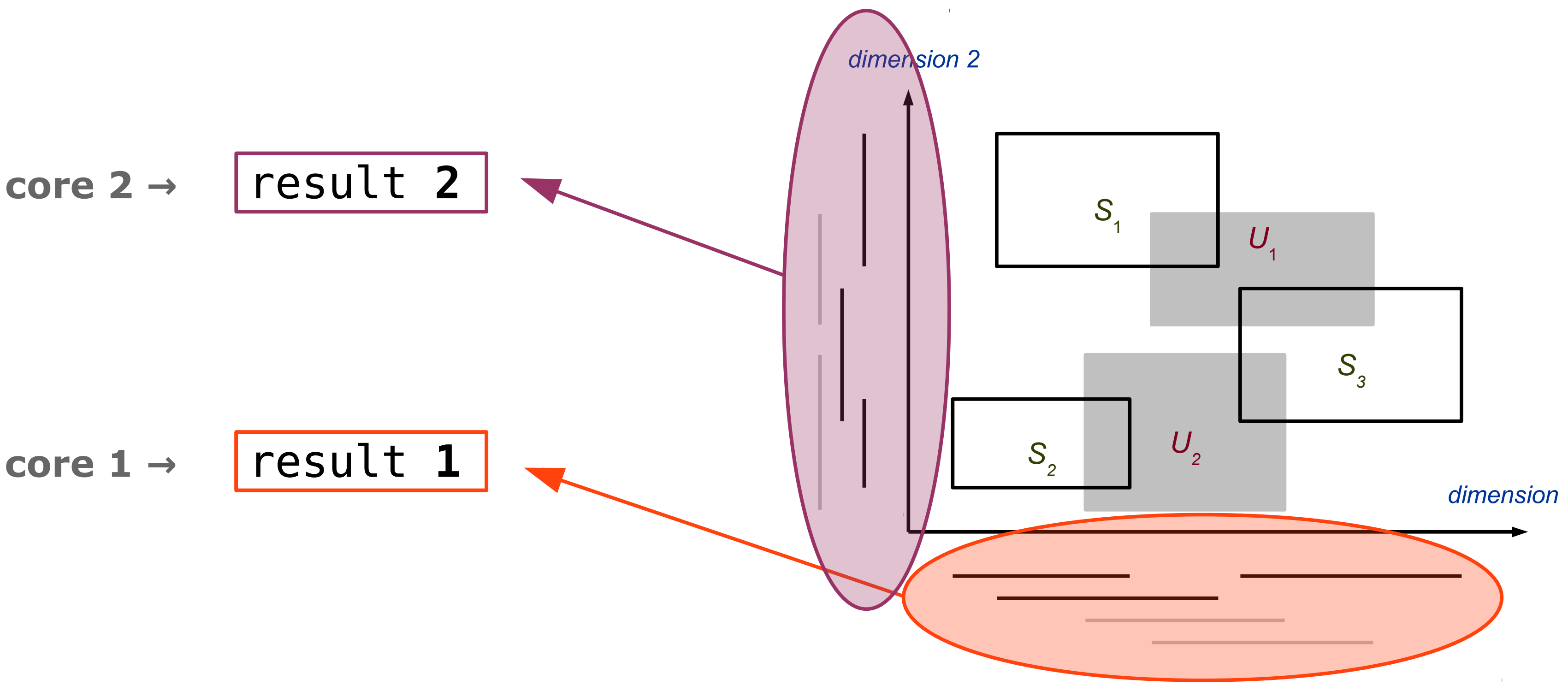

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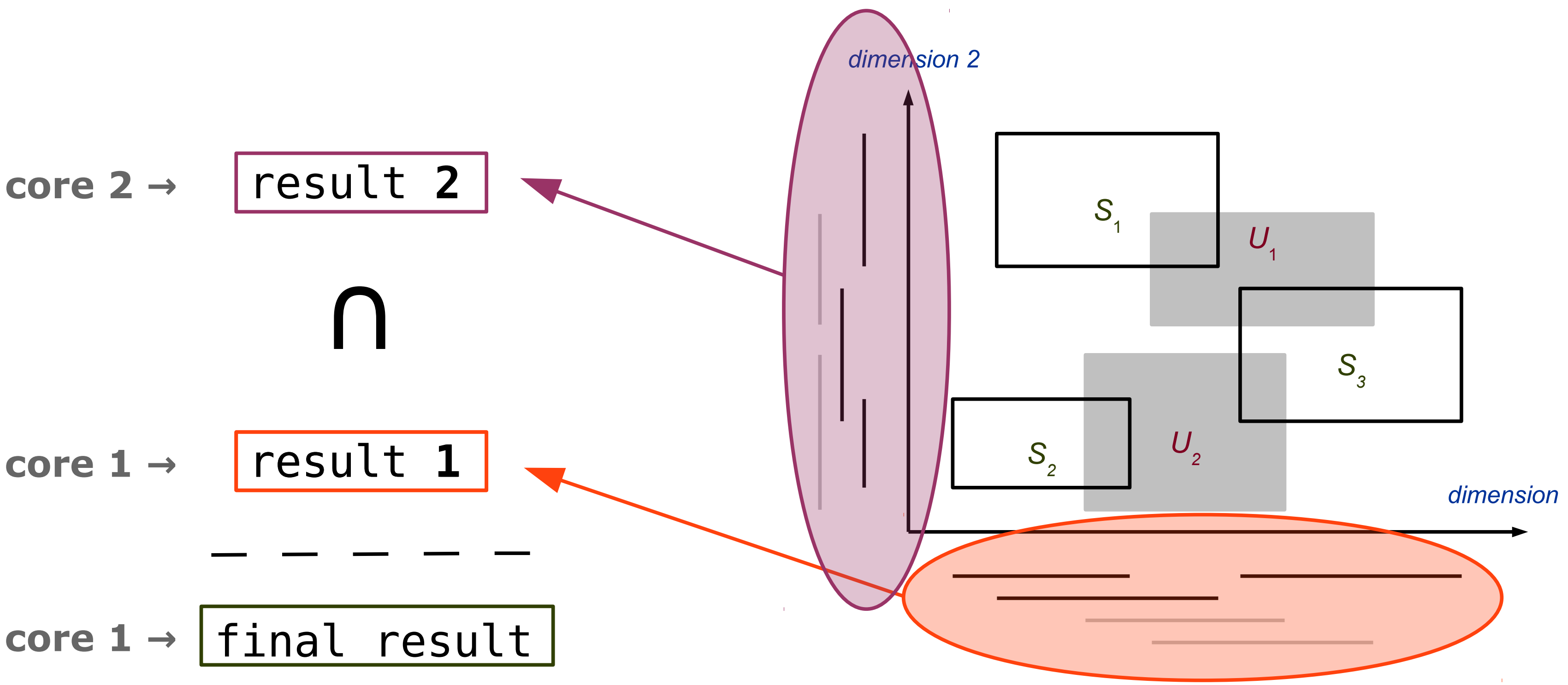


Parallel **D**ata **D**istribution **M**anagement

- **Easy solution**: each core (or CPU) is responsible of a specific dimension. The "master" core computes the final result
  - **PRO**: it can be applied to every DDM algorithm
  - **CONS**: what if the **number of cores**/CPUs is **larger** than the **number of dimensions**?

This solution is **not adequate** for "many core" environments

We need **parallel matching algorithms**

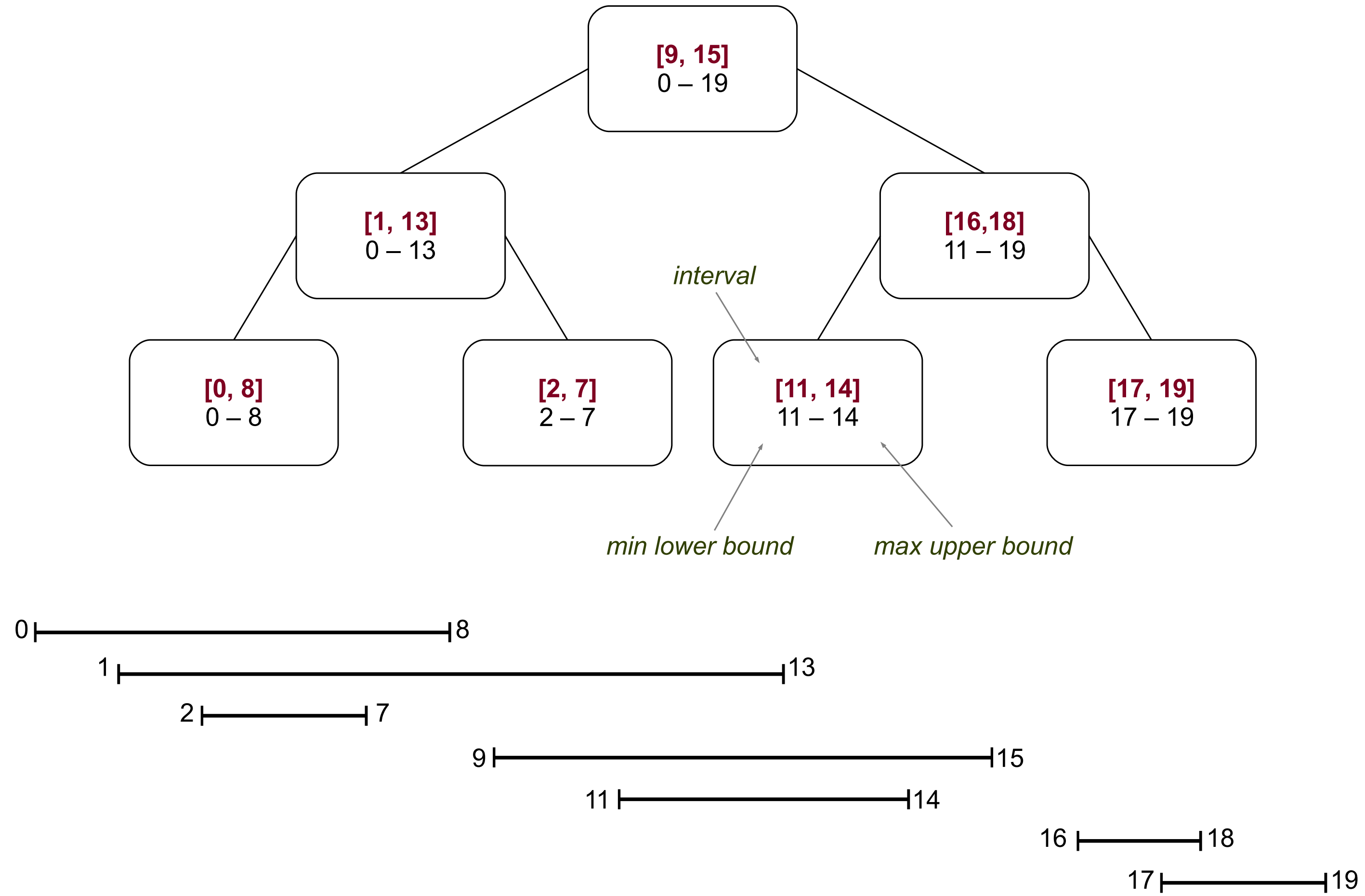
Parallel matching algorithms

- **Brute Force** (**BF**): inefficient, embarrassingly parallel
- **Sort-Based Matching** (**SBM**): efficient, not easy to parallelize
- **DESIDERATA**:
  - **efficient**
  - **easy** to parallelize
  - based on a **simple** data structure
  - that allows the efficient update/add/delete of extents

    (**dynamic interval management**)

Our proposal: **Interval Tree Matching (ITM)**

- Based on the simple **Interval Tree** data structure
- It can be implemented using priority search trees or augmented AVL trees. For simplicity we've used the last one



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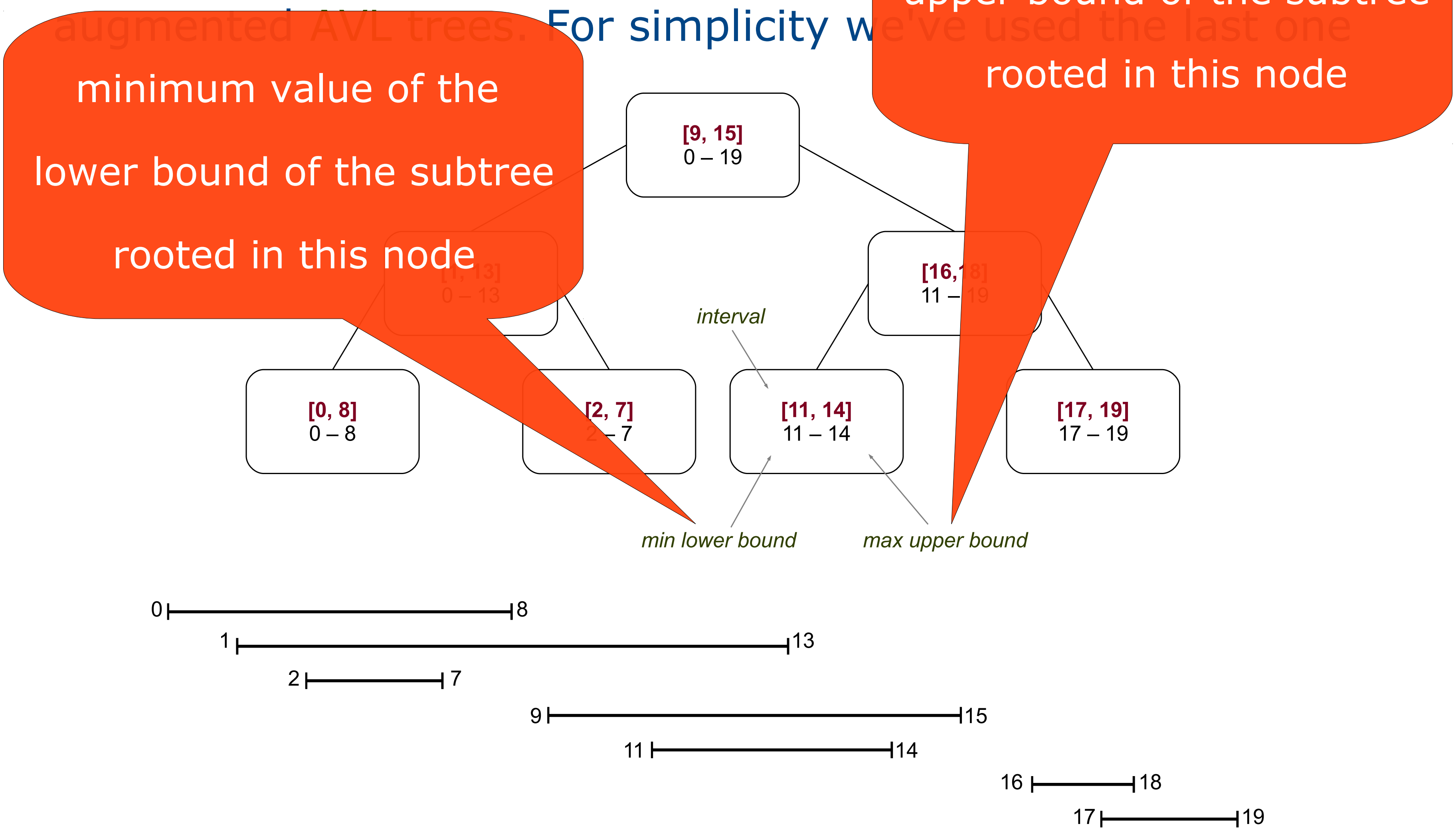

Our proposal: **Interval Tree Matching (ITM)**

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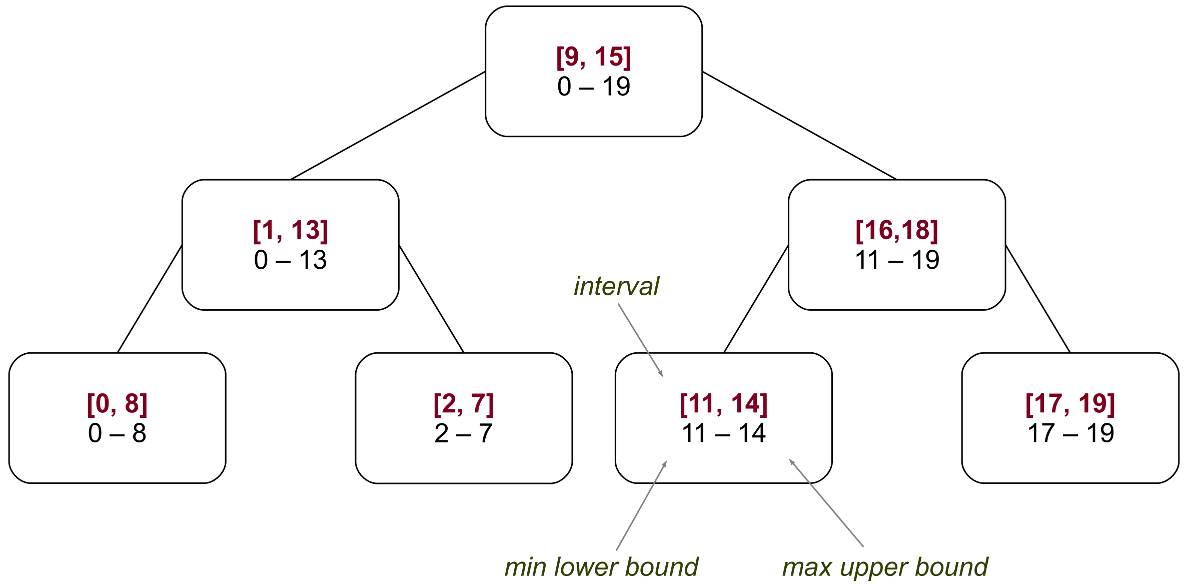
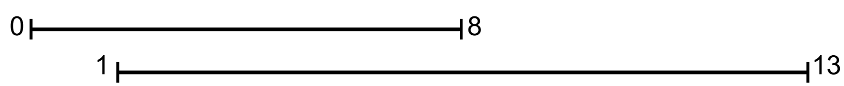
balanced tree

insertion and delete are efficient





it contains all the subscription (or the update) regions

Interval Tree Matching (ITM): algorithm description

- Support function **INTERVAL-QUERY**:

  returns the list of intervals intersecting a given extent

- **Main function**:

  1) ***create*** *the Interval Tree with all the subscription extents*

  2) ***for every*** *update extent perform an* ***INTERVAL-QUERY***

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Algorithm	Computational cost	Additional space
Brute force	O(n·m) with **n** subscription extents, **m** update extents	none
Sort-based	O((n+m)log(n+m)+n·m)	O(n+m)
Interval tree	O(min{n·m, (K+1)log n}) with **K ≤ n·m** that is the total number of intersections	O(n)

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Parallelization: the queries at point 2) are independent → it is trivial to parallelize

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Dynamic interval management: updates are efficient

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Experimental evaluation

- The very same methodology used in [Raczy et al. 2005]

- Instances with a single dimension are considered

- **Main parameters**:

  - N = *number of extents* = $[50 \times 10^3, 500 \times 10^3]$ with 50% of update extents

  - α = *overlapping degree* = $\dfrac{\sum \text{area of extents}}{\text{area of the routing space}} = \{0.01, 1, 100\}$

- **Execution platform**: Intel® Core© i7-2600 3.40 GHz CPU with **4** physical cores and Hyper-Threading (HT), 16 GB RAM, Ubuntu 11.04

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All the source code and scripts used for this performance evaluation are available with a Free Software license from:

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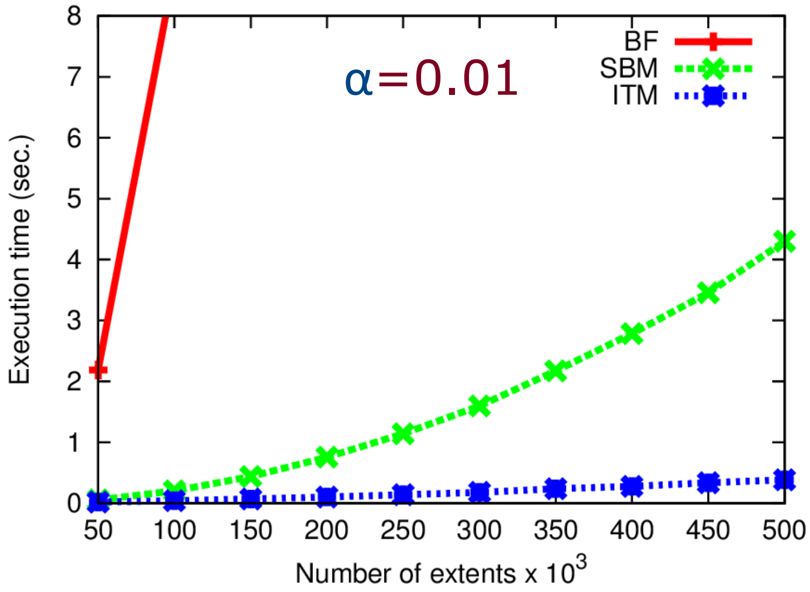
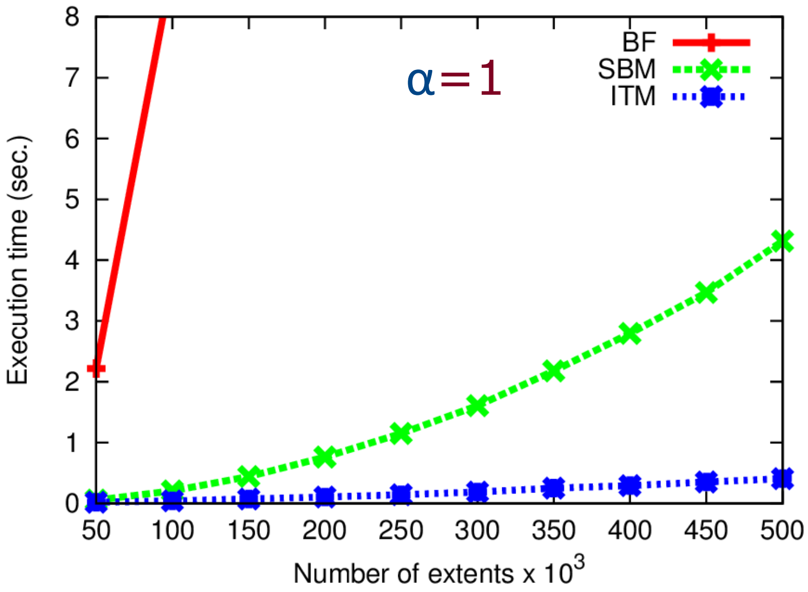
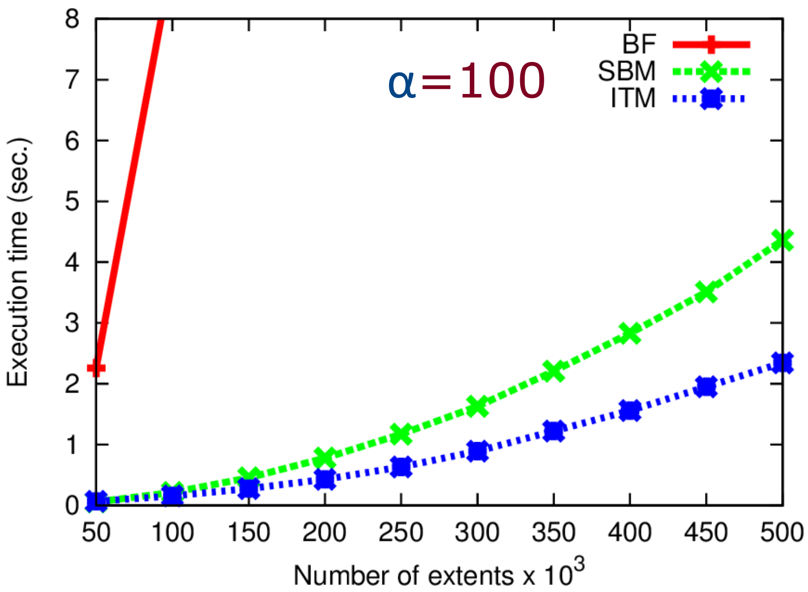
Experimental evaluation: sequential execution

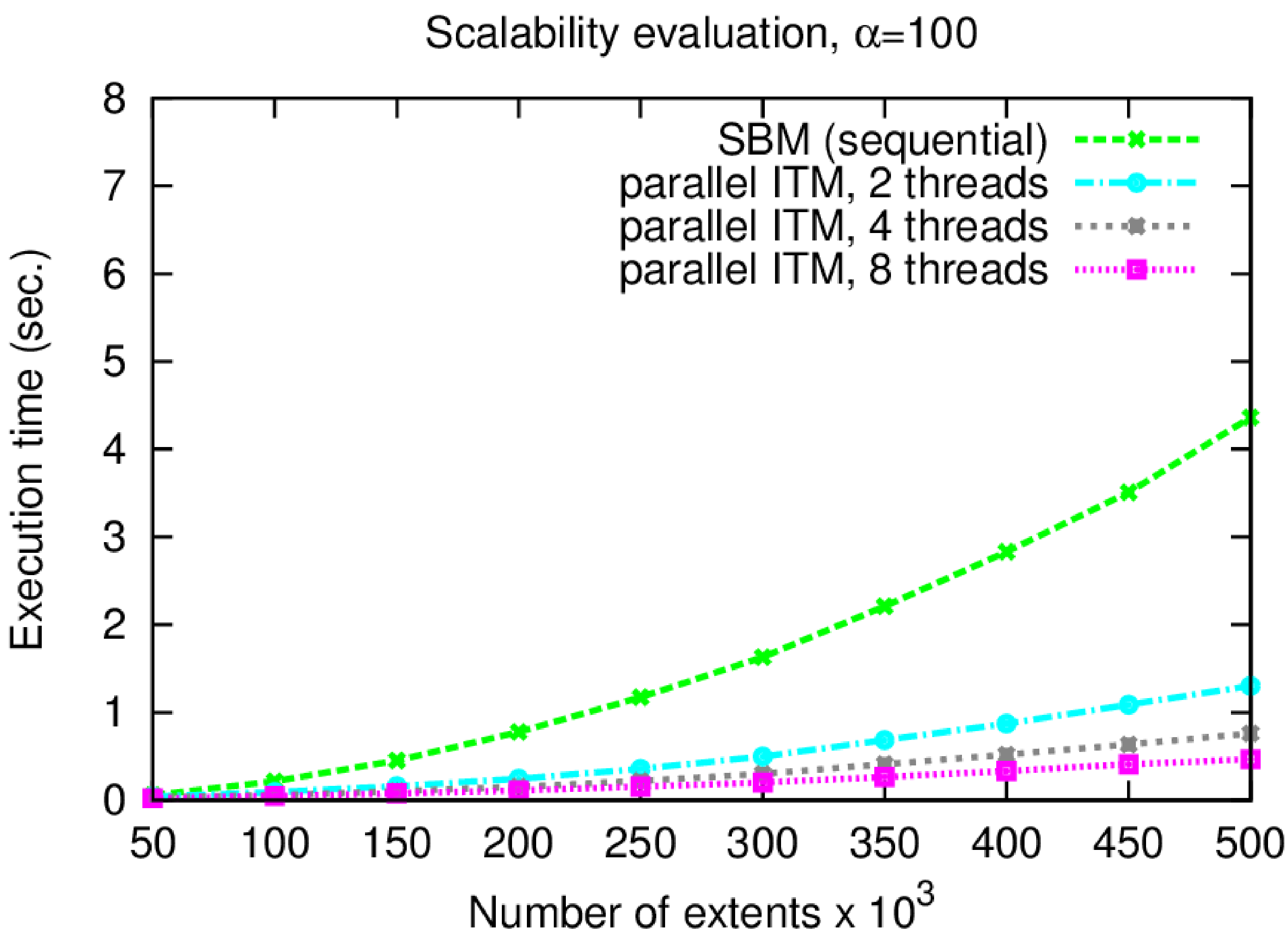




- **BF** is very slow
- **SBM** is unaffected by α
- **ITM** has the best performance
- Increasing α, the gap between **SBM** and **ITM** decreases
- Note that **α = 100** is a very high overlay degree



Experimental evaluation: parallel execution



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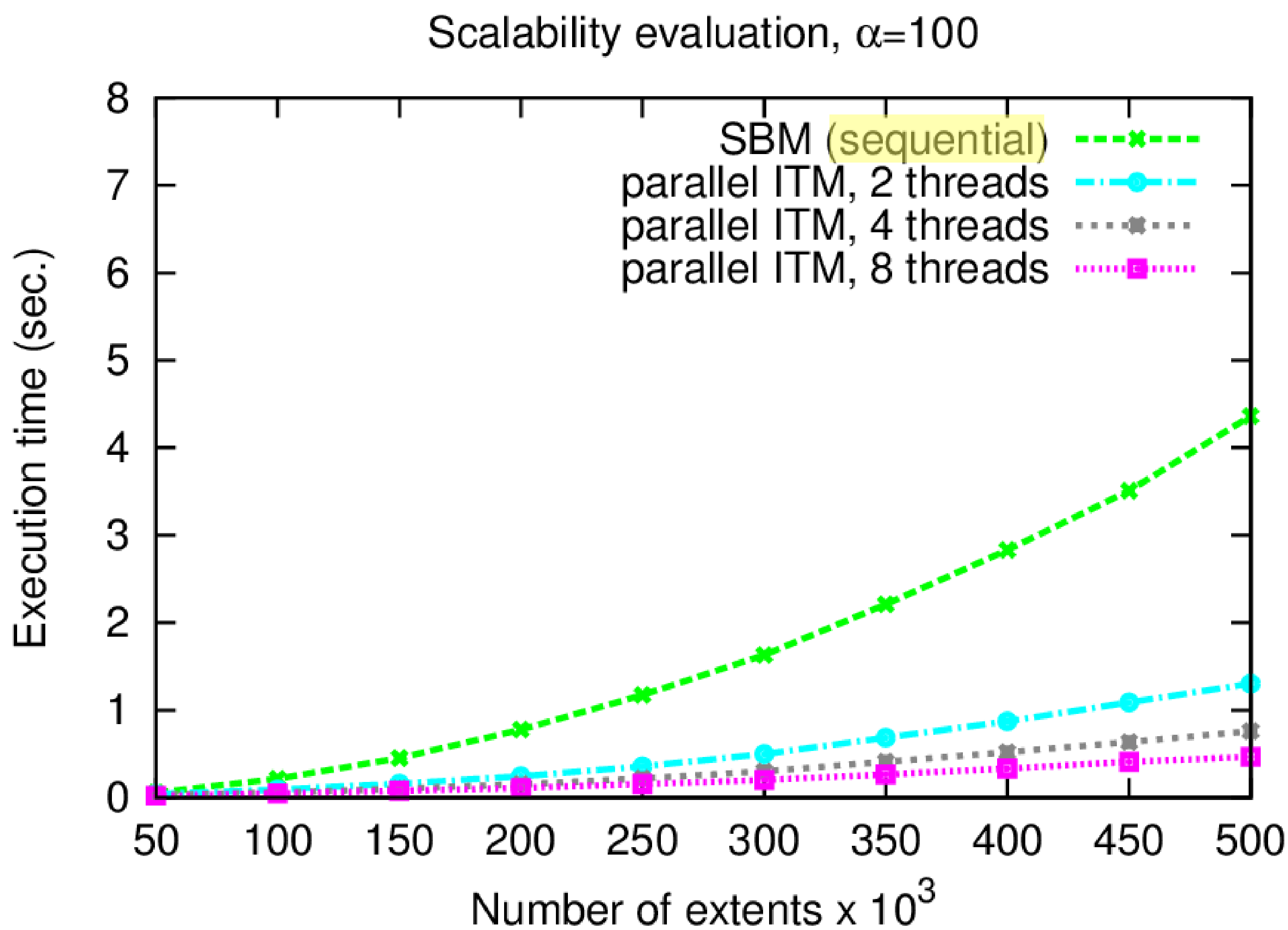

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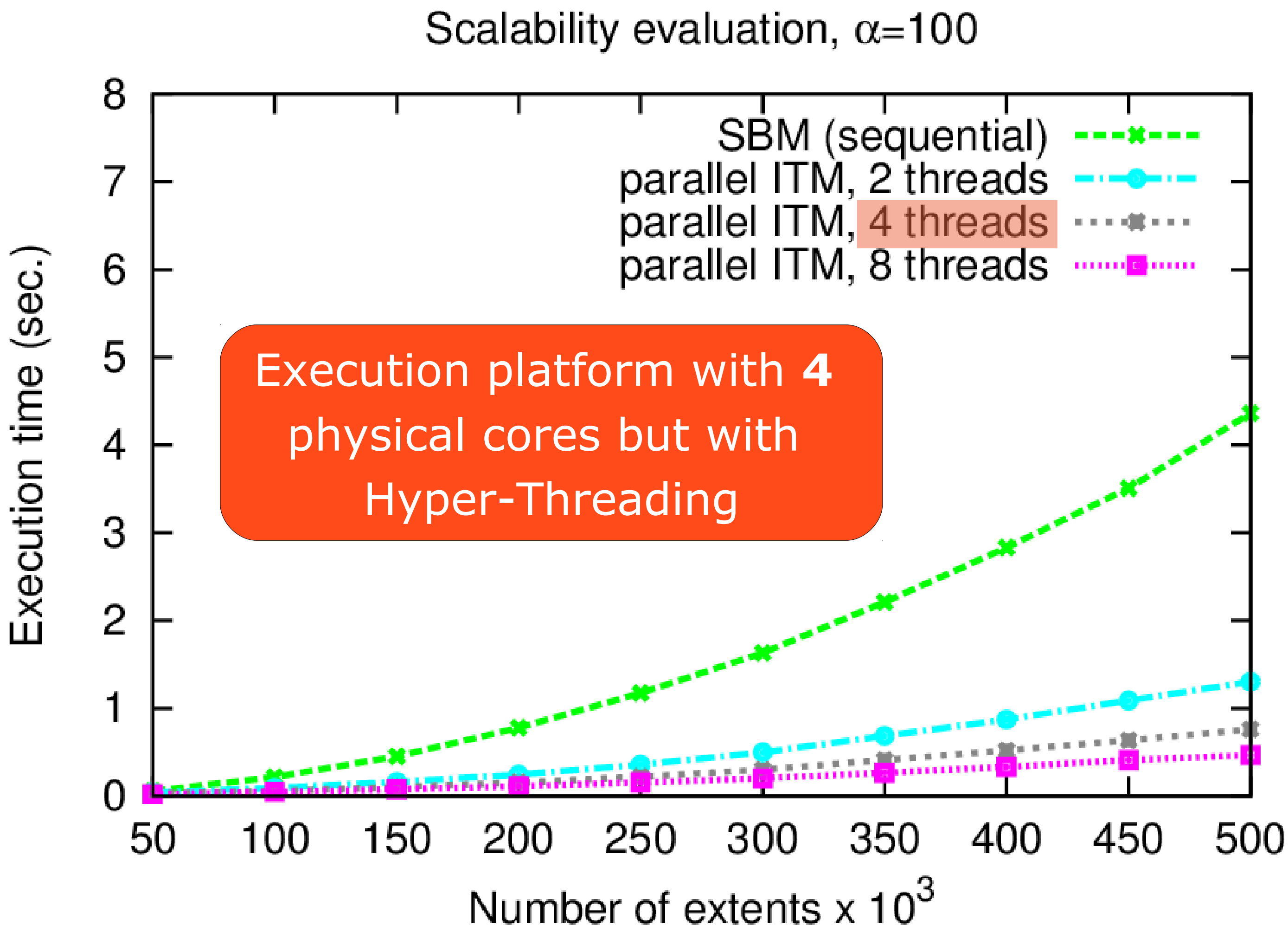

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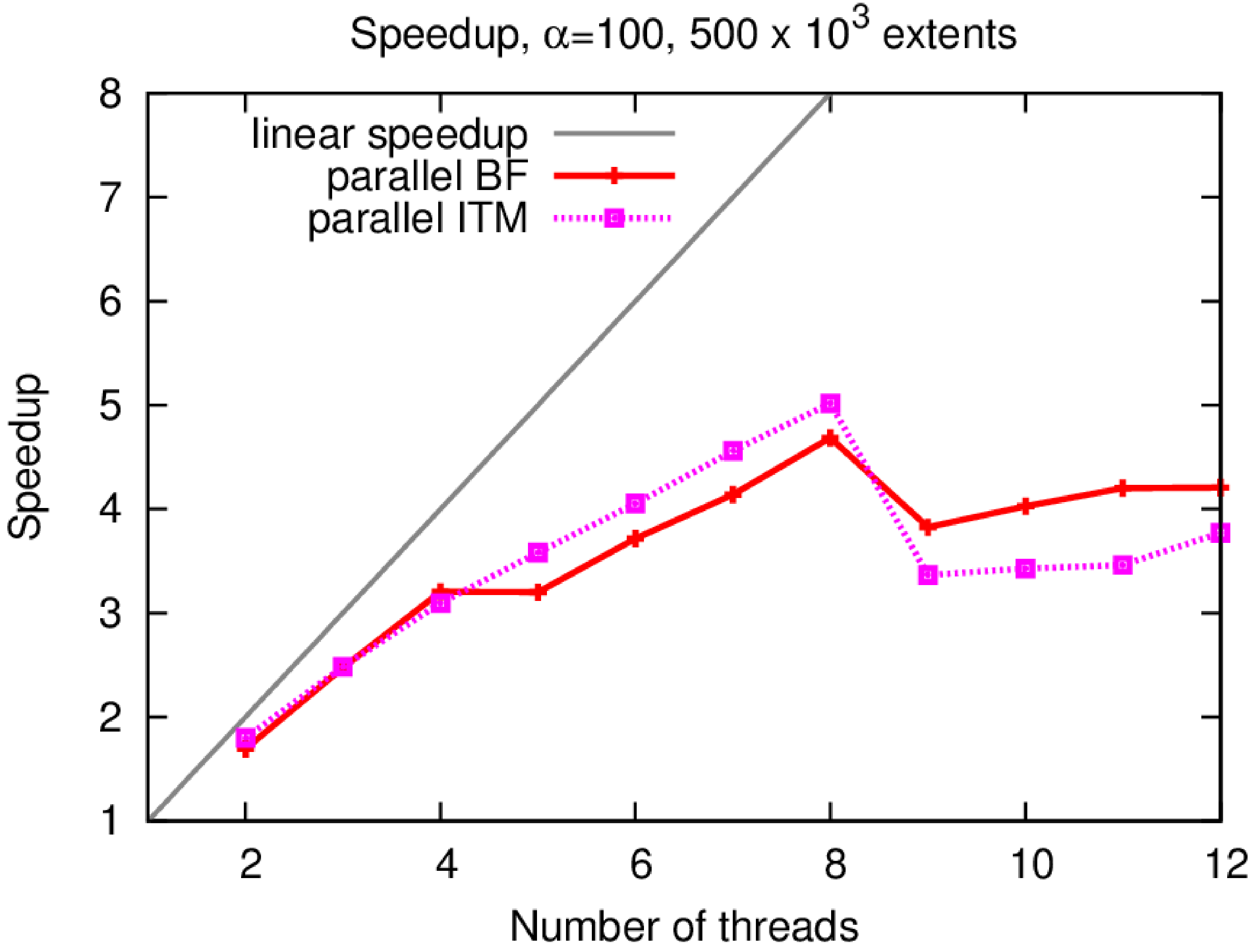

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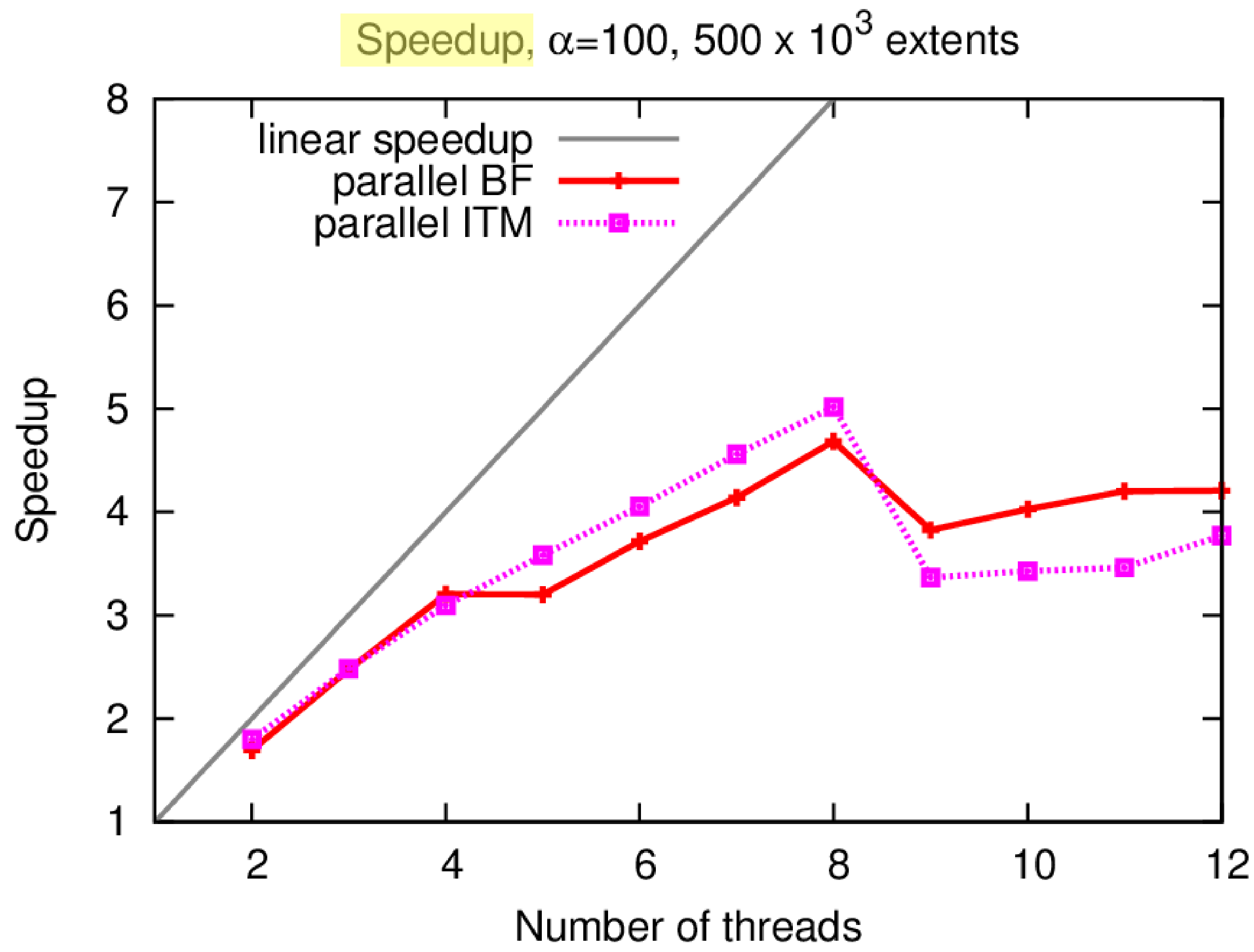

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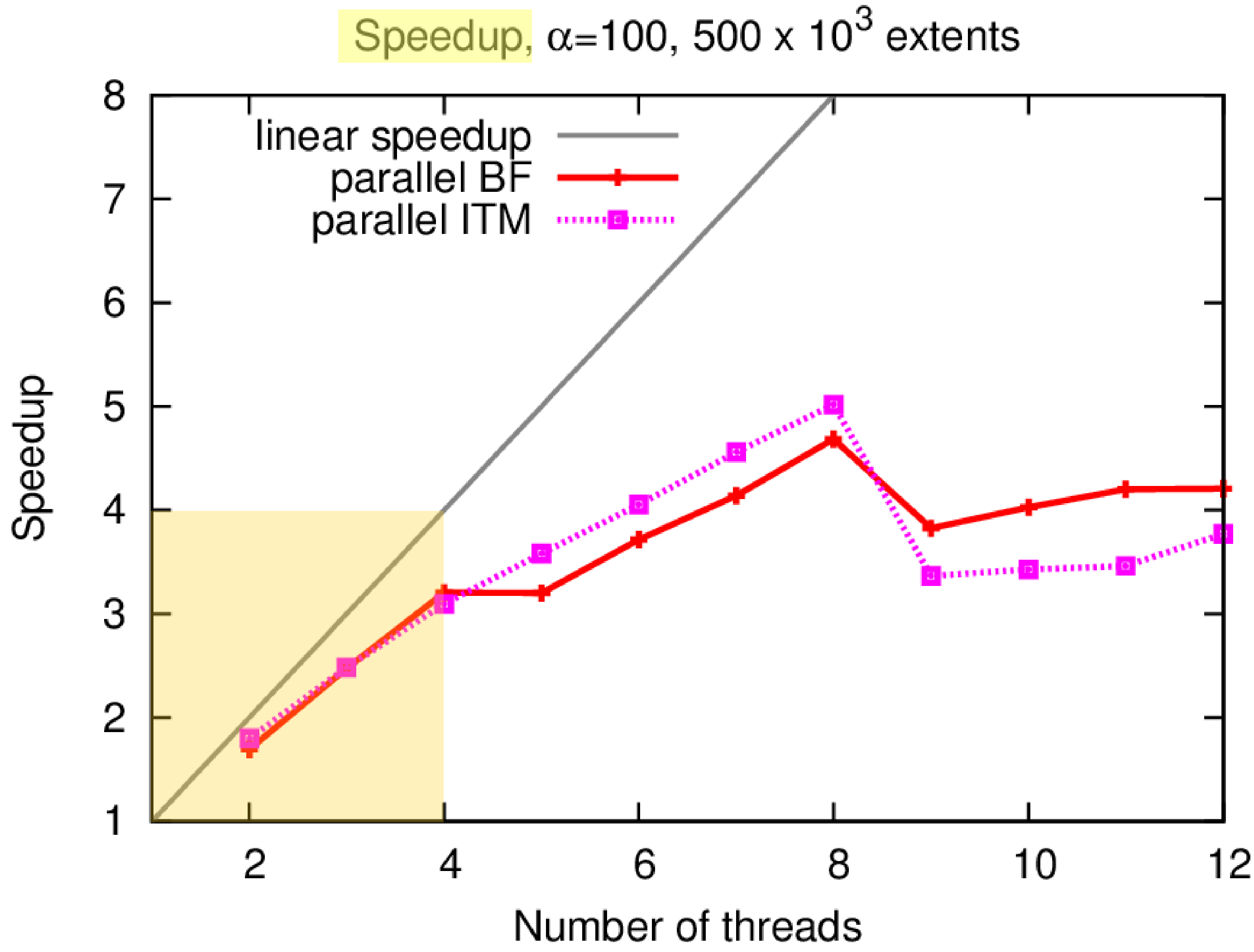
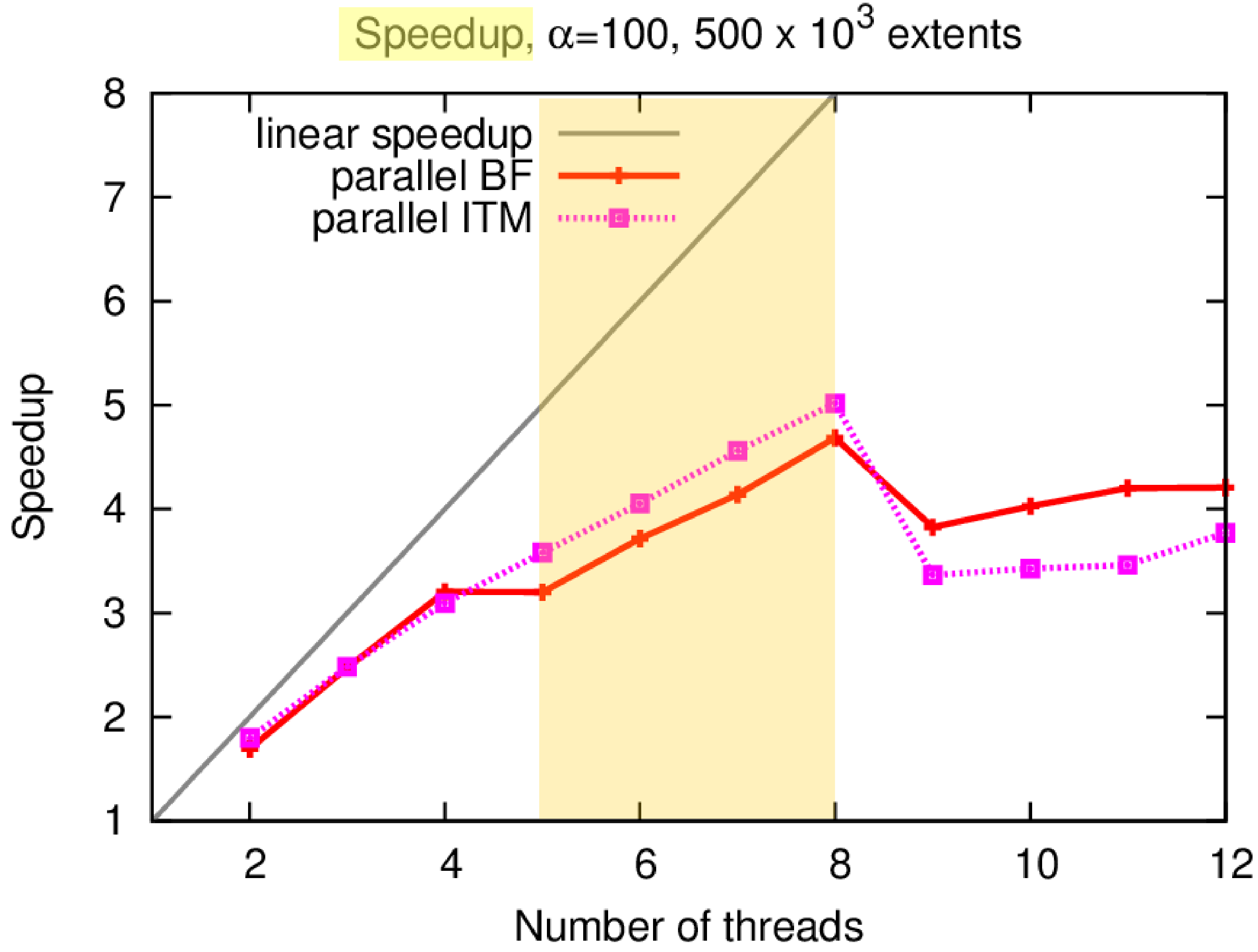


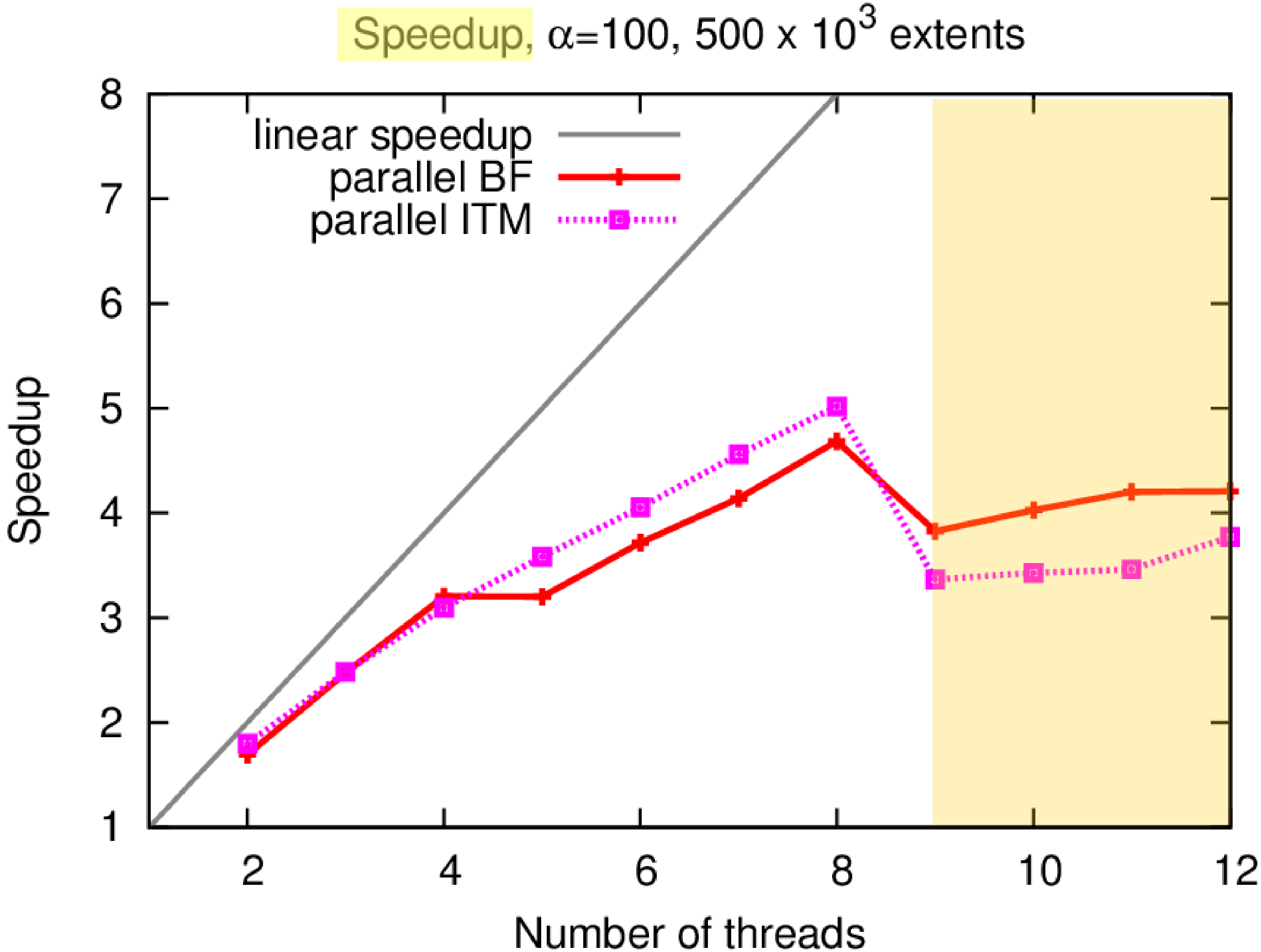
BF is embarrassingly parallel, in the range [1, 4] (physical cores) both algorithms obtain almost the same speedup

Experimental evaluation: parallel execution



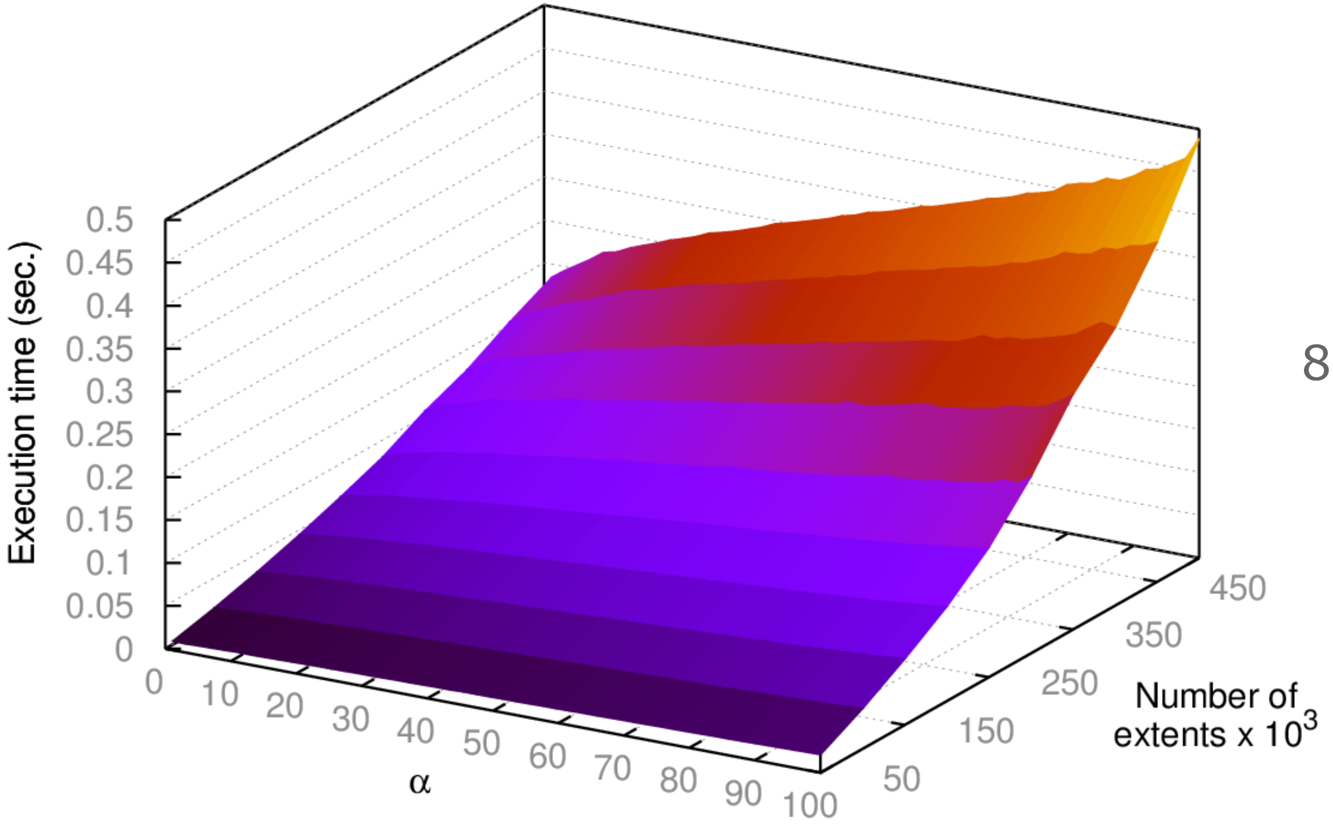
In the range [5, 8] (**H**yper-**T**hreading logical cores) **ITM** is better than **BF**. **HT** provides a performance boost

Experimental evaluation: parallel execution



With more threads than logical cores there is a significant performance drop

Experimental evaluation: parallel execution



8 threads

As expected, the **ITM** depends on both the **number of extents** and the **overlap degree** α

Conclusions

- We've proposed a new parallel **D**ata **D**istribution **M**anagement (**DDM**) mechanism called **I**nterval **T**rees **M**atching (**ITM**)

- Both sequential and parallel implementations of **ITM** show good results when compared to the state of the art

- Since updates on the interval tree are efficient, the **ITM** can be easily extended to deal with the **dynamic matching problem**

- All our source code is available with a Free Software license: we believe that all the published results **have to be reproducible**

Further information

Moreno Marzolla, Gabriele D'Angelo, Marco Mandrioli

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