Formalizing Data Locality in Task-Parallel Applications

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Erik Hagersten
David Black-Schaffer

TAPEMS@ICA3PP '16

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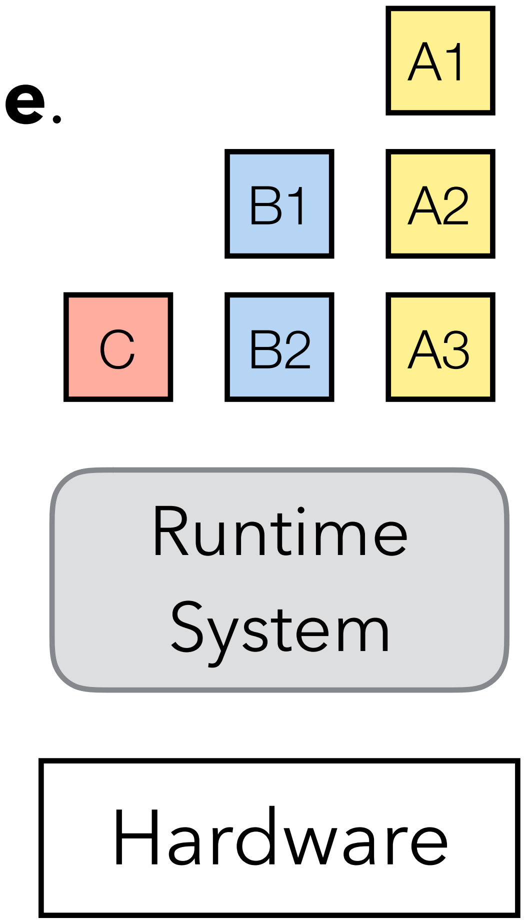
Tasks in the Multicore Era

Why Task-Based Programming?

- Easy to express parallelism (vs **threads**).
- Delegates many **programmer** decisions to the **runtime**.



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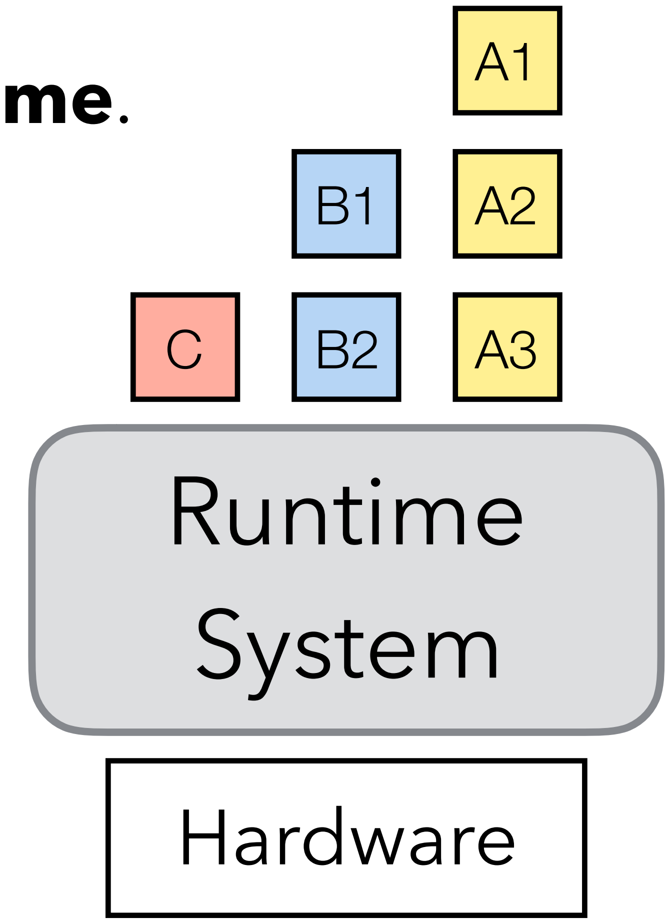
Tasks in the Multicore Era

Why Task-Based Programming?

- Easy to express parallelism (vs **threads**).
- Delegates many **programmer** decisions to the **runtime**.
- Allows runtime <u>optimizations</u>:
    - **Data Locality**
    - Memory Footprint
    - Energy Efficiency



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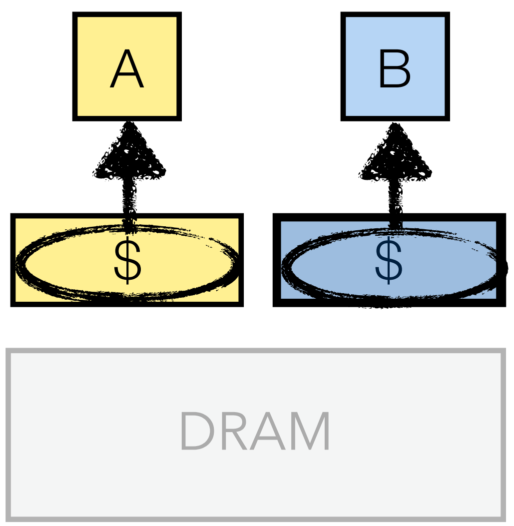
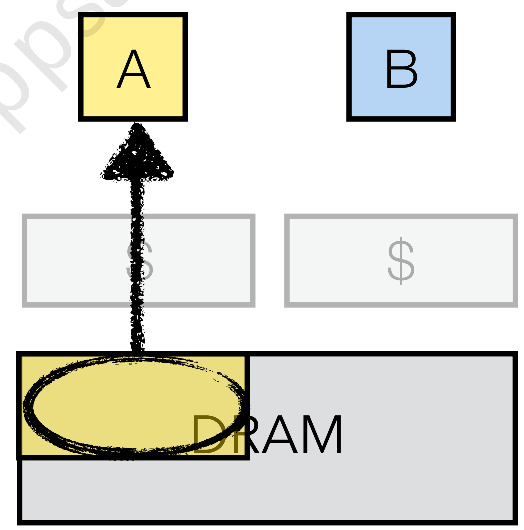
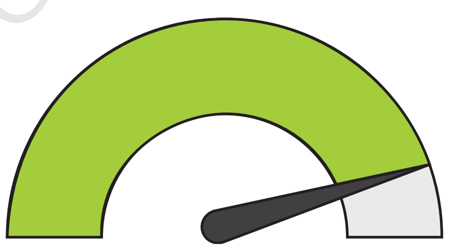
The Inconvenient Truths

1 Caches are **critical** for **performance**

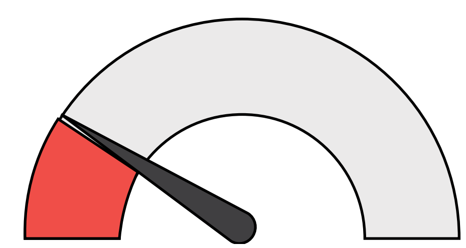




Faster!



Slower



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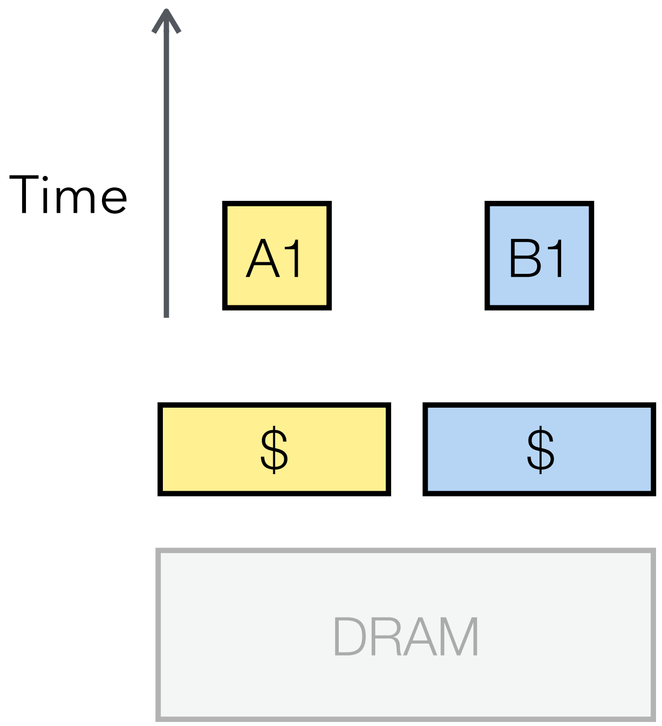
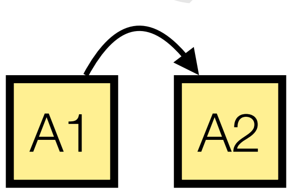
The Inconvenient Truths

2 Schedule **changes** how tasks **reuse** data





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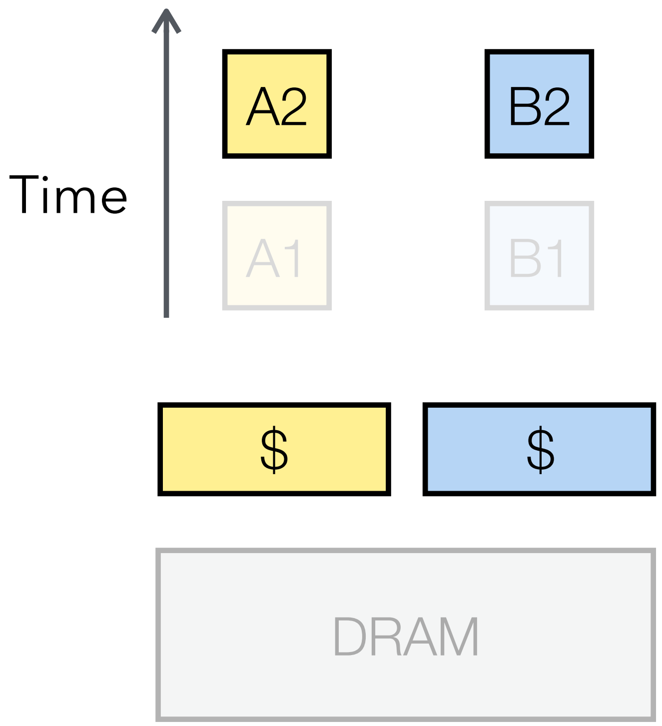

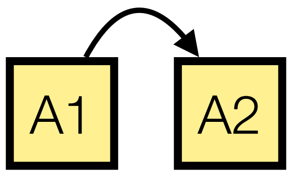

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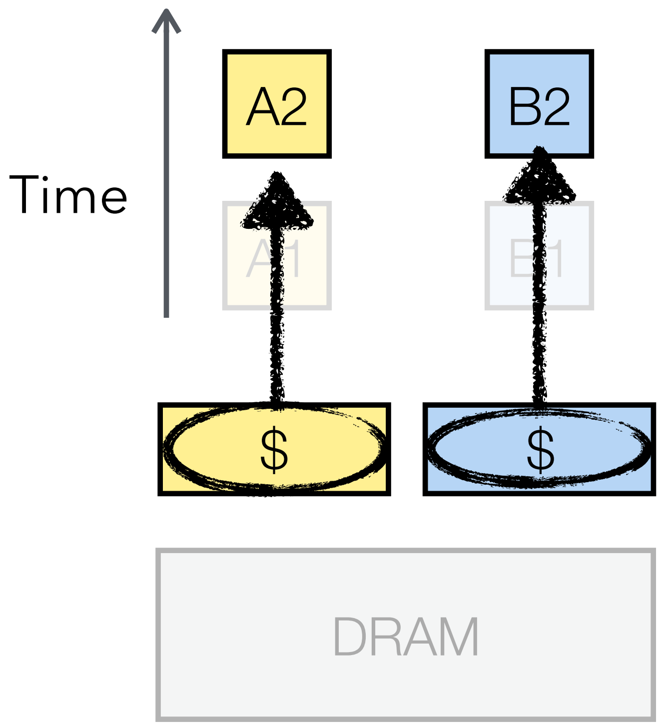

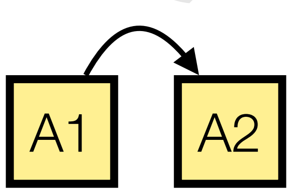

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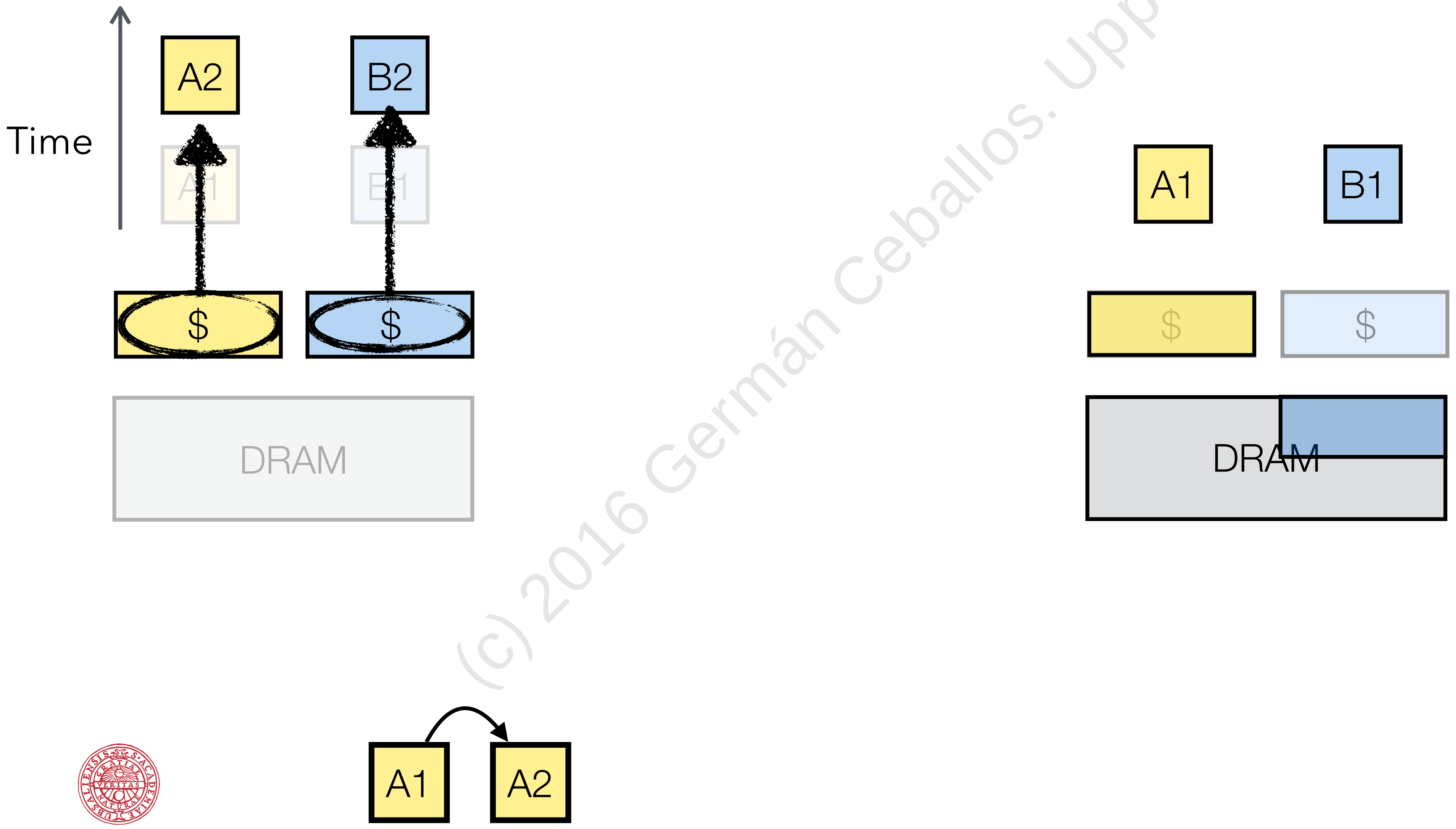

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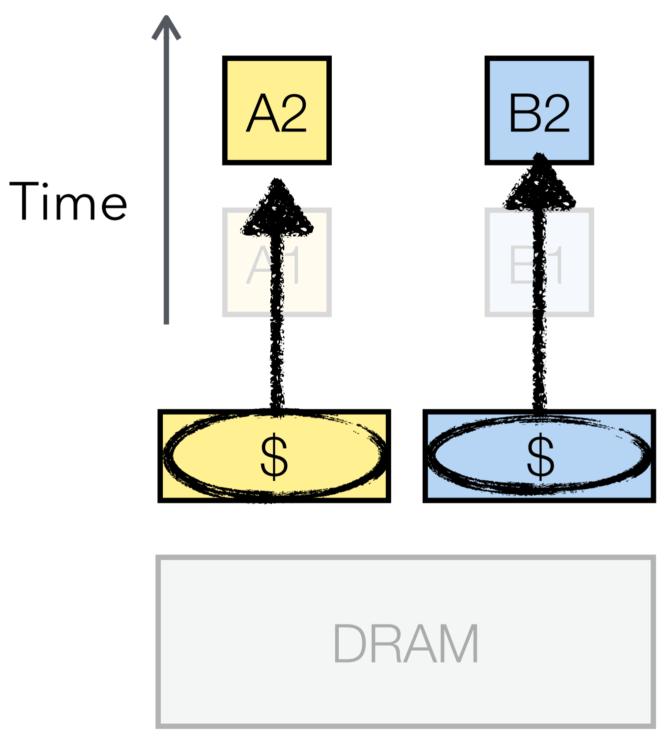

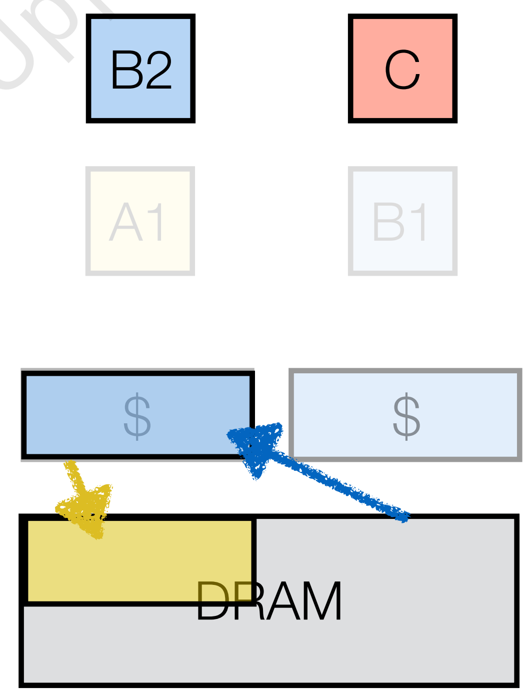

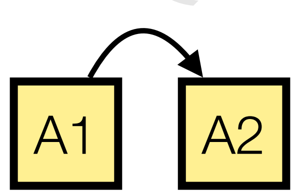

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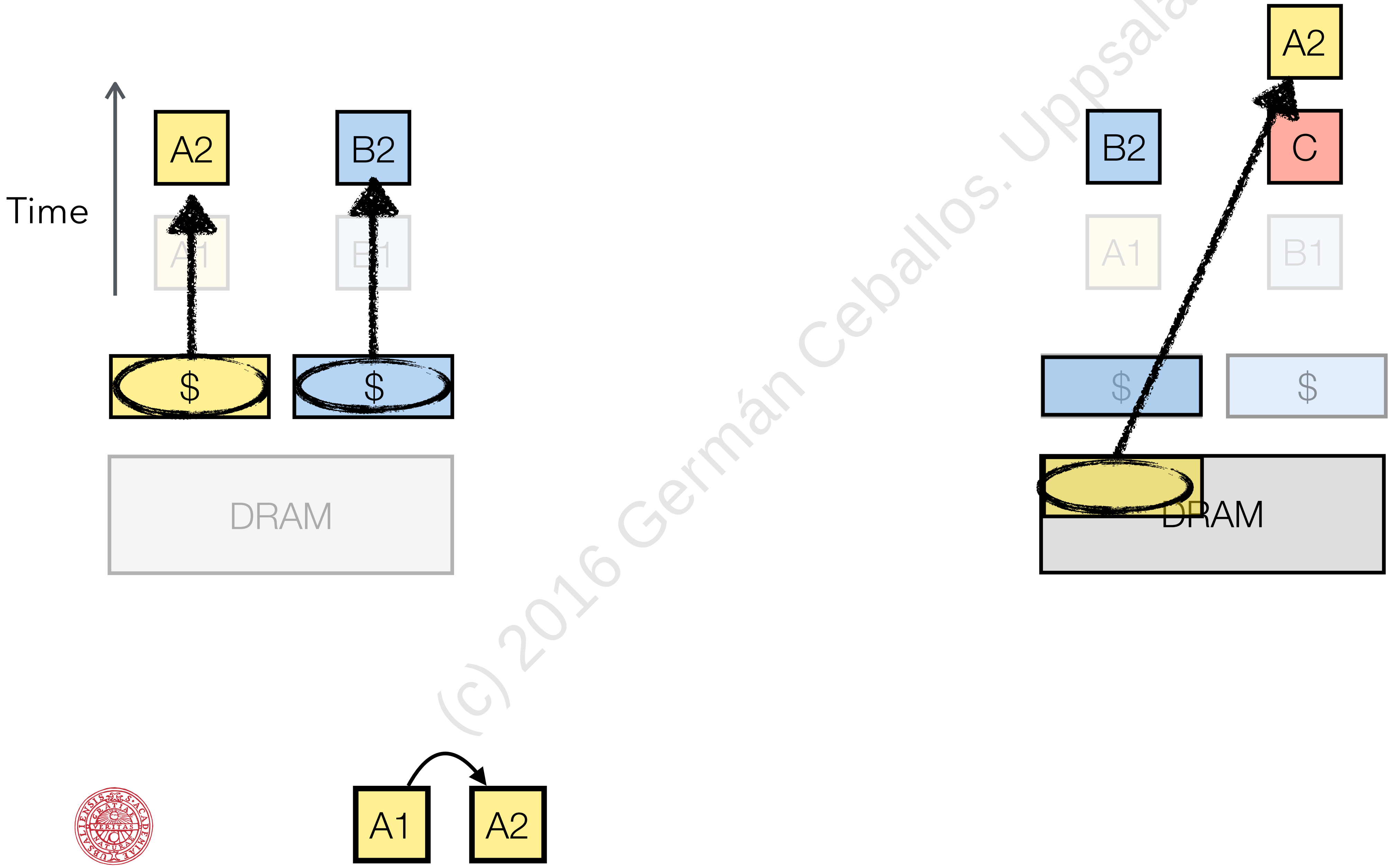

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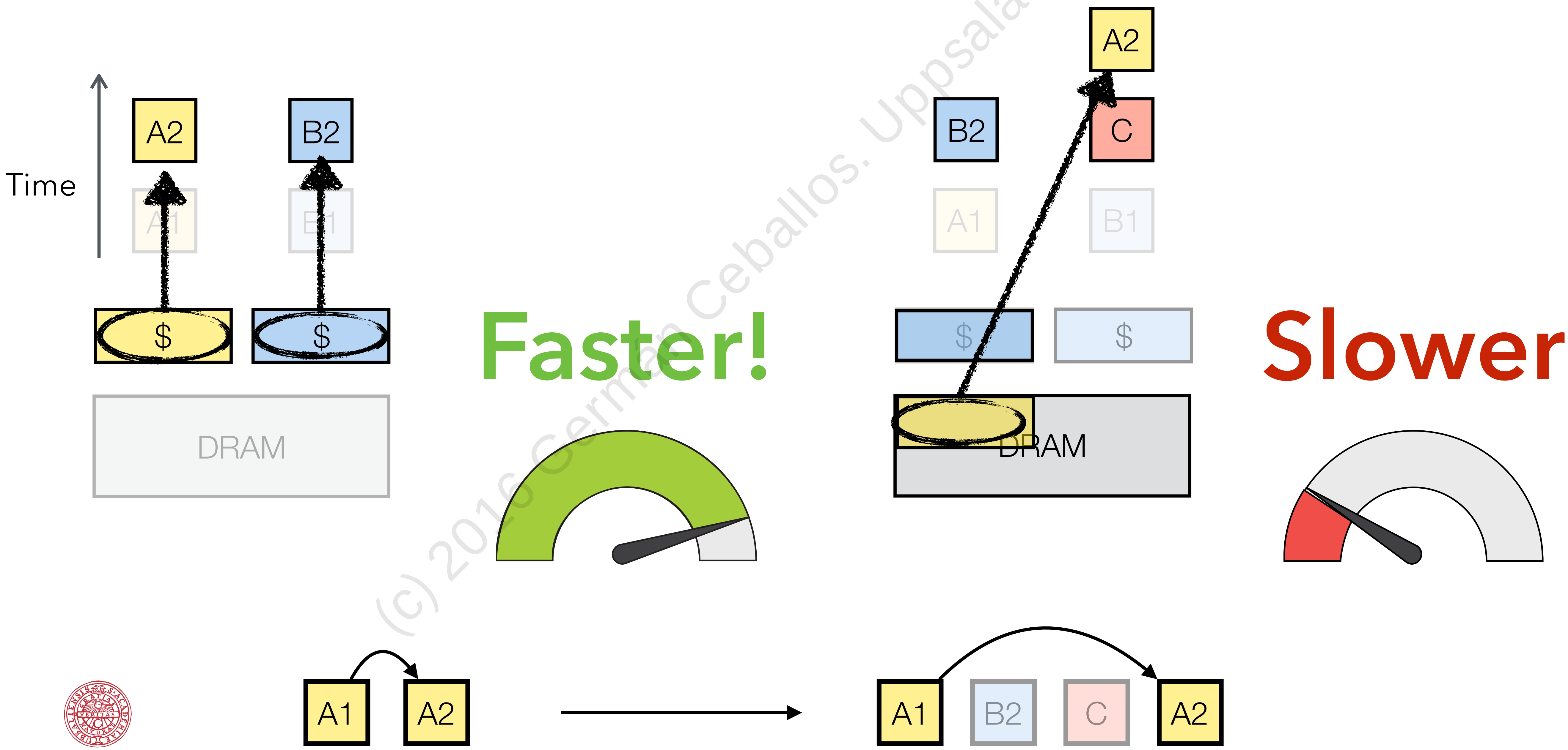

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The Inconvenient Truths

1. Caches are **critical** for **performance**
2. Schedule **changes** how tasks **reuse** data

≠ schedules → **≠ reuses** → **≠ performance**

What if we could **predict** effects of **scheduling** in **memory**?

(just from looking at one schedule)

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The StatTask Model

Our Contributions

- A **formal description** of the task-based execution model both as:
  - Sequence of memory accesses.
  - Sequence of tasks.
  - Equivalence between them.
- **StatTask: new** Statistical Cache Model
  - **What?**: **Predicts** memory (cache) behaviour for arbitrary schedules
  - **Accurate**: compared to measured results
  - **Flexible**: predicts from a **single** profile
  - **Robust**: predicts similar behaviour for inputs of roughly same size

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Why?

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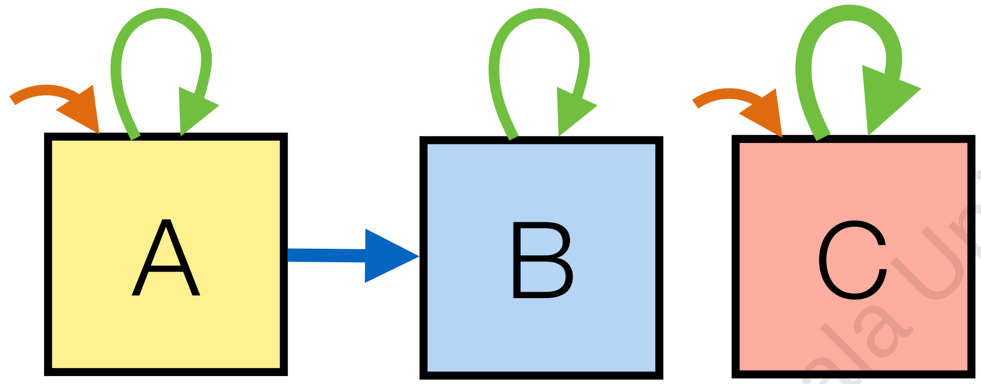
Potential: Reuse Classification



Type	Where?	Depending on
DRAM Access	DRAM	Data Set Size
Private Reuse	Cache/DRAM	Memory Access Pattern Cache Size
Shared Reuse	Cache/DRAM	Schedule

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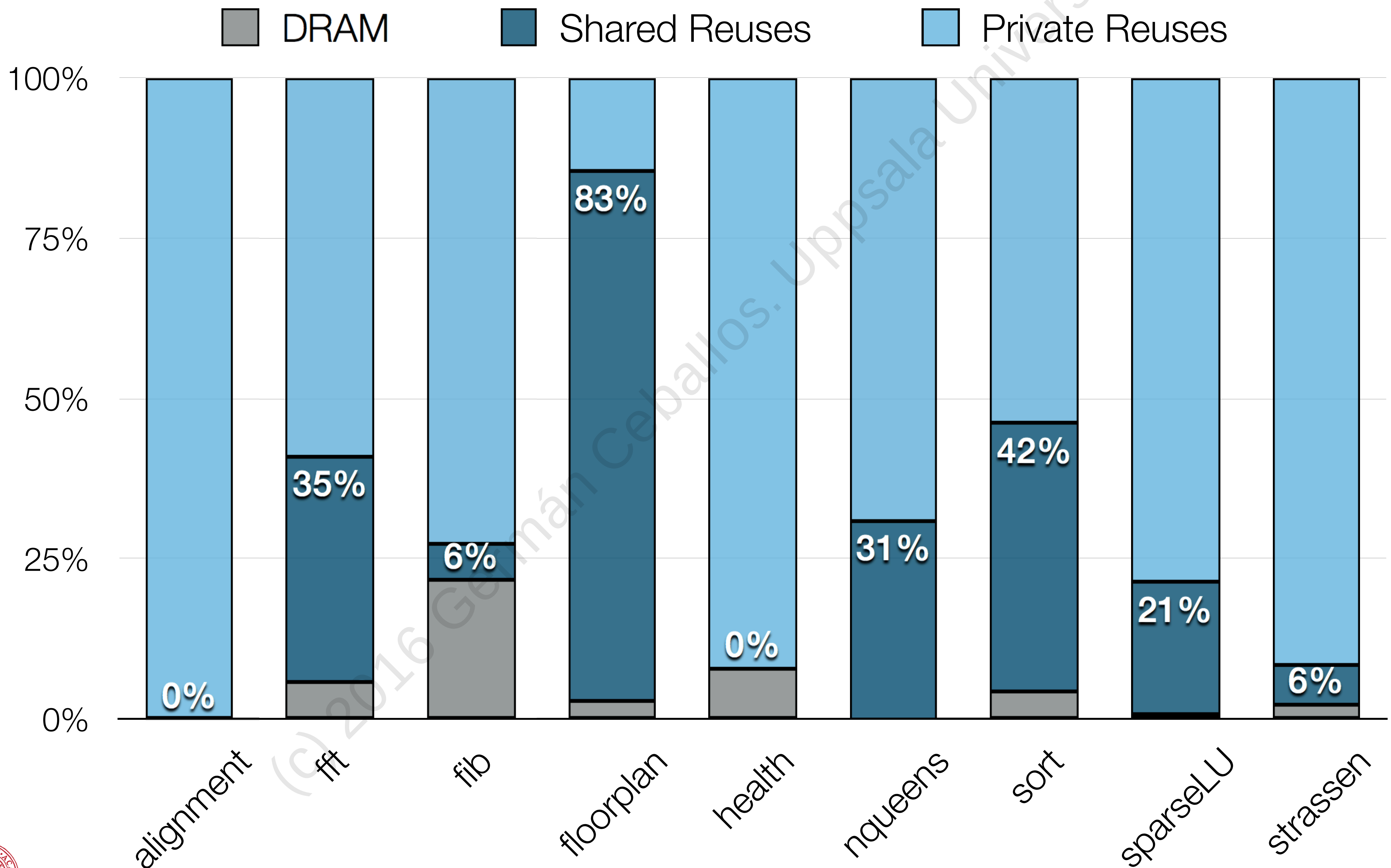
BOTS Reuse Potential



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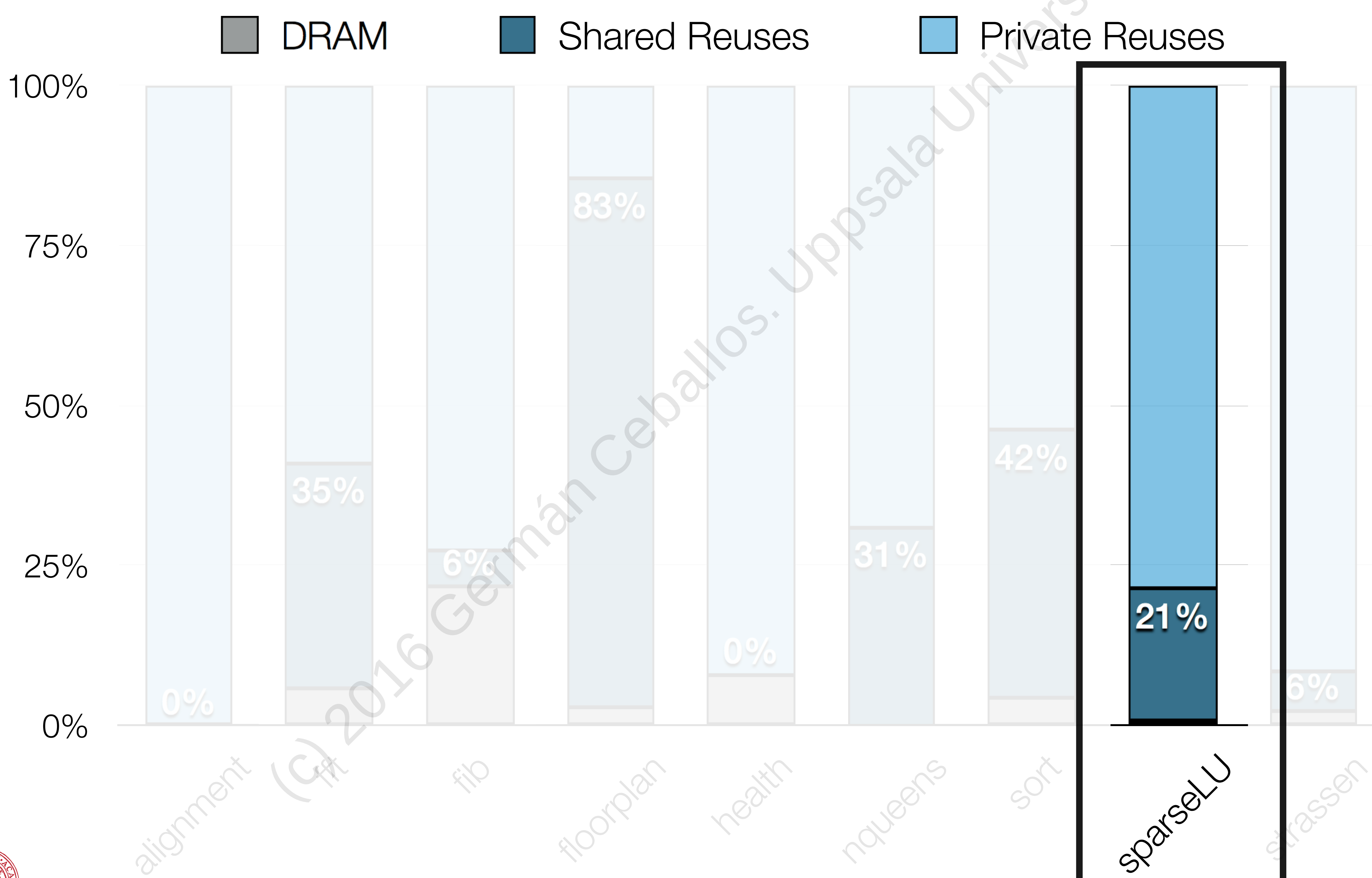

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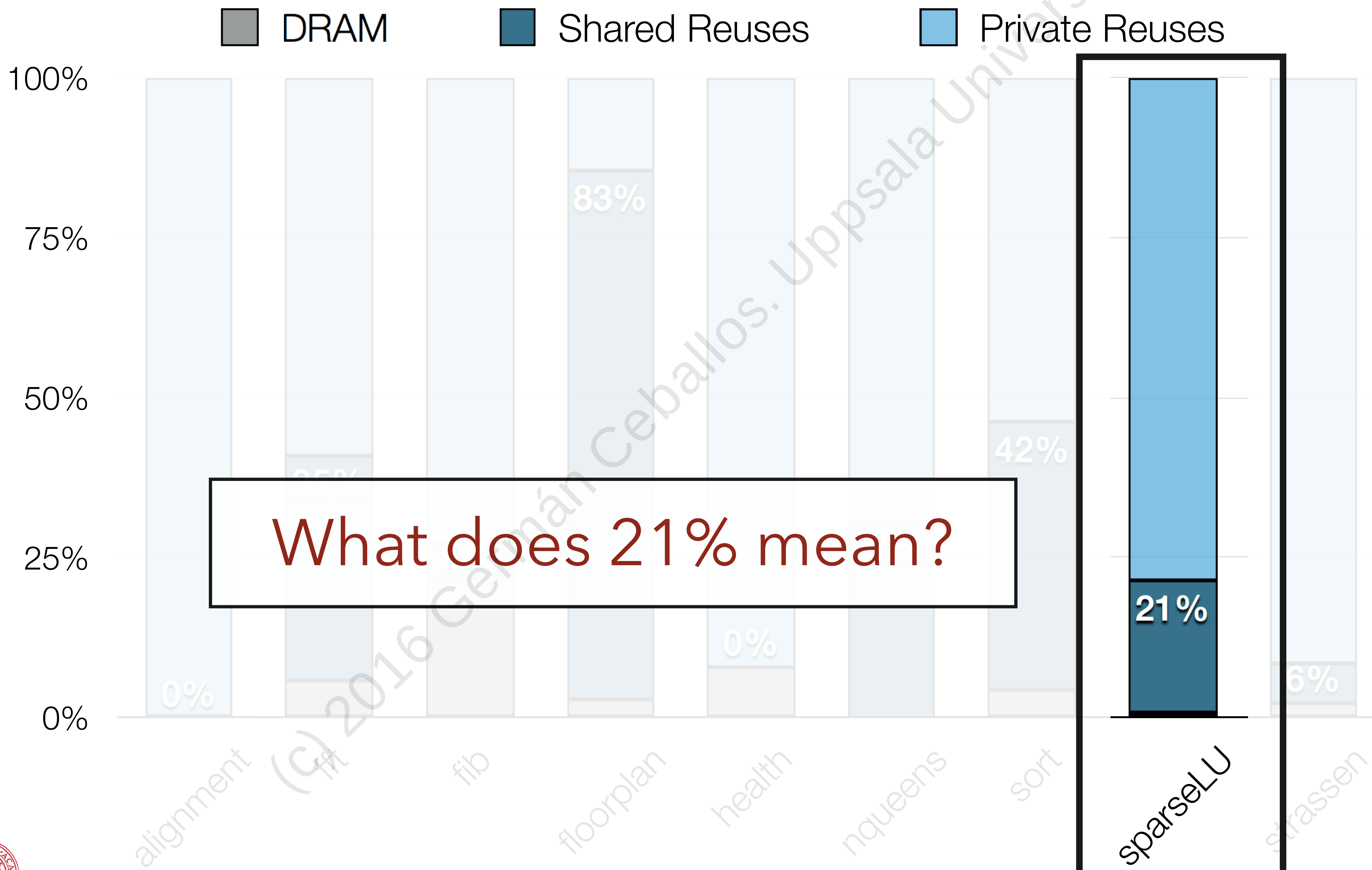

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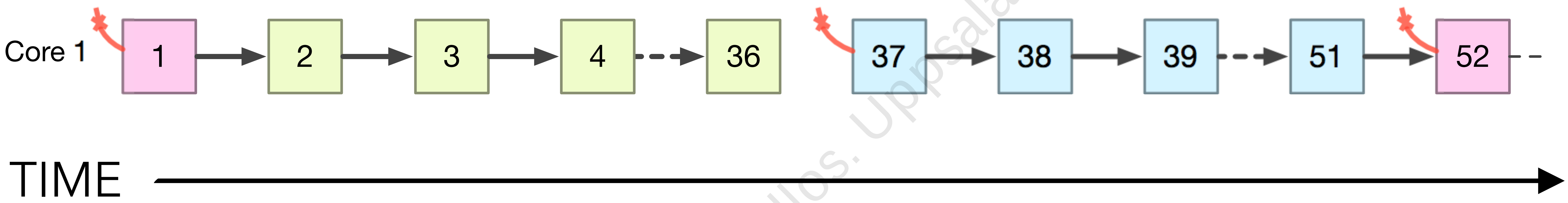
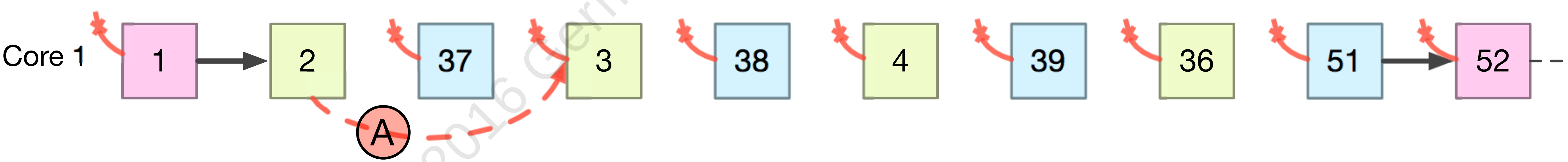
SparseLU Schedules (ST)

Good Schedule



Bad Schedule



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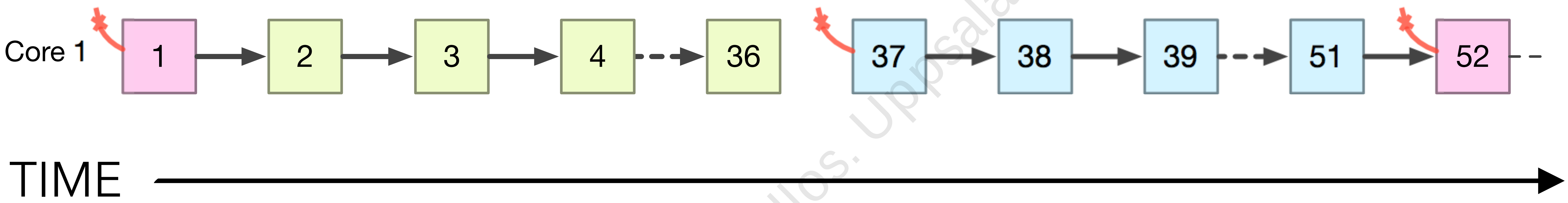
SparseLU Schedules (ST)

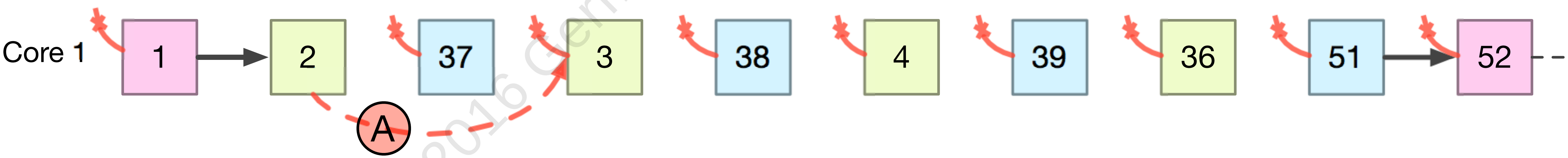
Good Schedule

Miss Ratio: 0,27%



Bad Schedule

Miss Ratio: 8,01%



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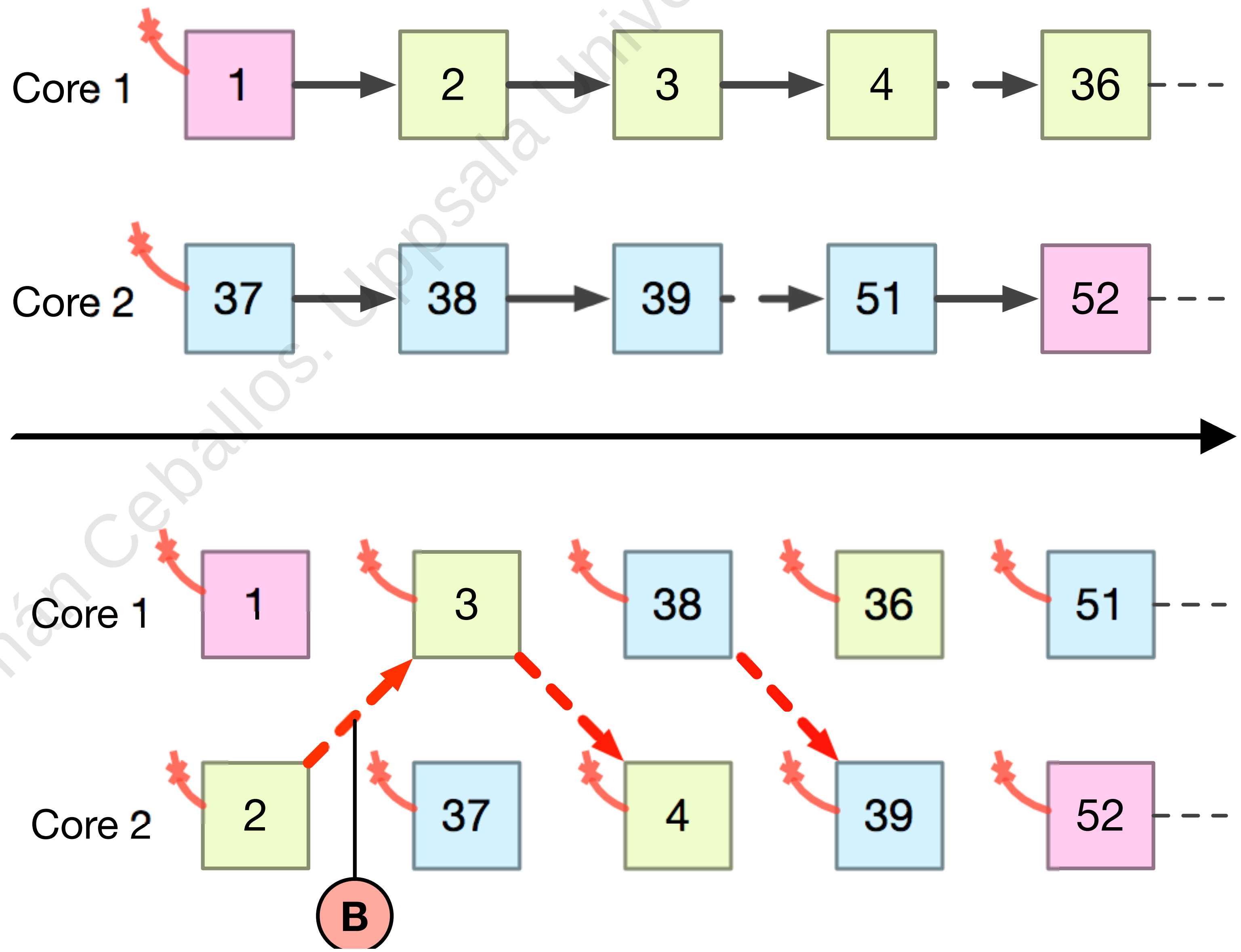
SparseLU Schedules (MT)

Good Schedule

Miss Ratio: 0,04%



Bad Schedule

Miss Ratio: 8,01%

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Good Schedule

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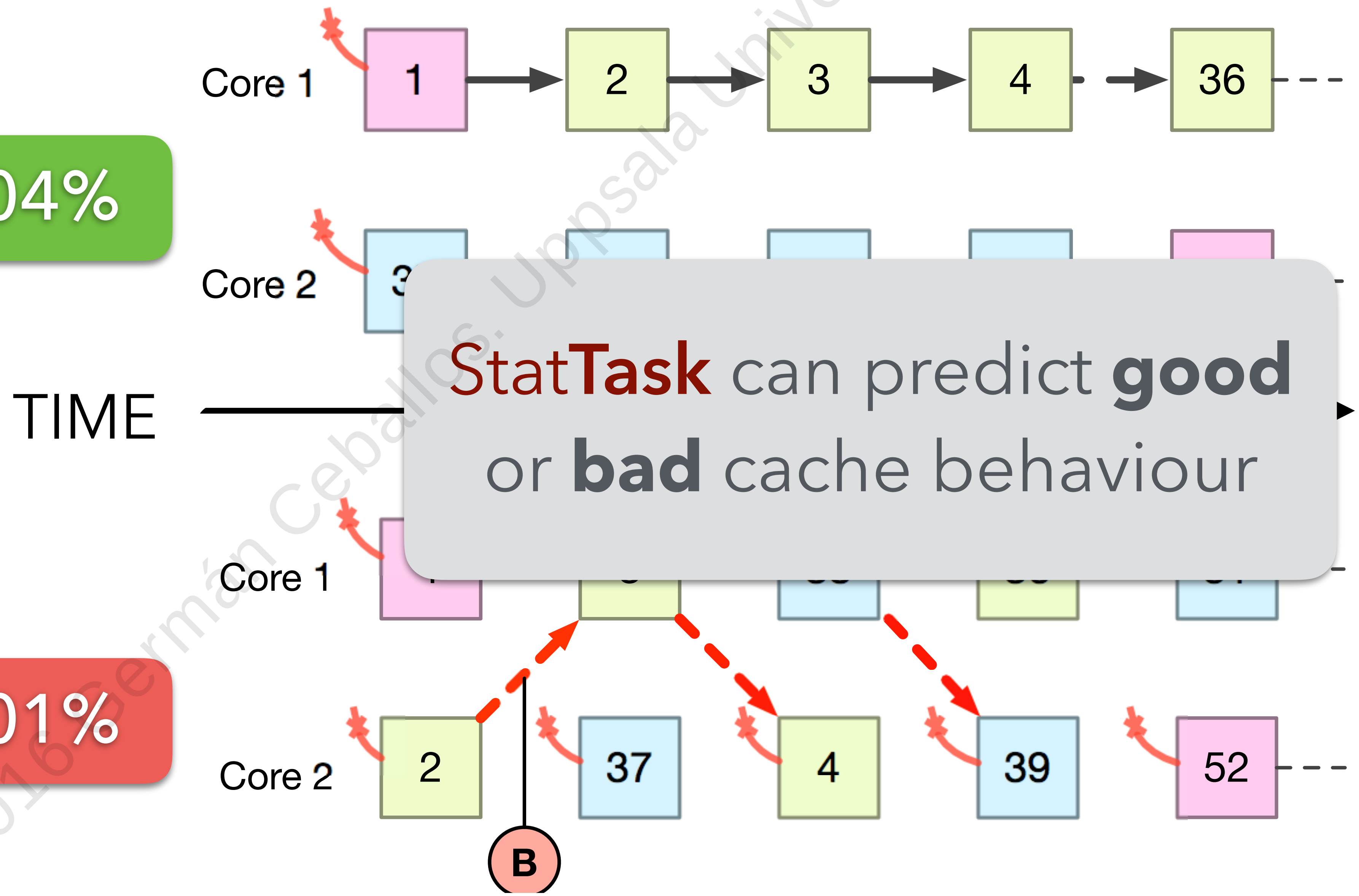

StatTask can predict **good** or **bad** cache behaviour

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How can we study data locality?

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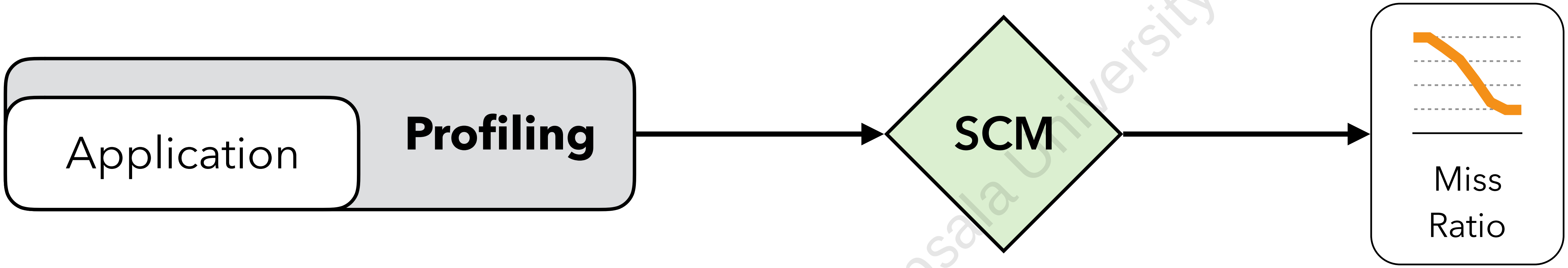
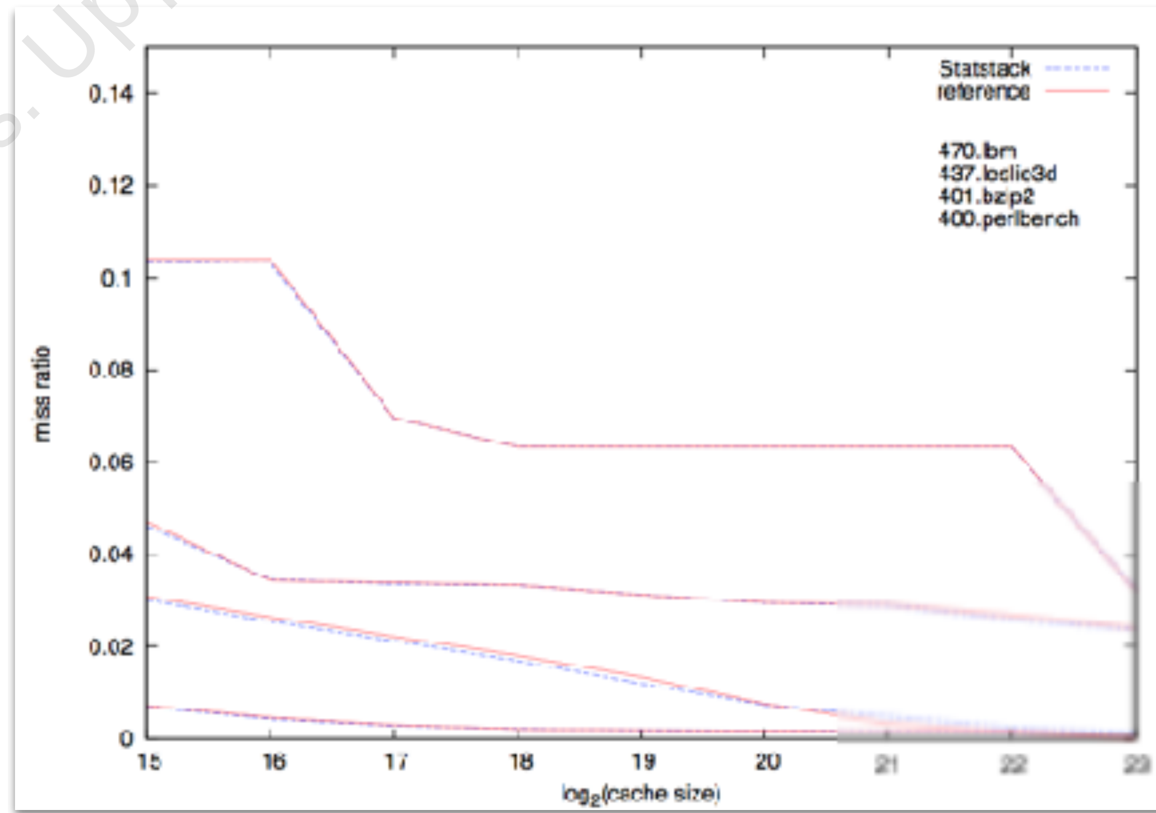
Statistical Cache Models*



Why SCM?

- Fast + Low Overhead
- Accurate
- Just a single profile needed
- Flexible (different cache sizes)



* E. Berg and E. Hagersten. 2004.
StatCache: a probabilistic approach to efficient and accurate data locality analysis.
In *Proceedings of the 2004 IEEE International Symposium on Performance Analysis of Systems and Software* (ISPASS '04). USA

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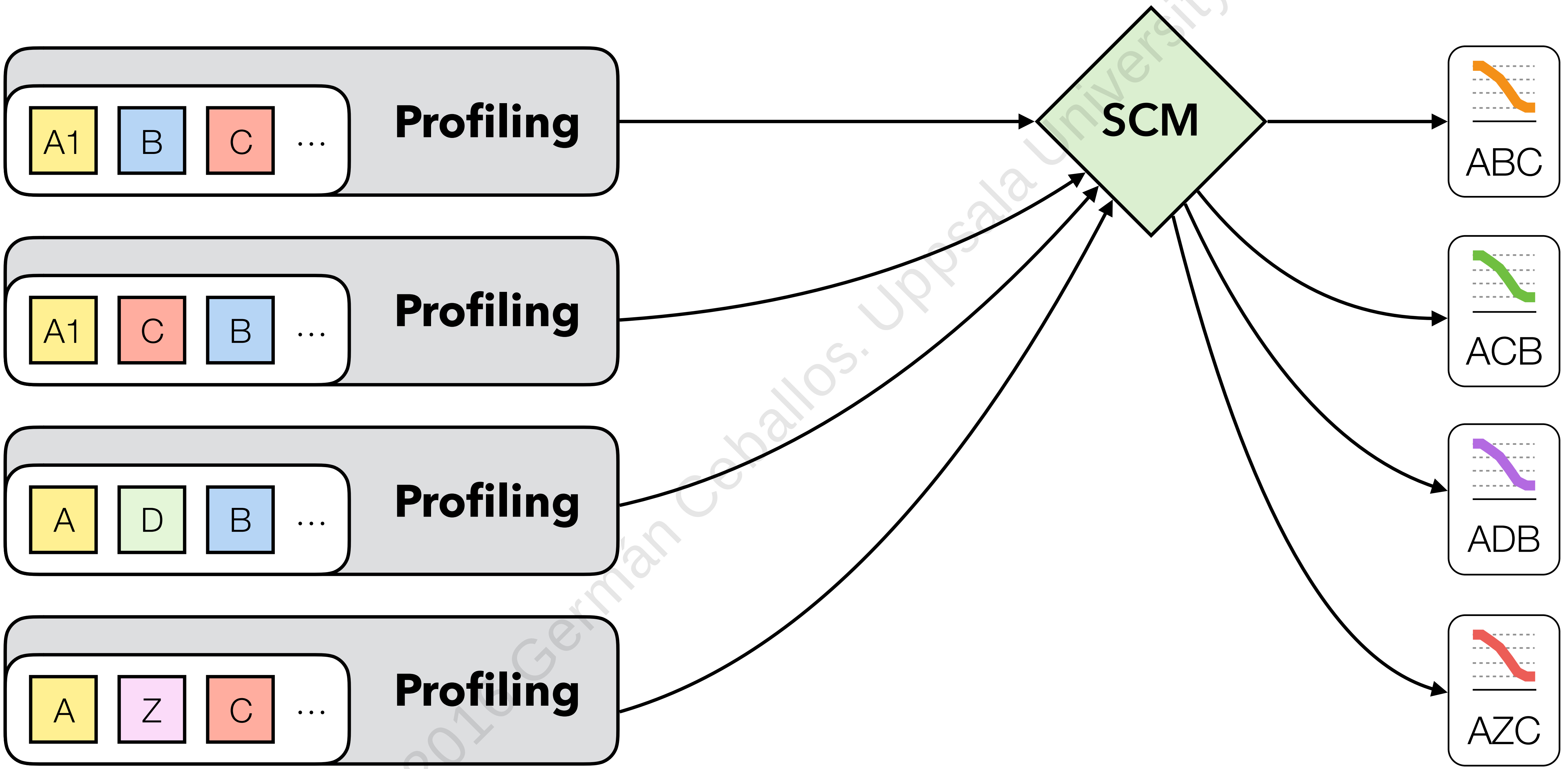
The Problem



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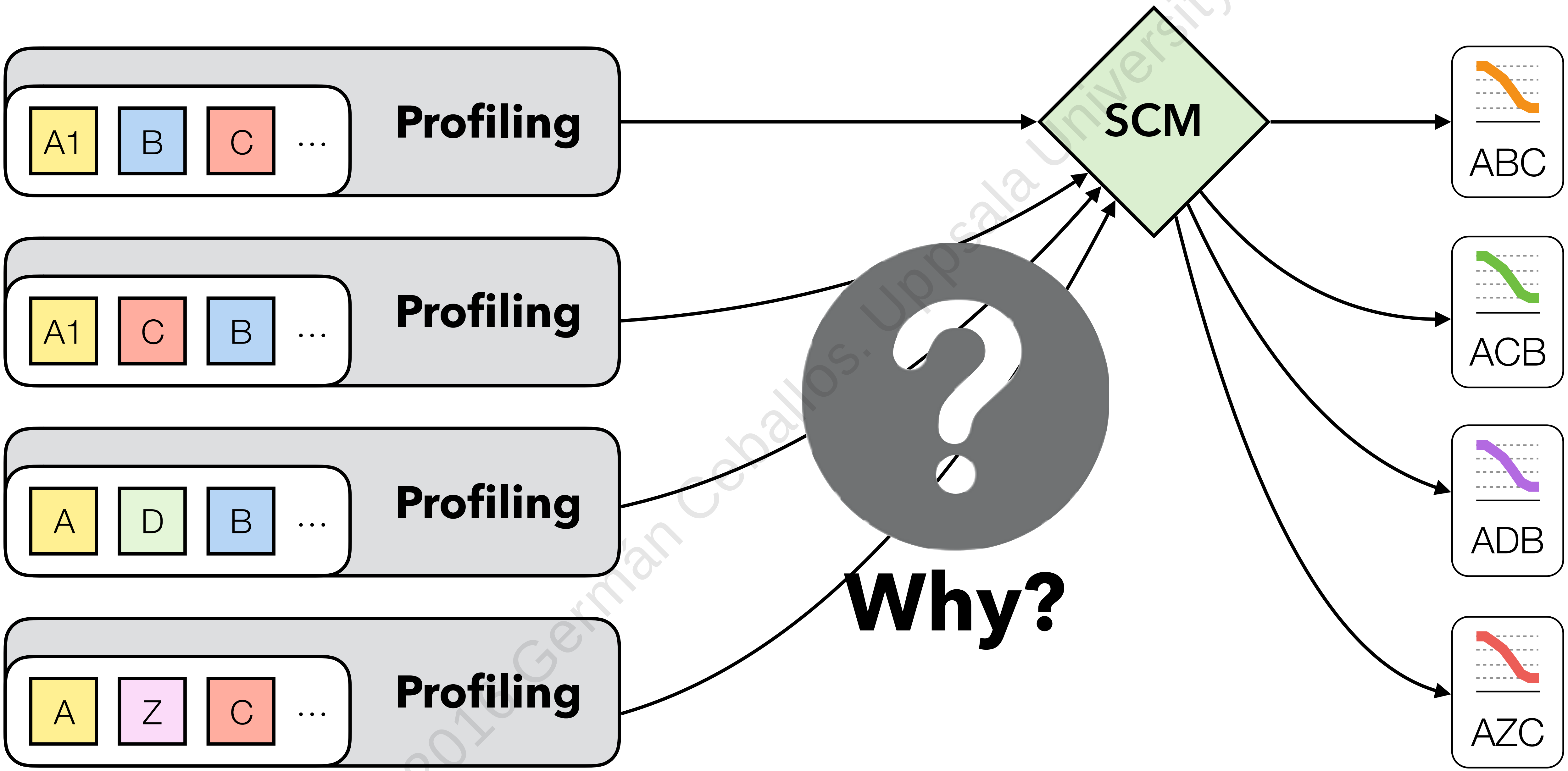

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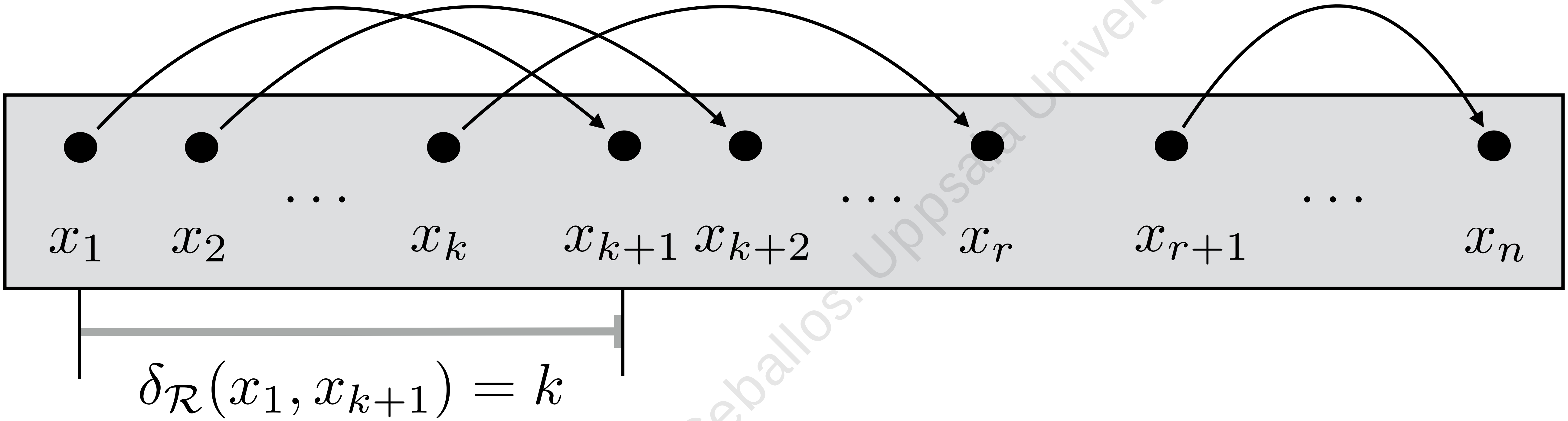
Statistical Cache Models



1. Sample memory accesses
2. Identifying consecutive reuses between them
3. Counting intervening accesses between reuses
4. Use statistical inference to estimate cache behaviour

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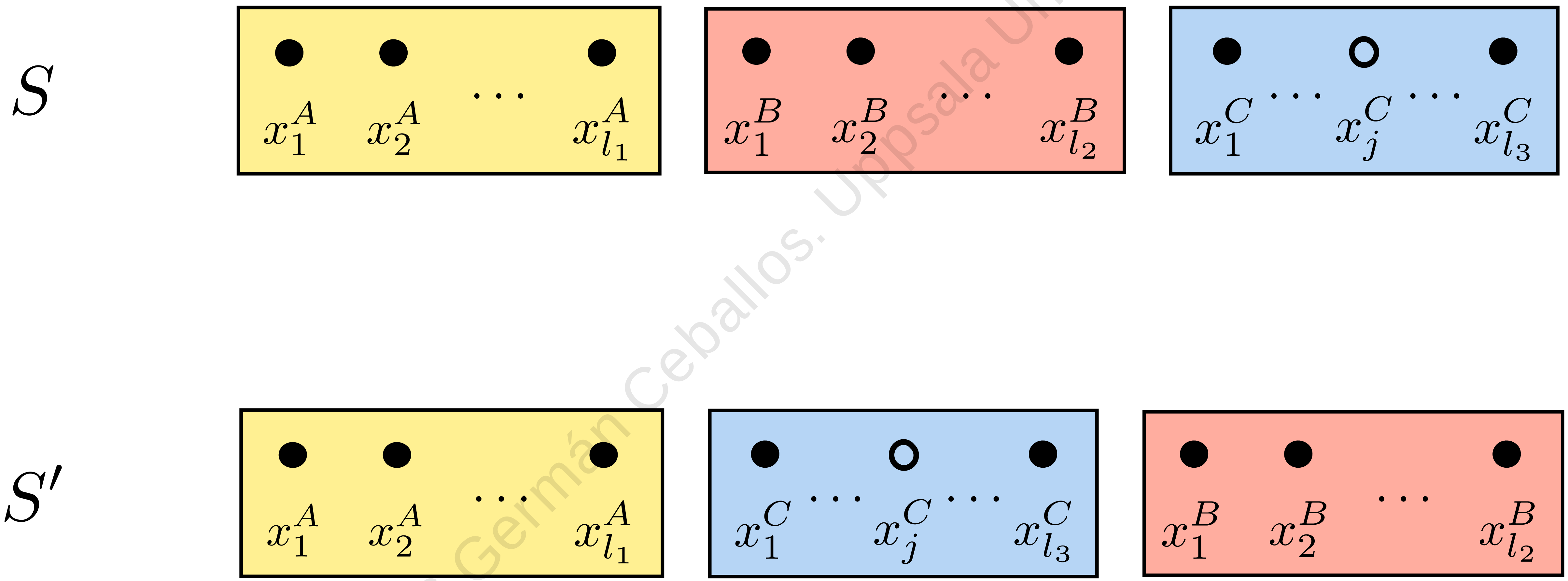
SCM with **Tasks**



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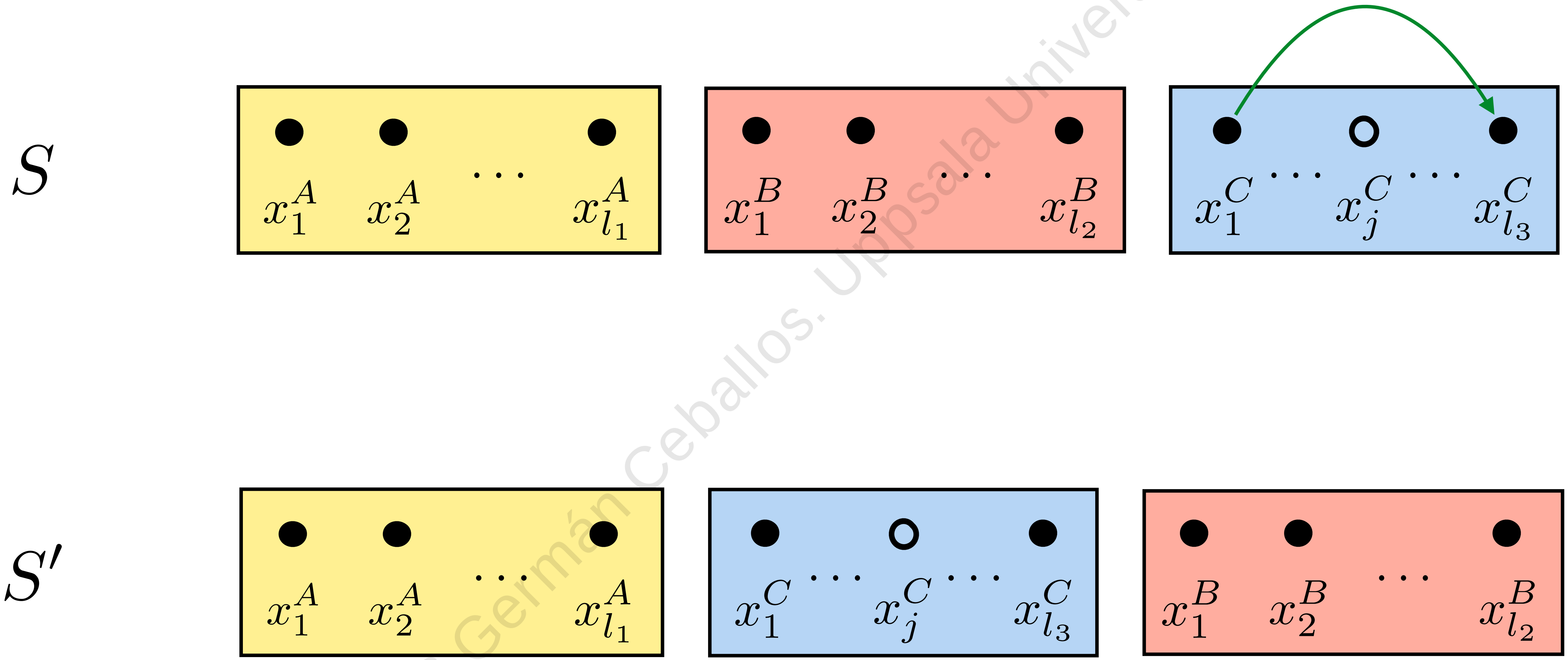

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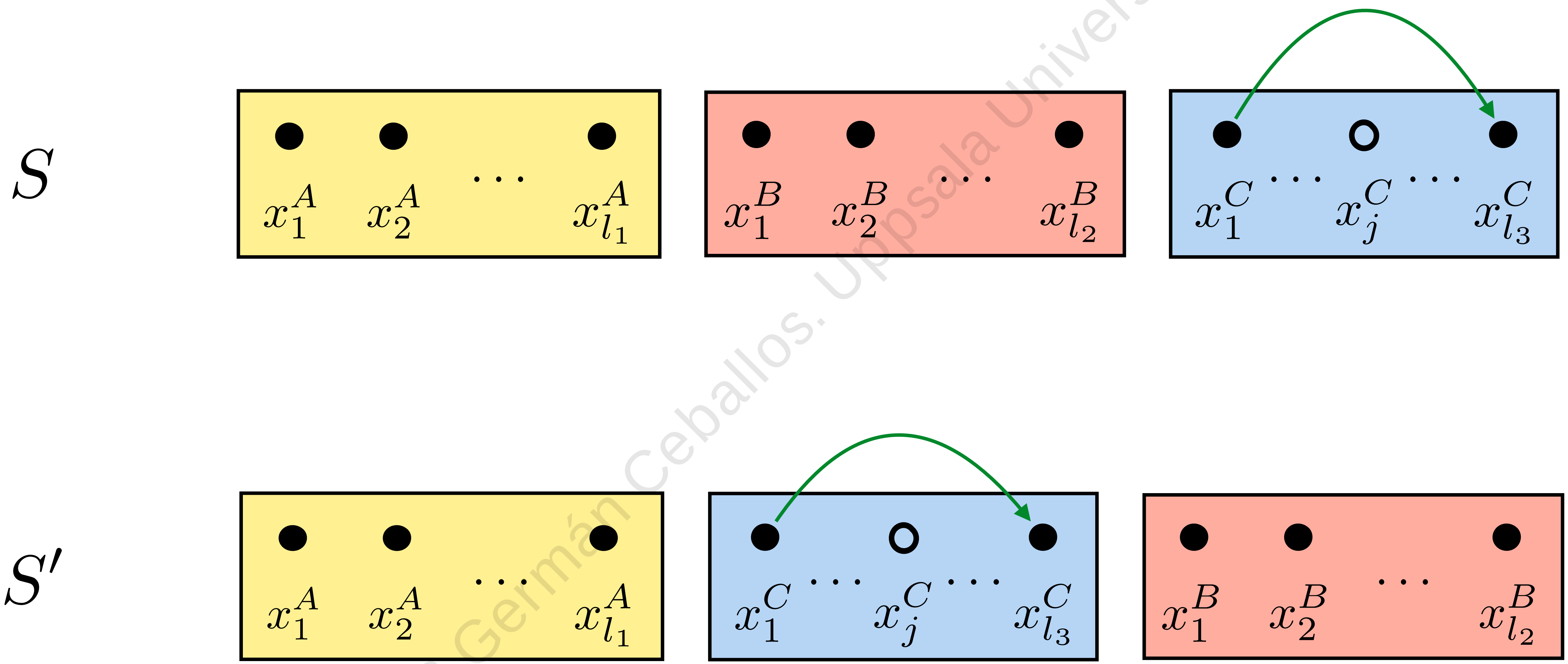

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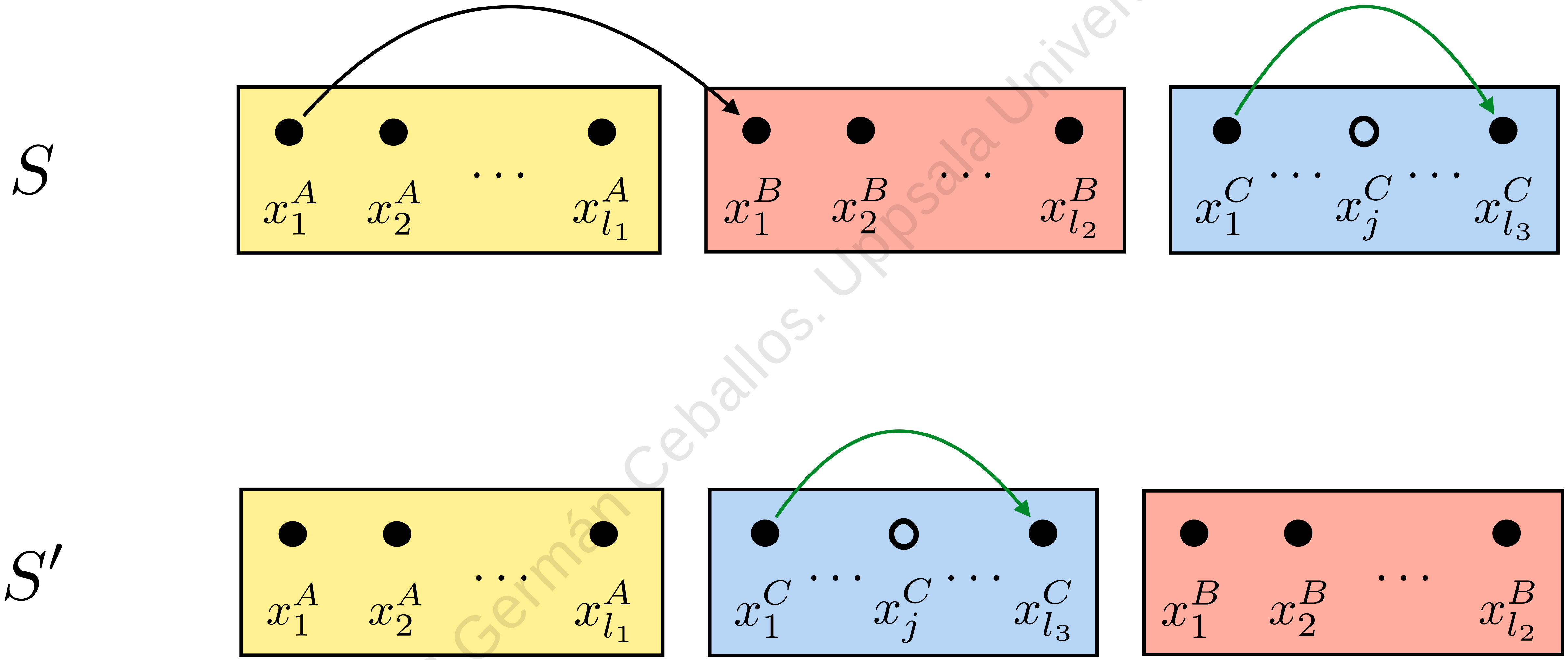

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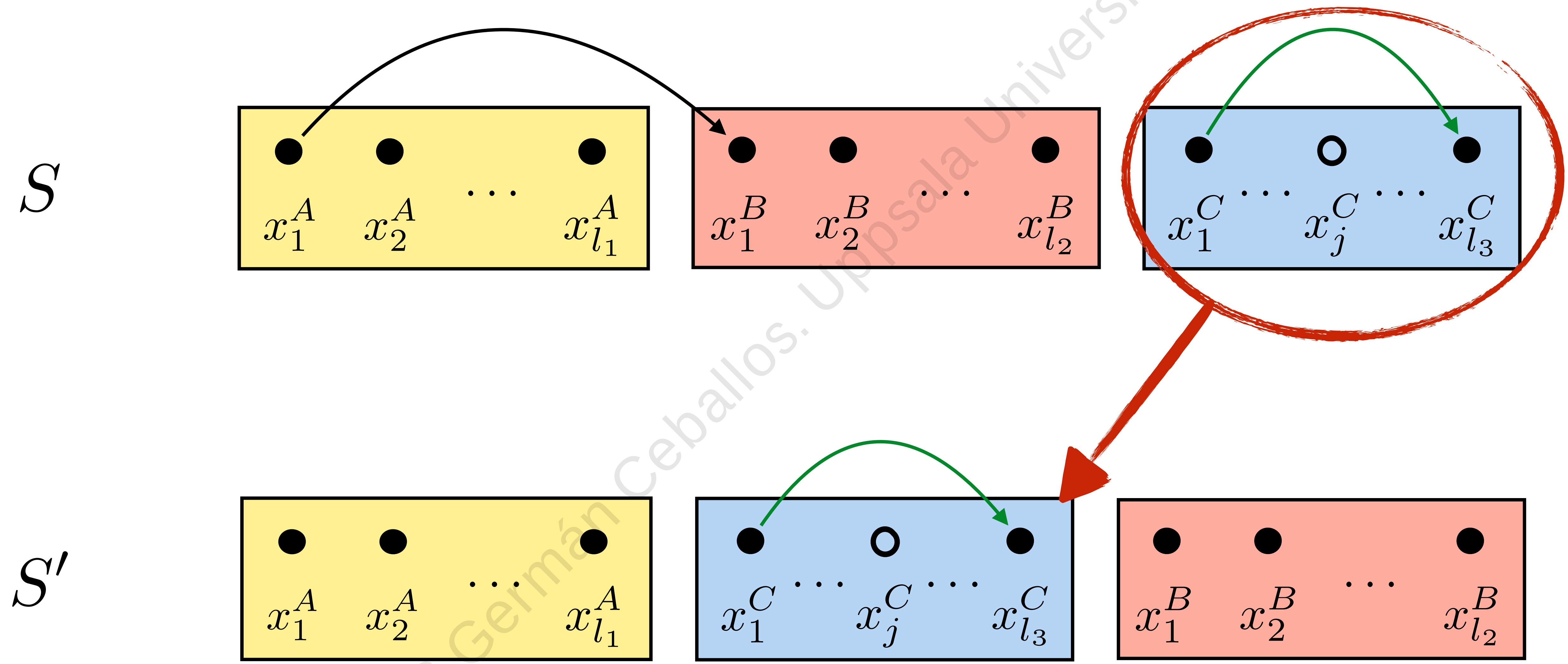

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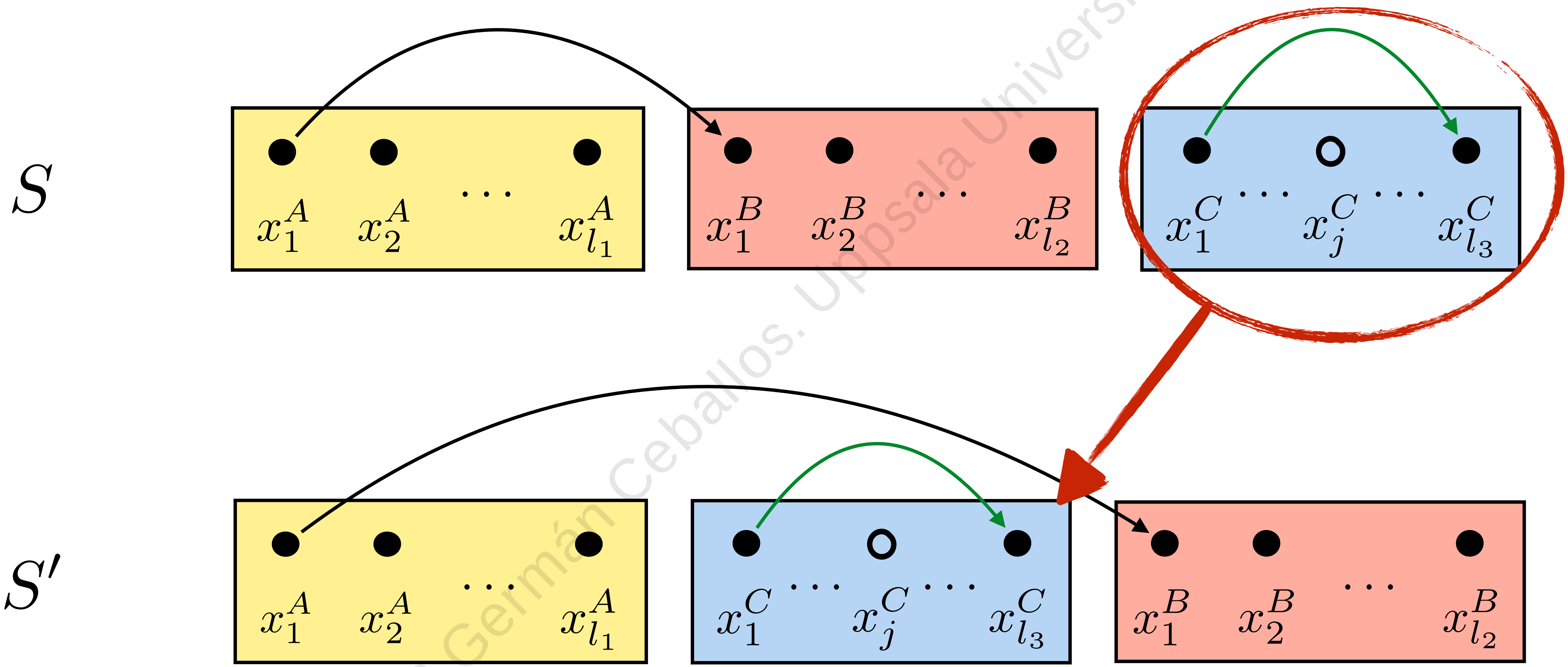

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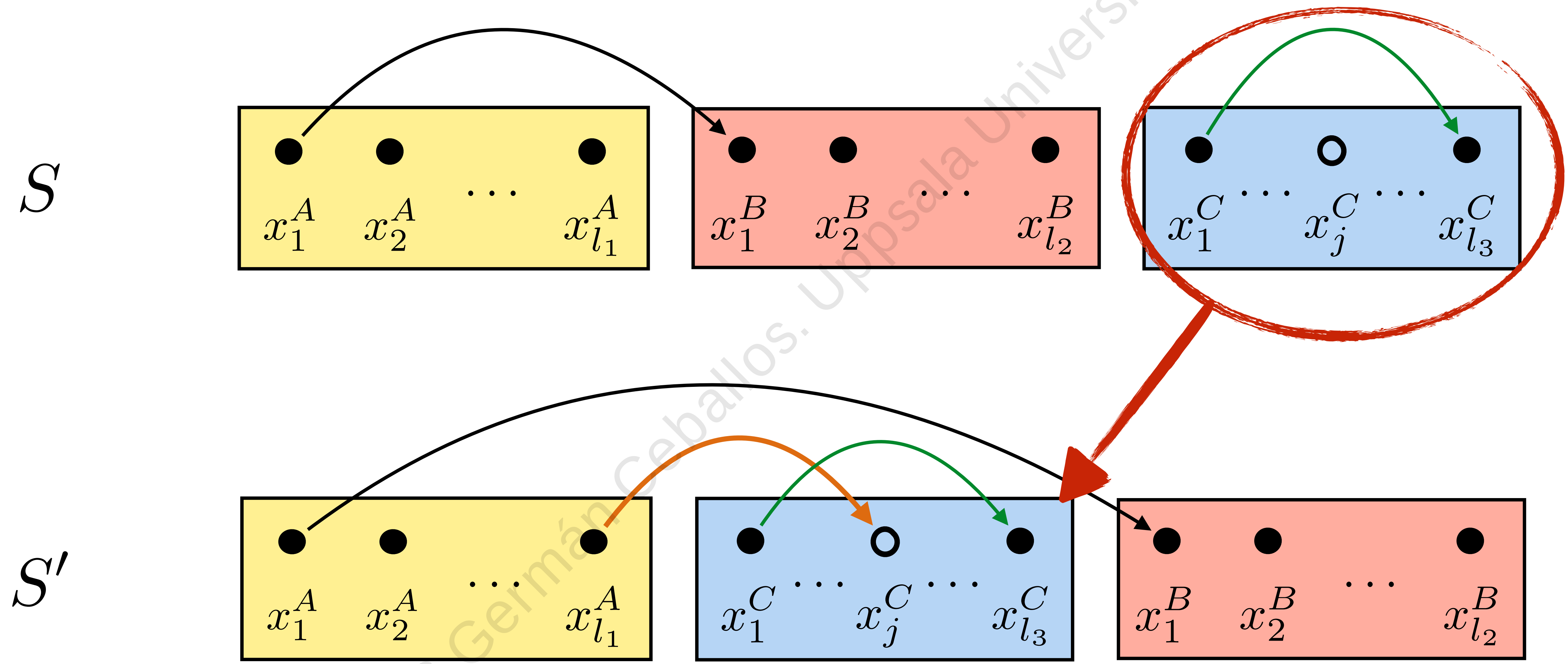

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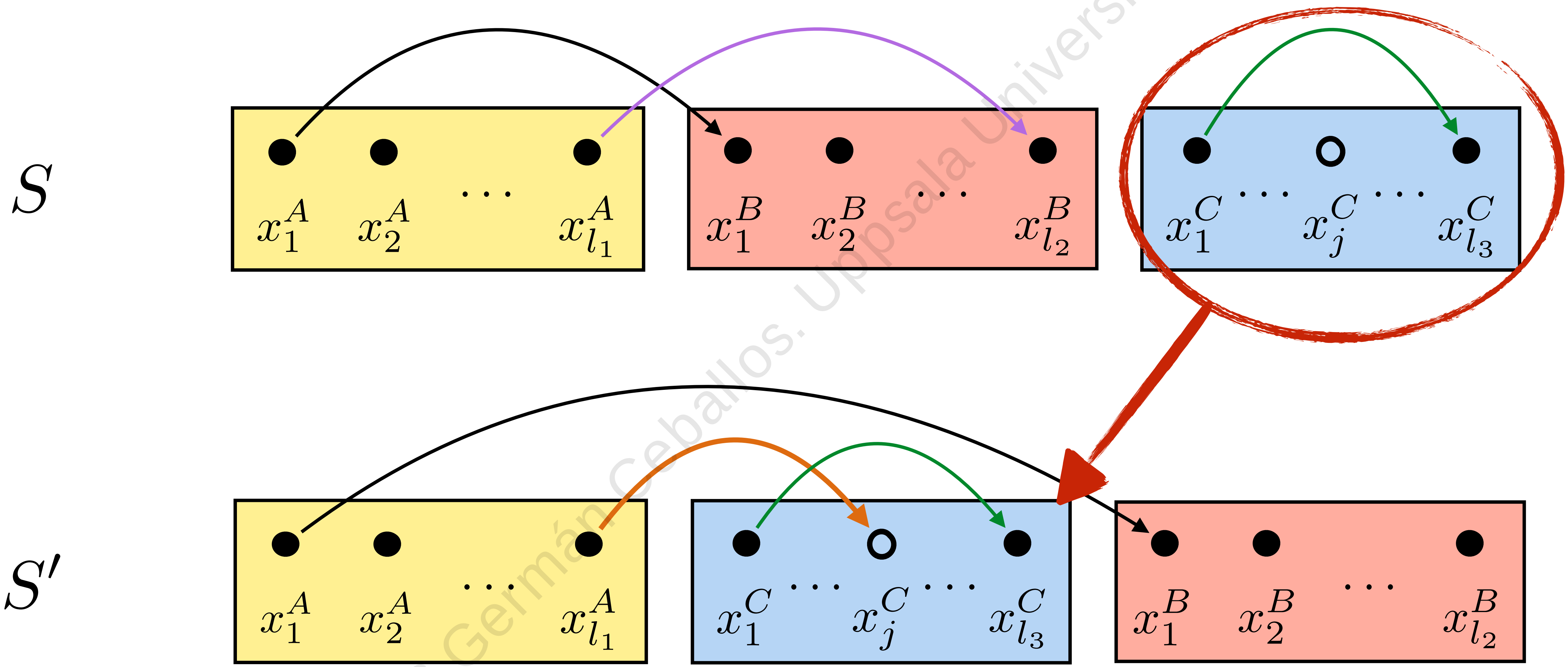

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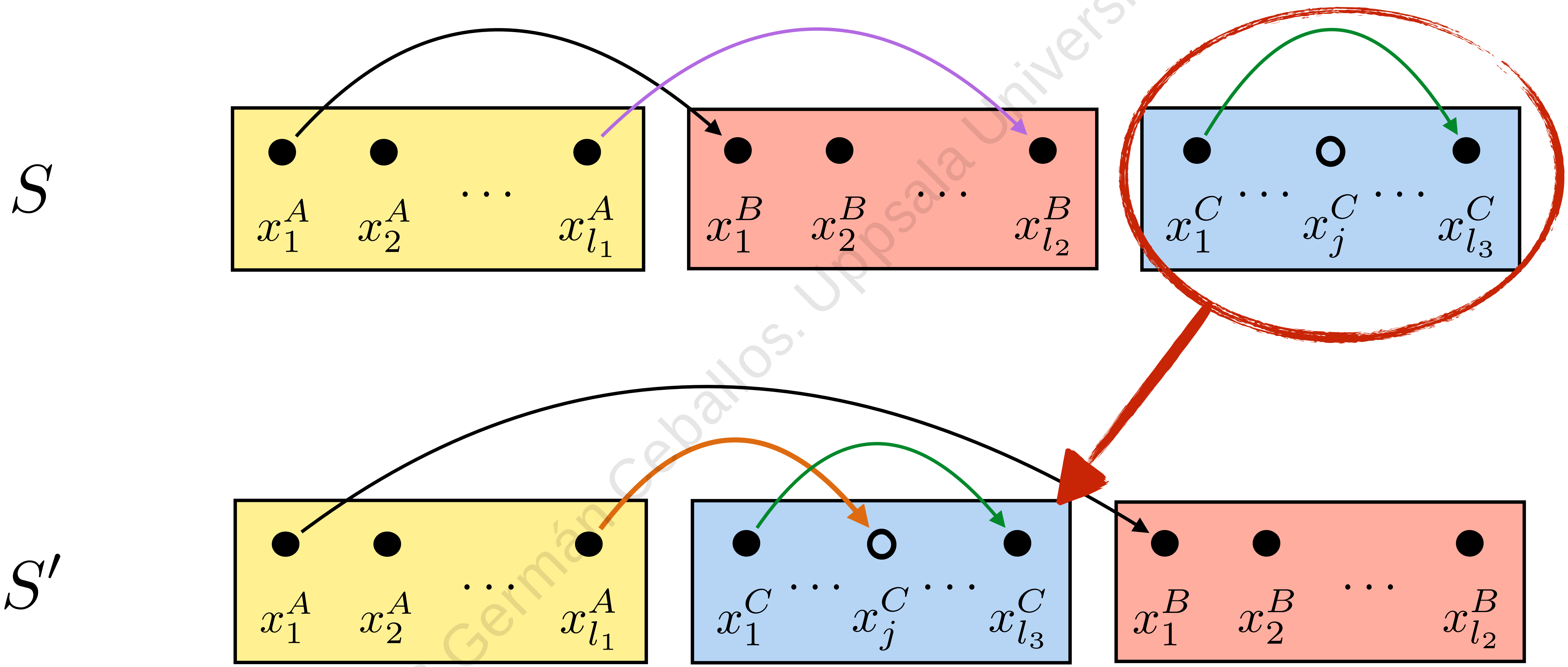

Reuses can change!

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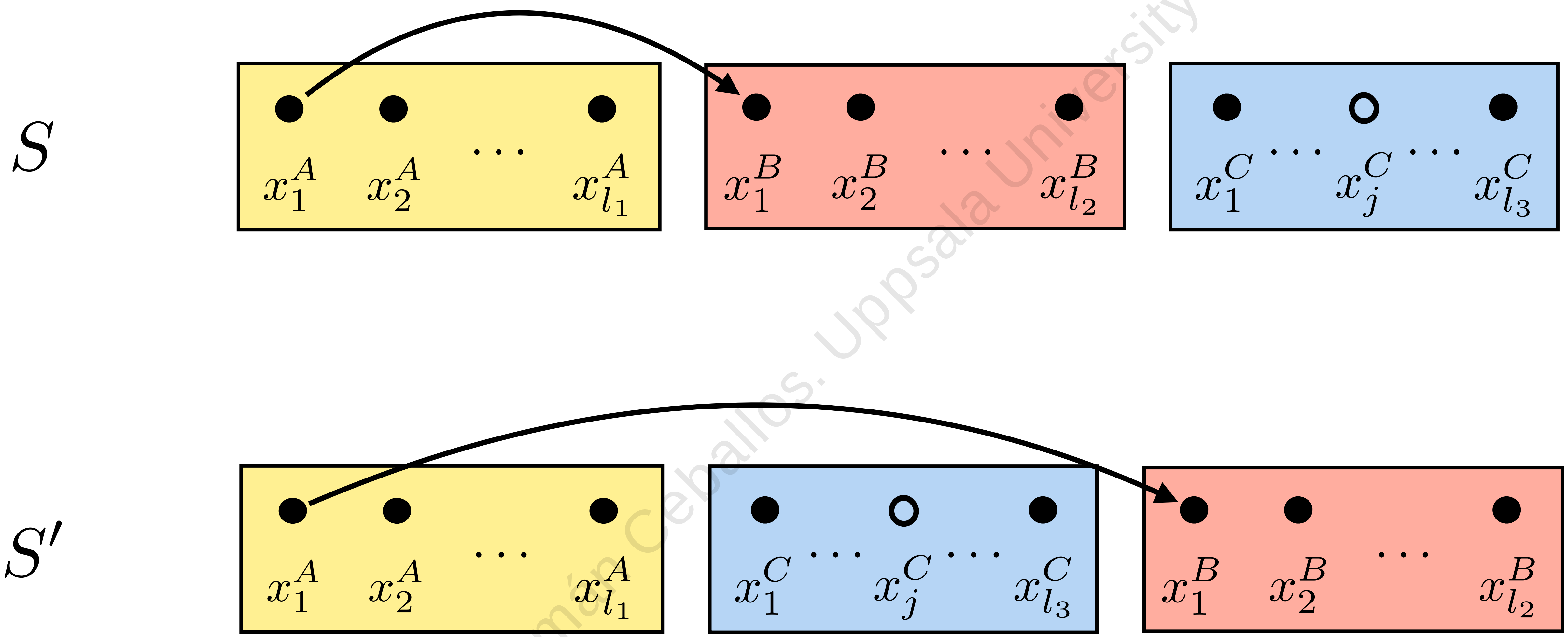

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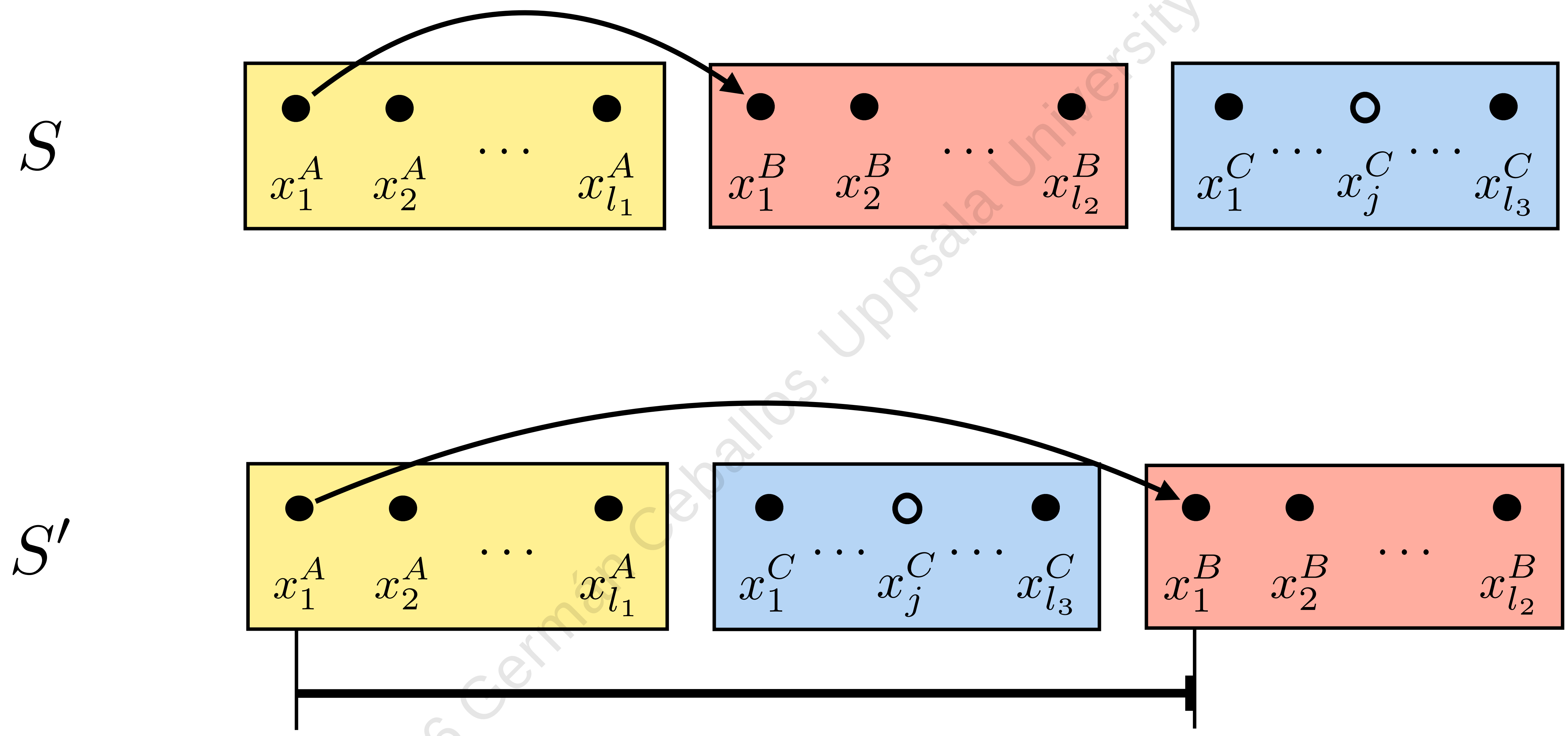

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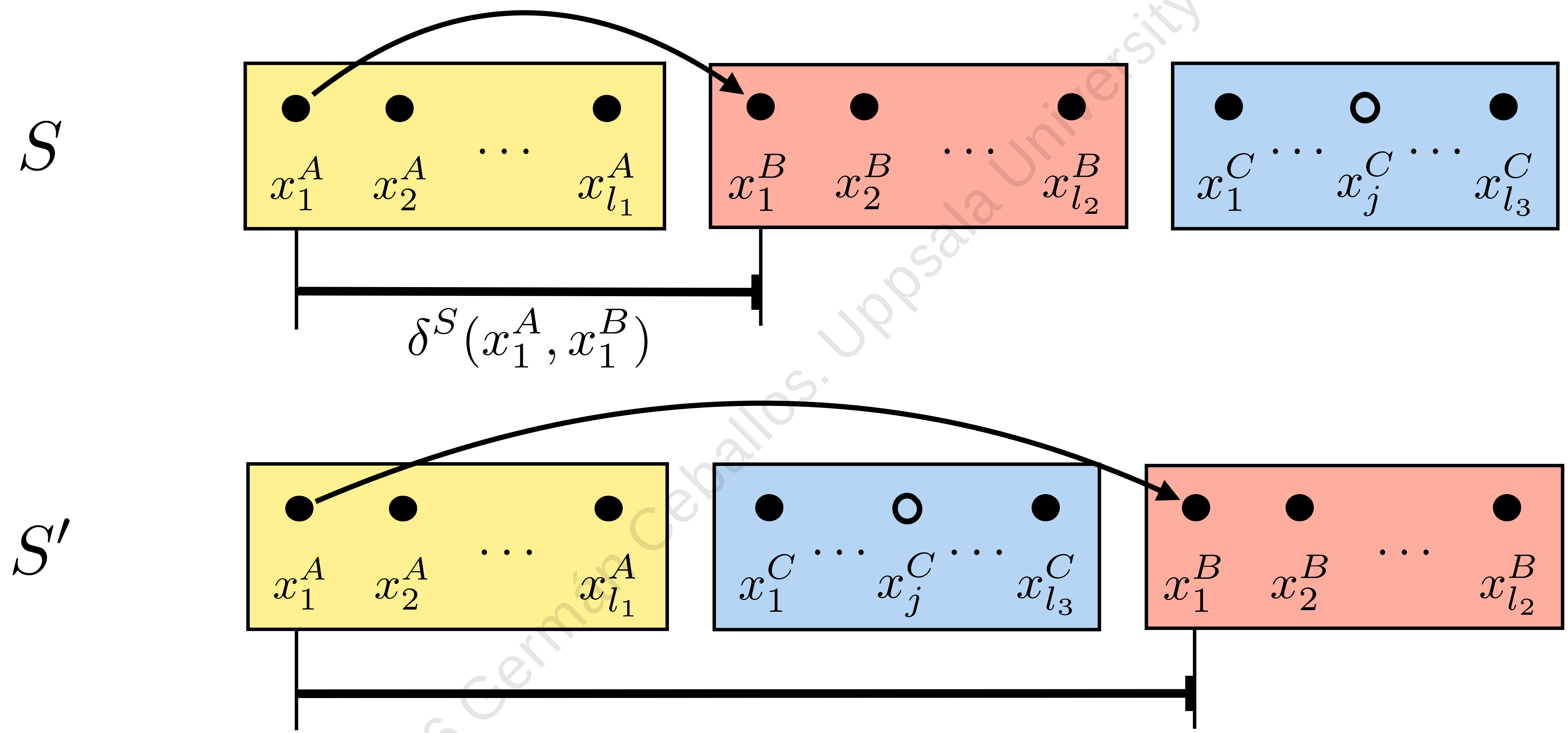

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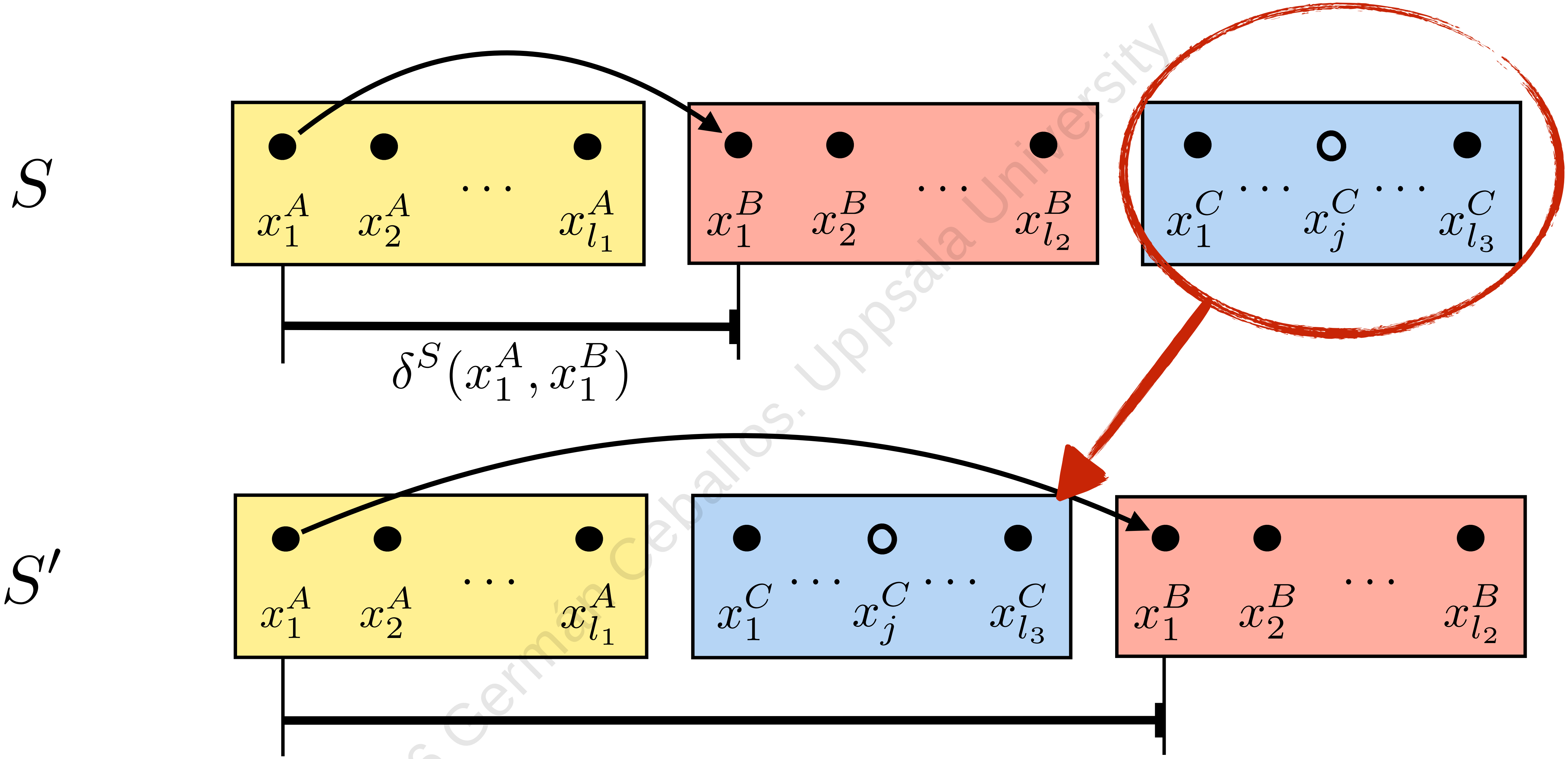

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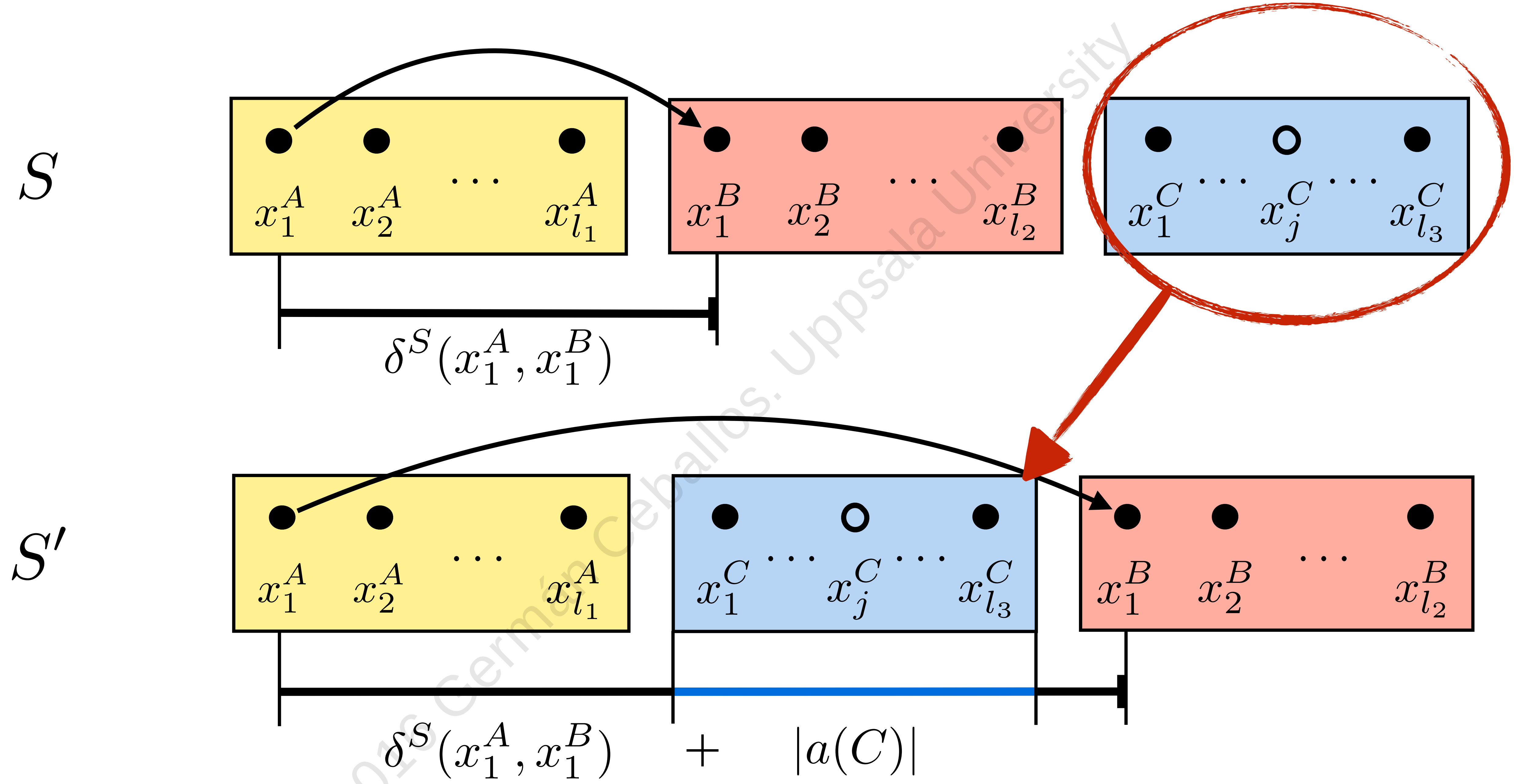

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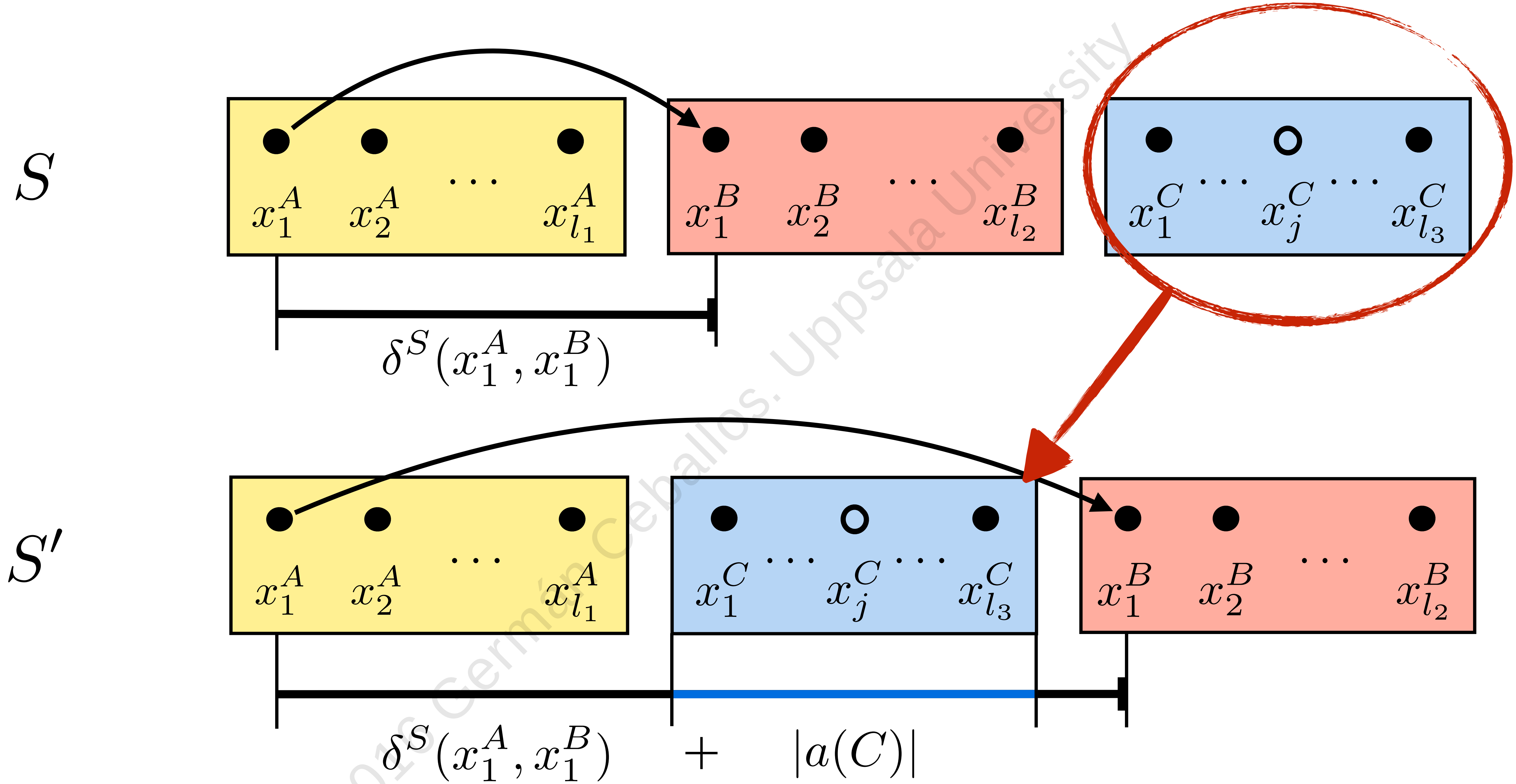

Distances can change!

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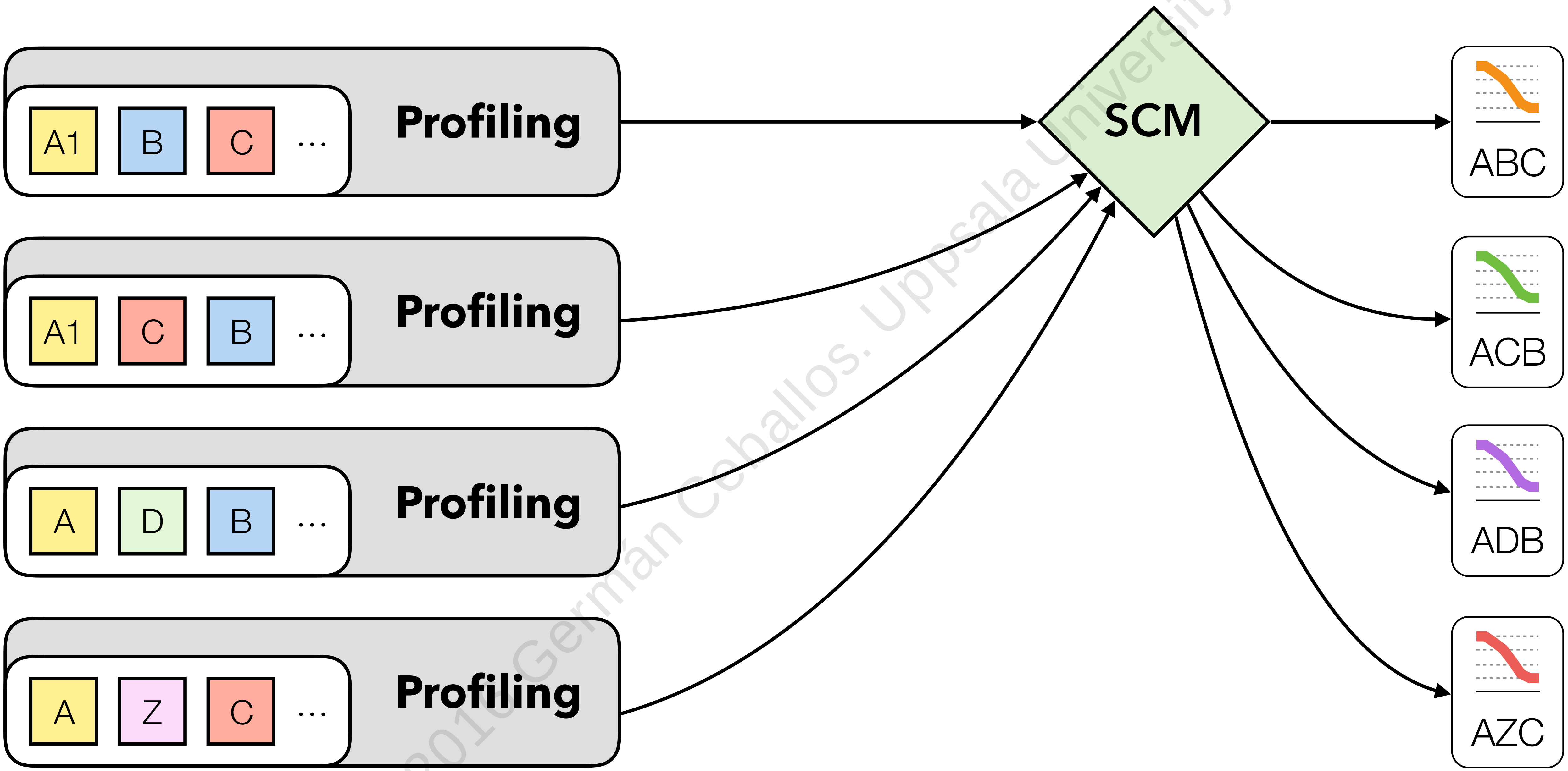
The Problem



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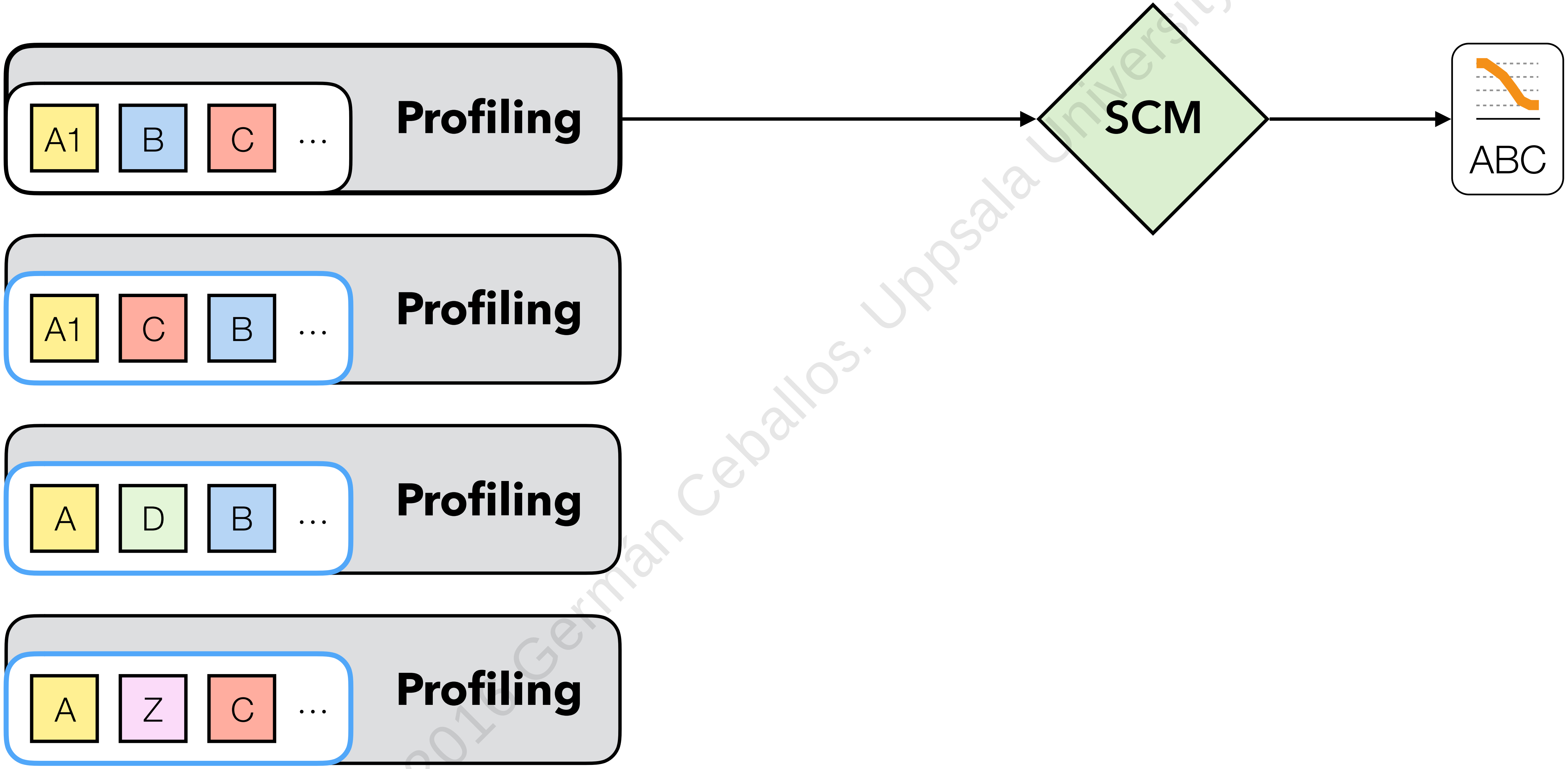
The Solution



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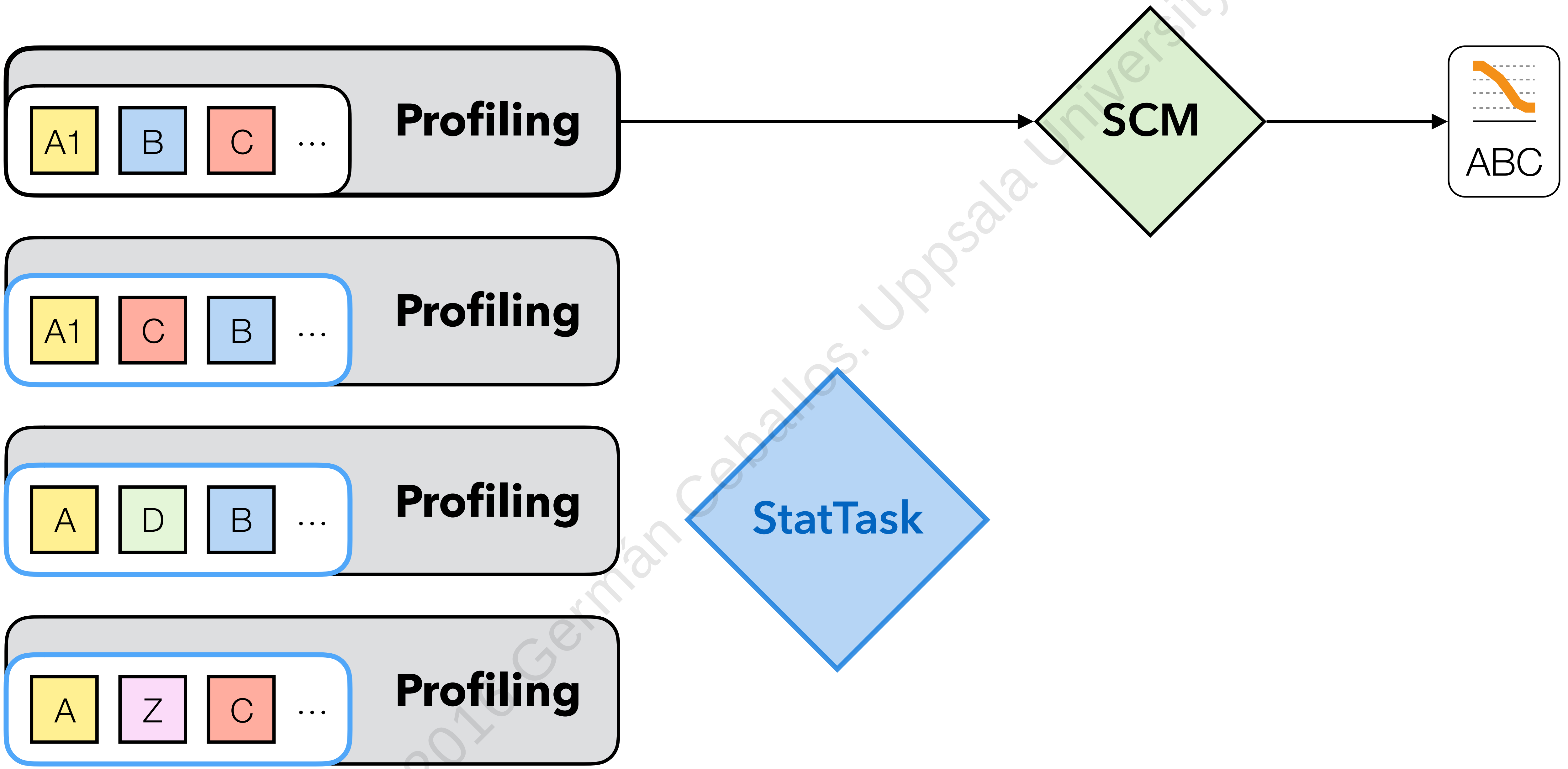

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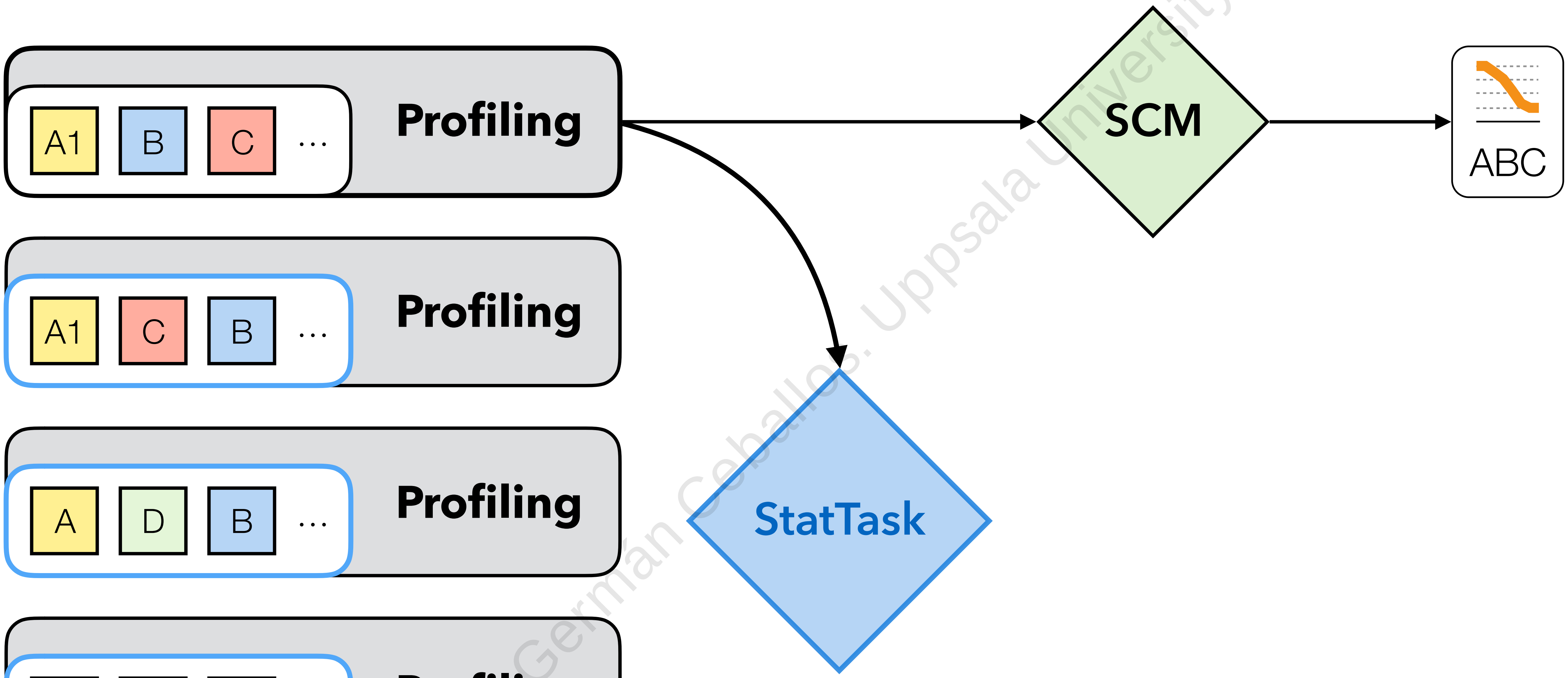

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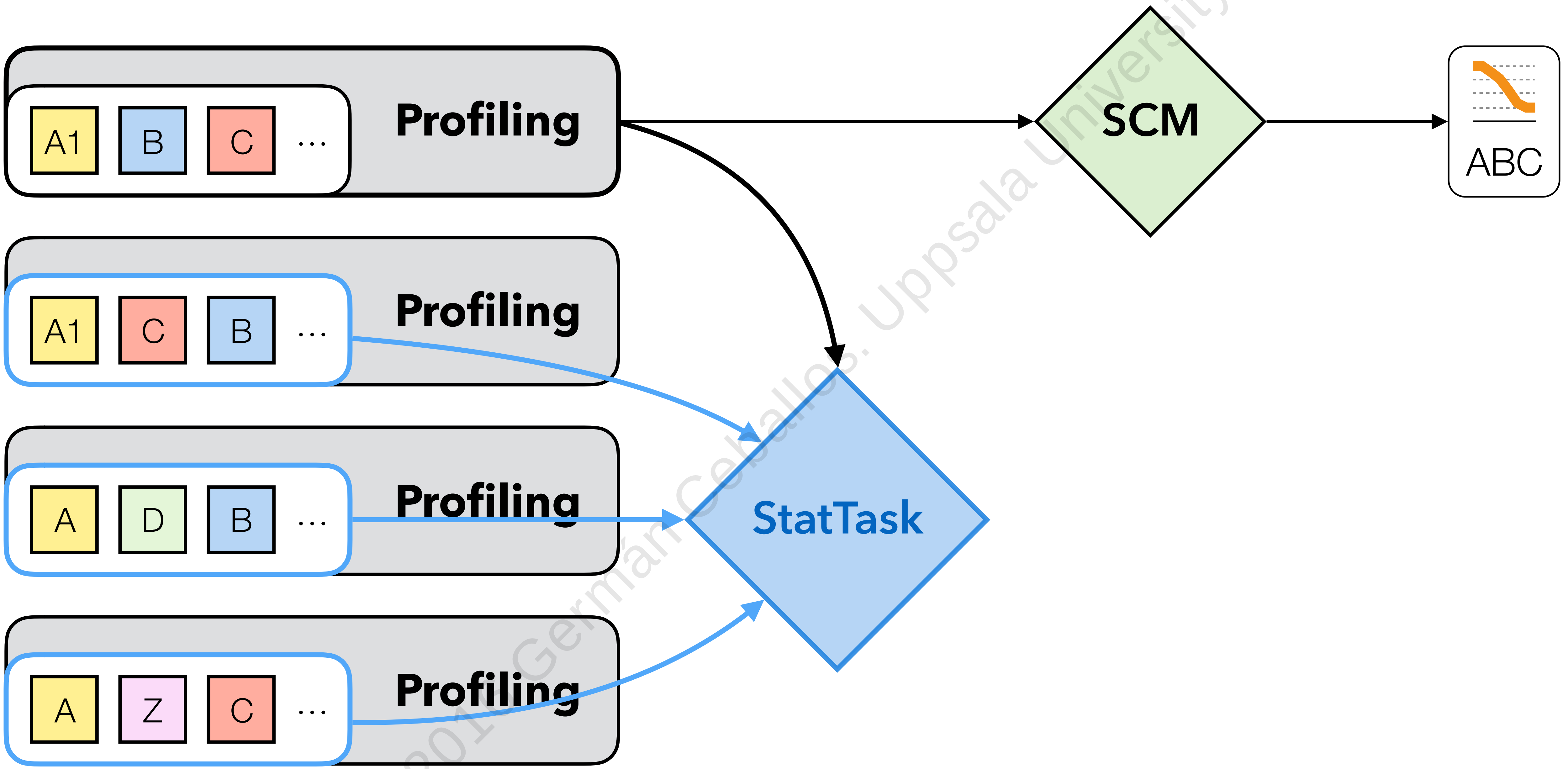

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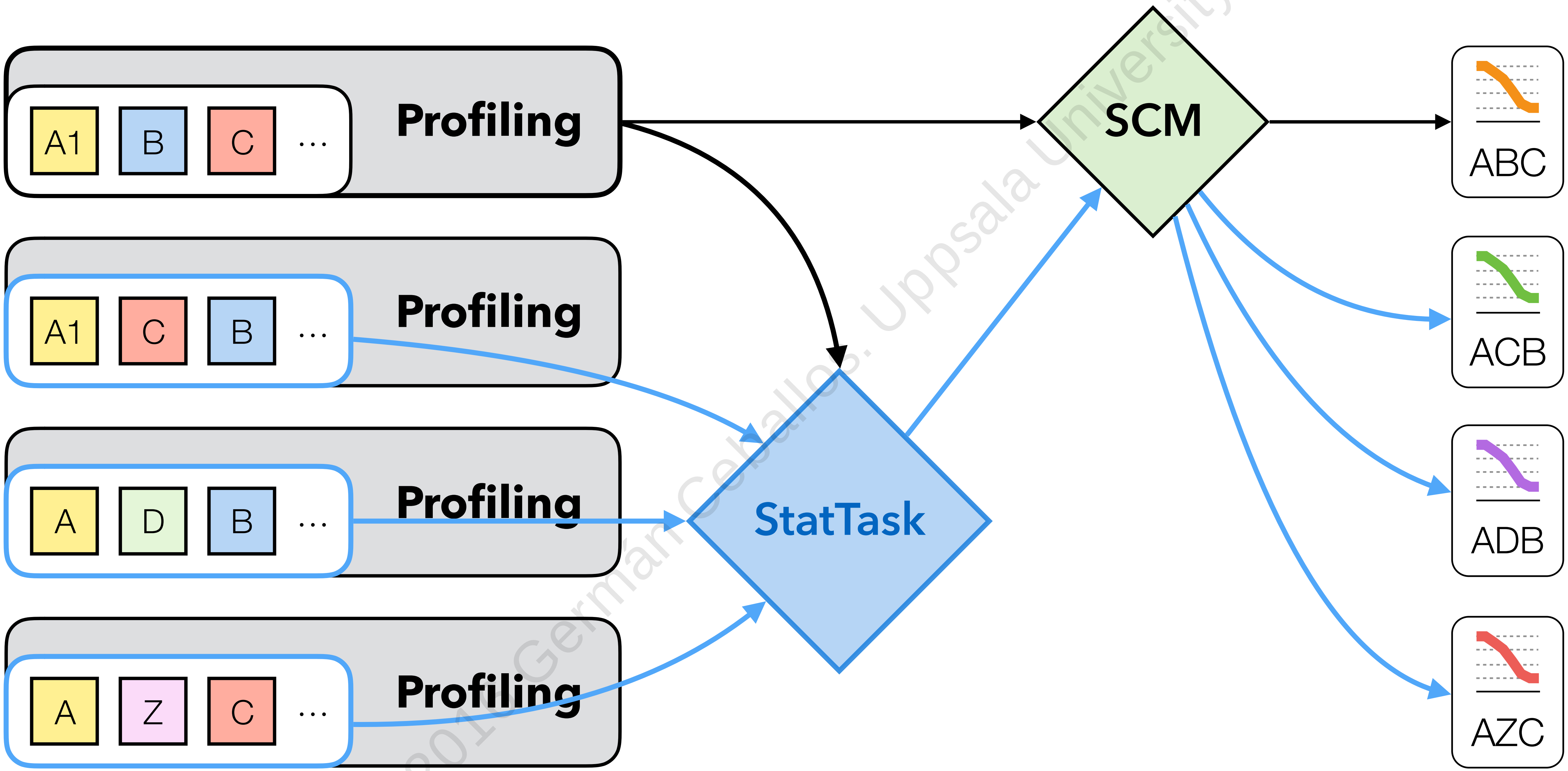

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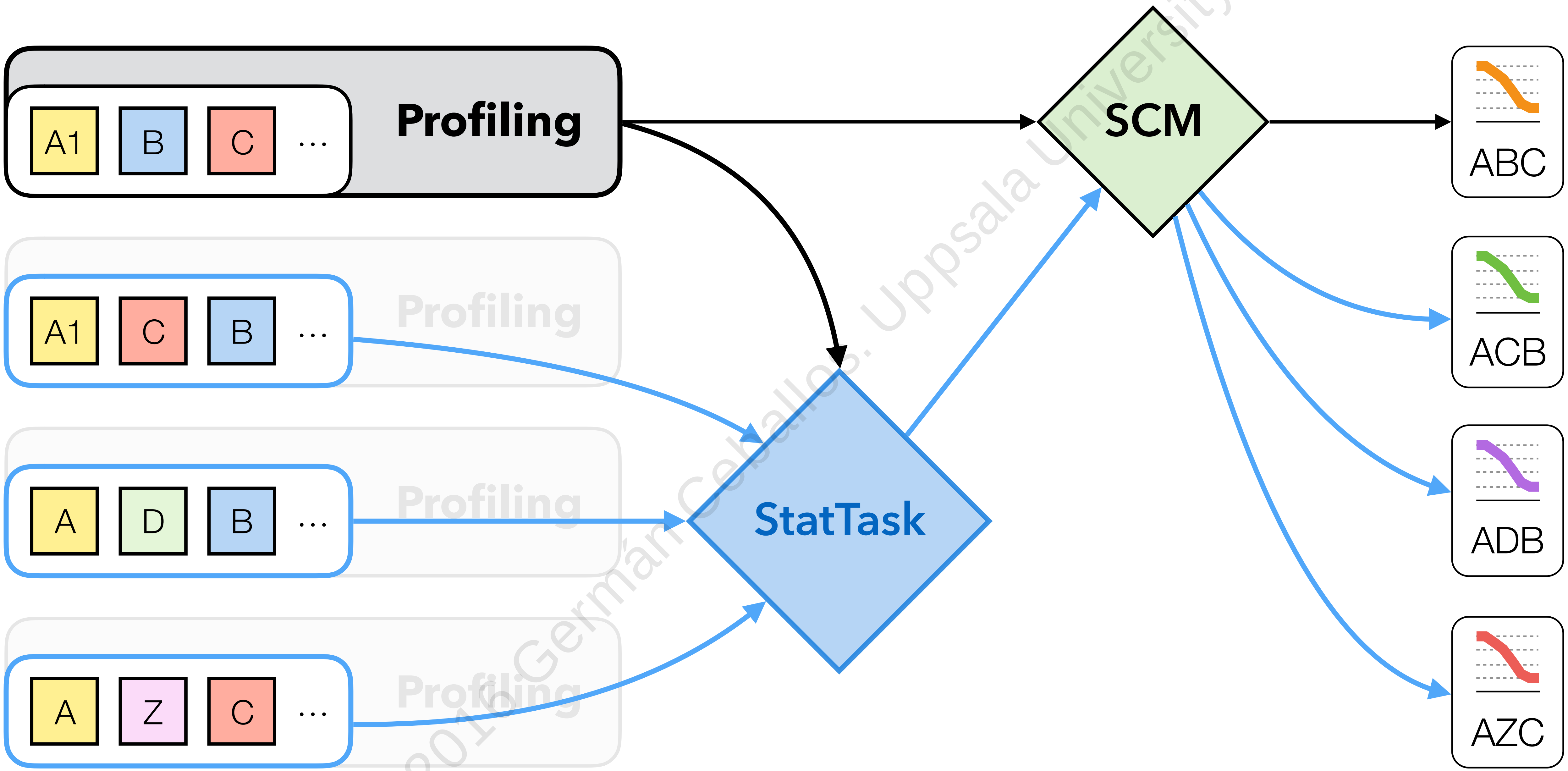

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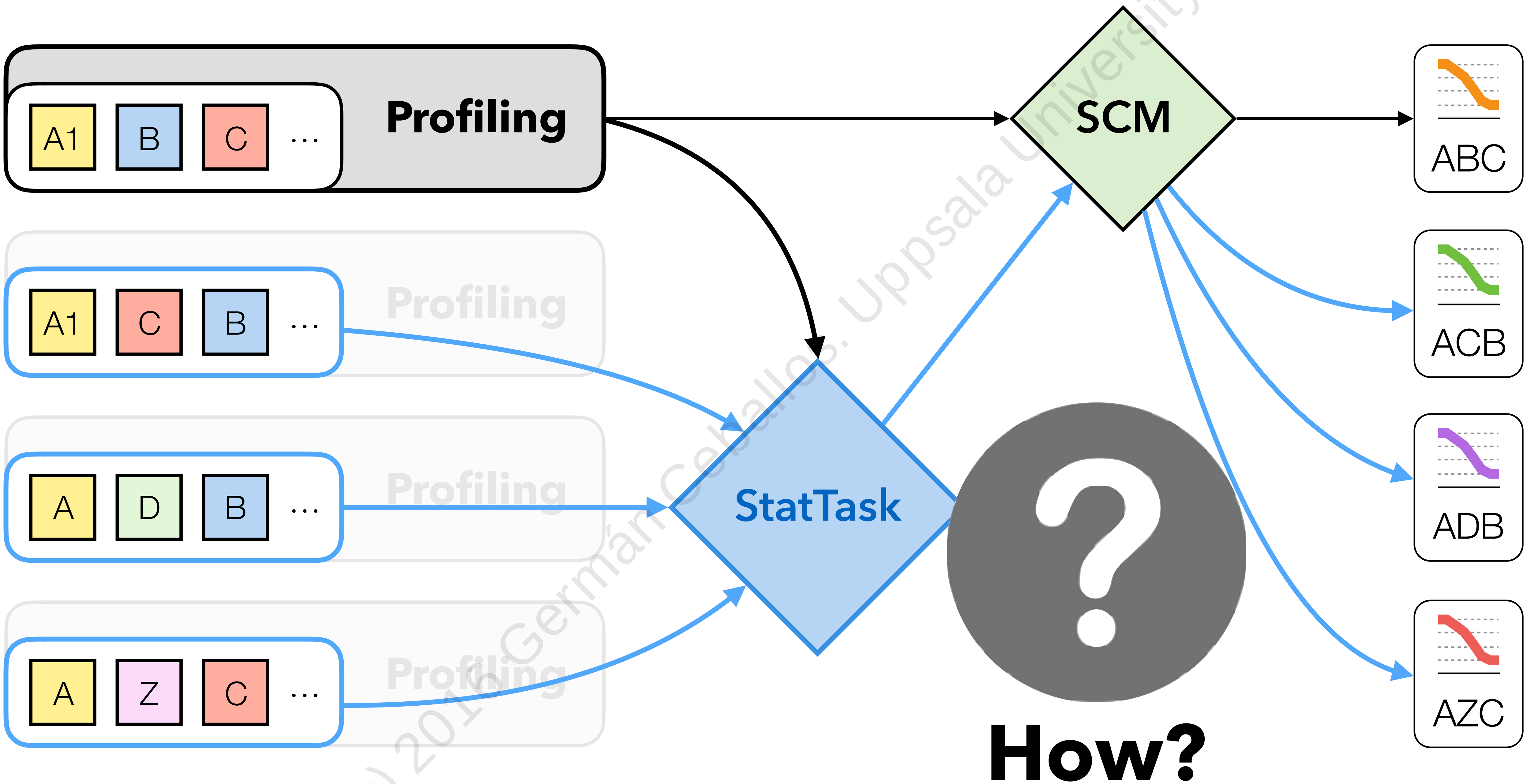
The Solution



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StatTask Overview

1. Profile **one** schedule for the application
2. Build the pair of reuses
3. Input a **new** schedule
4. Rebuild the pair of reuses for the new schedule
5. Recalculate the reuse distances
6. Use statistical cache models to estimate miss ratios

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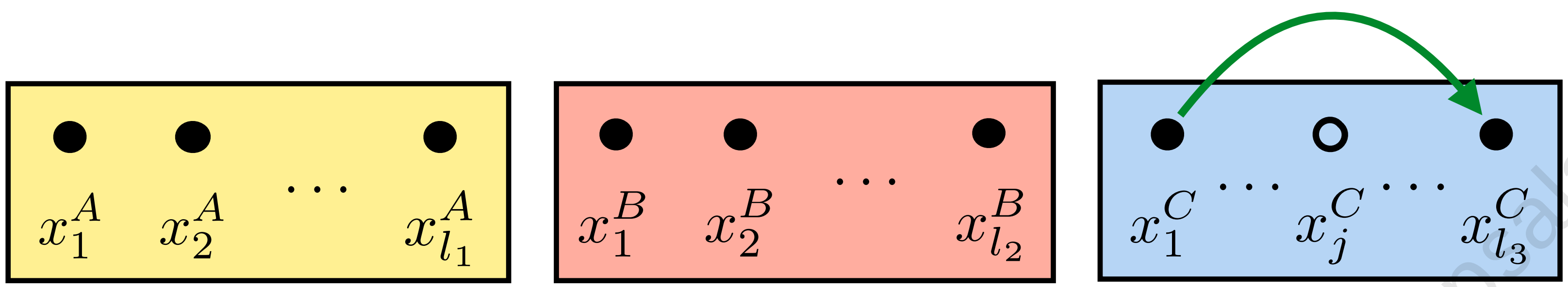
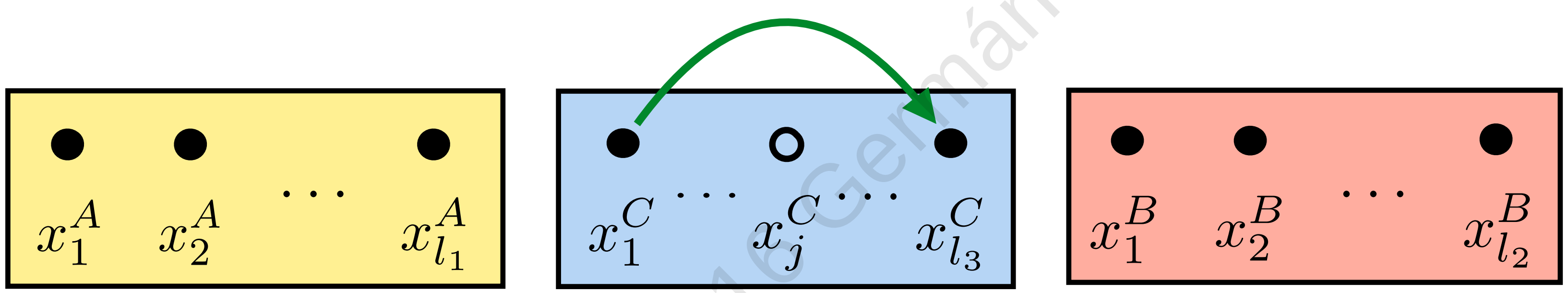
Rebuild Reuses



1. Private Reuses
   - All are kept



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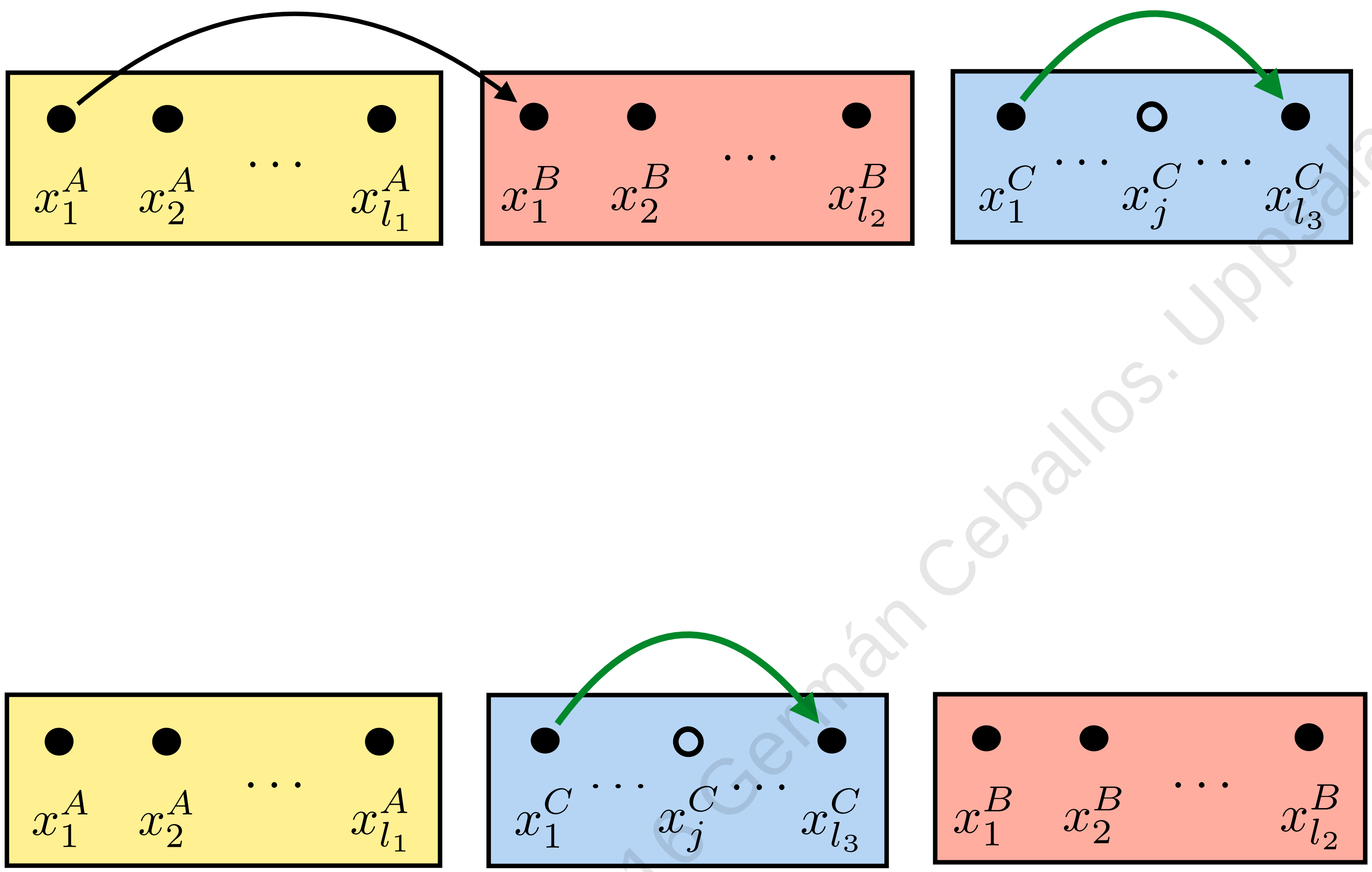
Rebuild Reuses



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2. Shared Reuses
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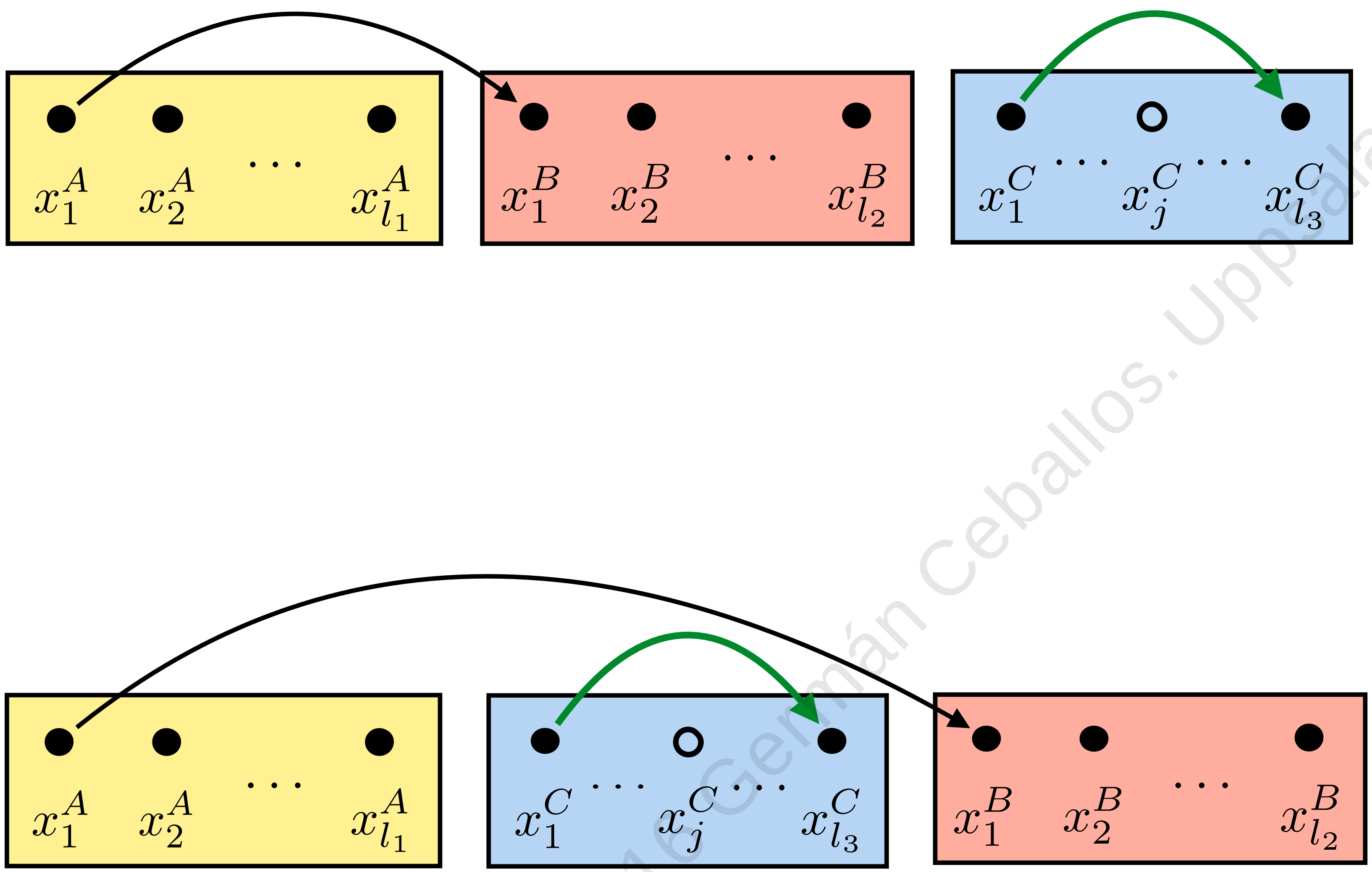
Rebuild Reuses



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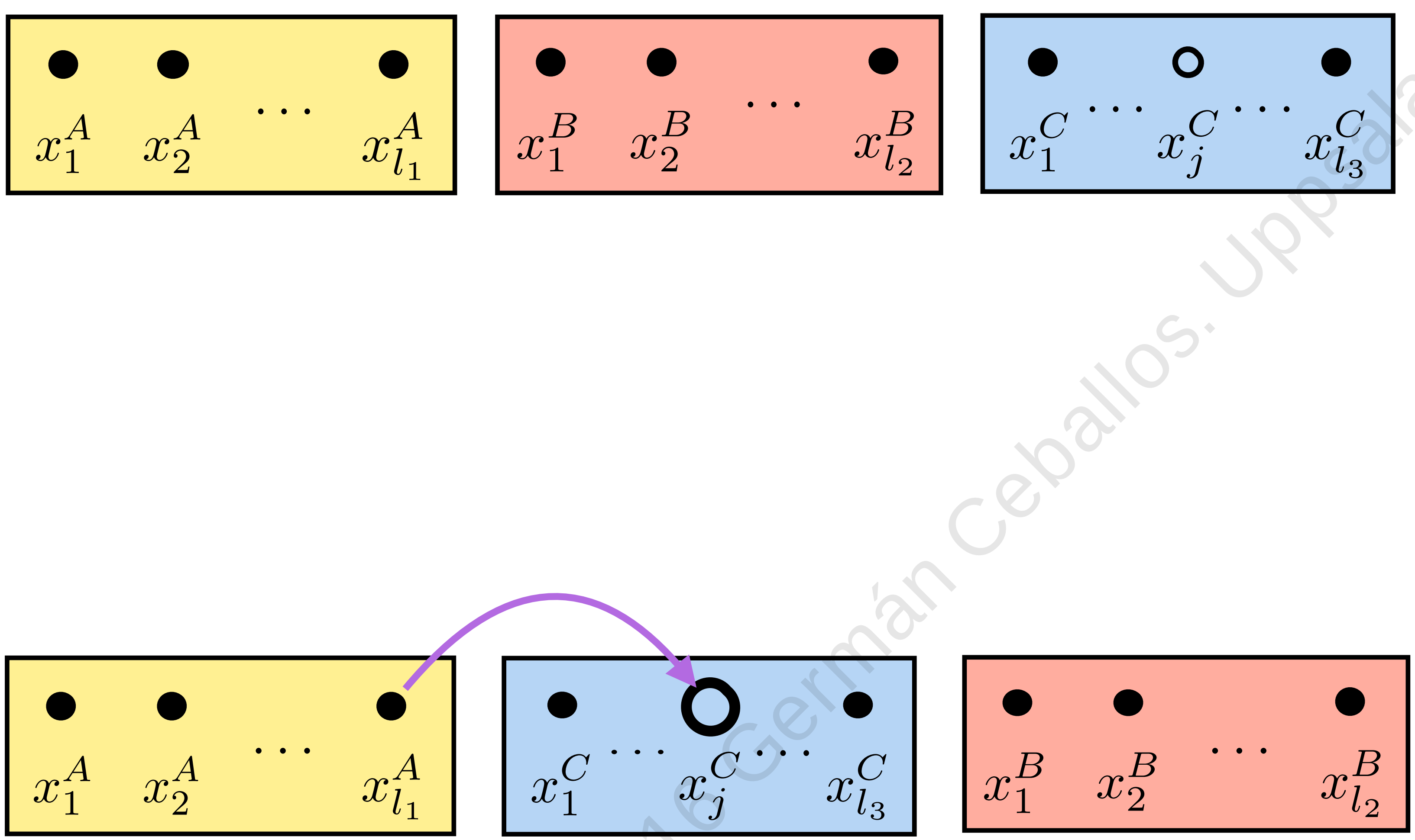
Rebuild Reuses



1. Private Reuses
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   - Some appear

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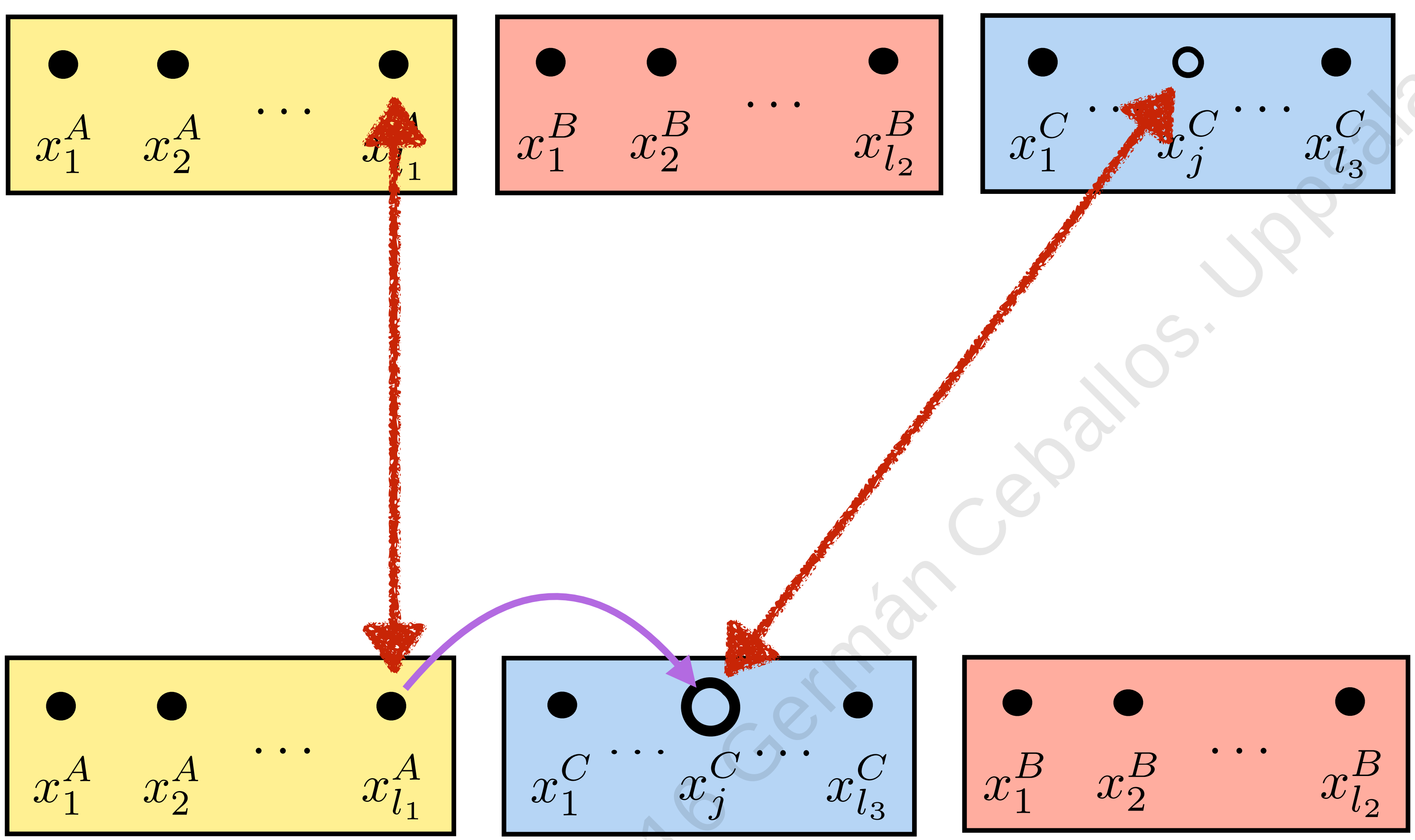

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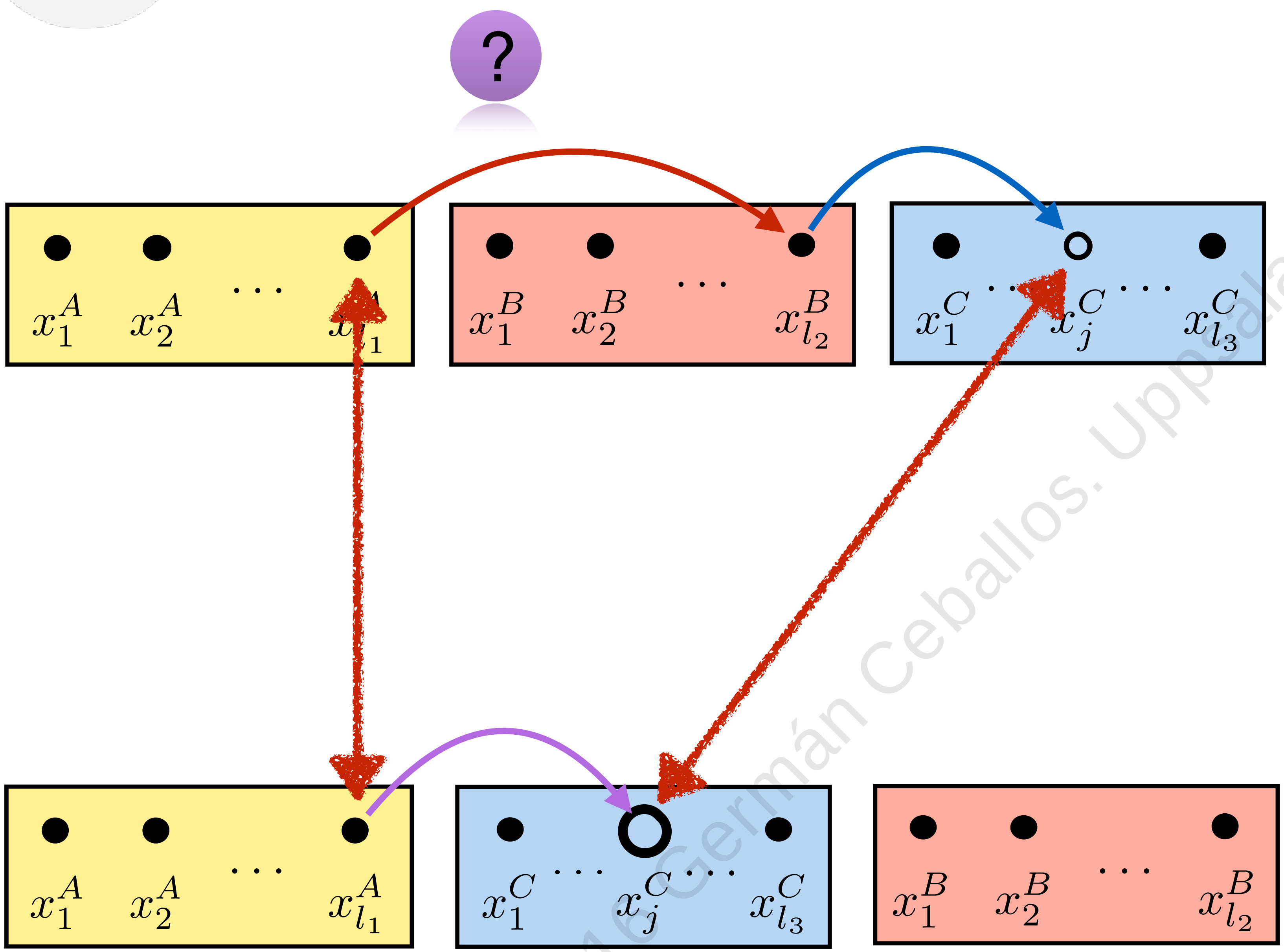

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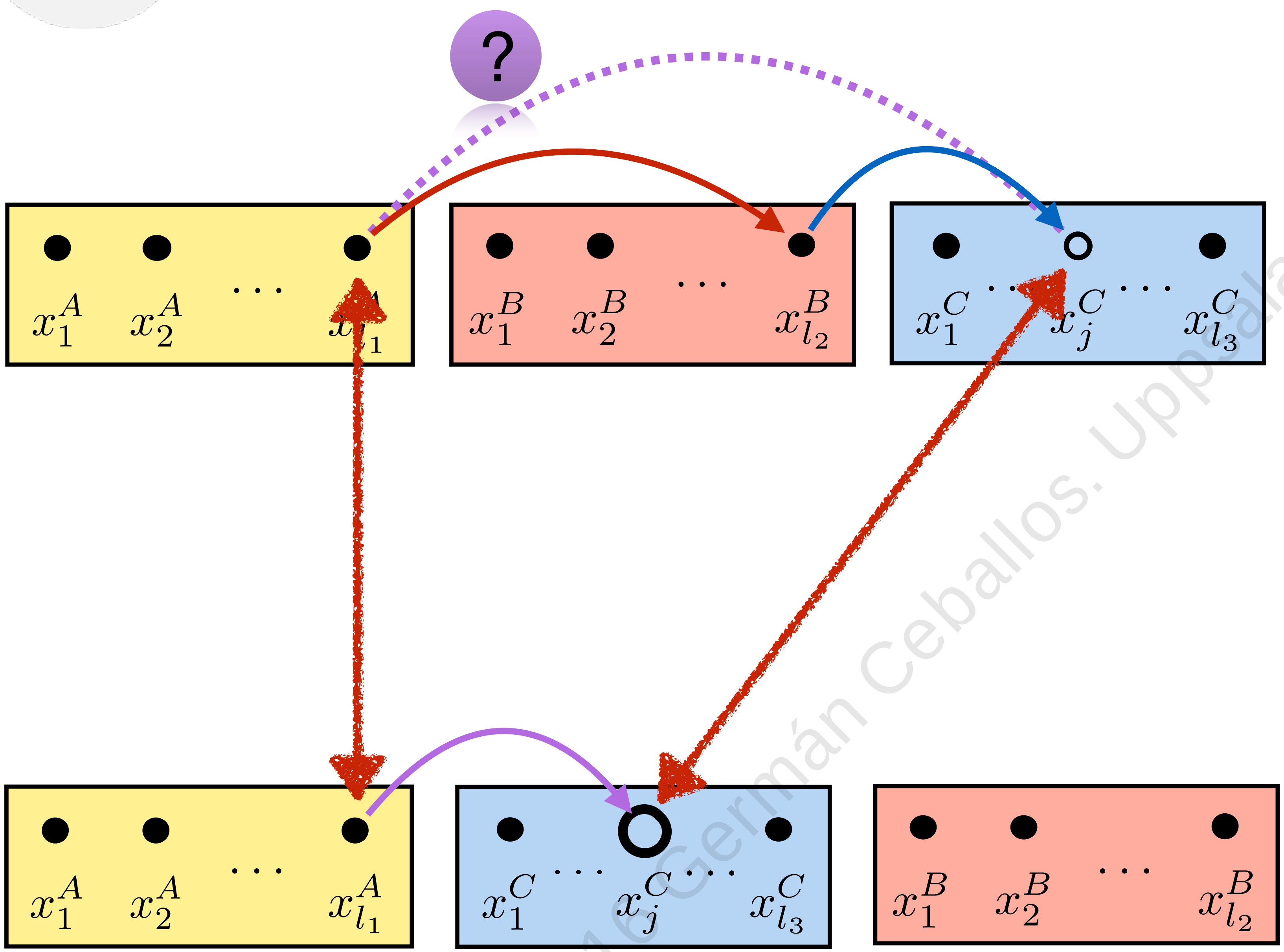

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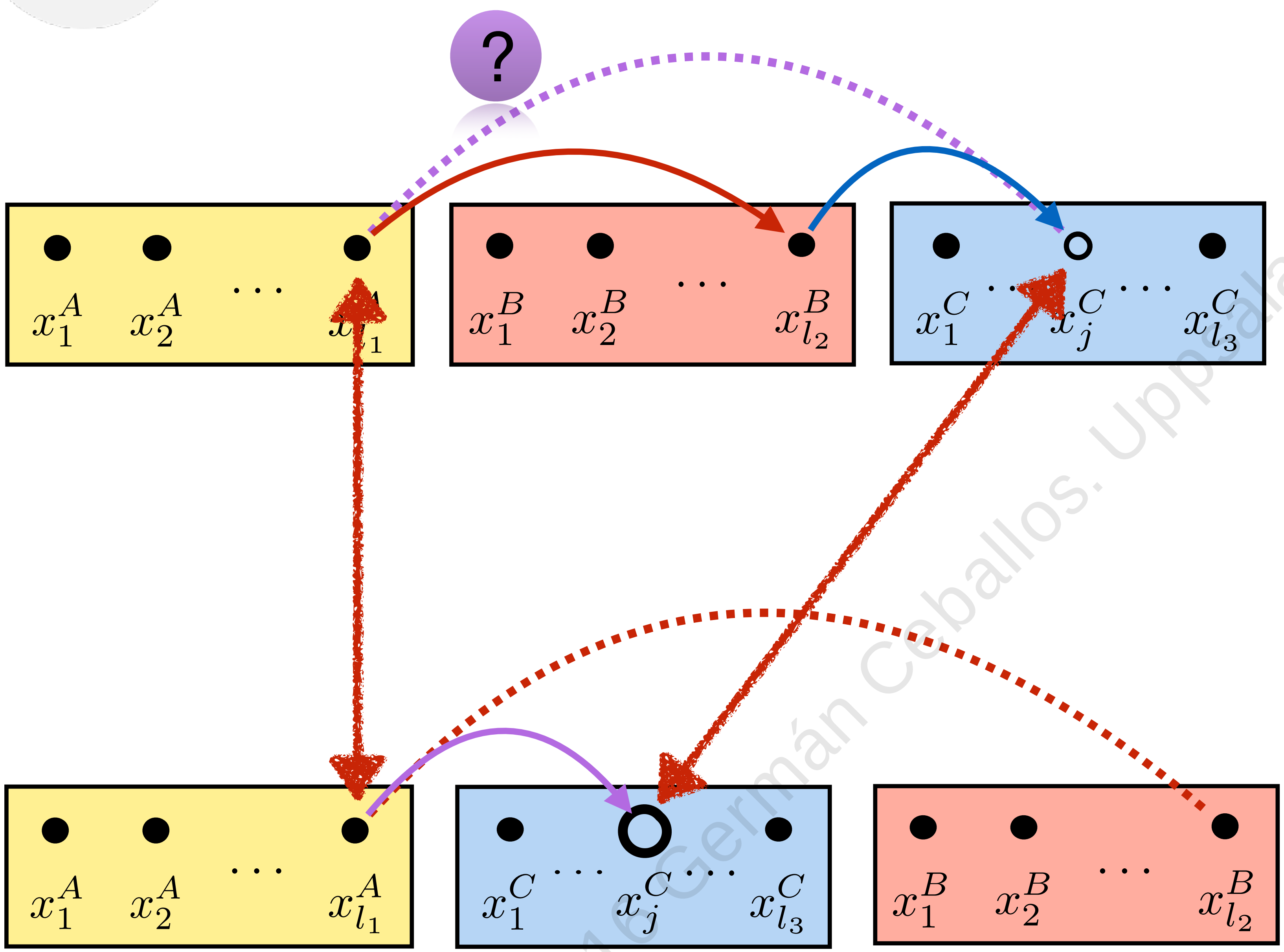

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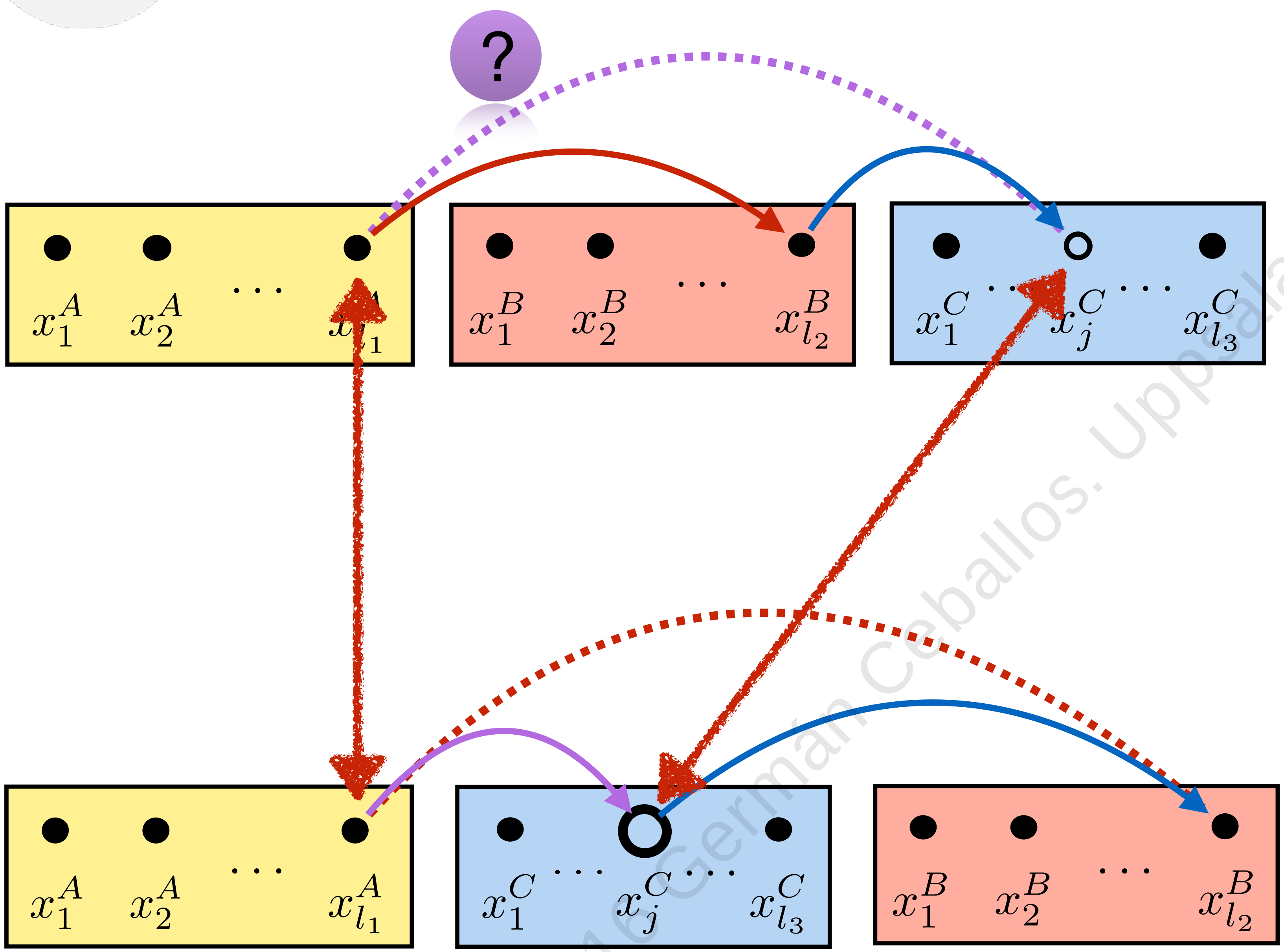

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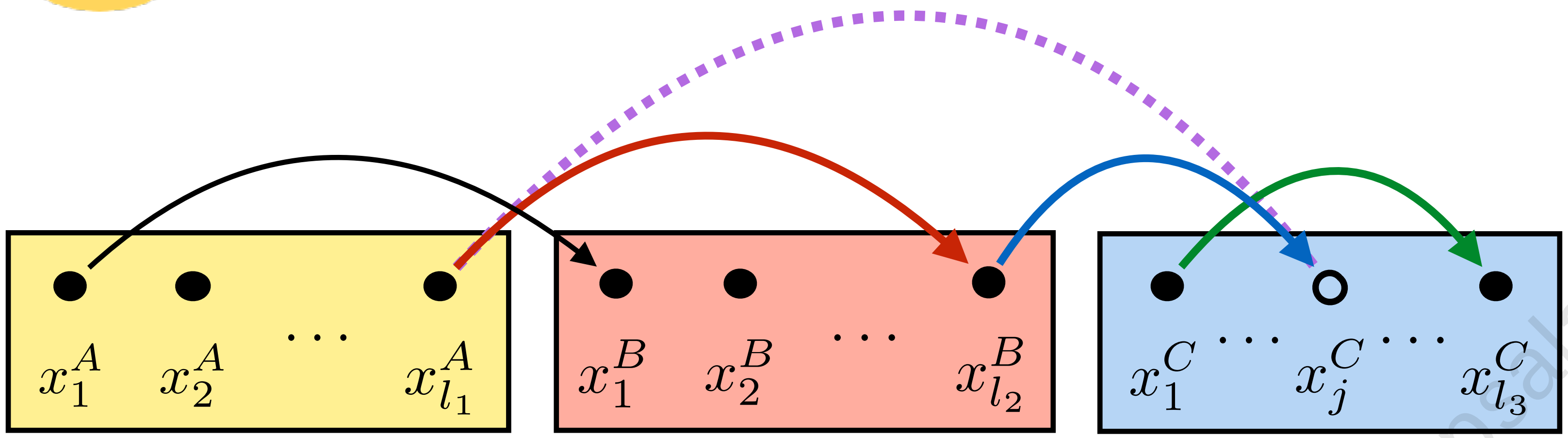
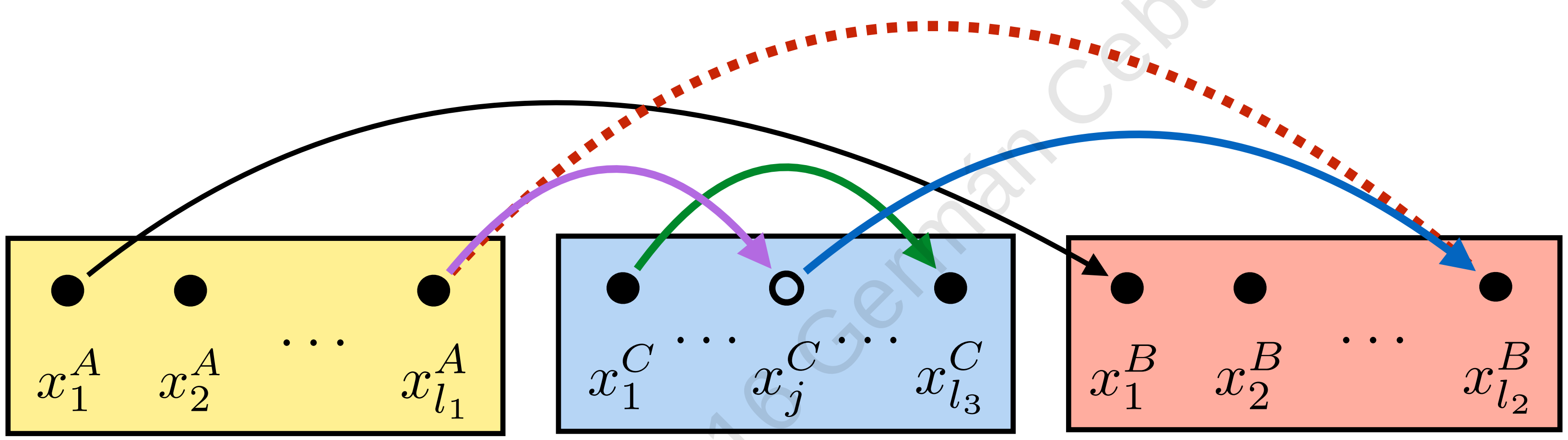
Recalculate Distances



1. Private Reuses
   - Same distance



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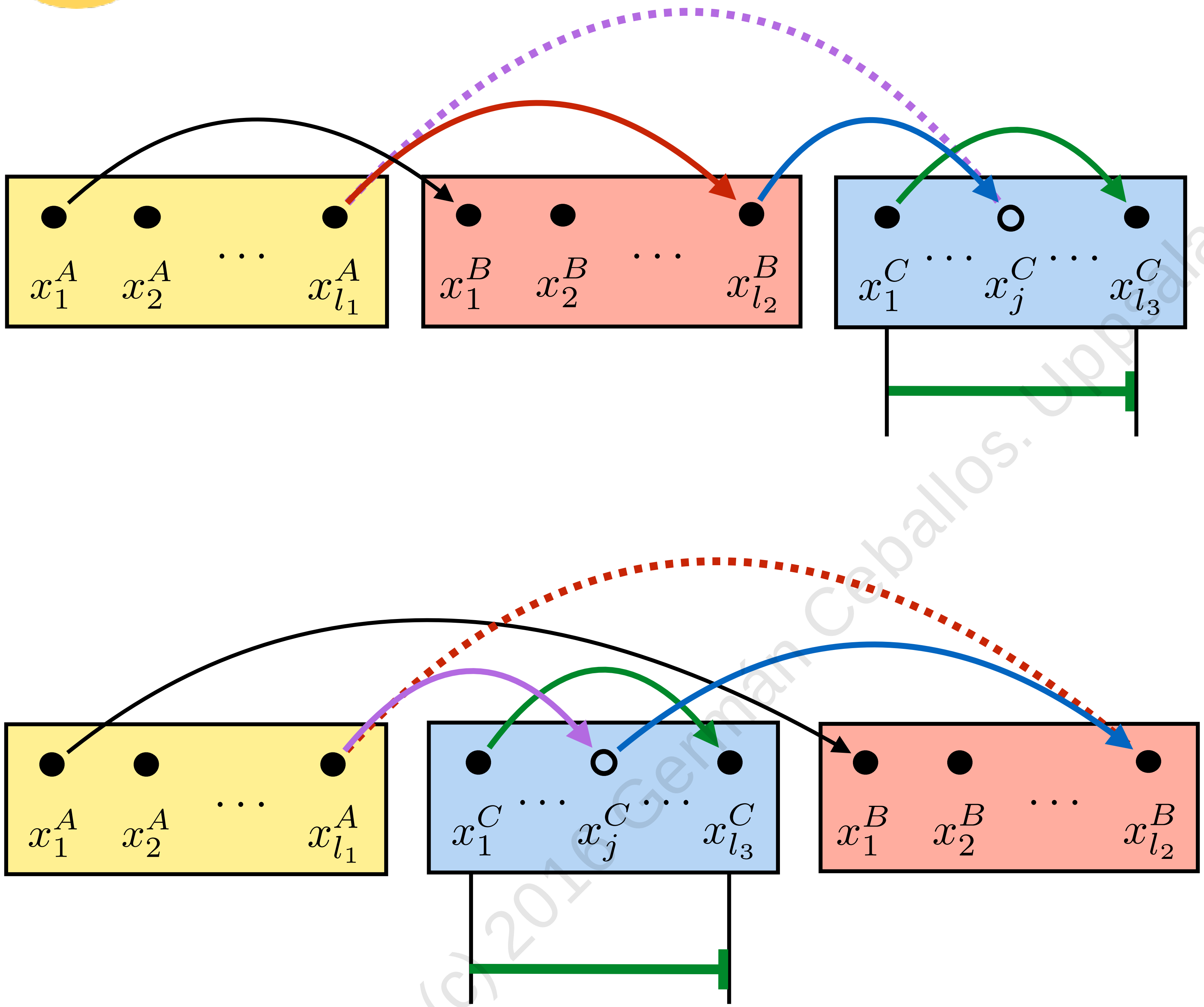
Recalculate Distances



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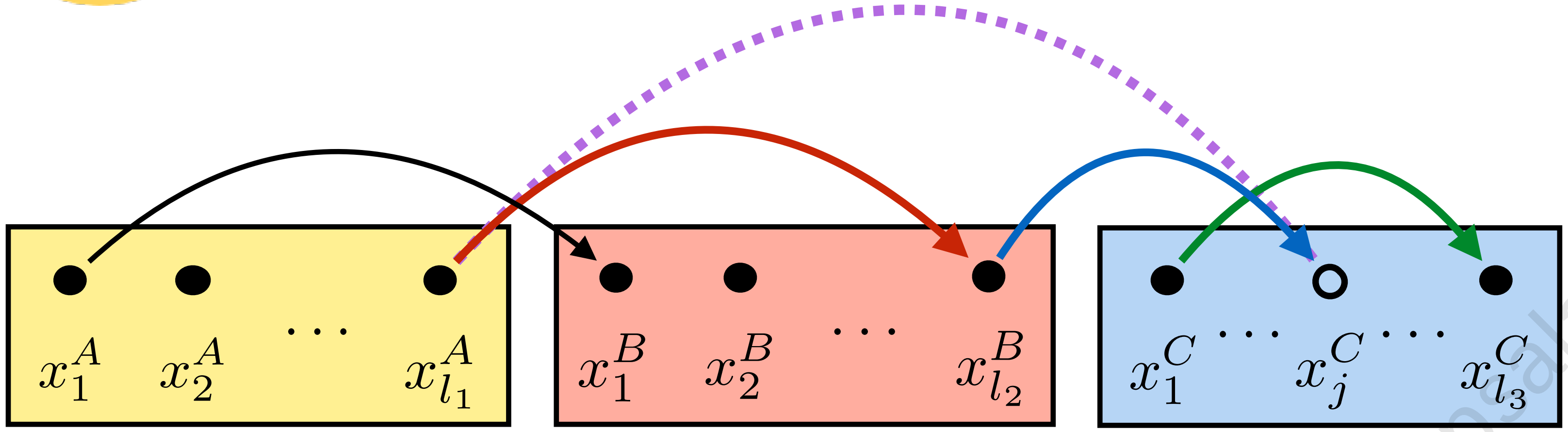

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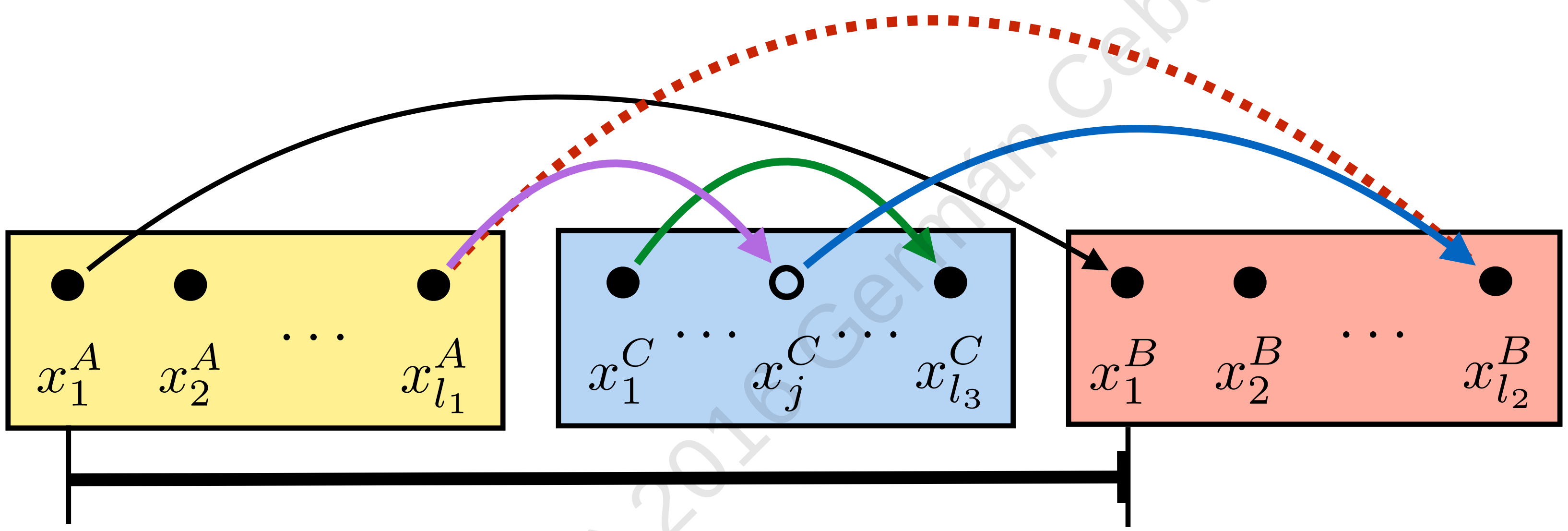

2. Shared Reuses
   - Kept reuses

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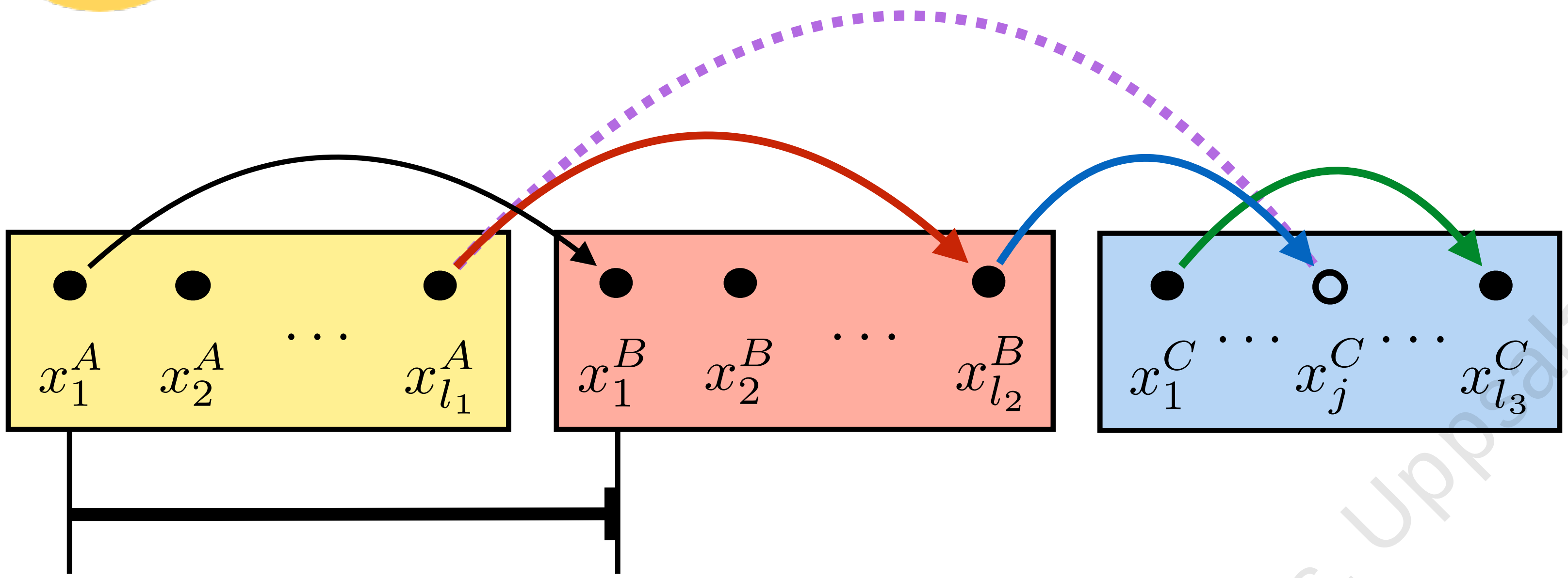
Recalculate Distances



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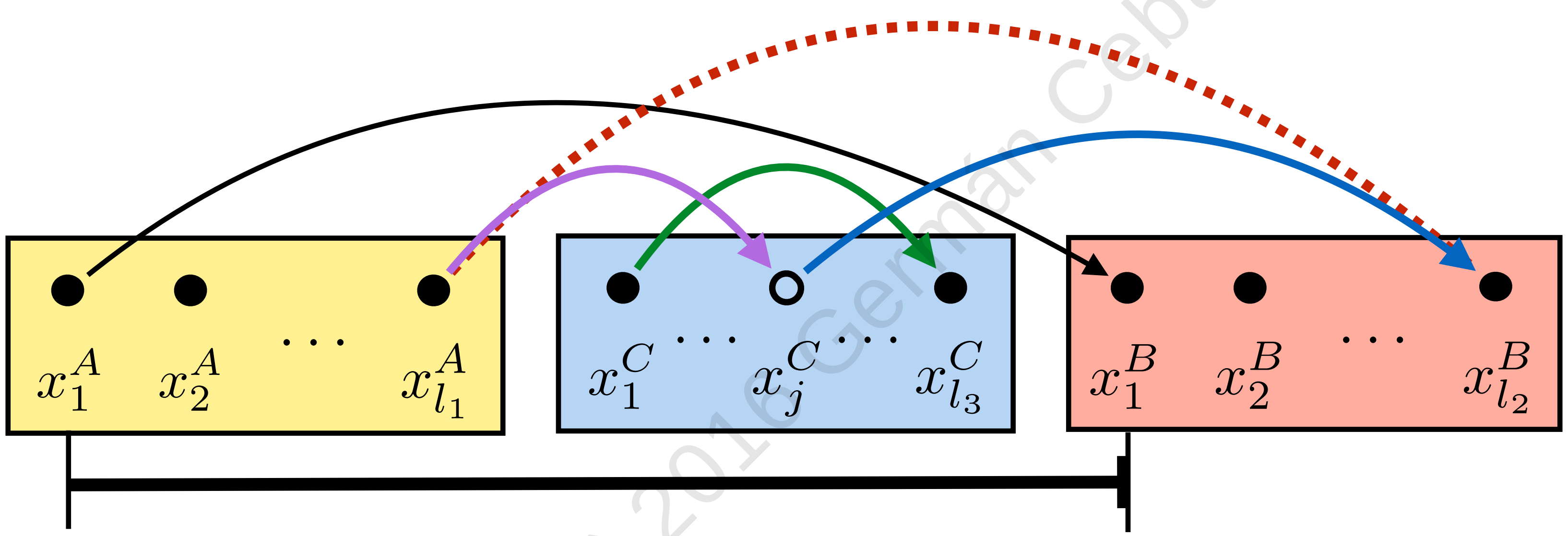

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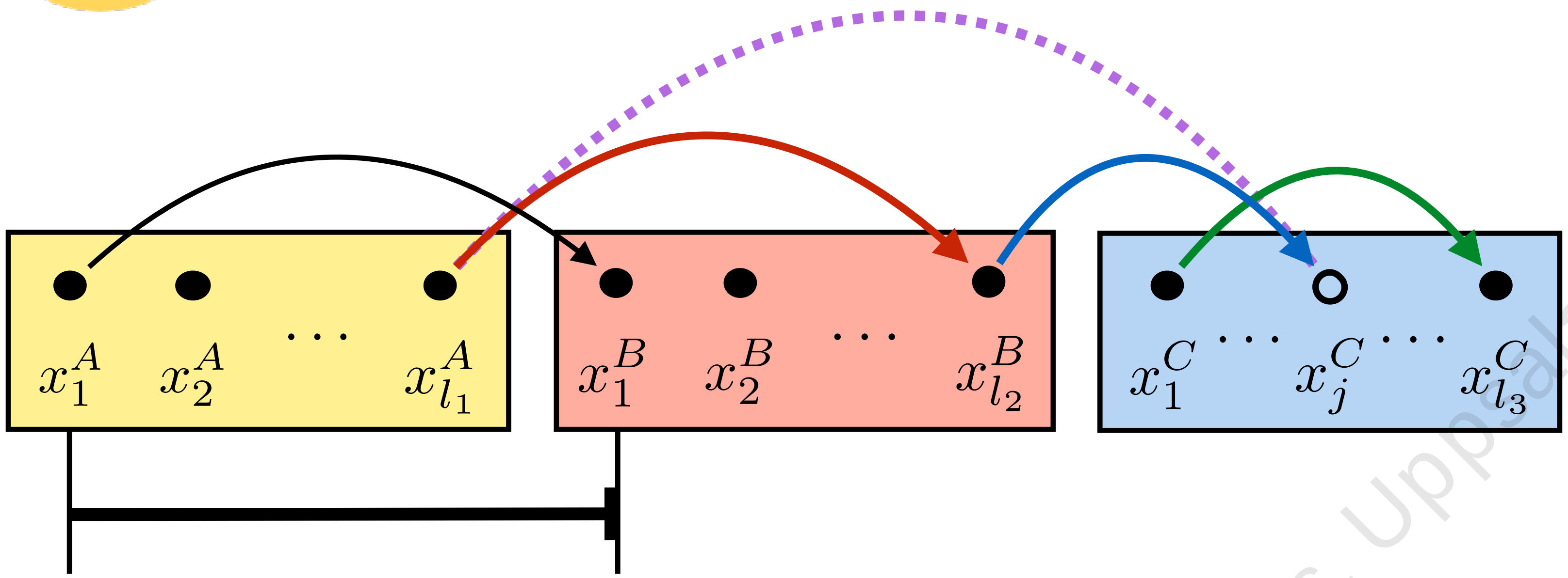
Recalculate Distances



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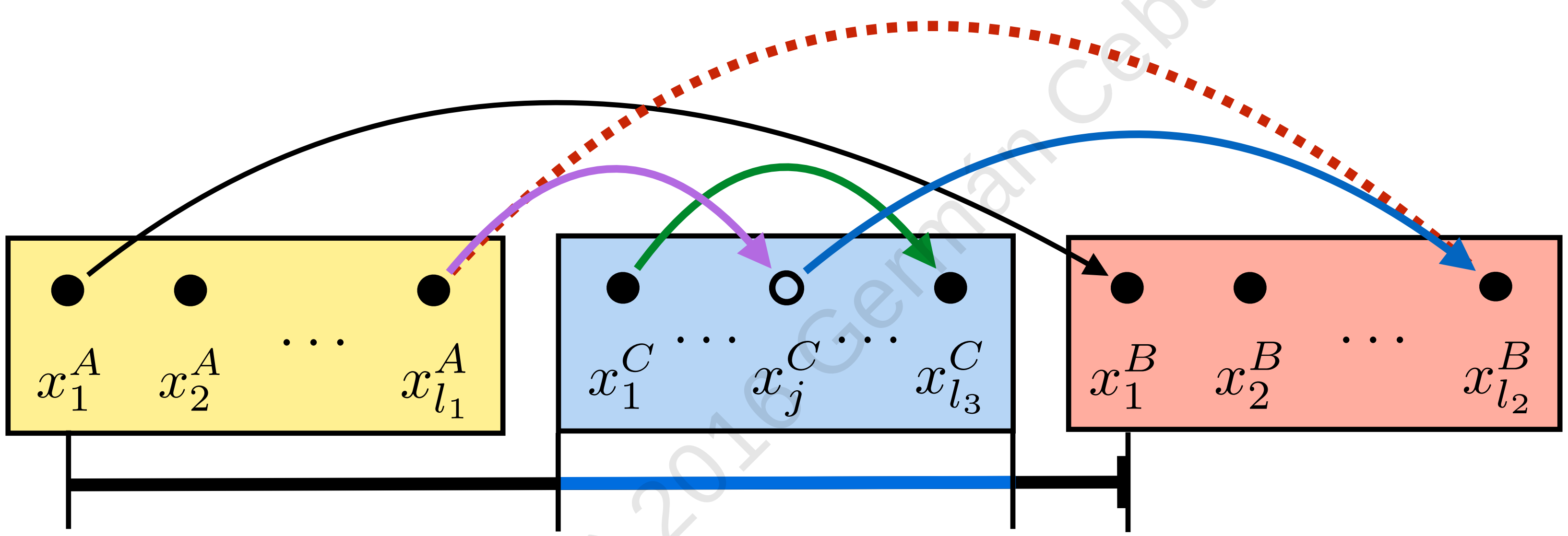

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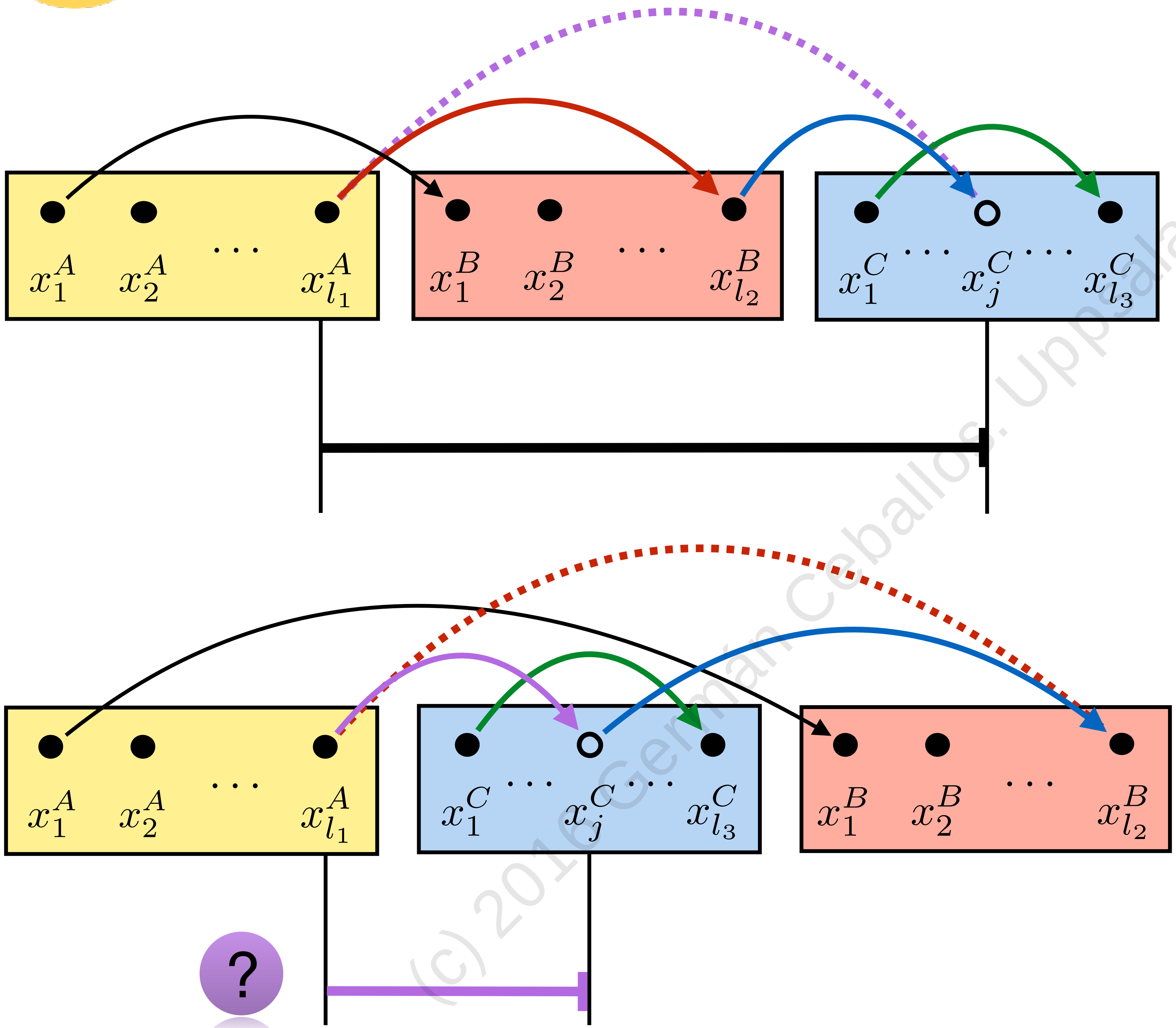
Recalculate Distances



1. Private Reuses
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2. Shared Reuses
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   - New reuses

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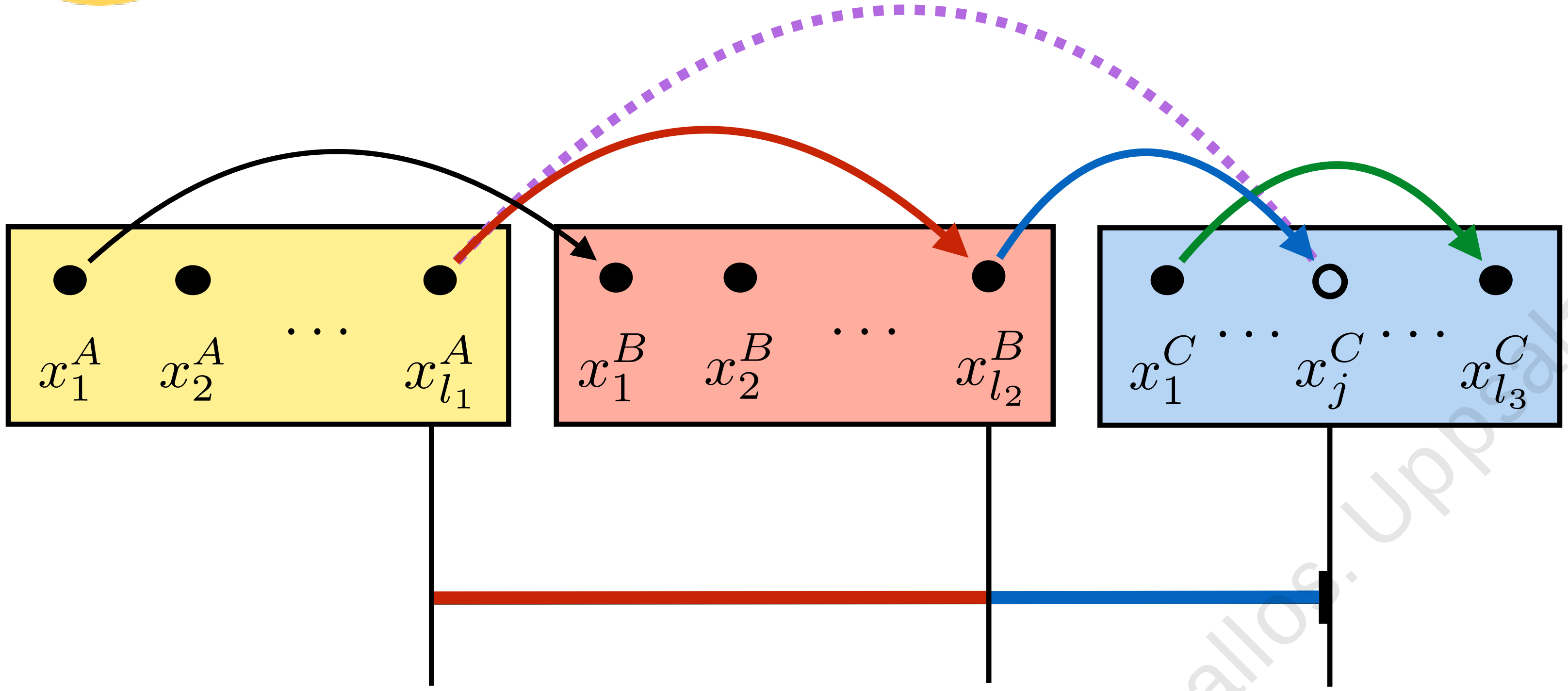
Recalculate Distances



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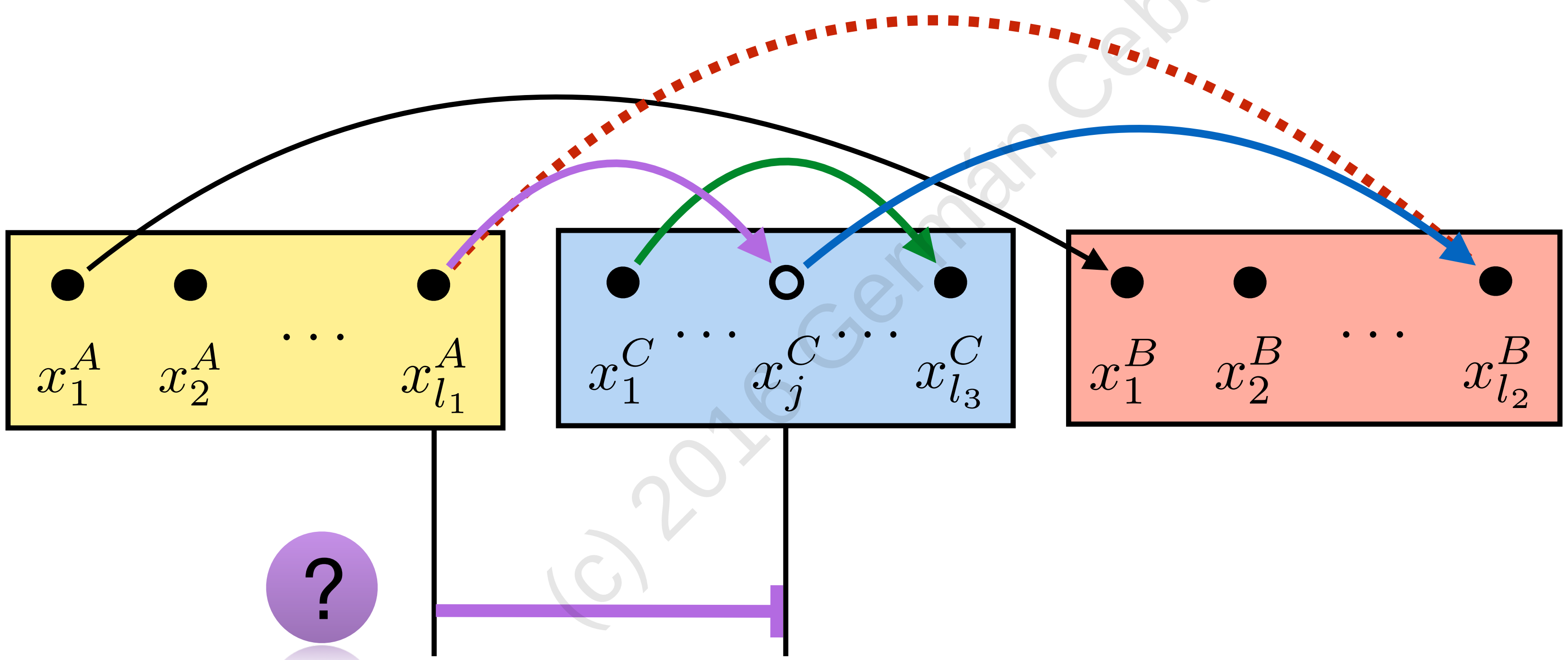

2. Shared Reuses
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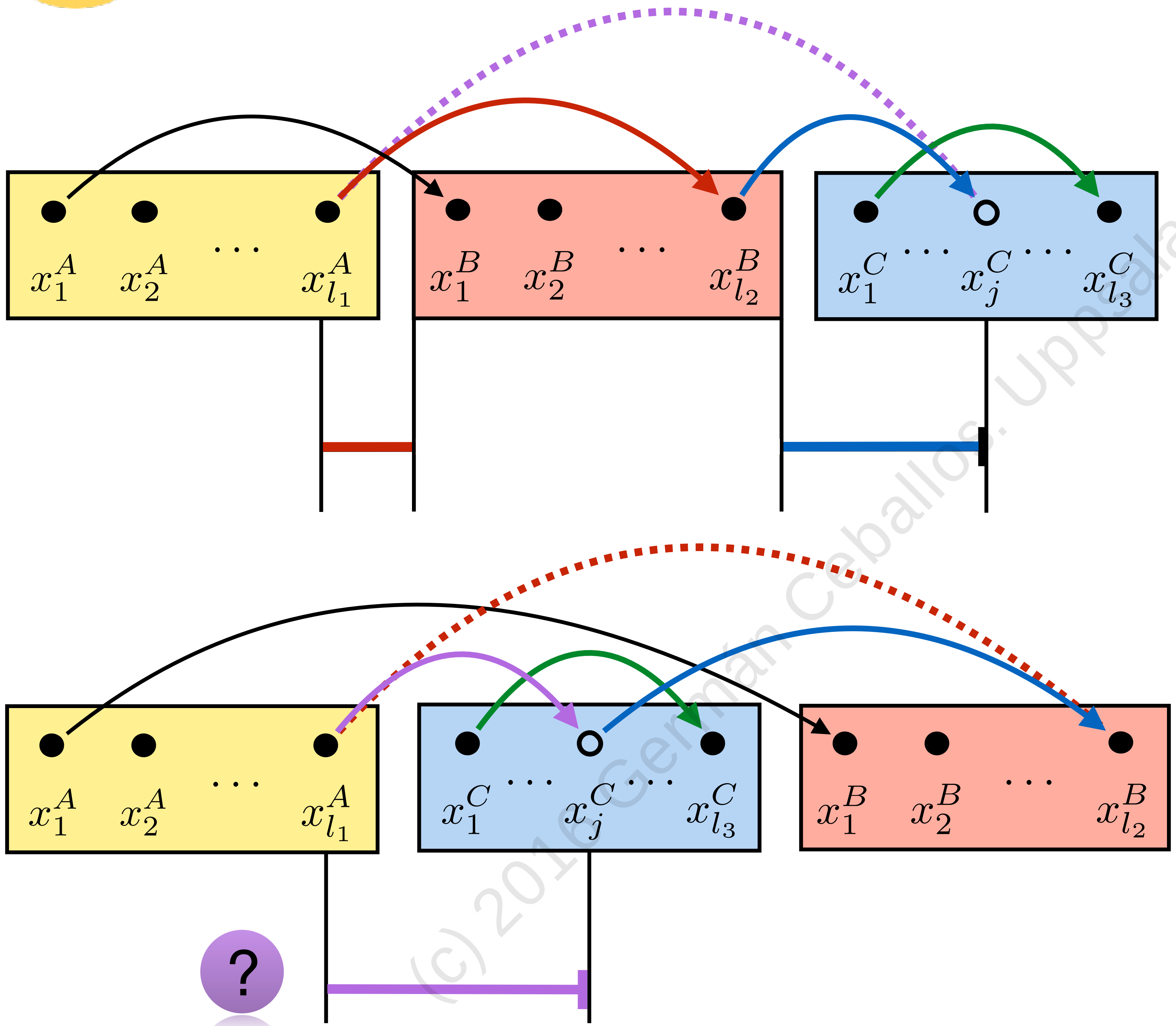
Recalculate Distances



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Evaluation & **Results**

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Results

- Barcelona OpenMP Tasks Suite (BOTS)*
- Quad-core Intel Sandy Brige.
  - 8KB private L1
  - 256KB private L2.
  - 6MB shared L3.
  - 32GB RAM
- **Evaluation**
  - **Accuracy**: predicted vs measured miss ratios for **same schedule**
  - **Flexibility**: predicted miss ratio from **different schedules**
  - **Robustness**: sensitivity to different data set of same size (10% difference)

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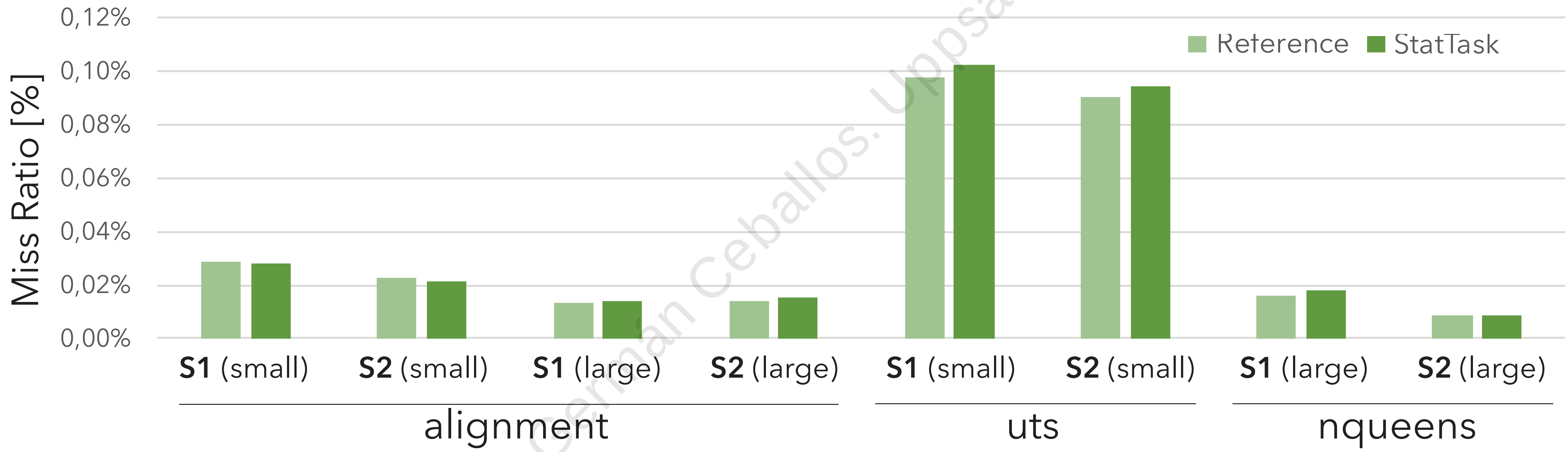
*Alejandro Duran, Xavier Teruel, Roger Ferrer, Xavier Martorell, and Eduard Ayguade. 2009.
Barcelona OpenMP Tasks Suite: A Set of Benchmarks Targeting the Exploitation of Task Parallelism in OpenMP.
In *Proceedings of the 2009 International Conference on Parallel Processing* (ICPP '09). Washington, DC, USA.

StatTask's Accuracy

Low Miss Ratios



Reference: HW Performance Counters for Last Level Cache (L3)

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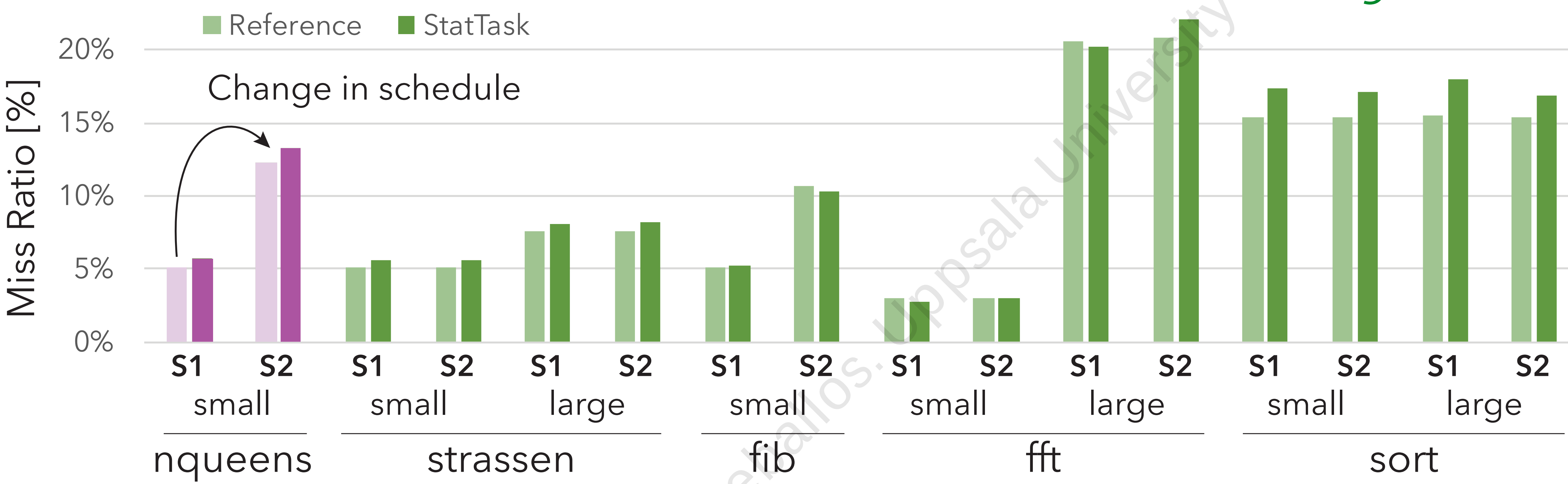
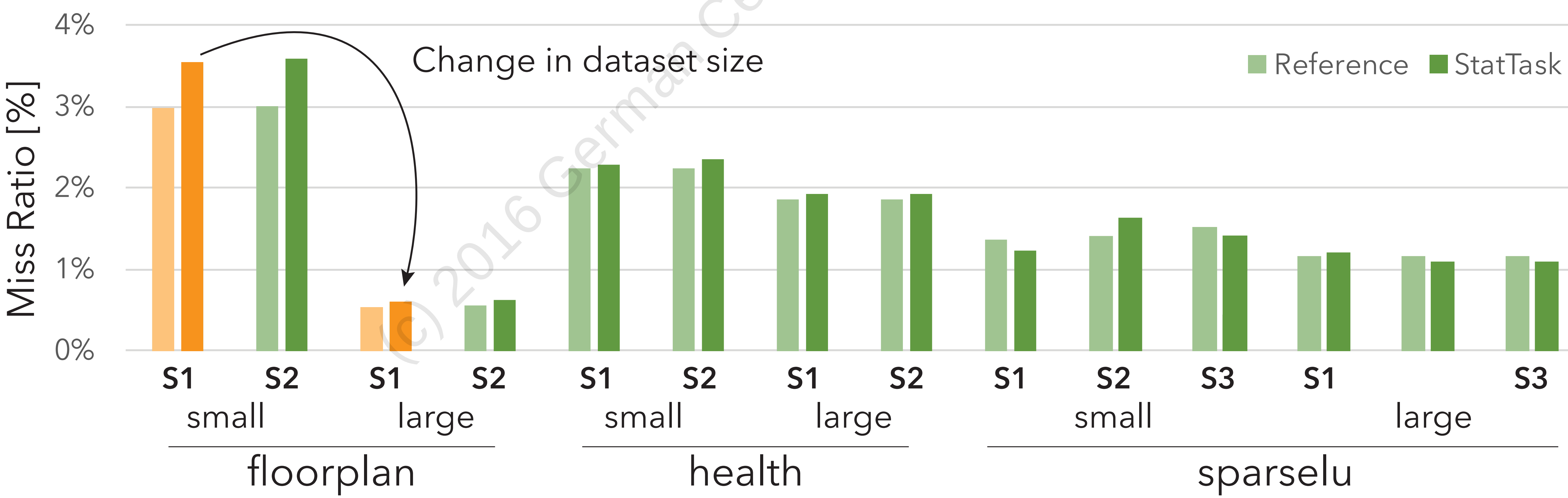
StatTask's Accuracy





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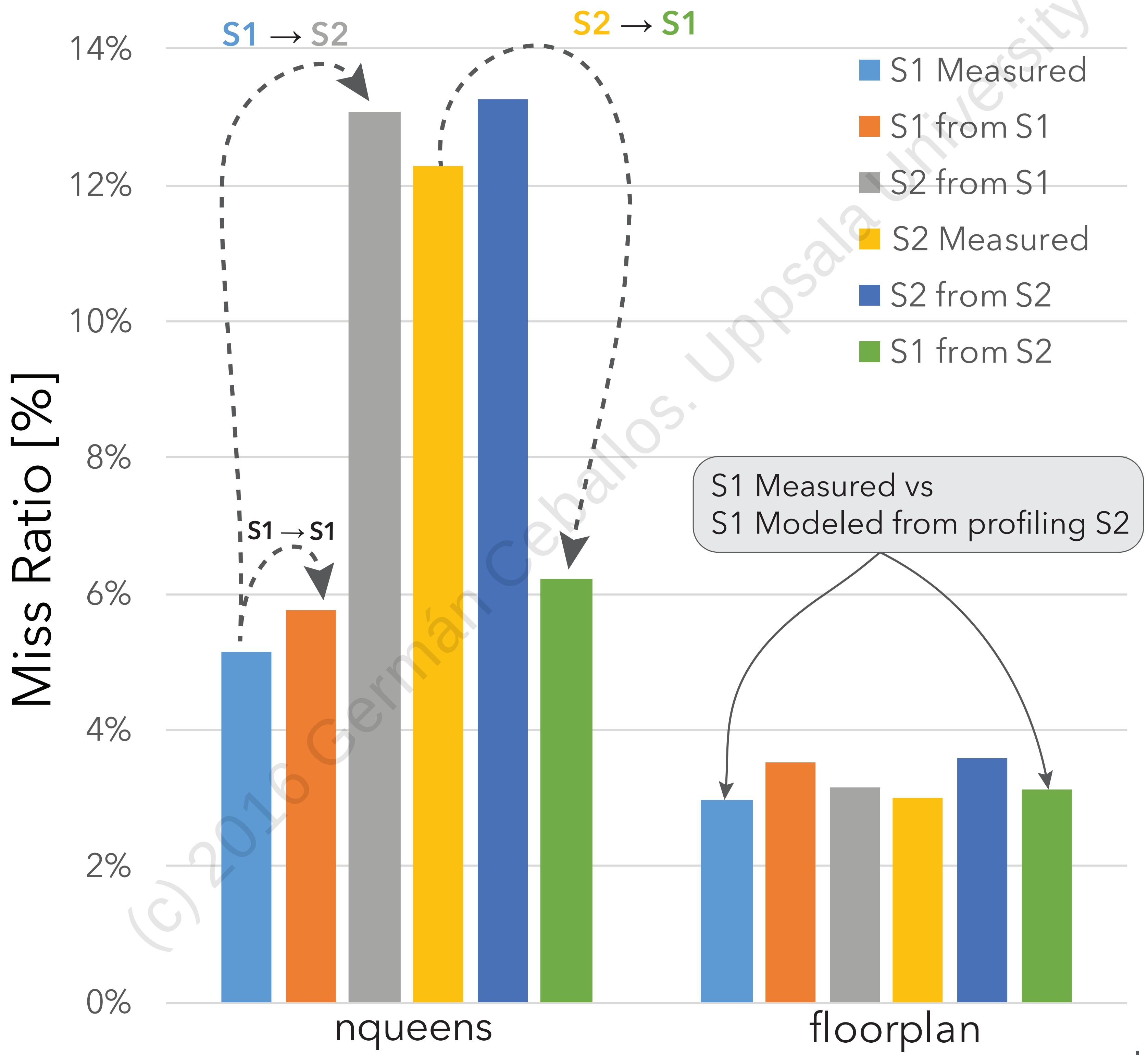
StatTask's Flexibility



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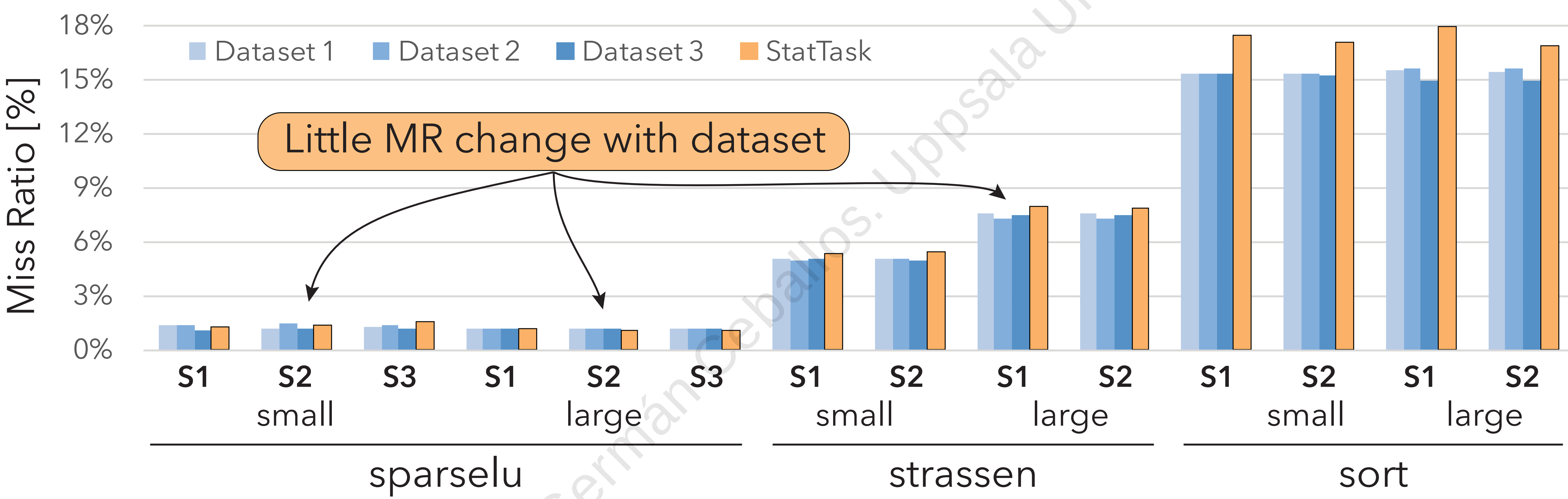
StatTask's Robustness



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Conclusion

- Different task **schedules** have different **cache behaviour**

  ≠ schedules ⟶ **≠ reuses** ⟶ **≠ performance**

- **Statistical Cache Models** can be used to predict different schedules
    - Need to be leveraged to **recompute reuses**
- **StatTask**
    - Formalizes the task-based execution model
    - **Accurate**: compared to measured results
    - **Flexible**: predicts from a **single** profile
    - **Robust**: predicts similar behaviour for inputs of roughly same size

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Formalizing Data Locality in Task-Parallel Applications

Germán Ceballos
Erik Hagersten
David Black-Schaffer

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Thank You!

ICA3PP '16

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