Handing Data Skew in MapReduce

B. Gufler♠, N. Augsten♣, A. Reiser♠, A. Kemper♠

♠Technische Universität München ♣Free University of Bolzano-Bozen

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Cloud Data Processing with MapReduce

MapReduce for Business

- usage statistics, index building, . . .
- simple reducer tasks

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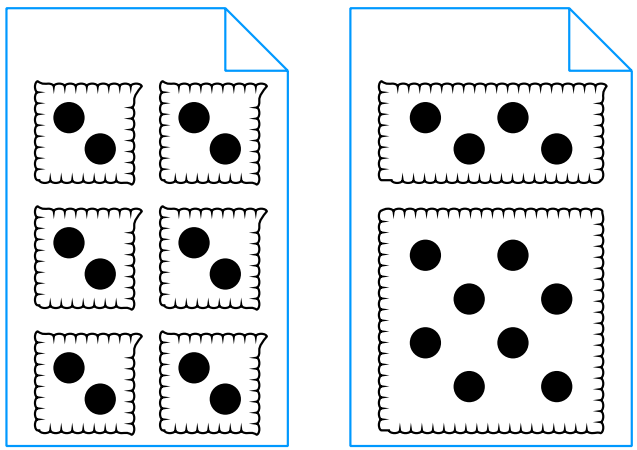
MapReduce for eScience: new challenges

1. heavy data skew



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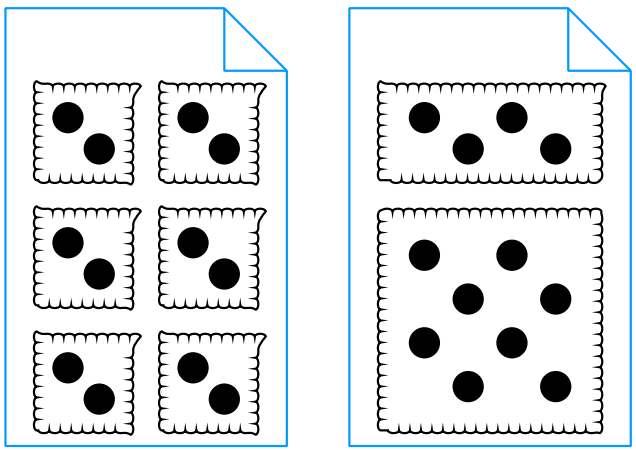

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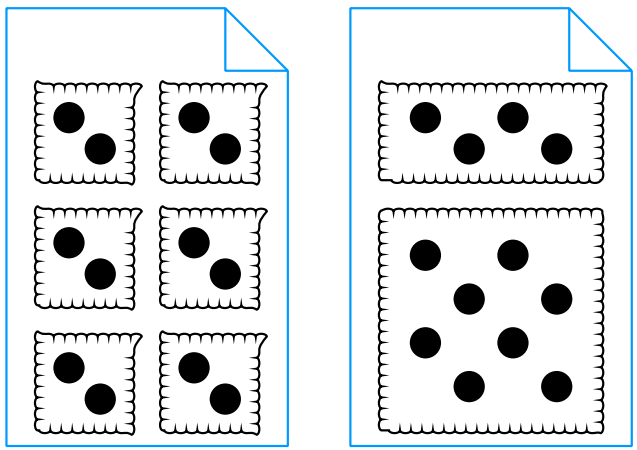
MapReduce for eScience: new challenges

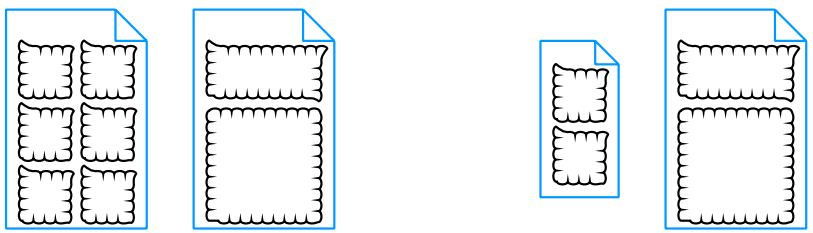
1. heavy data skew
2. complex reducer tasks

$\rightsquigarrow$ **How to deal with these problems?**

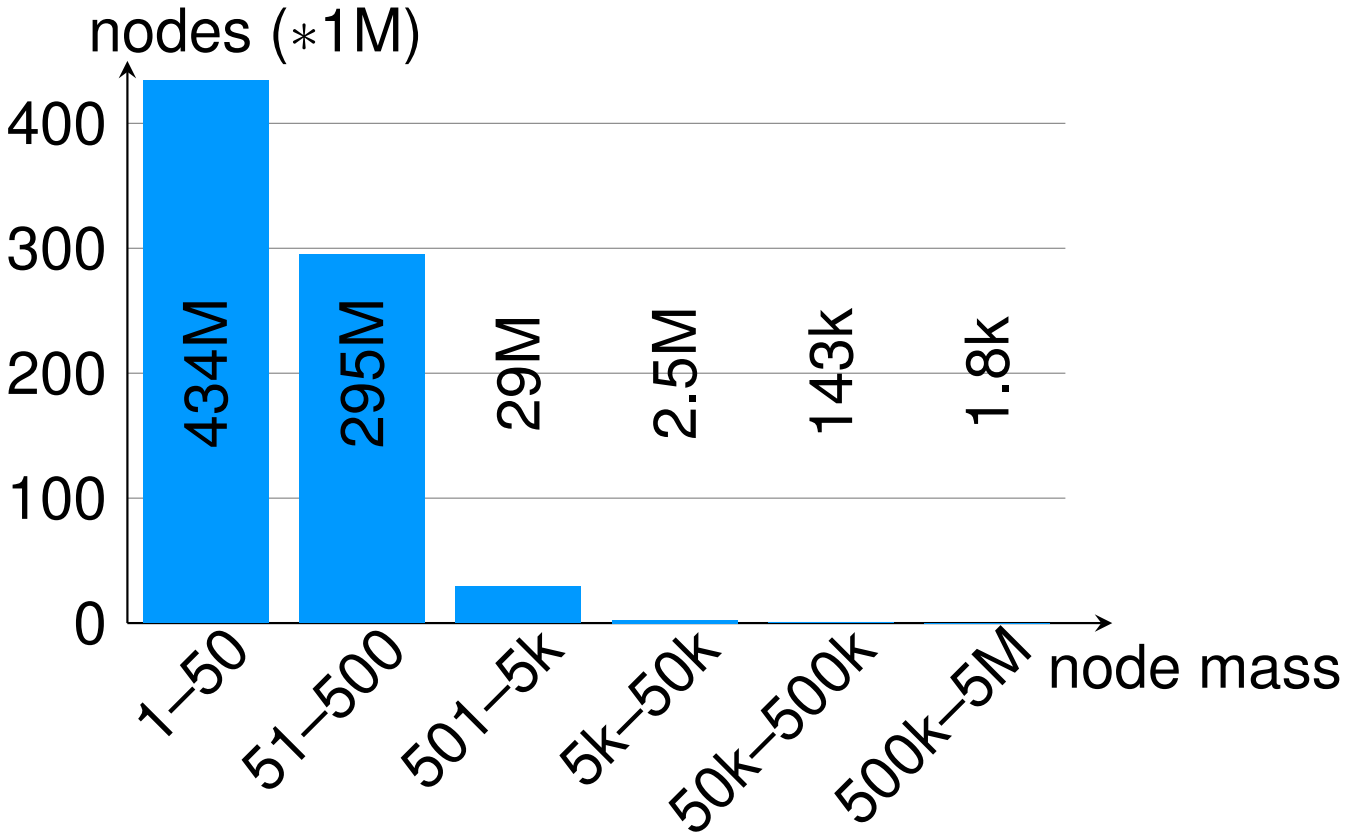


Data Skew

- values of an attribute not evenly distributed
- very common in scientific data
- causes load imbalance if attribute is used for partitioning

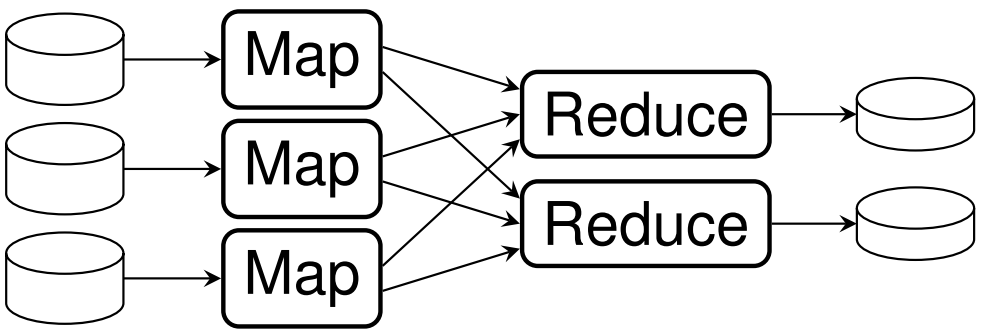


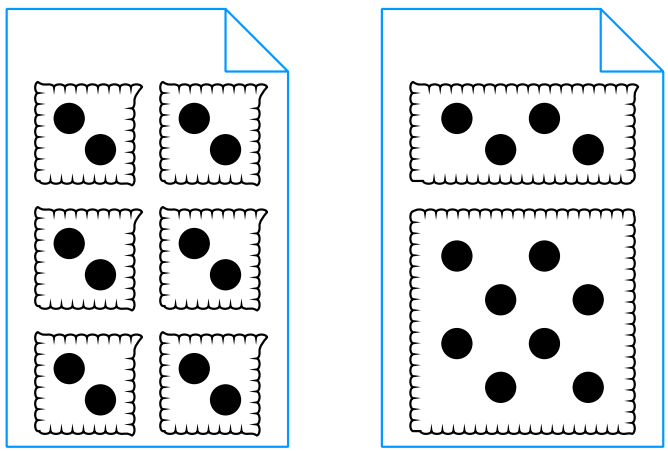
Example: Node Masses in Millennium Simulation



Complex Reducer Tasks

- complex scientific analysis algorithms
  - often polynomial or even exponential complexity
- amplifies load imbalance





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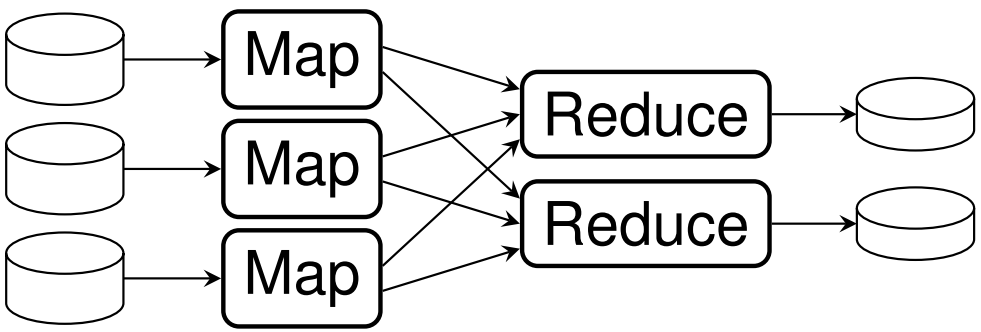

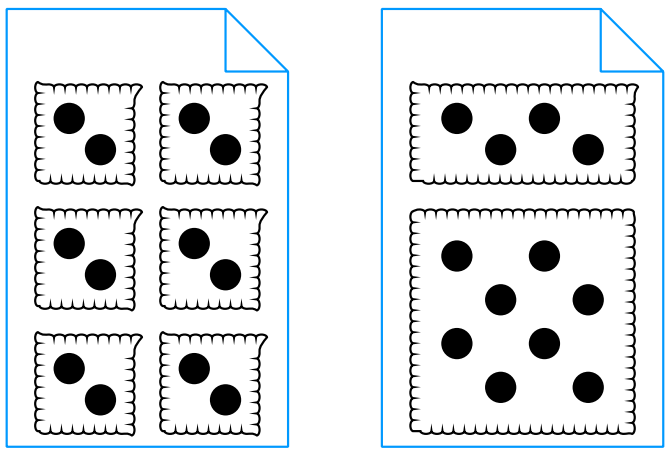

$$6 \cdot 2^2 = 24$$

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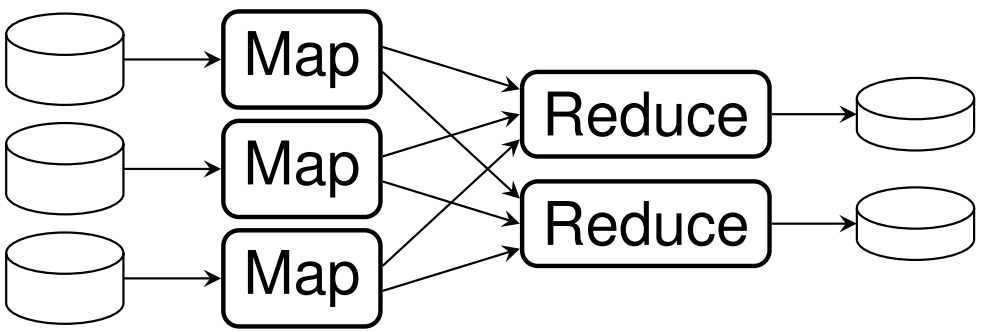
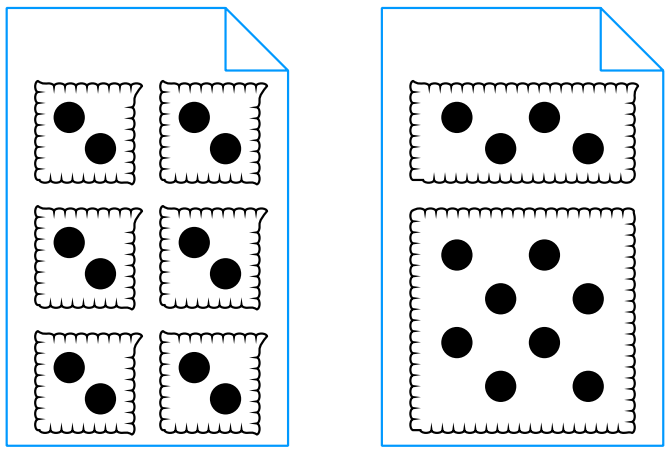
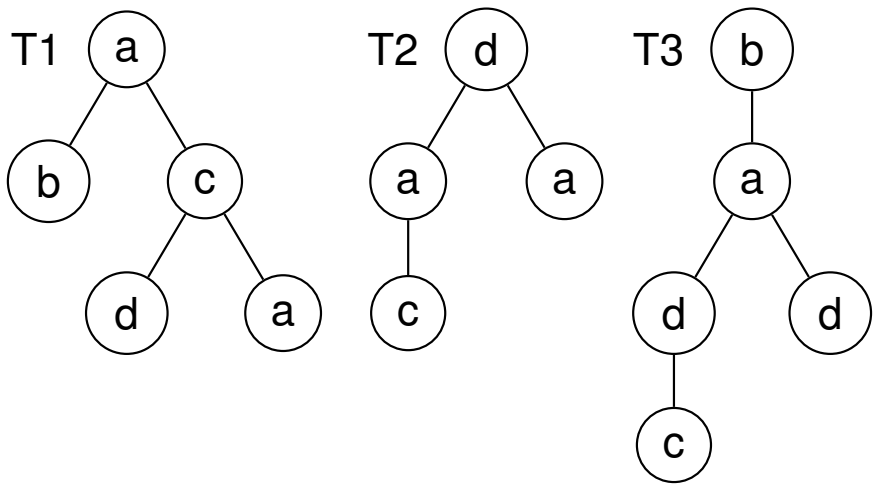




$6 \cdot 2^2 = 24$ $4^2 + 8^2 = 80$

Example: Frequent Subtree Mining

- find common substructures in (large parts of) a forest
- exponential complexity for unordered subtrees



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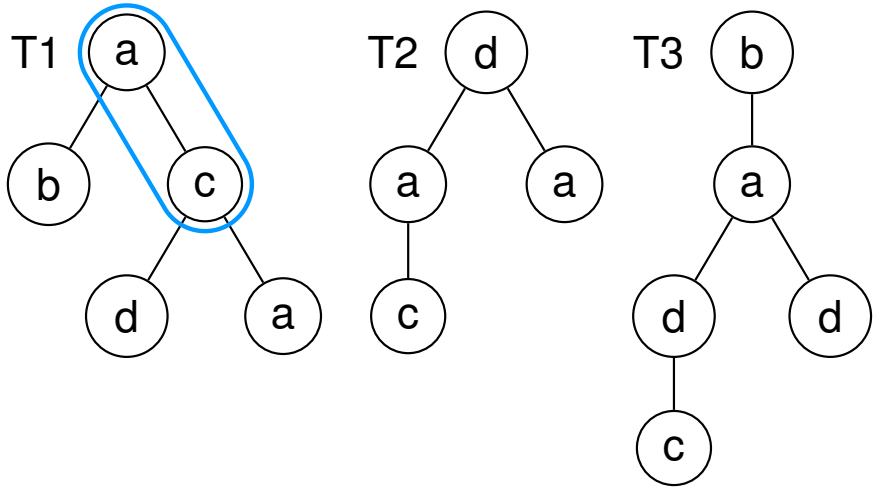

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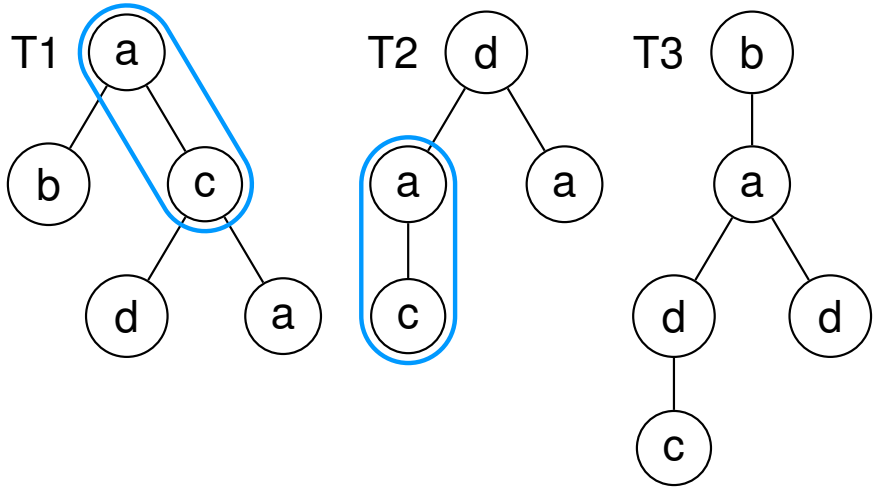

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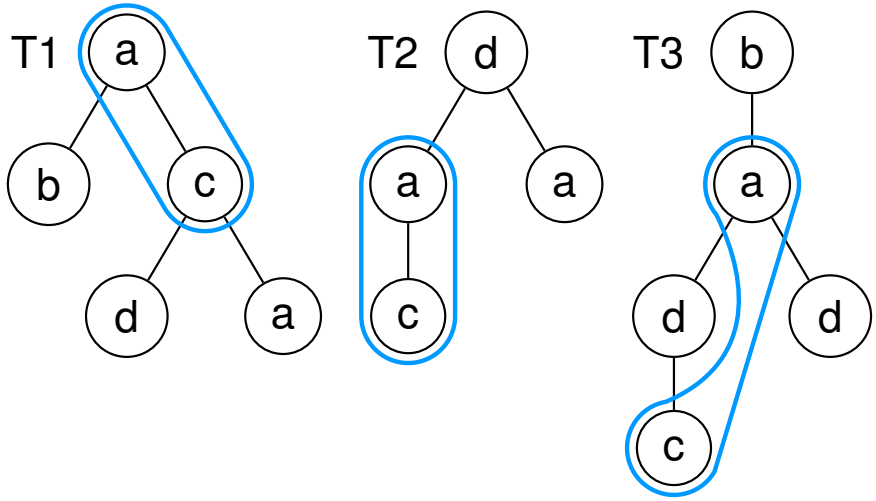


Summary: MapReduce for eScience

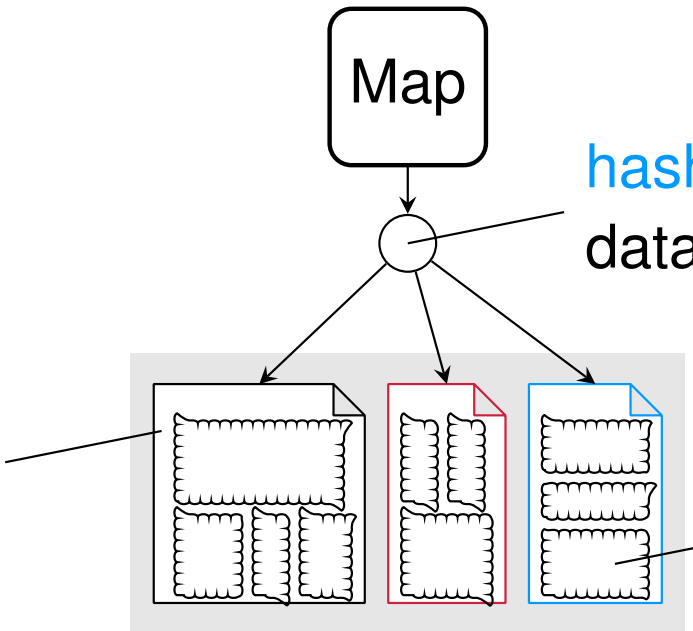
Challenges

- load imbalance due to data skew
- complex analysis amplifies execution time differences
- example: frequent subtree mining (PathJoin algorithm)
  - 16 GB data set (subset of the Millennium simulation)
  - cluster of 16 nodes
  - total execution time: 8 hours
  - execution time difference of reducers: up to 6 hours

Agenda

- Motivation
- Load Balancing in MapReduce: Big Picture
- Estimation of Partition Cost
- Assignment of Partitions to Reducers
- Number of Partitions
- Evaluation

Data Partitioning in MapReduce

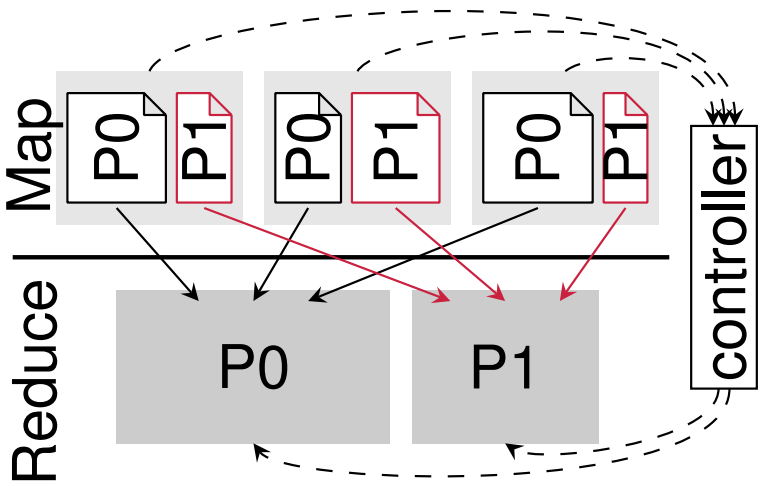


hash function for data partitioning

partition: all keys with the same hash values

cluster: all items with the same key

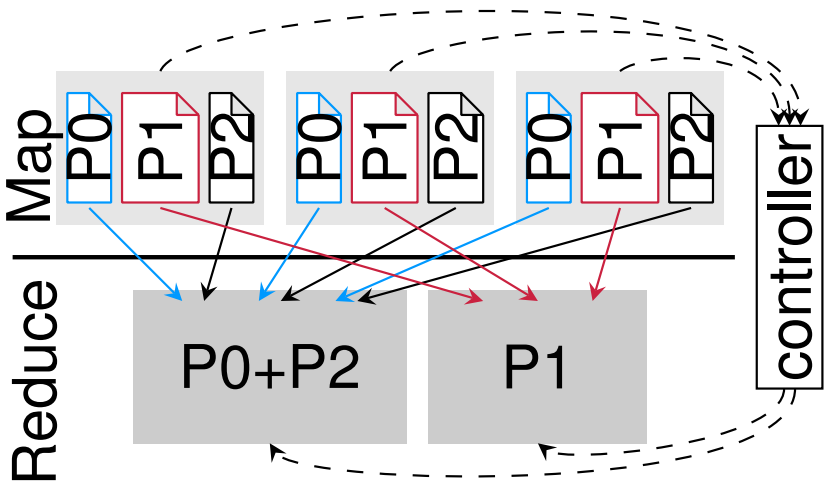
Load Balancing: Current MapReduce



- hash partitioning on each mapper
- static 1:1 assignment of partitions to reducers
- balances number of keys per reducer instead of workload
- no flexibility

Improved Load Balancing

- create more partitions than there are reducers
- cost-based assignment of partitions to reducers



- flexibility for load balancing
- challenges
  1. compute number of partitions
  2. estimate partition cost
  3. assign partitions to reducers

Estimate Partition Cost

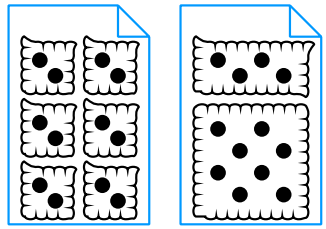
partition cost depends on

1. number and size of the clusters within the partition
   - locally monitored on each mapper
   - centrally aggregated on one controller
2. complexity of the reducer algorithm
   - specified by the user

$\rightsquigarrow$ estimate cluster cost based on this information

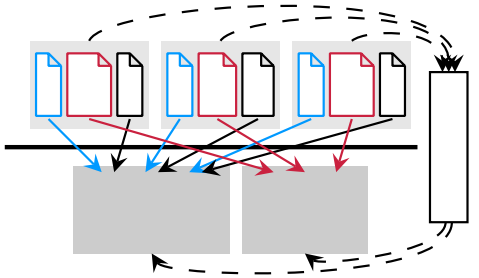
$\rightsquigarrow$ sum up cluster costs to obtain partition cost

Estimate Partition Cost: Monitoring



- tuple count
  - monitor local count on every mapper
  - sum up on controller
- cluster count
  - create Bloom filter on every mapper
  - employ Linear Counting on controller

Estimate Partition Cost: Monitoring



Mapper 1

P0

tuples: 31

clusters: [01011]

Mapper 2

P0

tuples: 17

clusters: [10011]

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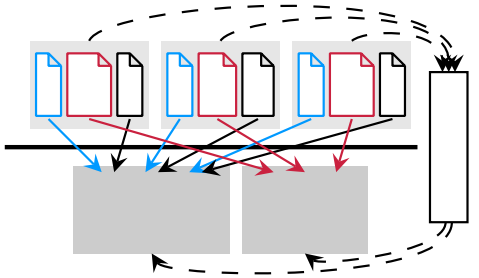

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Aggregate

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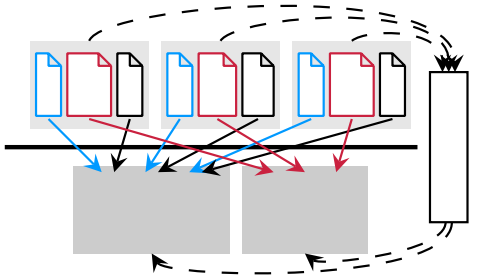

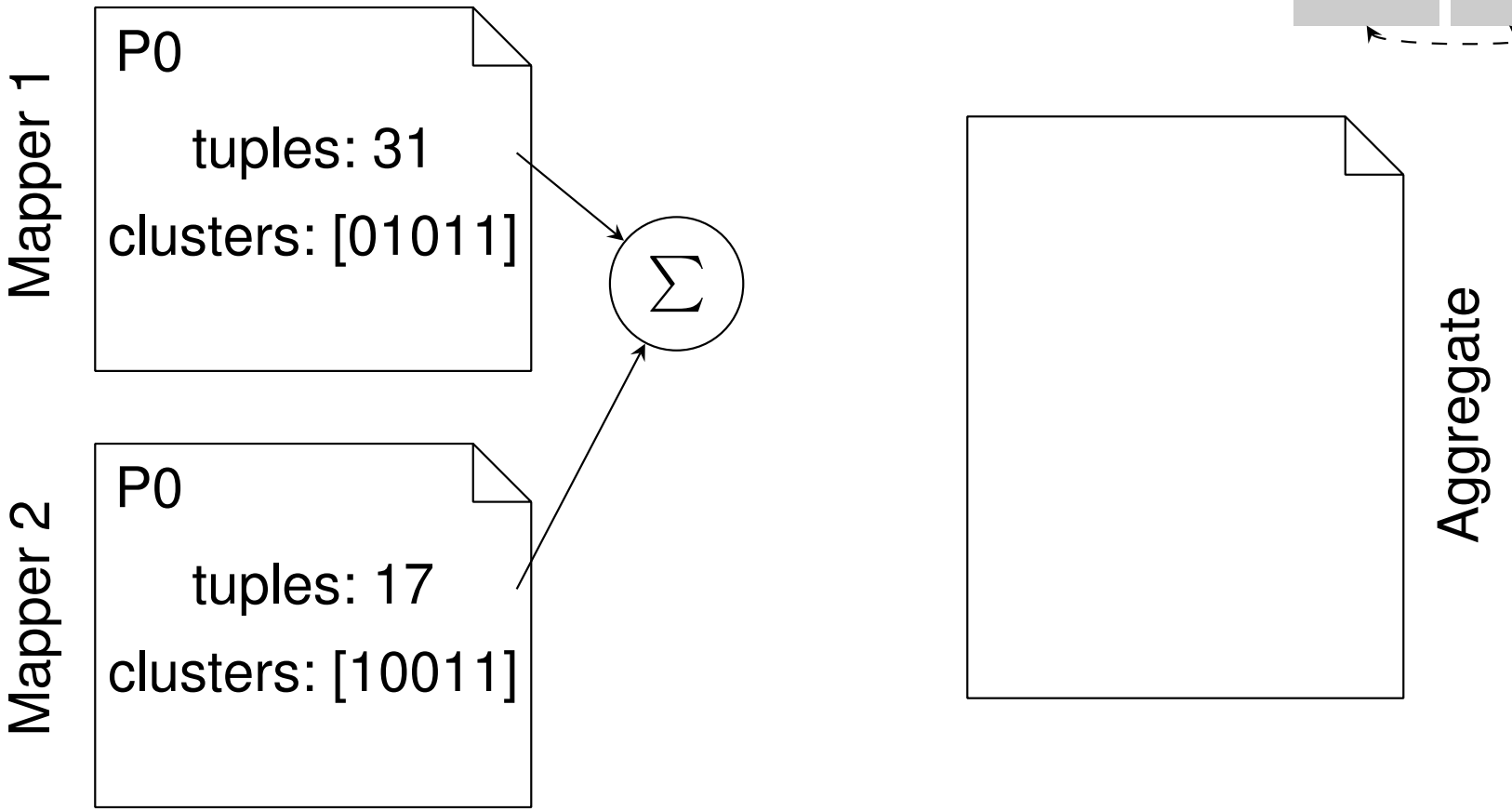

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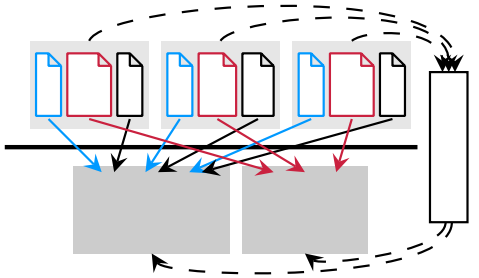

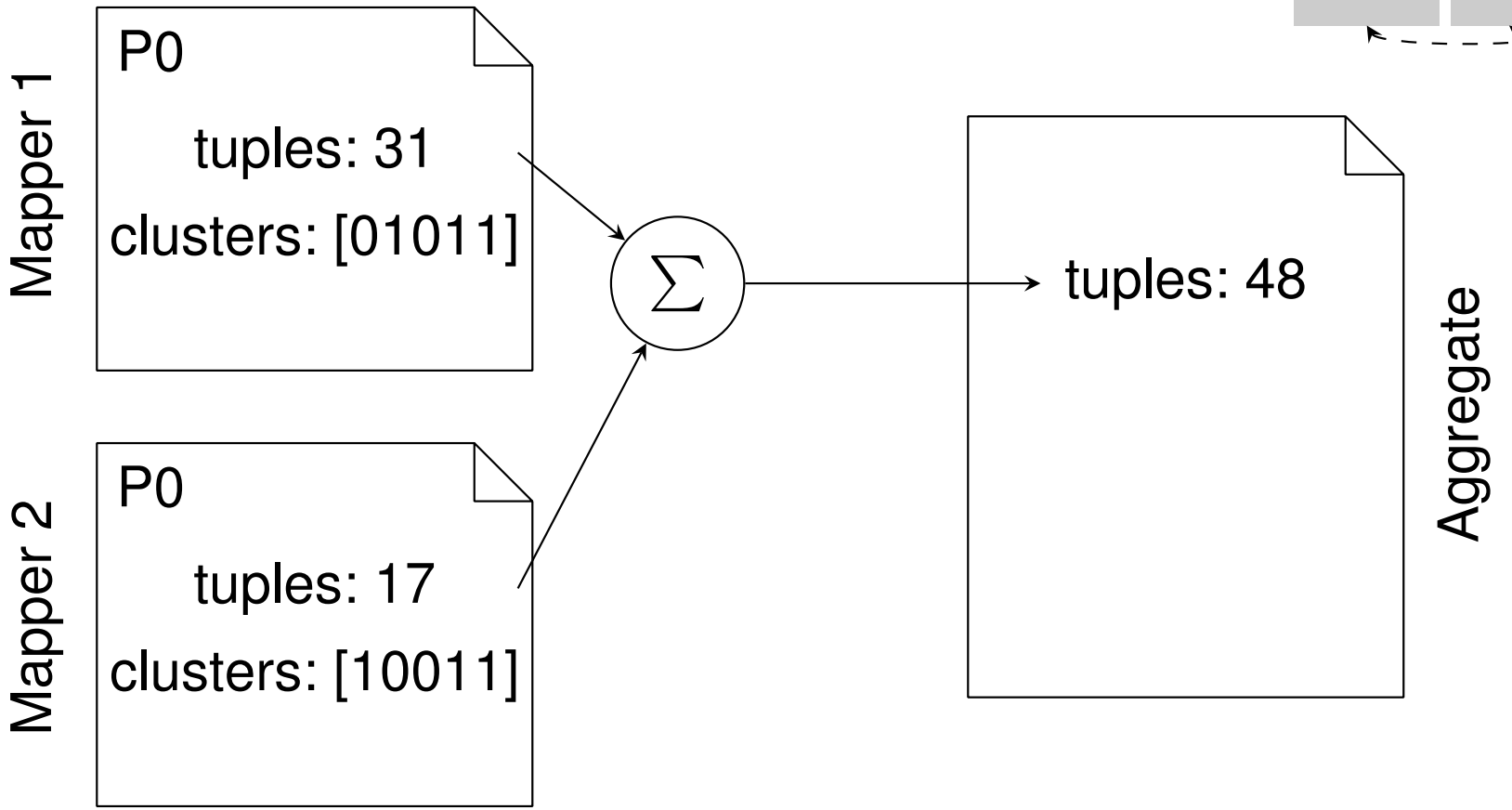

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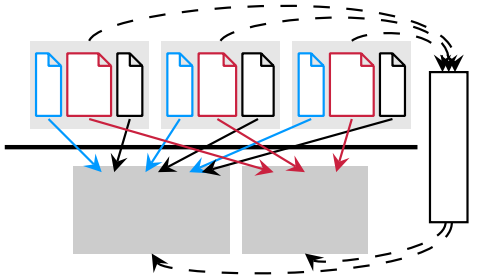

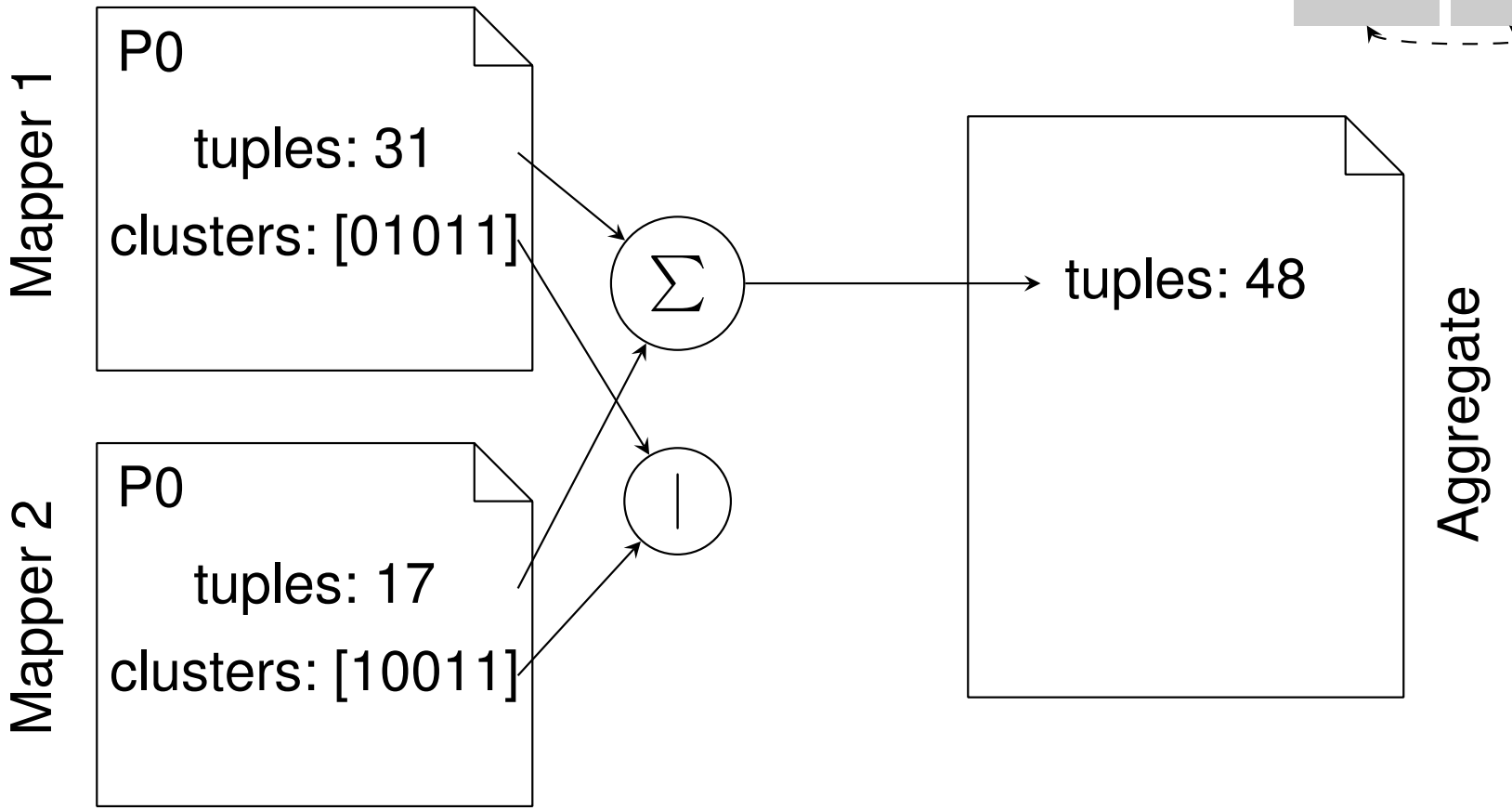

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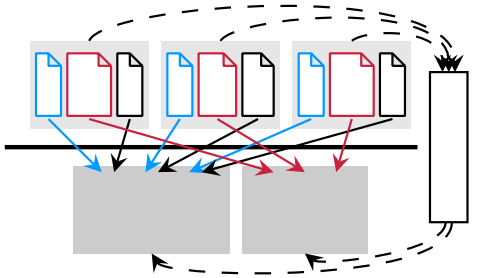

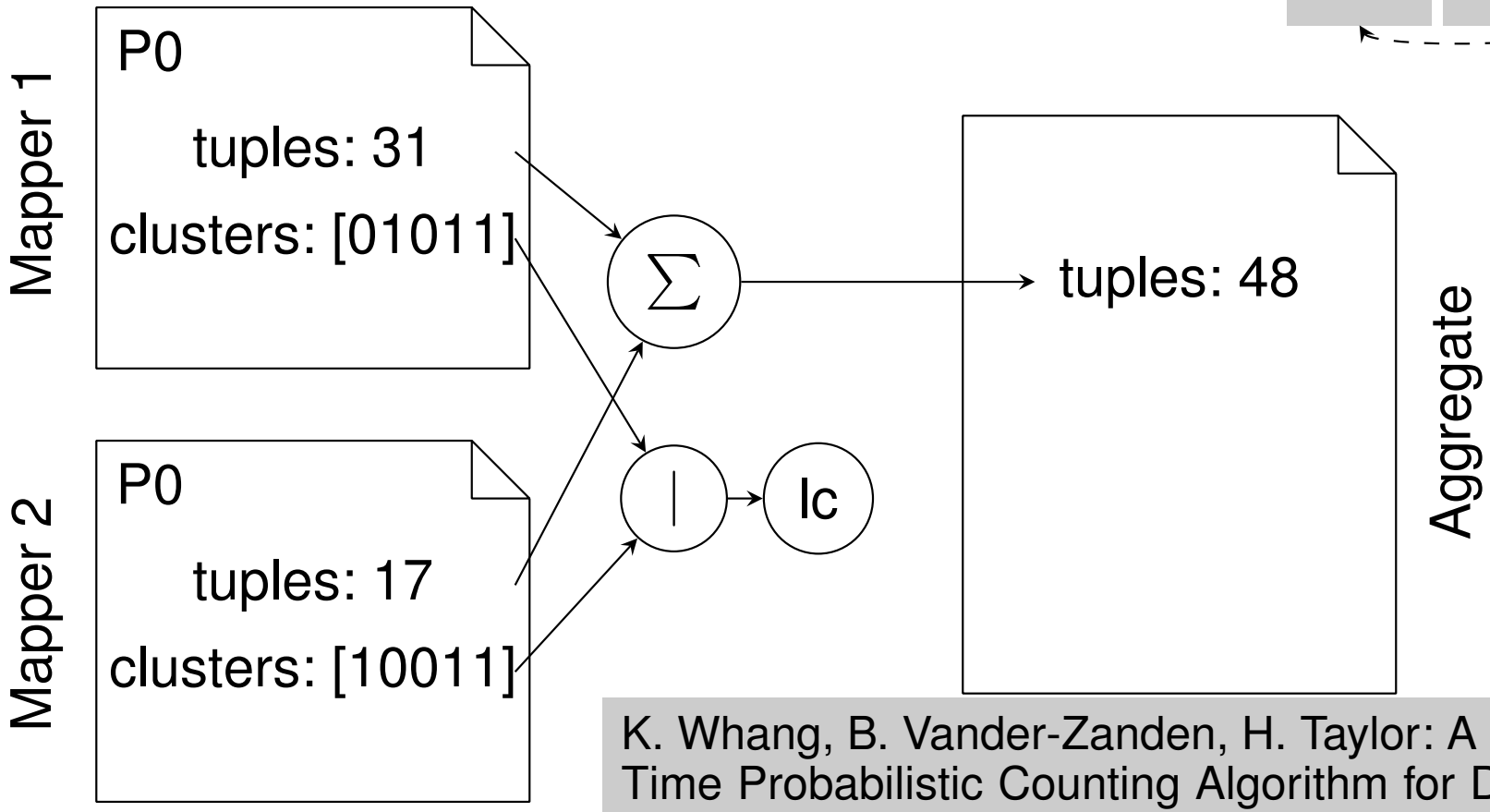

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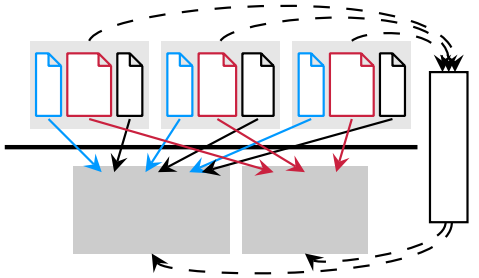

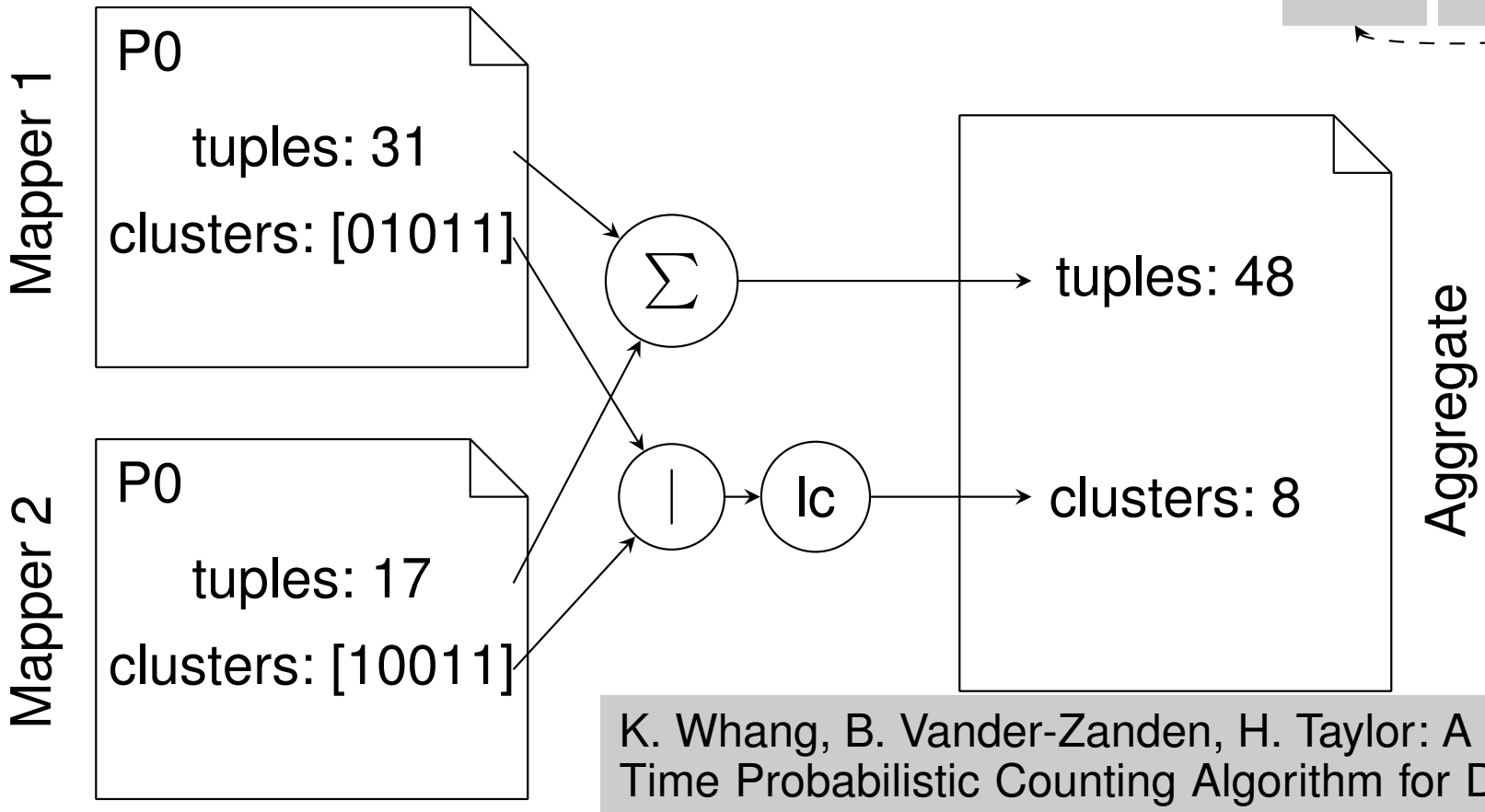

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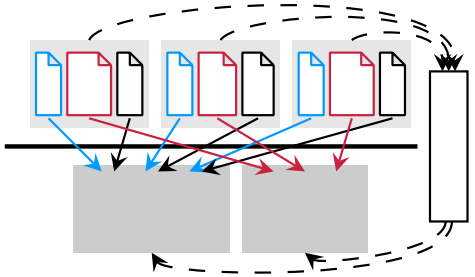

reducer complexity: quadratic
(e. g., pairwise comparison)

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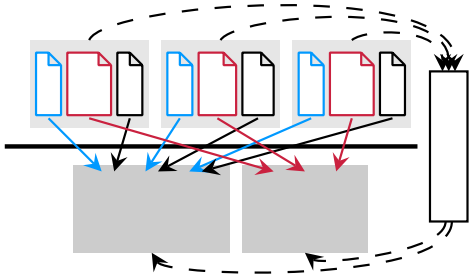

- average cluster size: $\frac{48}{8} = 6$

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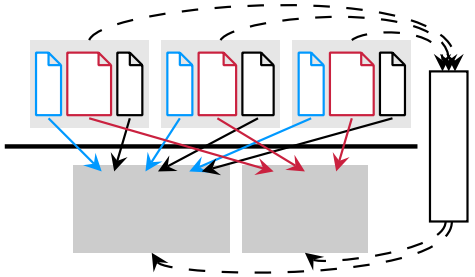

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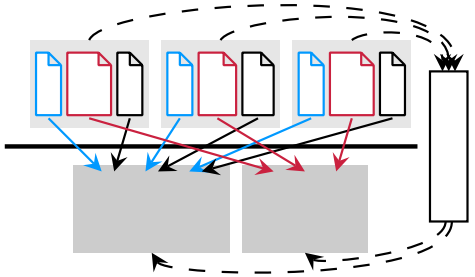

reducer complexity: quadratic
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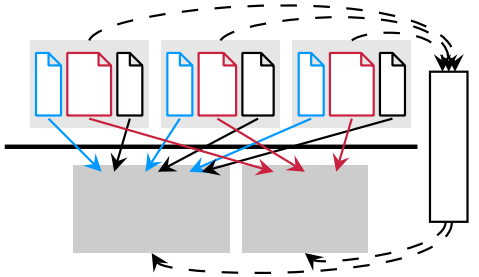
- average cluster size: $\frac{48}{8} = 6$
- cluster cost: $6^2 = 36$
- partition cost: $8 \cdot 36 = 288$

Assign Partitions to Reducers



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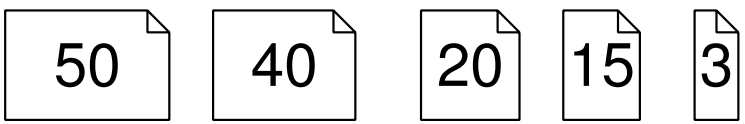
- bin packing problem, but: *NP*-hard
- rely on a heuristic instead



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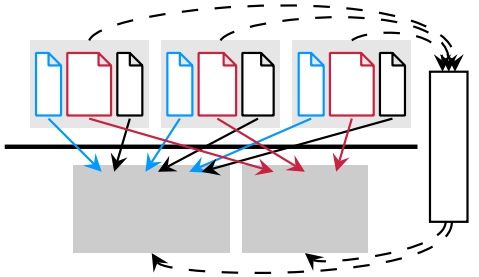

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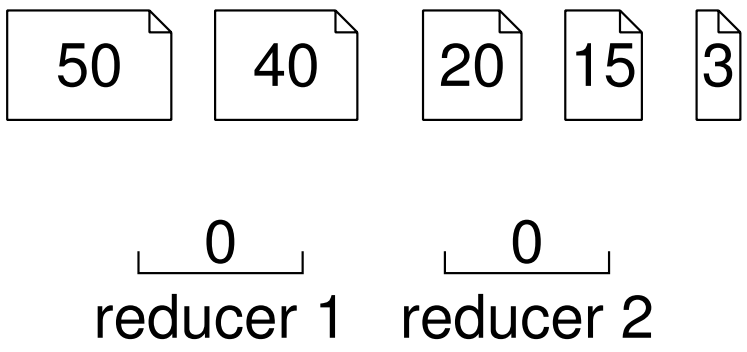

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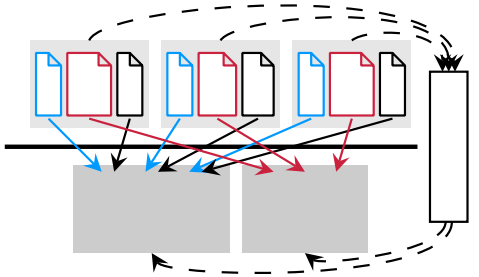

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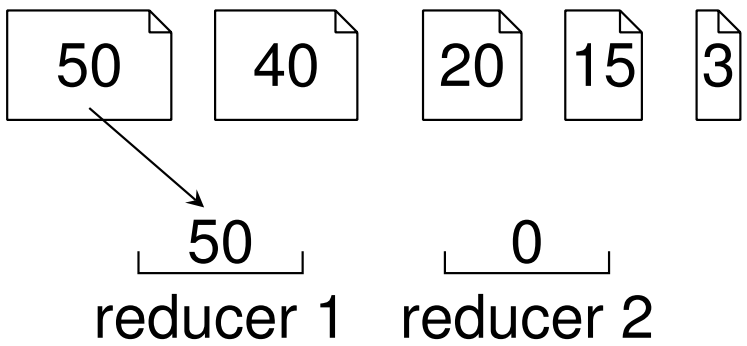

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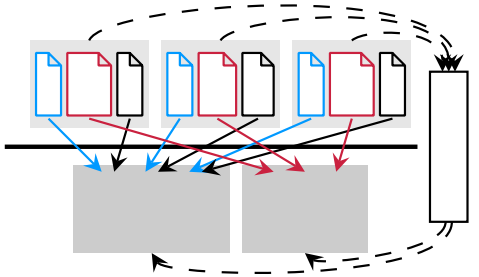

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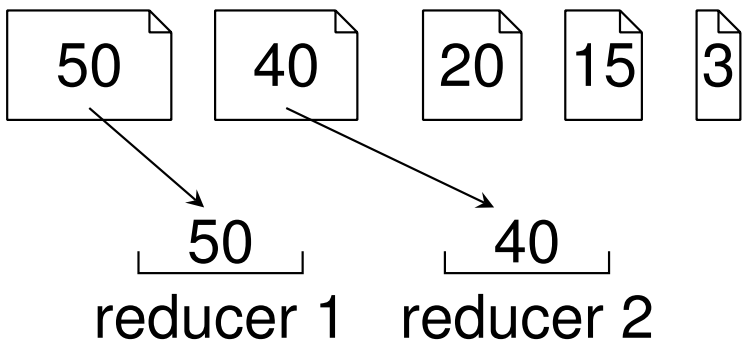

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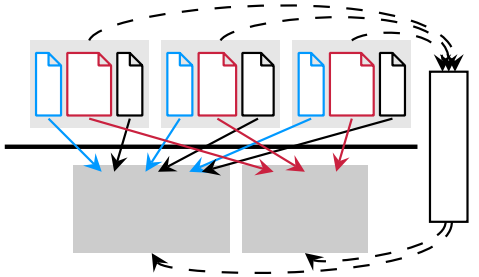

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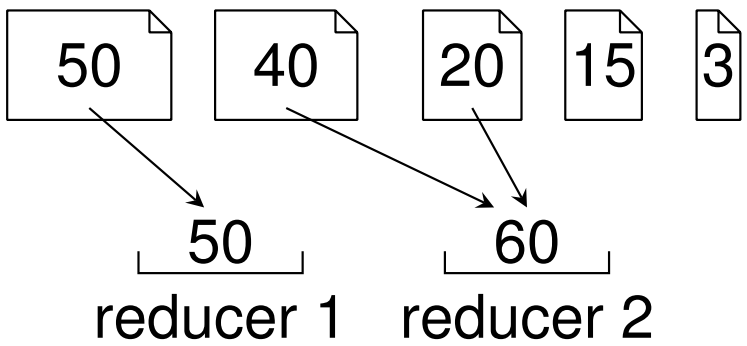

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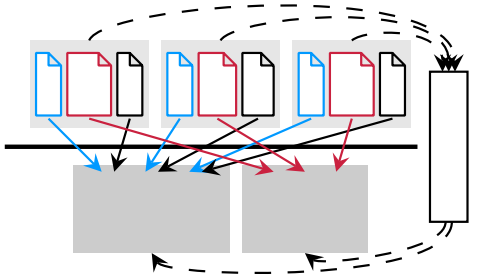

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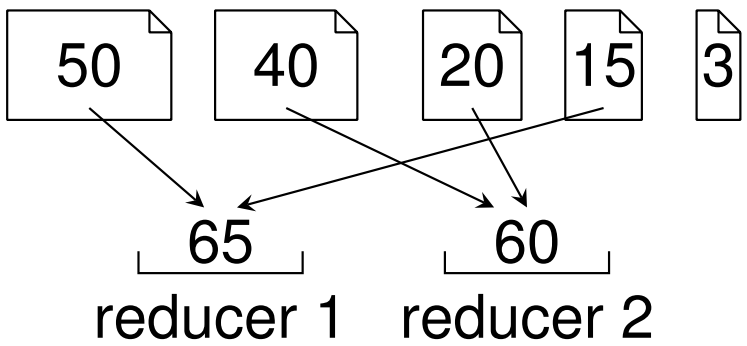

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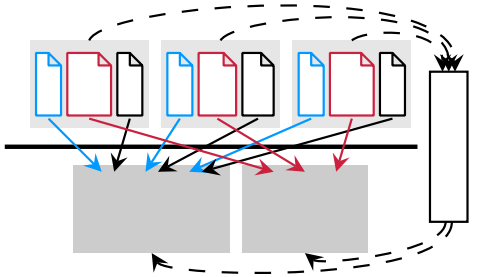

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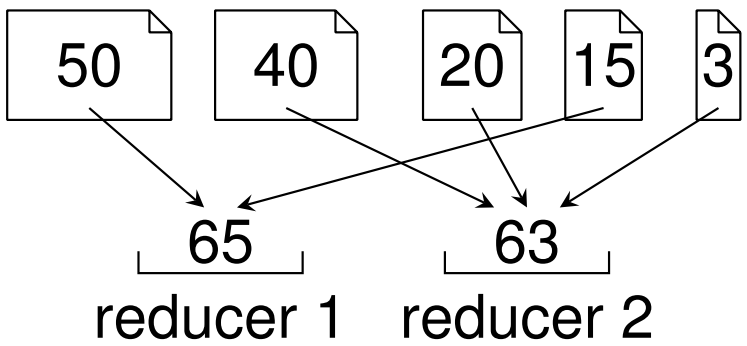
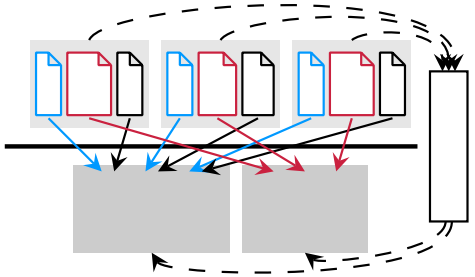
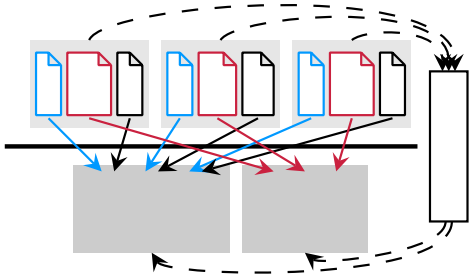


How many Partitions?



- static approach
  - number of partitions fixed beforehand by controller
  - matching partitions created on every mapper

How many Partitions?



- static approach
  - number of partitions fixed beforehand by controller
  - matching partitions created on every mapper
- dynamic approach
  - only initial number of partitions fixed
  - mappers may split some partitions further

Evaluation

- load balancing quality
- influence on execution time

Synthetic Data Sets

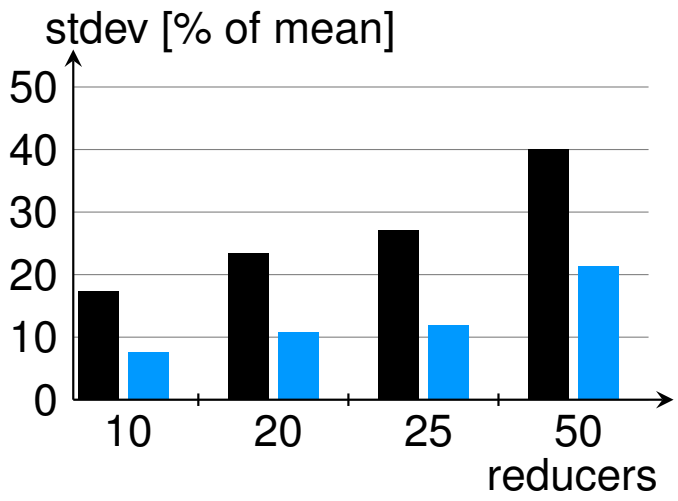
- 520M tuples
- 2 000 clusters
- Zipf distributions

Millennium Data Set

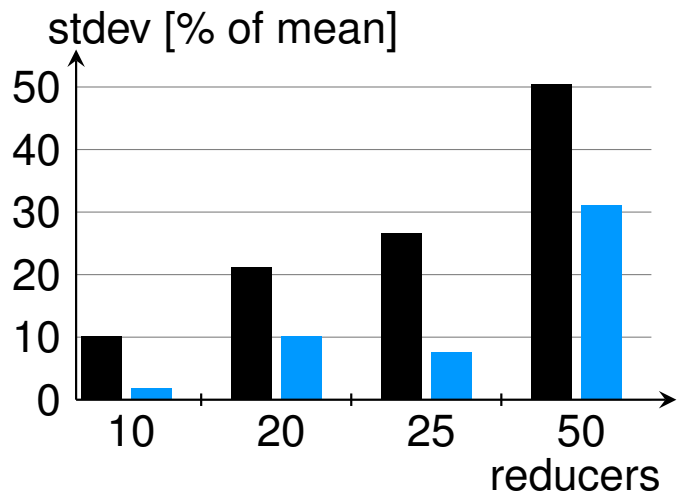
- 760M tuples
- $\approx$ 32 000 clusters

Evaluation: Load Balancing

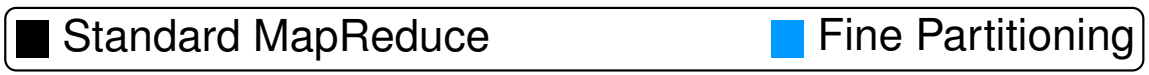
- measure standard deviation of partition cost per reducer
- small is good: small differences between reducers



Synthetic Data, Moderate Skew

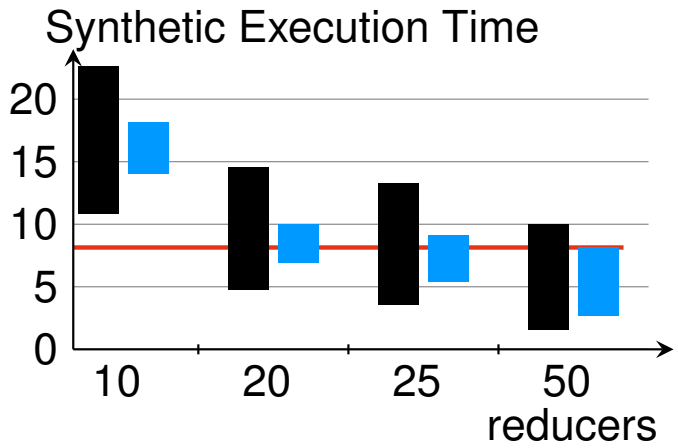


Millennium Data

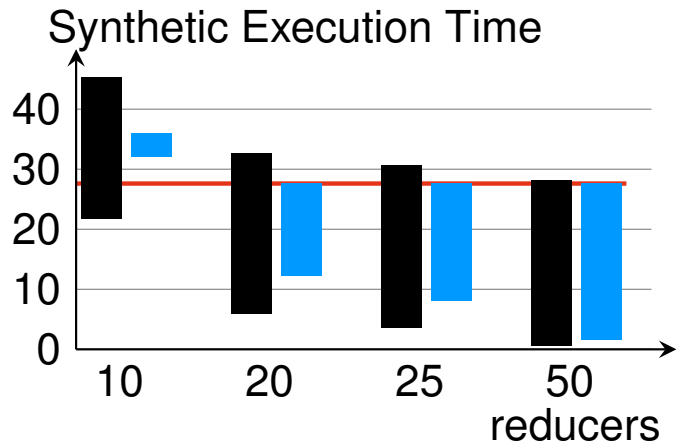


Evaluation: Execution Time

- measure execution time per reducer
- max time: overall time of reduce job

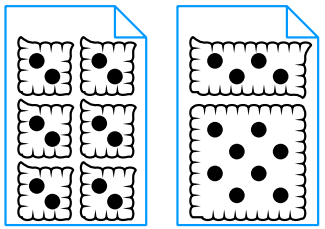


Synthetic Data, Moderate Skew

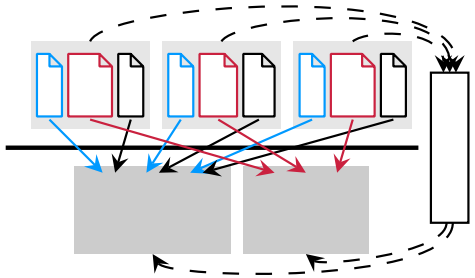


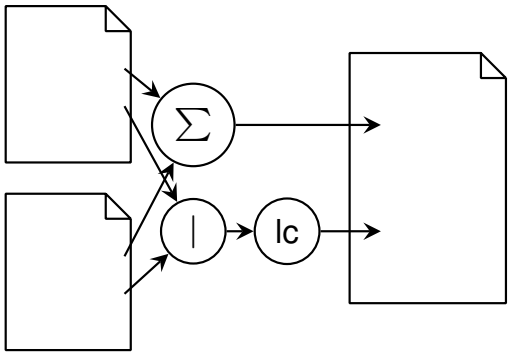
Millennium Data

Summary



- scientific data analysis with MapReduce
- partition-based load balancing
- distributed monitoring for cost estimation
- experimental evaluation
  - better load balancing
  - reduced overall execution time





Thank you!