Global Analytics in the Face of Bandwidth and Regulatory Constraints

Vulimiri et al.

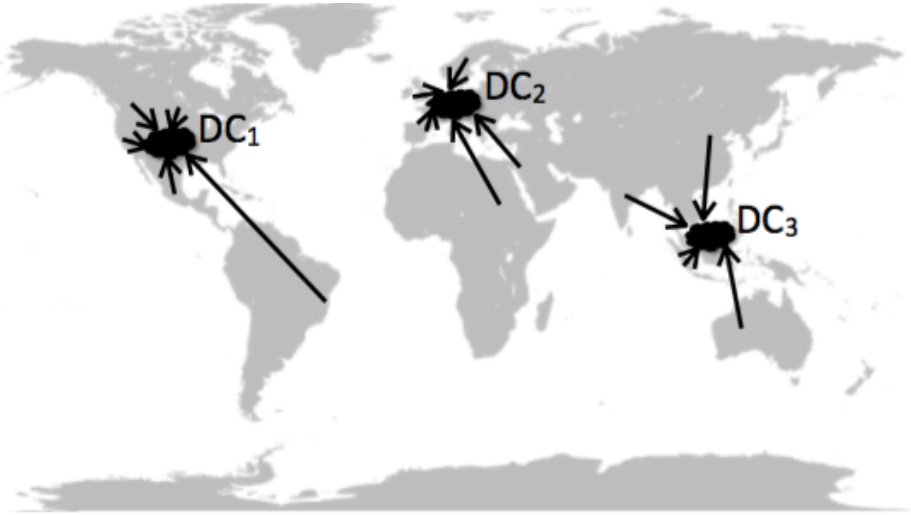
NSDI'15

Massive Data Volume

Facebook	600 TB/day
Twitter	100 TB/day
Microsoft	10s TB/day
LinkedIn	10 TB/day
Yahoo!	10 TB/day

Use case:

- User activity logs
- Monitoring remote infrastructure
- …



Collected across several data centers for low user latency

SQL analytics across geo-distributed data to extract insight

Consider an analytical query reporting statistics of users generating at least $100 in ad revenue

SQL analytics across geo-distributed data to extract insight

ClickLog
(source IP,
destURL,
visitData,
adRevenue,
…)

SQL analytics across geo-distributed data to extract insight

PageInfo
(pageURL,
pageSize,
pageRank, …)

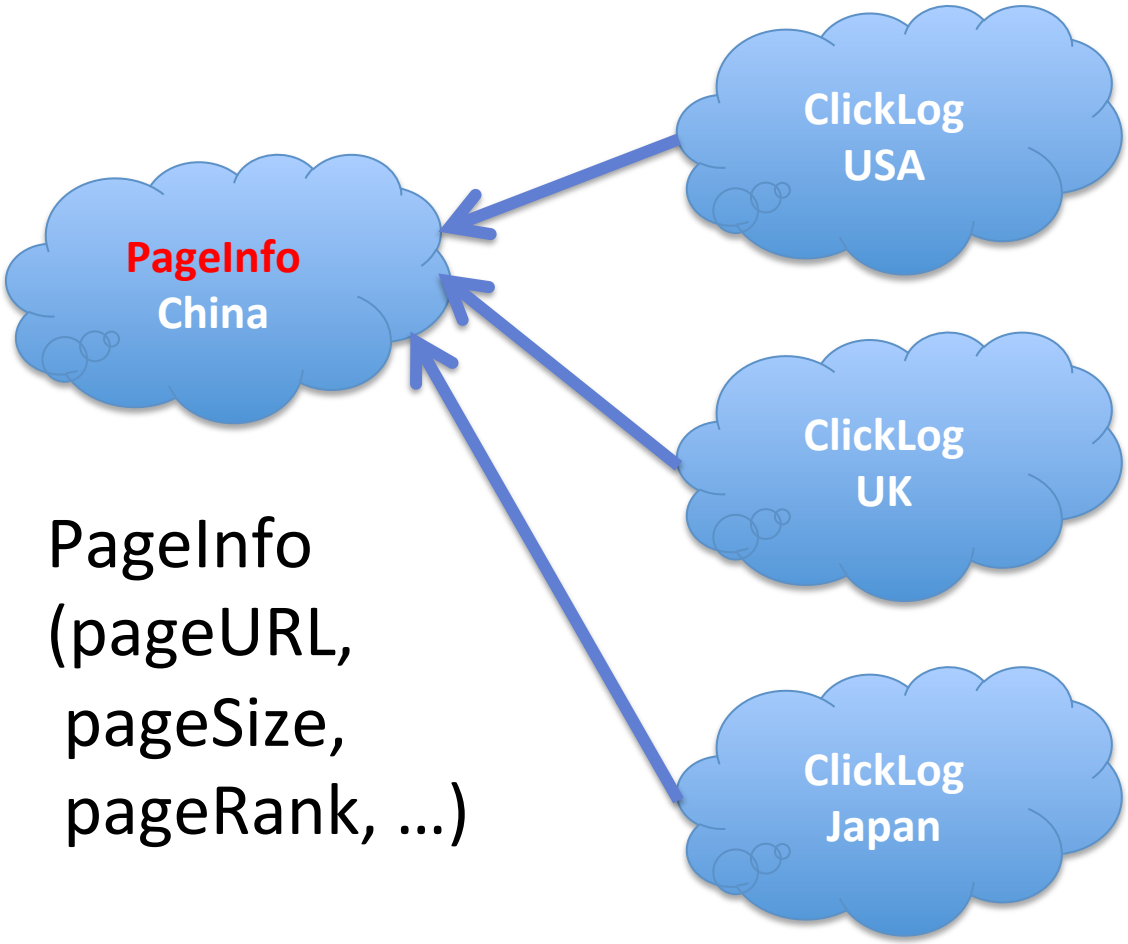
ClickLog
(source IP,
destURL,
visitData,
adRevenue,
…)

SQL analytics across geo-distributed data to extract insight

ClickLog (source IP, destURL, visitData, adRevenue, …)
PageInfo (pageURL, pageSize, pageRank, …)

Q: SELECT sourceIP, sum(adRevenue), avg(pageRank)
FROM ClickLog cl JOIN PageInfo pi
ON cl.destURL = pi.pageURL
WHERE pi.pageCategory = 'Entertainment'
GROUP BY sourceIP
HAVING sum(adRevenue) >= 100

Centralized method



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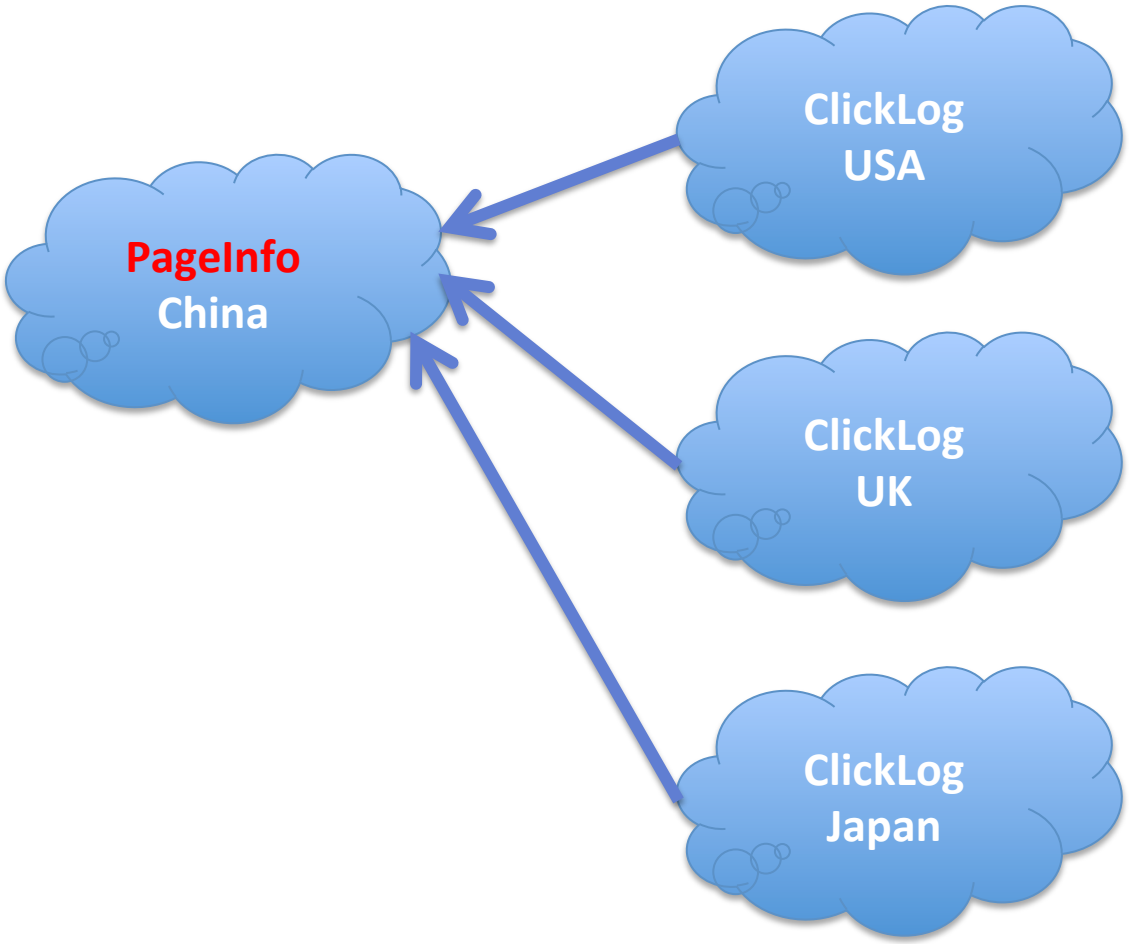
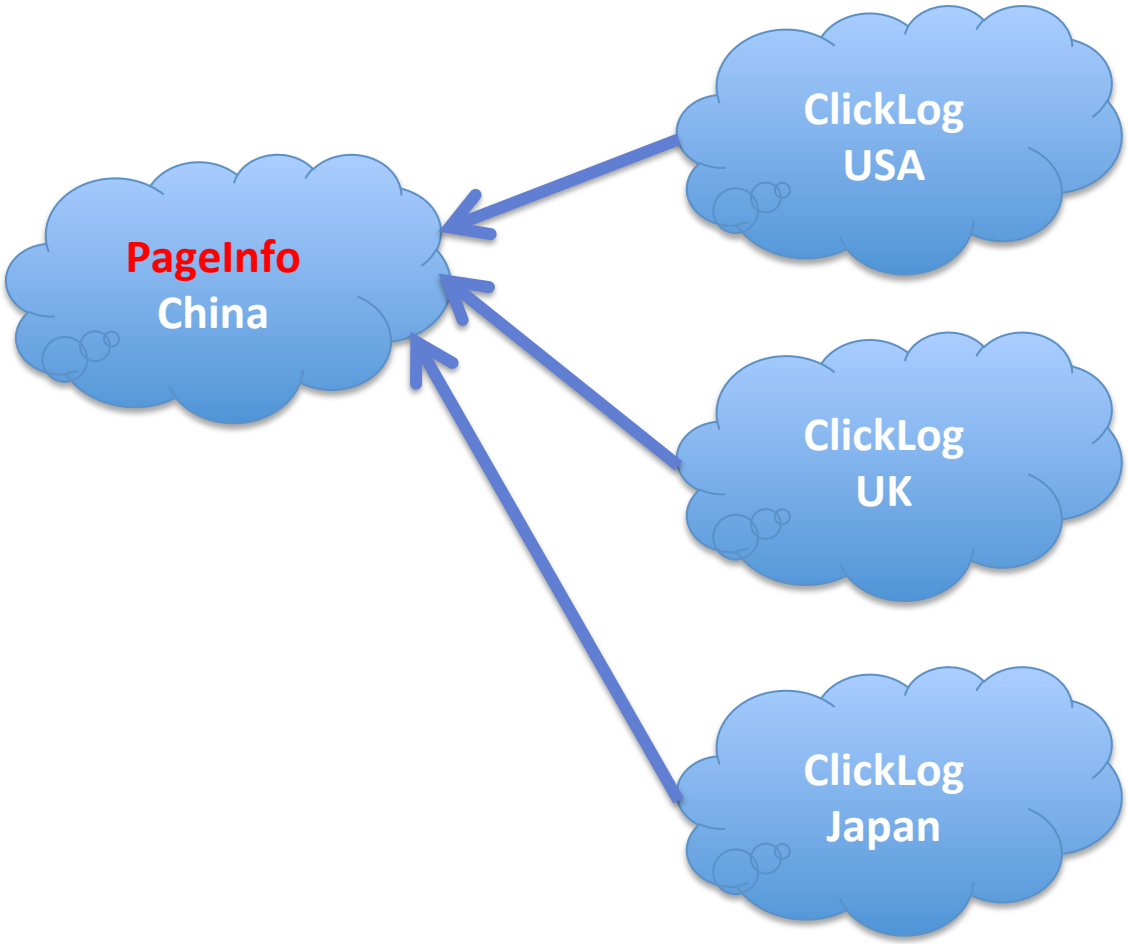
Centralized method



- Copy all ClickLog data to central DC

- Run the query there

Centralized method



- 1B users
- 6 pages visited per user
- 200 bytes per ClickLog row

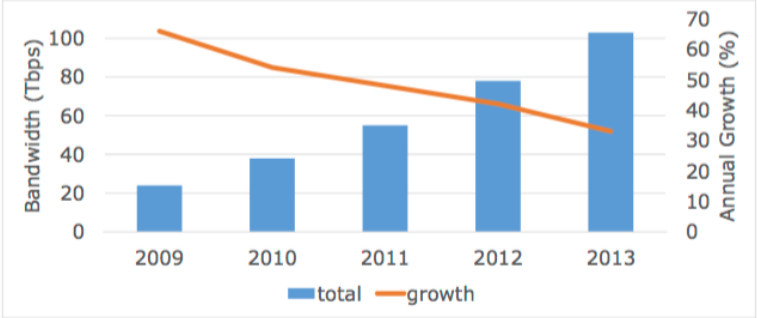
Total data transfer: 1B * 6 * 200 = 1.2 TB

Centralized approach is inadequate

- Consumes scarce, expensive cross-DC bandwidth

Rising costs

Slowing bandwidth growth



Centralized approach is inadequate

- Consumes scarce, expensive cross-DC bandwidth

- Incompatible with sovereignty concerns

  -- Many countries considering restricting moving cities' data

  -- Could render centralized method impossible

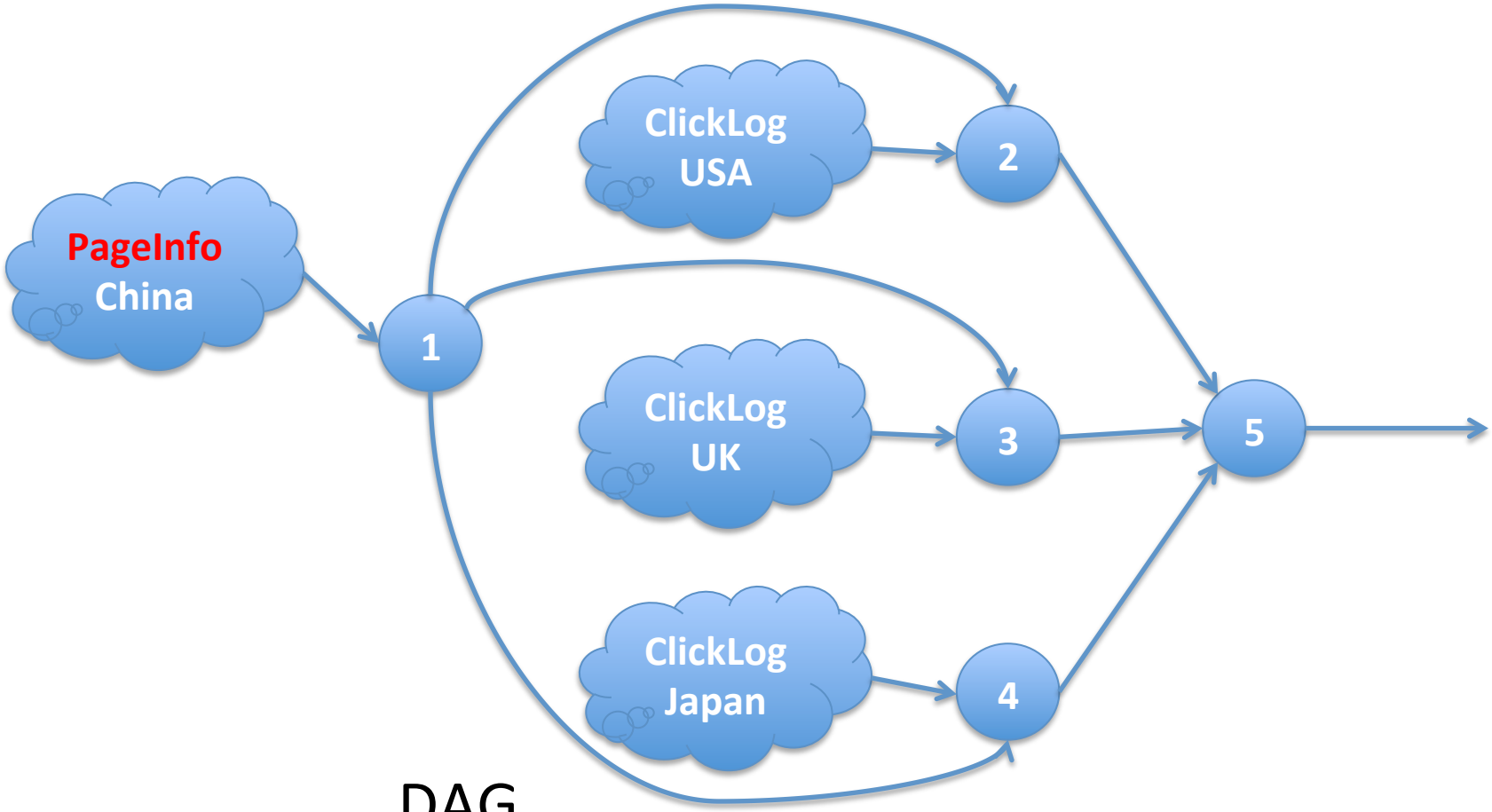
  -- Derived information might still be acceptable

Geo-distributed SQL analytics

PageInfo
(pageURL,
pageSize,
pageRank, …)

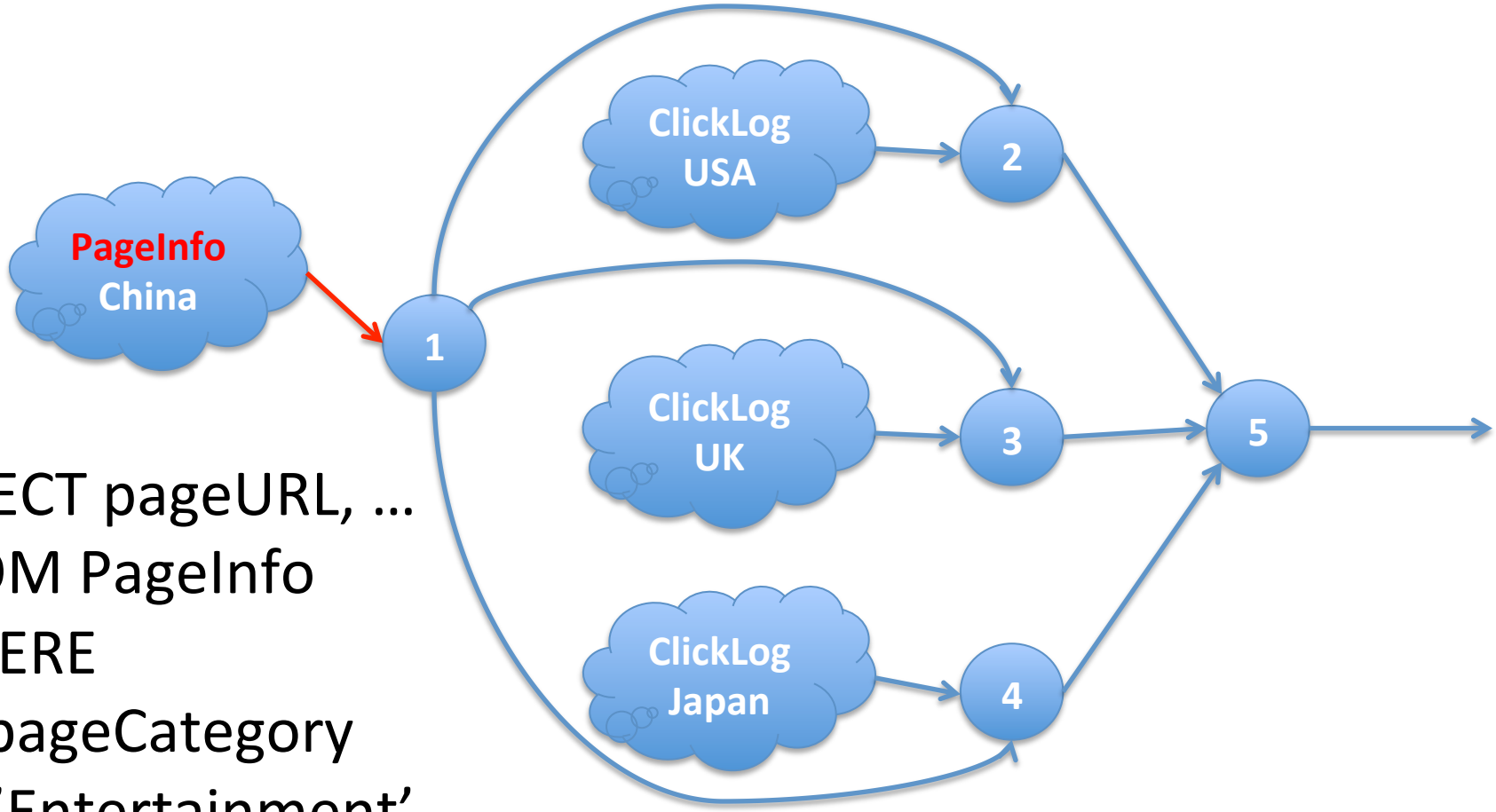
ClickLog
(source IP,
destURL,
visitData,
adRevenue,
…)

Geo-distributed SQL analytics



DAG

Geo-distributed SQL analytics




```
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FROM PageInfo
WHERE
    pageCategory
 =  'Entertainment'
```
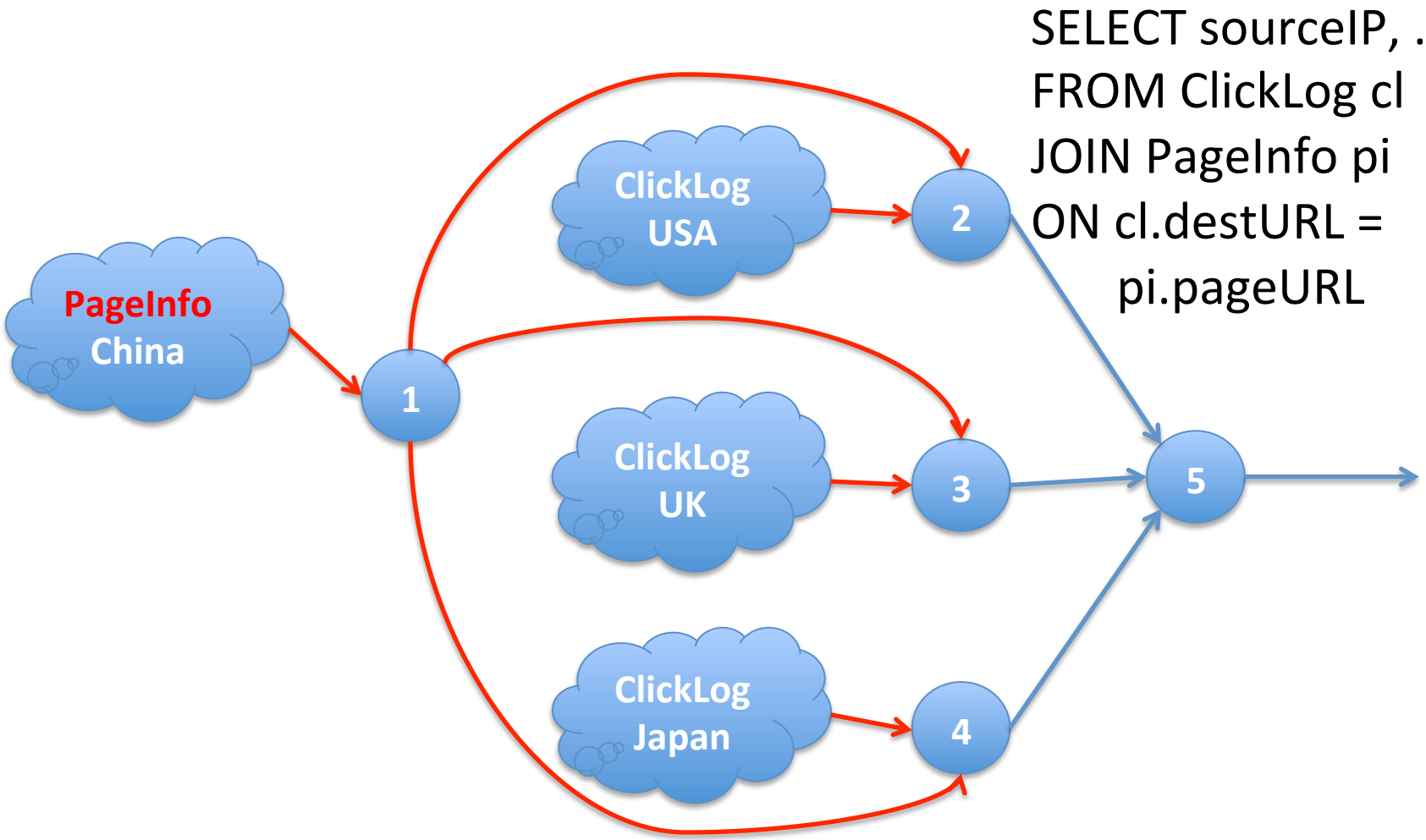
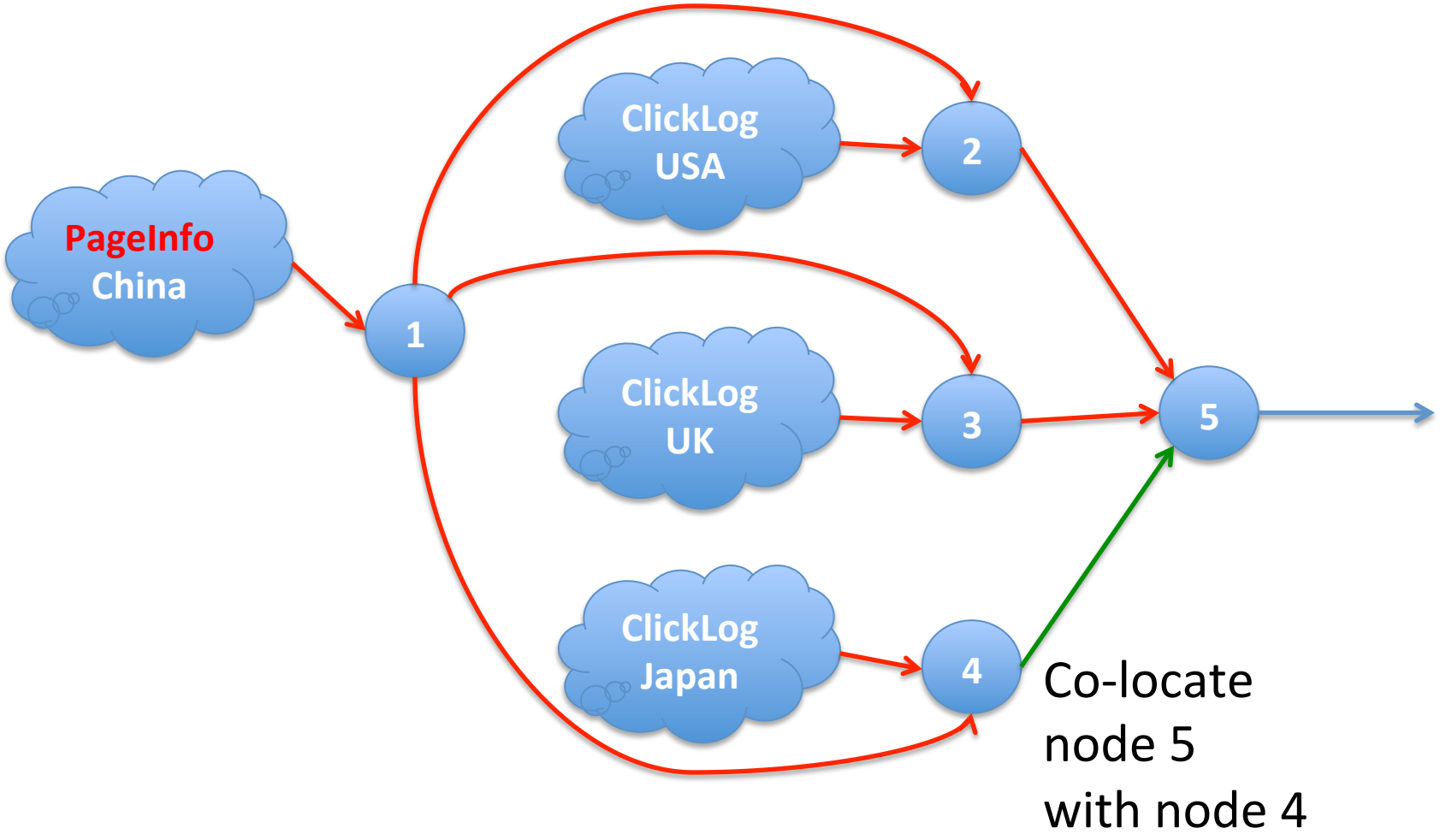

Geo-distributed SQL analytics



Geo-distributed SQL analytics



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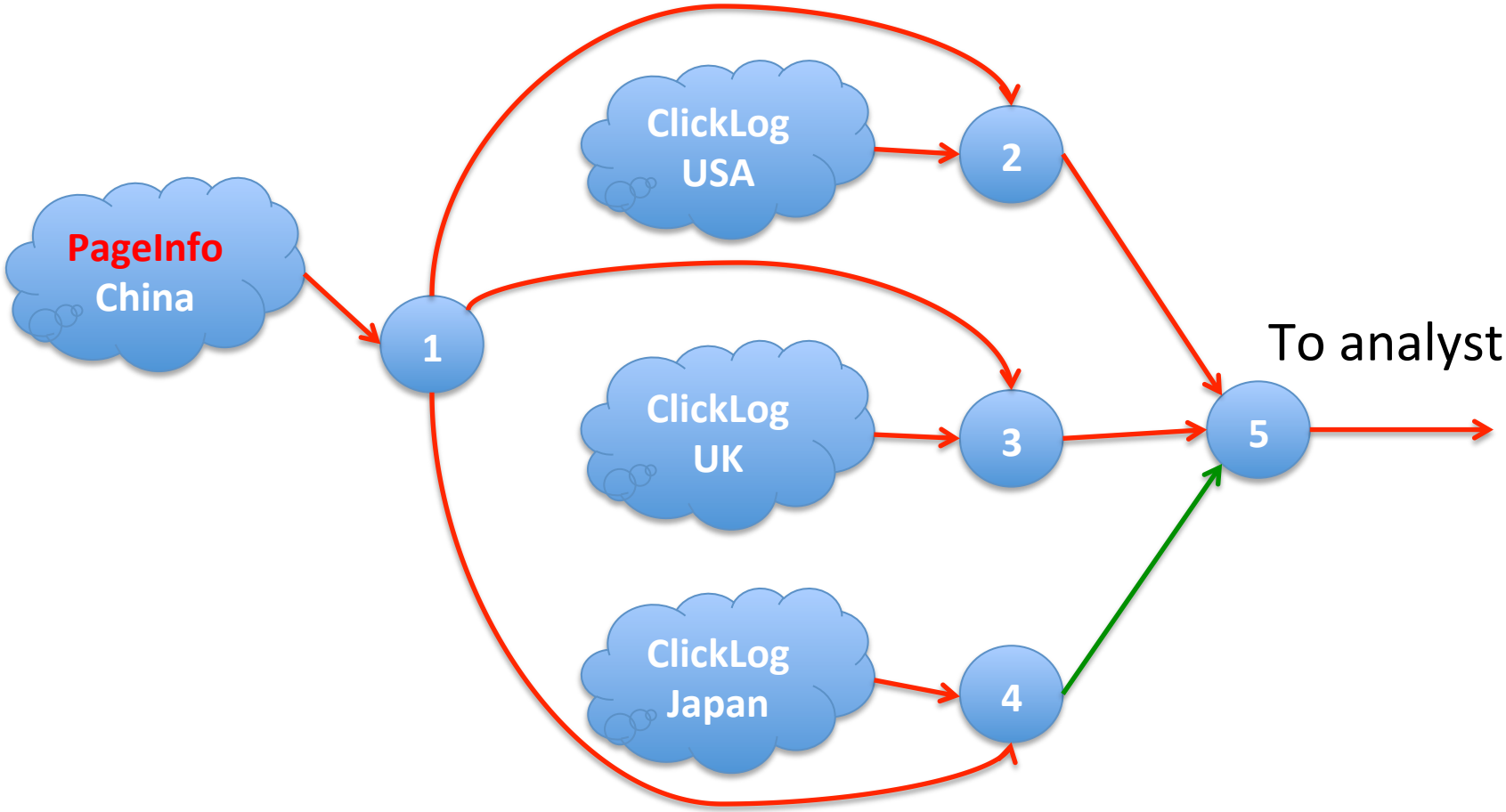
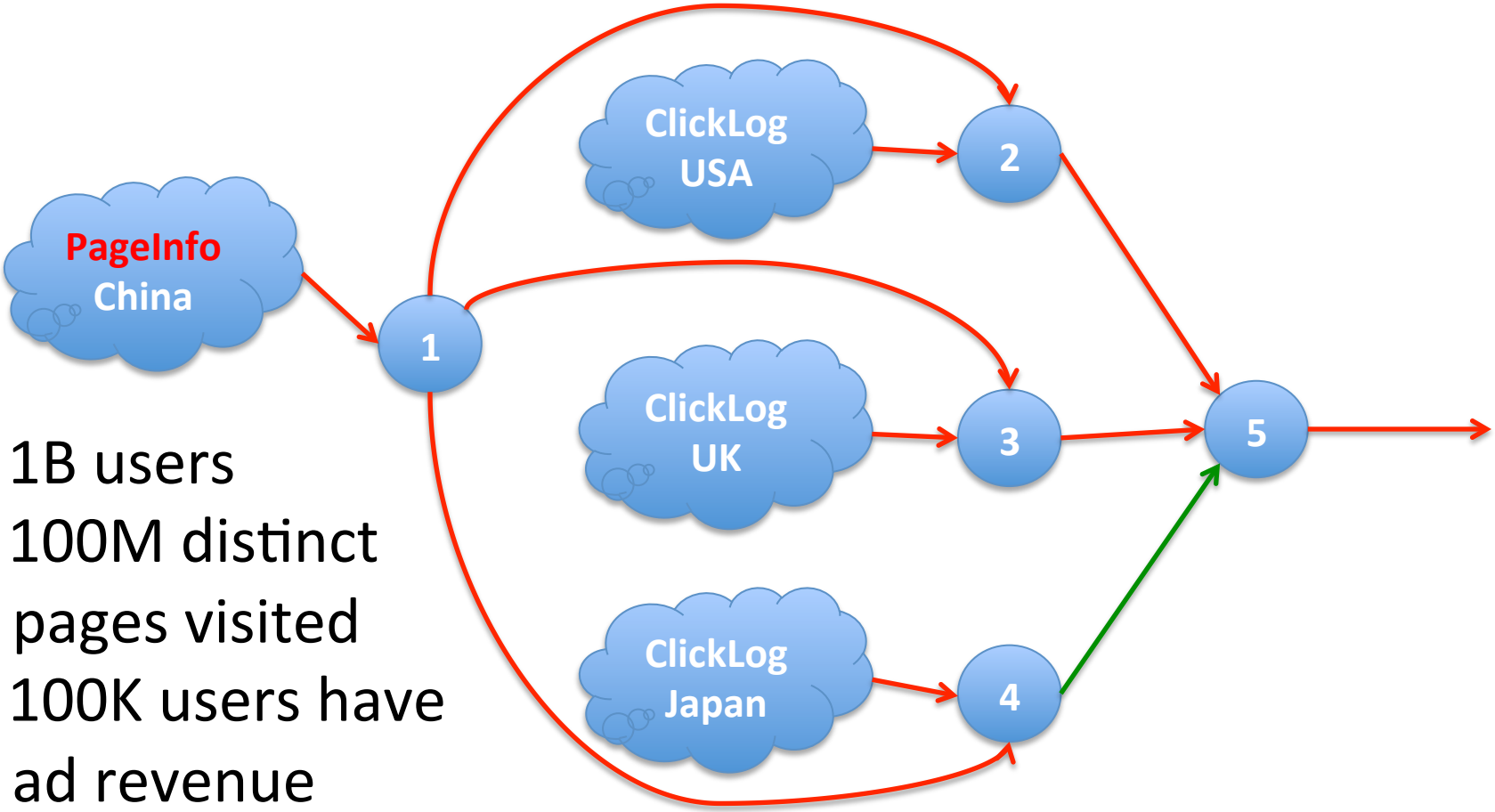
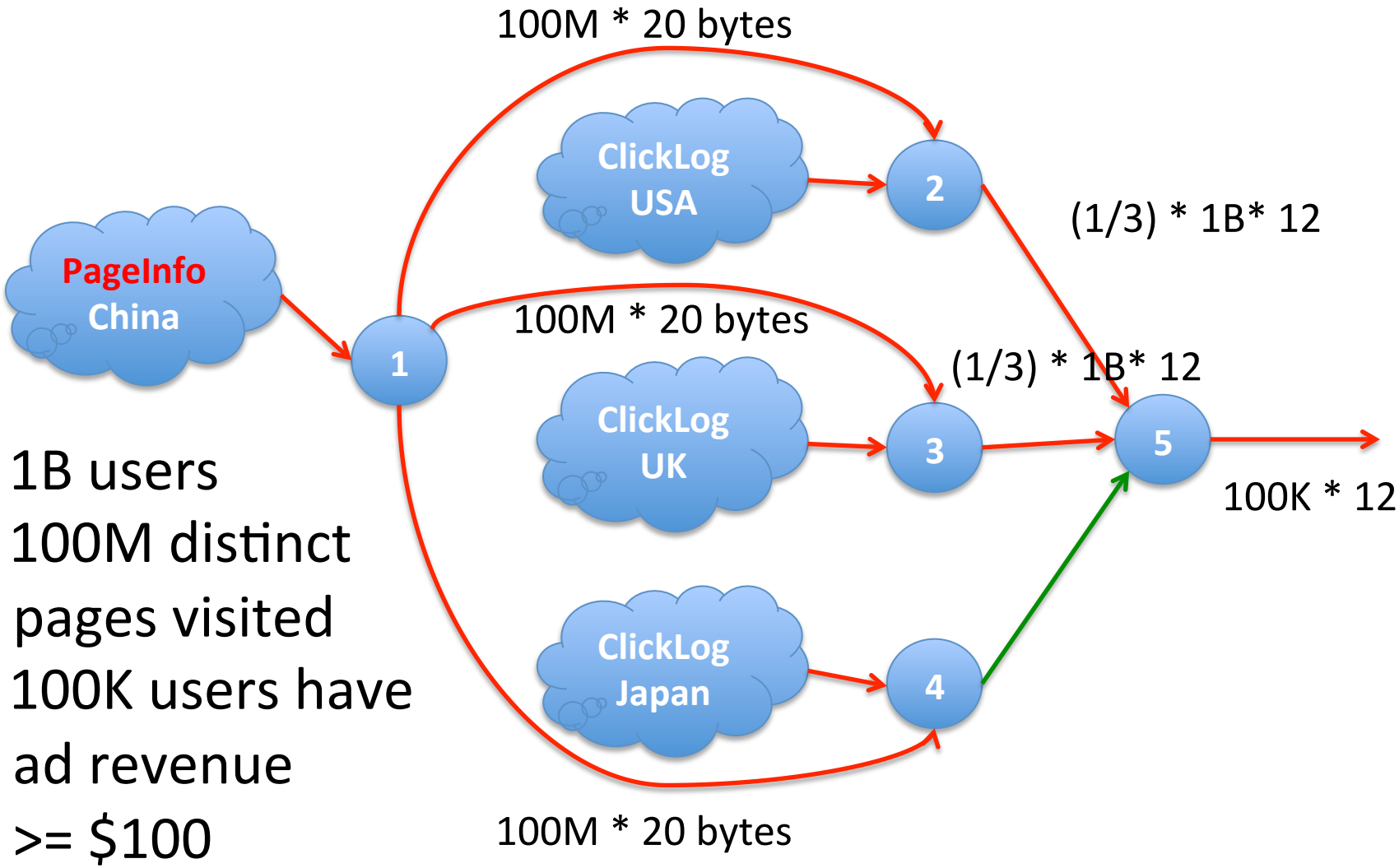




-- 1B users
-- 100M distinct pages visited
-- 100K users have ad revenue >= $100



-- 1B users
-- 100M distinct pages visited
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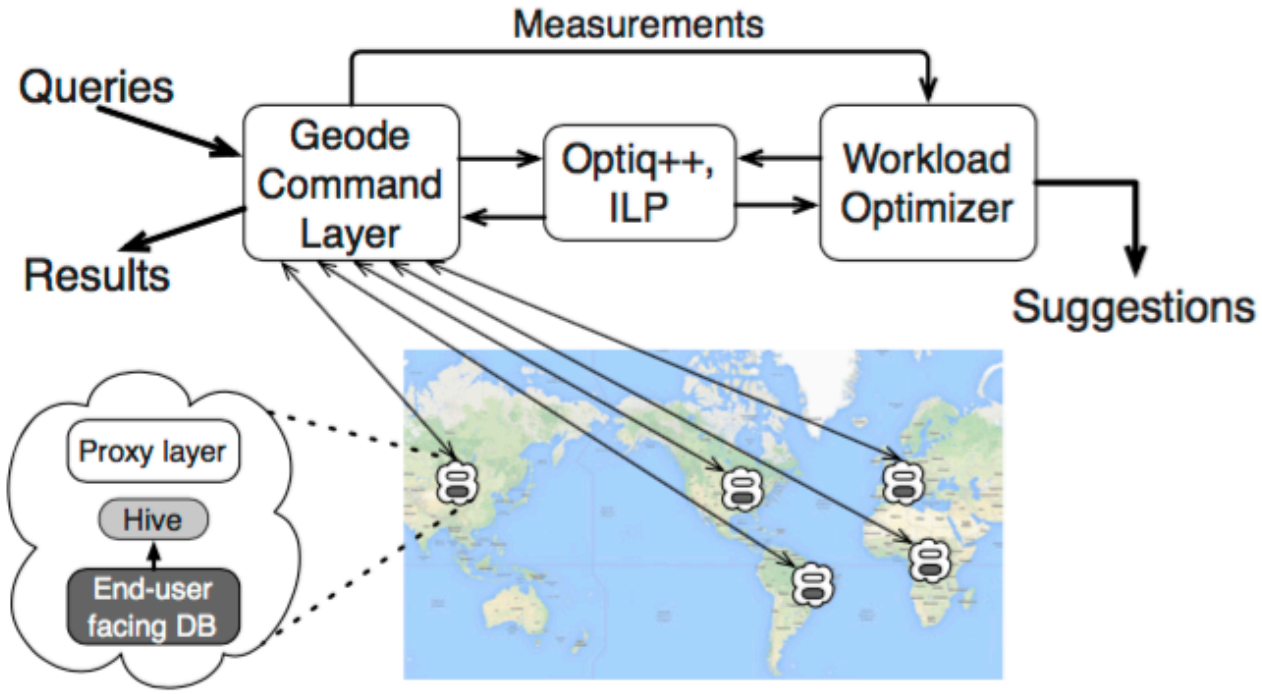
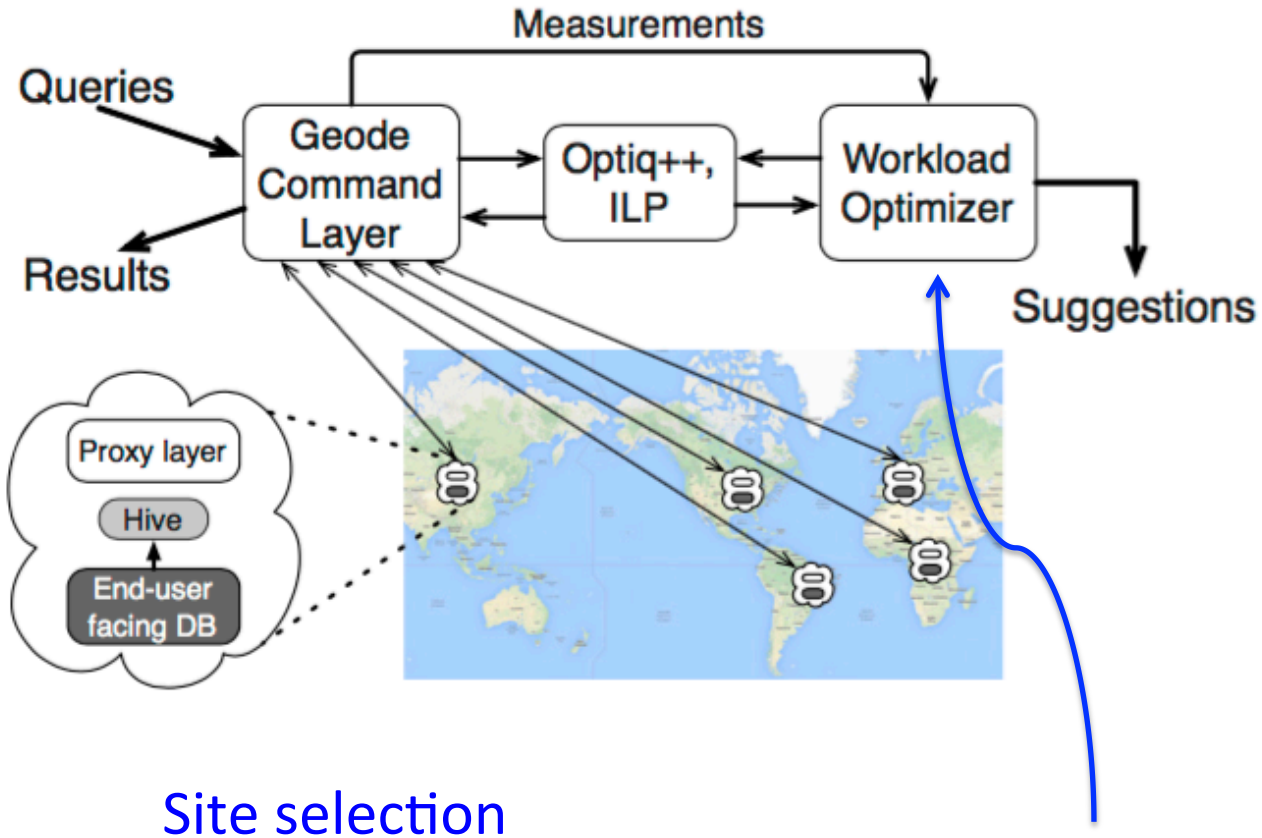
Total data transfer in inter-DC links:
3 * 100M * 20 + (2/3) * 1B* 12
+ 100K * 12 = 14GB << 1.2TB

Geo-distributed prototype (Geode) architecture



Geode architecture



Site selection

Data (Input data partitions) replication

$$\text{replCost} = \sum_{p=1}^{P} \sum_{d=1}^{D} \text{update\_rate}_p * x_{pd} * \text{link\_cost}_{homeDC(p),d}$$

$$\text{execCost} = \sum_{g \in E} \sum_{d=1}^{D} \sum_{e=1}^{D} y_{gde} * b_g * \text{link\_cost}_{de}$$

copy data partition p from original DC to DC d

transfer data on edge g from DC d to DC e

data volume on edge g

$$\underset{X,Y}{\text{minimize}} \quad \text{replCost} + \text{execCost}$$

subject to

$$\forall (p,d) \in R : x_{pd} = 0$$

$$\forall p : \sum_d x_{pd} \geq f_p$$

$$\forall d \forall e \forall g \mid src(g) \text{ is a partition} : y_{gde} \leq x_{src(g),d}$$

$$\forall d \forall e \forall g \mid src(g) \text{ is a task} : y_{gde} \leq z_{src(g),d}$$

$$\forall n \forall e \forall g \mid dst(g) = n : z_{ne} = \sum_d y_{gde}$$

$$\forall n \forall p \forall d \mid n \text{ reads from partition } p \wedge (p,d) \in R : z_{nd} = 0$$

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subject to

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fault tolerance constraint

$$\forall d \forall e \forall g \mid src(g) \text{ is a partition} : y_{gde} \leq x_{src(g),d}$$

$$\forall d \forall e \forall g \mid src(g) \text{ is a task} : y_{gde} \leq z_{src(g),d}$$

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$$\forall n \forall p \forall d \mid n \text{ reads from partition } p \wedge (p,d) \in R : z_{nd} = 0$$

regulatory constraint

$$\forall n : \sum_d z_{nd} \geq 1$$

Greedy heuristic

for all DAG $G \in$ workload **do**
    for all task $t \in$ toposort(G) **do**
        for all data center $d \in$ legal_choices(t) **do**
            cost(d) = total cost of copying all of t's inputs to d
        if lowest cost is zero **then**
            assign copies of t to every data center with cost = 0
        else
            assign t to one data center with lowest cost
for all $(p,d) \notin R$ **do**
    check if replicating p to d would further reduce costs
translate decisions so far into values for x, y, z variables in ILP above
solve simplified ILP with pinned values

Greedy heuristic

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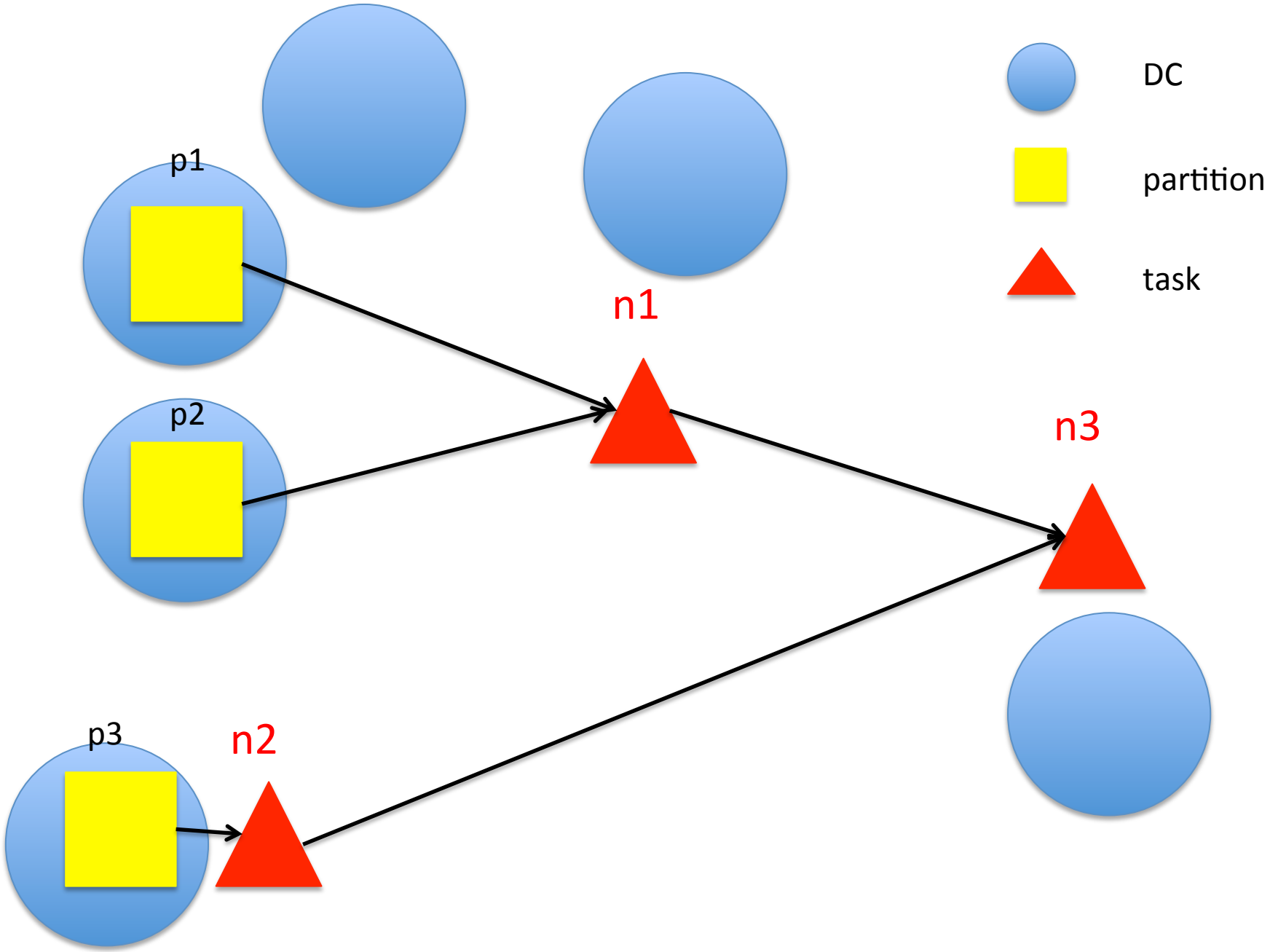
    else
      assign t to one data center with lowest cost → each z_{td}
for all $(p,d) \notin R$ **do**
  check if replicating p to d would further reduce costs
translate decisions so far into values for x, y, z variables in ILP above
solve simplified ILP with pinned values

↓

Solve x, y with fixed z and part of y


DC
partition
task
p1
p2
p3
n1
n2
n3

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$$\underset{X,Y}{\text{minimize}} \qquad \text{replCost} + \text{execCost}$$

$x_{homeDC(p)}=1$,
Other $x_{pd}=0$

subject to

$$\forall (p,d) \in R : x_{pd} = 0$$

$$\forall p : \sum_{d} x_{pd} \geq f_p$$

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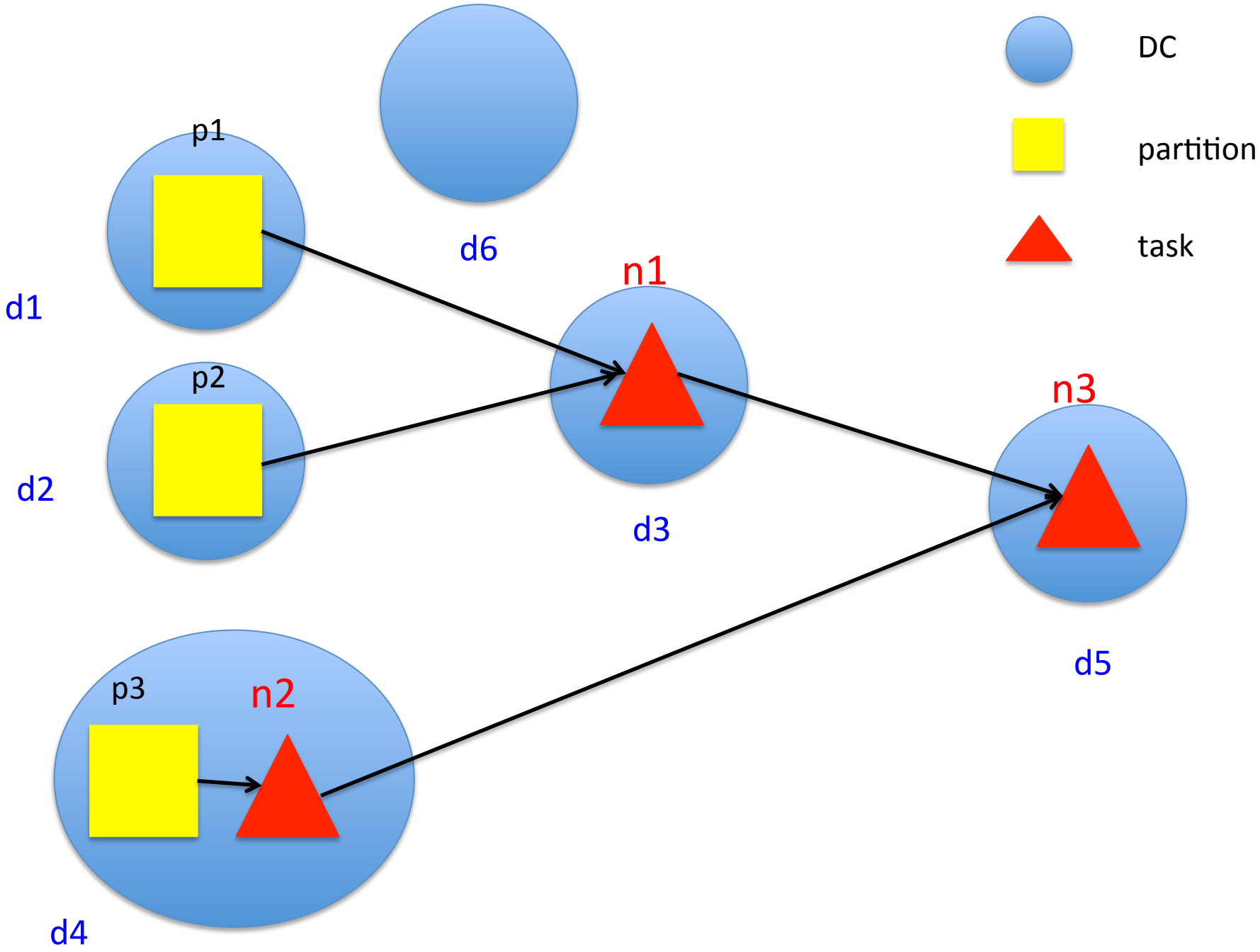
DC
partition
task
p1
d1
p2
d2
p3
n2
d4
d6
n1
d3
n3
d5

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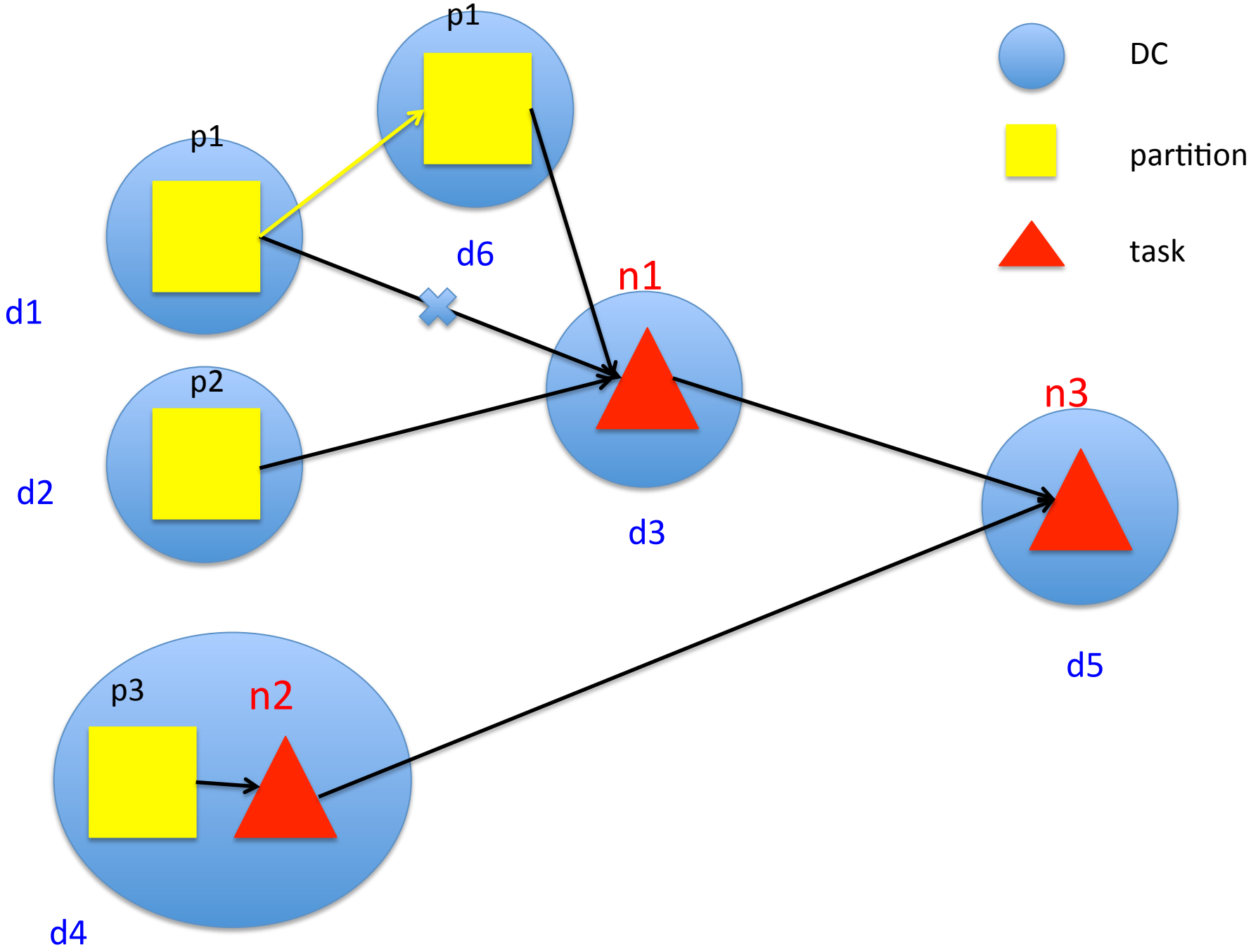
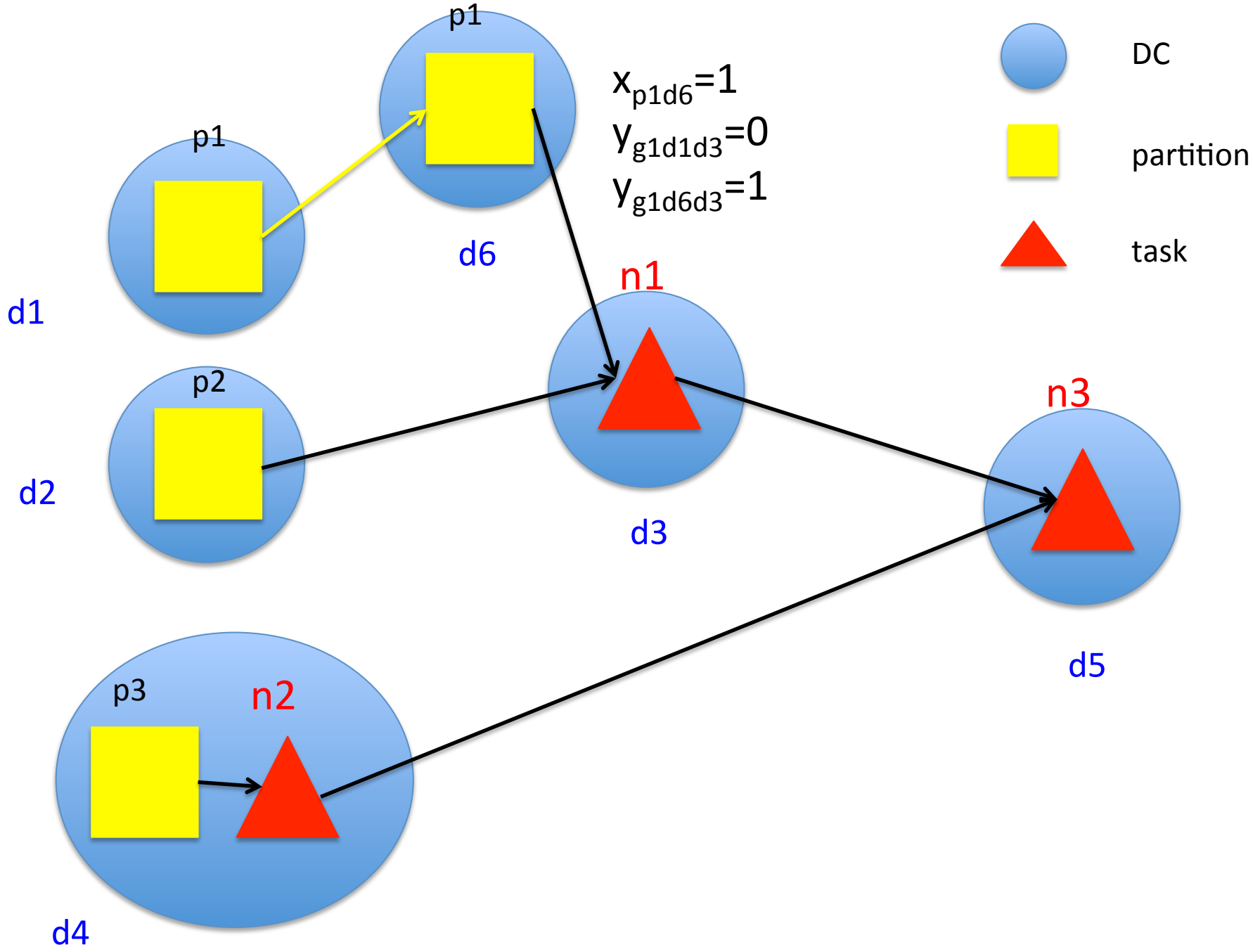
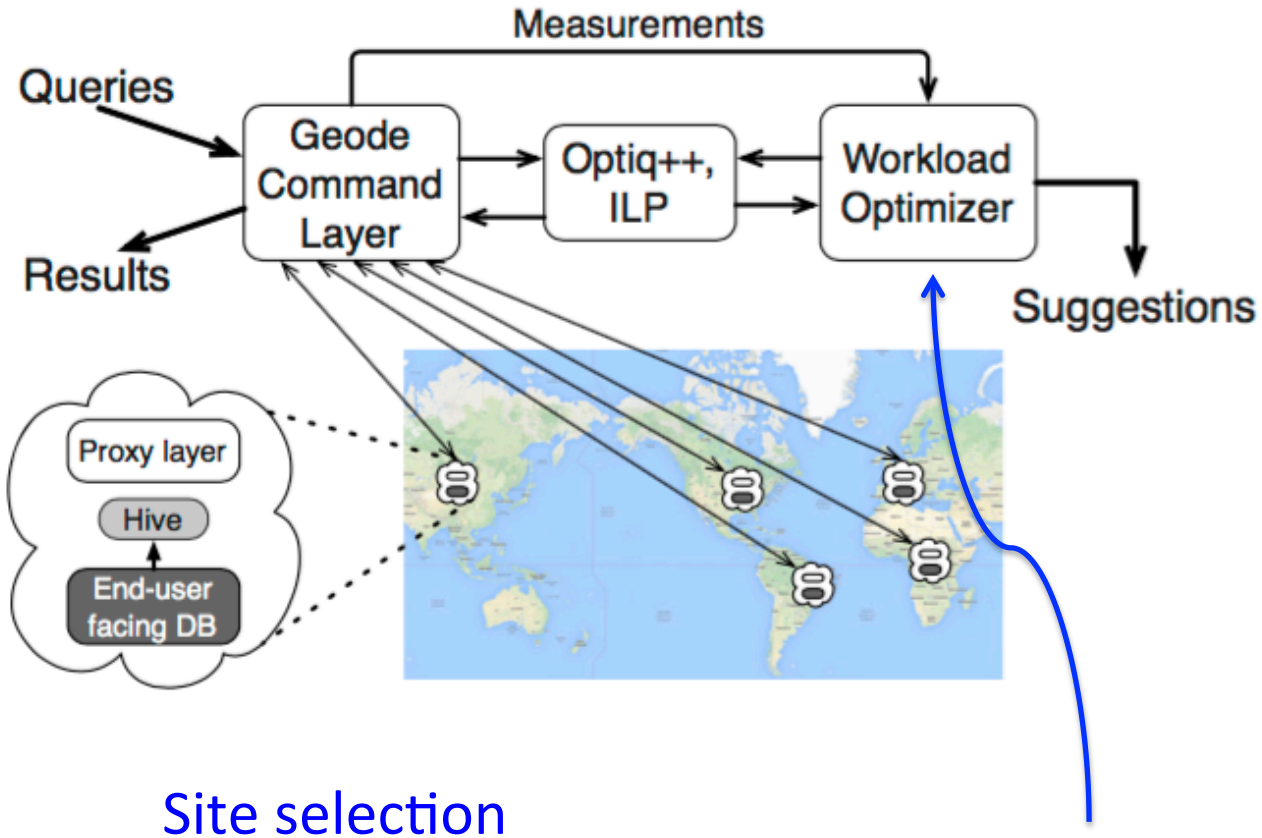
fixed when we solve replication decision


p1
p1
d6
d1
n1
p2
d2
d3
n3
d5
p3
n2
d4
DC
partition
task


p1
p1
p1
d1
d6
$x_{p1d6}=1$
$y_{g1d1d3}=0$
$y_{g1d6d3}=1$
DC
partition
task
n1
p2
n3
d2
d3
d5
p3
n2
d4

Geode architecture

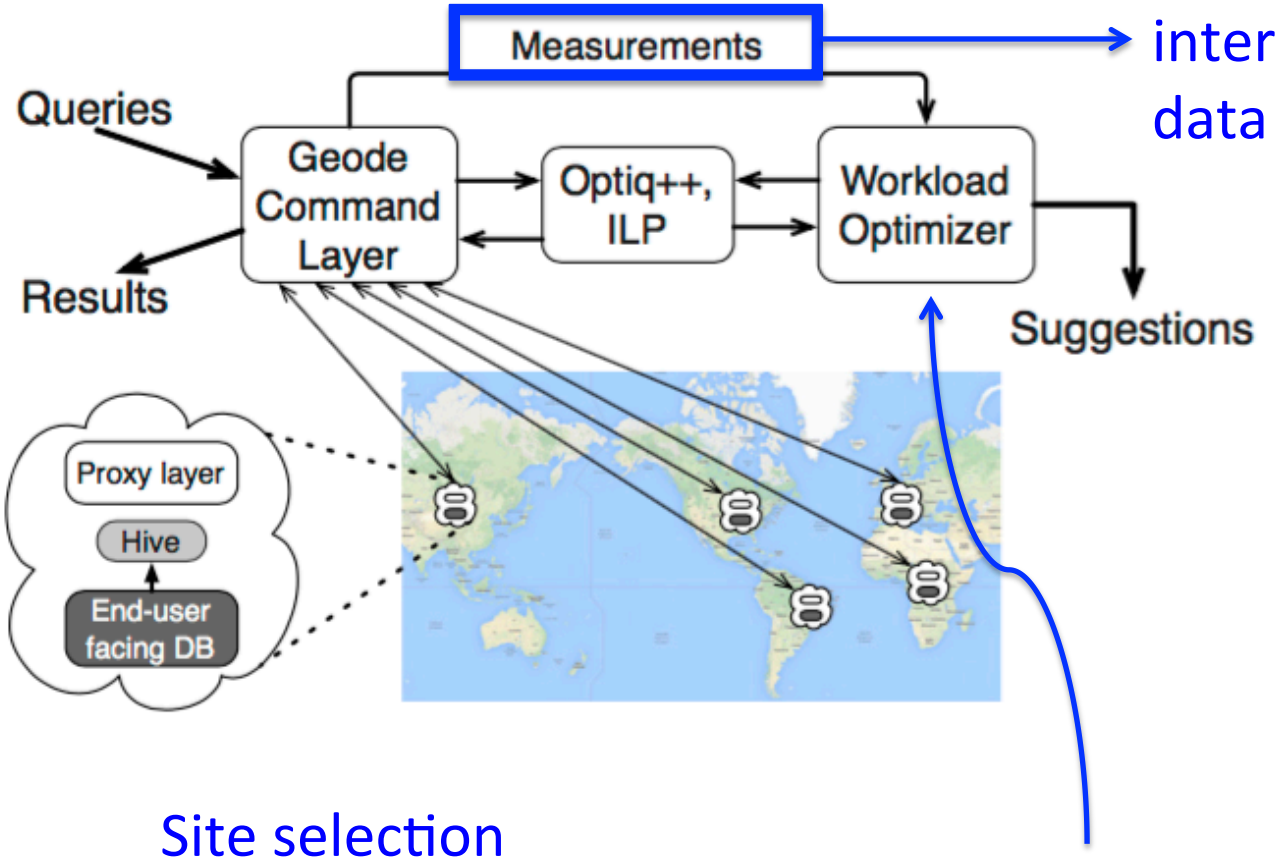


Site selection

Data (Input data partitions) replication

Geode architecture

input data volume, intermediate data volume



Site selection

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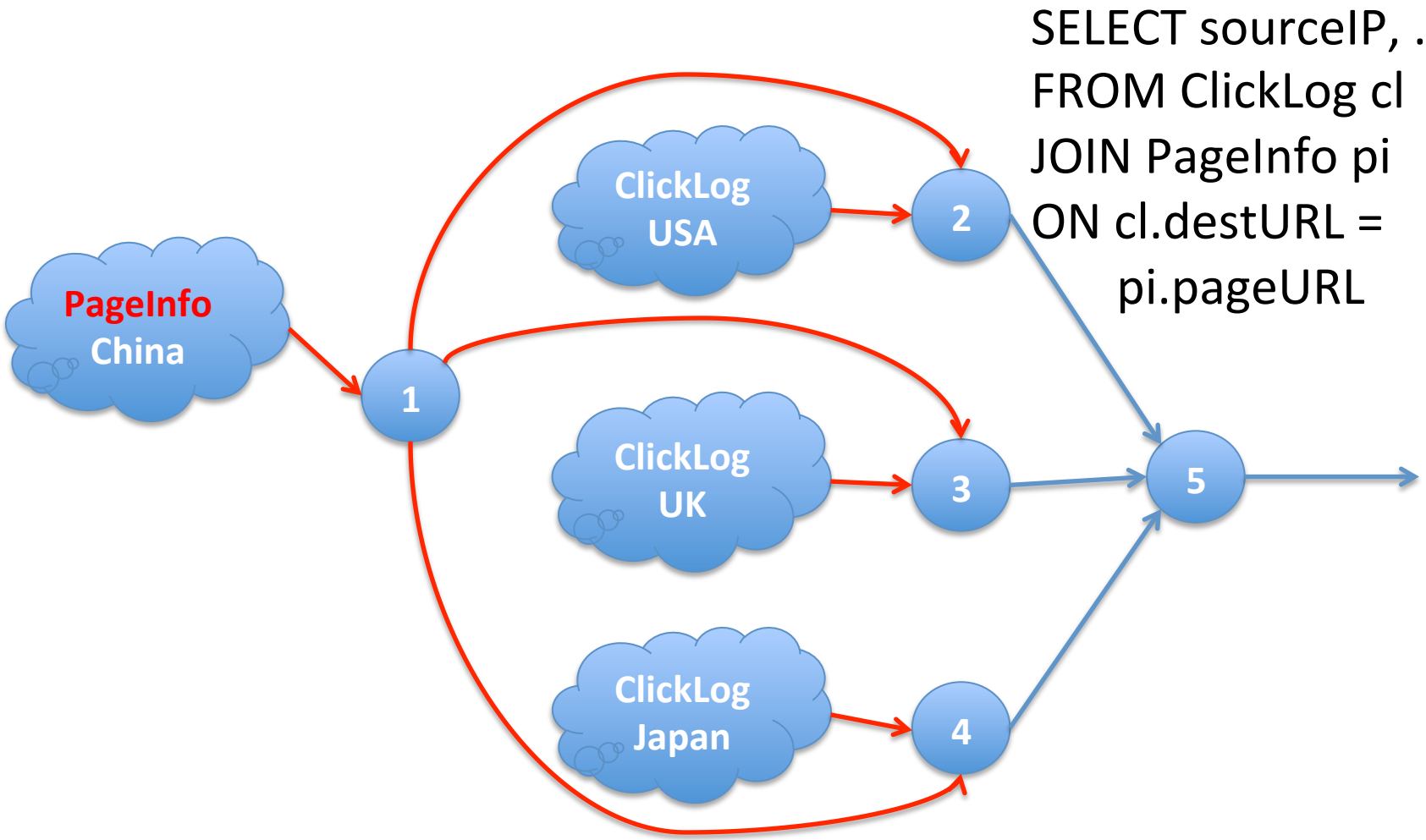
Geo-distributed SQL analytics

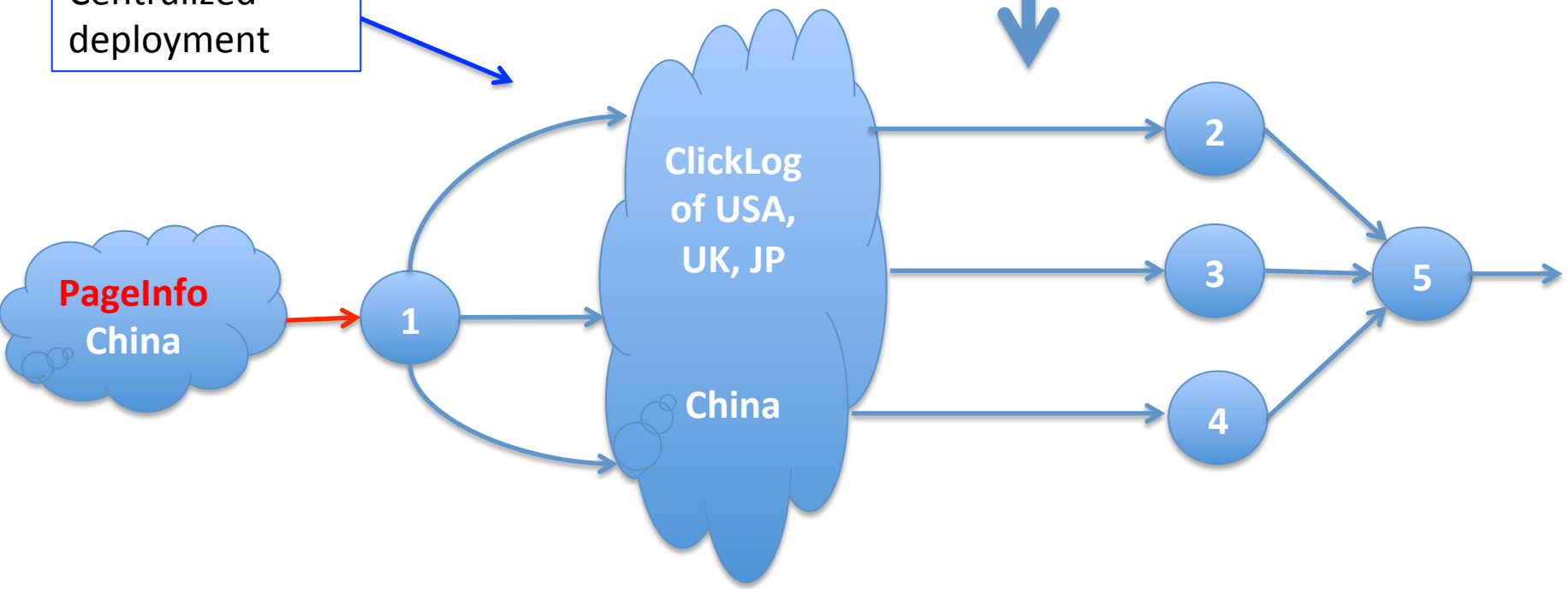


Pseudo-distributed execution

Rewrite queries →

```
SELECT sourceIP, …
WHERE country = X
FROM ClickLog cl
JOIN PageInfo pi ON cl.destURL = pi.pageURL
```

Centralized deployment



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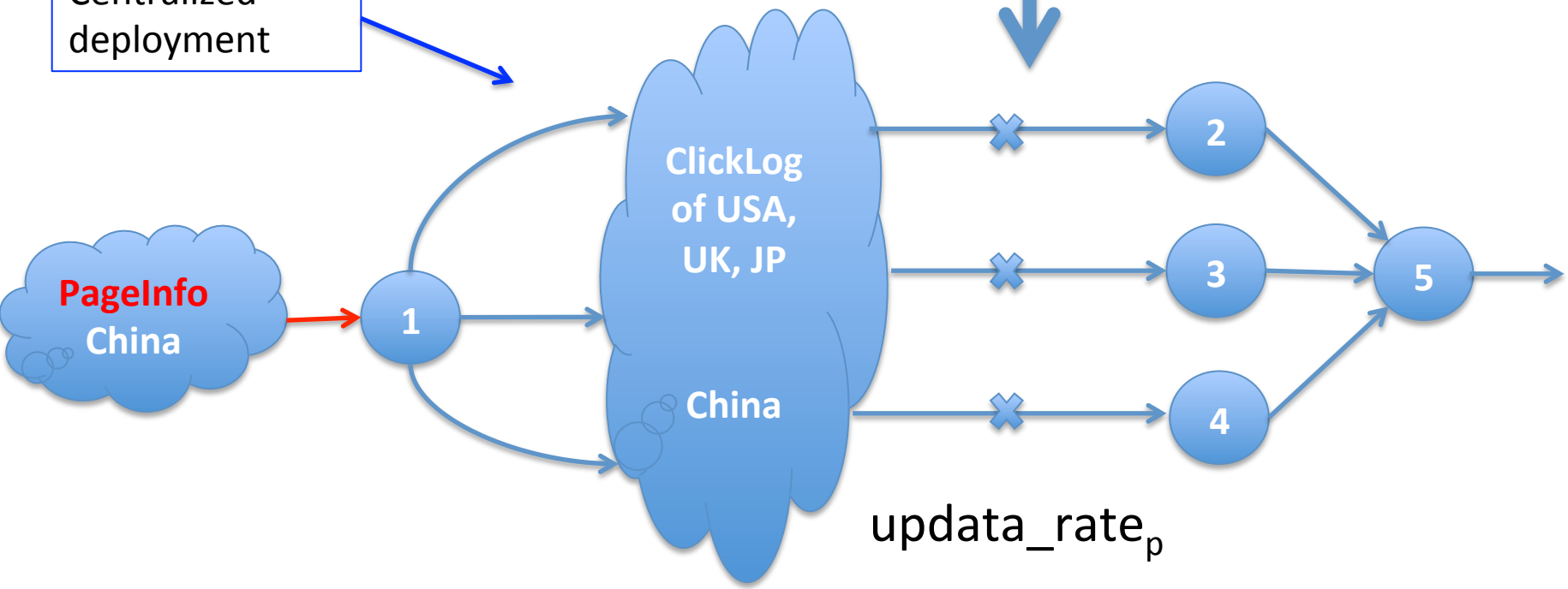

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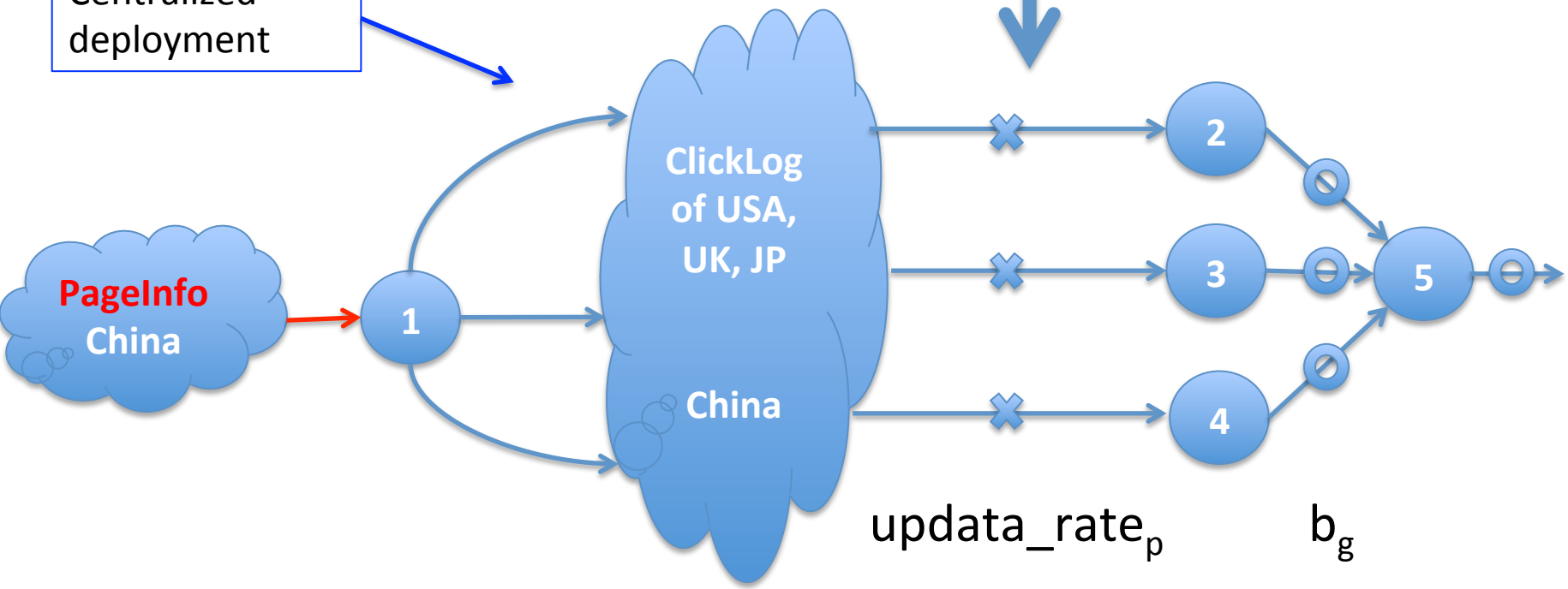

input data volume

highly accurate estimations

Intermediate data volume

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$$\underset{X,Y}{\text{minimize}} \quad \text{replCost} + \text{execCost}$$

subject to

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$$\forall n \forall p \forall d \mid n \text{ reads from partition } p \wedge (p,d) \in R : z_{nd} = 0$$

$$\forall n : \sum_d z_{nd} \geq 1$$

Technique contributions

- Execution strategy to minimize bandwidth cost

  -- Classical query planning optimizes join order

- Measurement of data transfer costs across DCs

  -- Classical database techniques are inaccurate

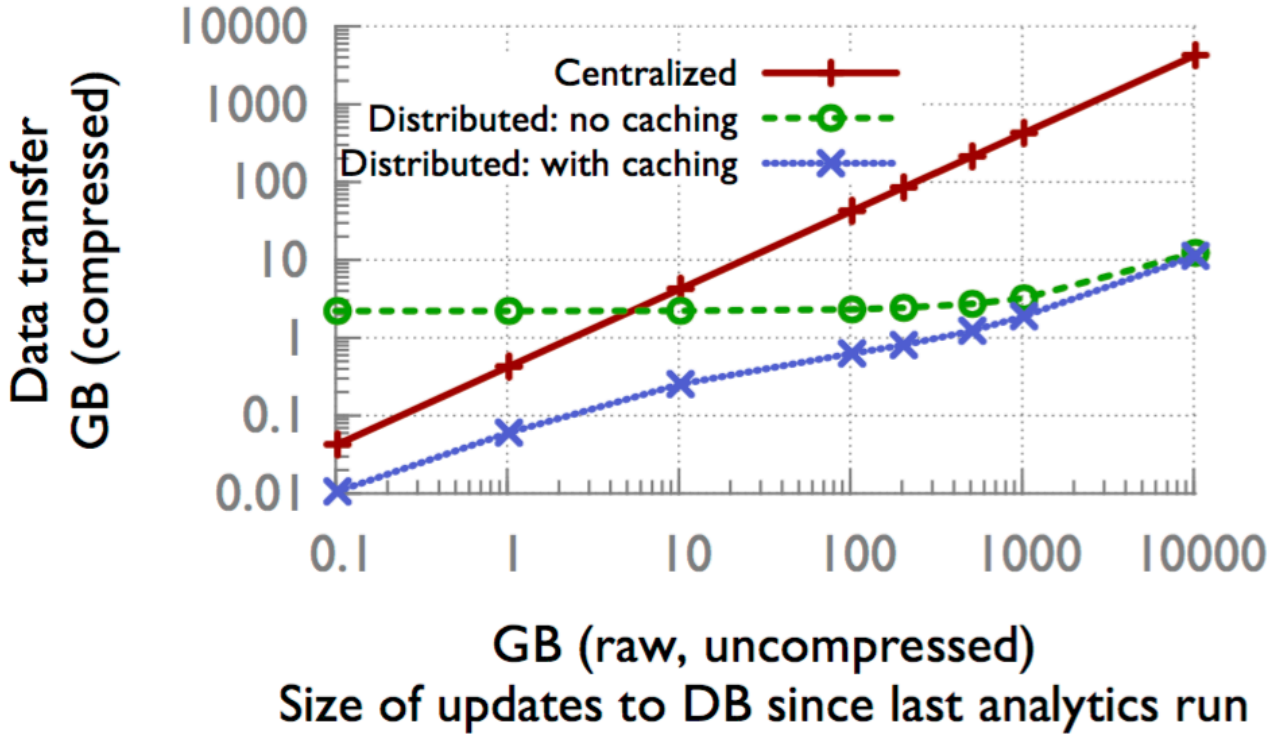
Experimental Evaluation

- How much of the bandwidth saving does the system yield on real workloads?
- What is the tradeoff between solution quality and processing time?
- What is the runtime overhead of collecting the measurements?

Experiment Setup

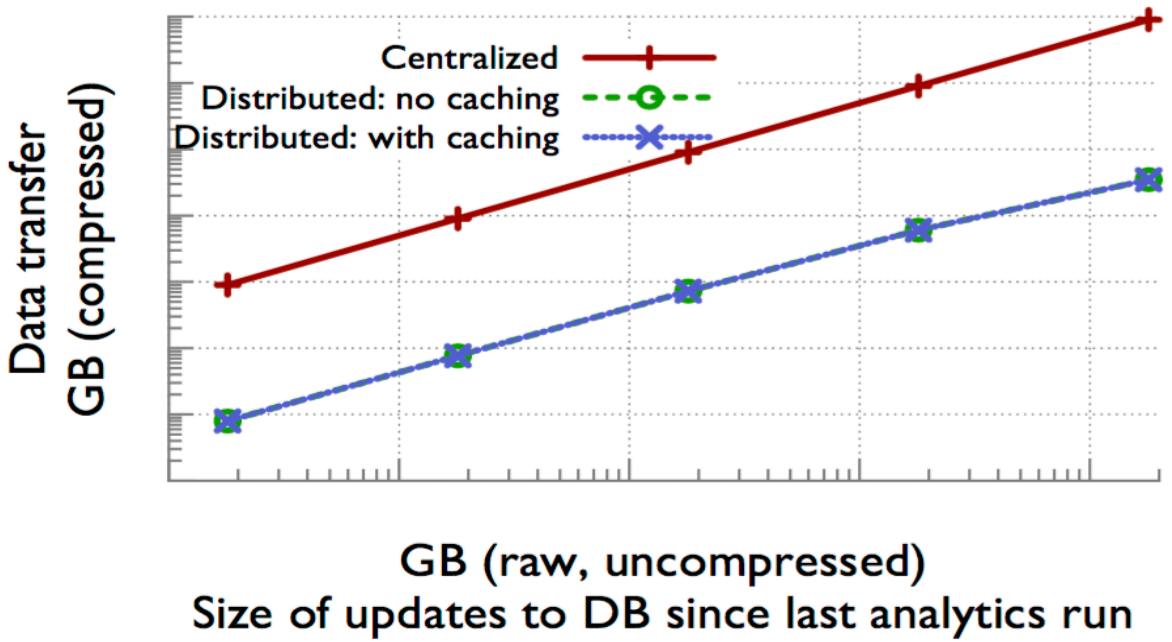
- Centralized VS geo-distributed
  - Three DCs in the US, Europe, and Asia
  - A large centralized cluster
- Input data: 6 workloads
  - E.g., Microsoft production workload
- With Cache VS Without Cache
  - With Cache: cache all the intermediate data
  - Advantage of With Cache: queries are repeated

Bandwidth saving



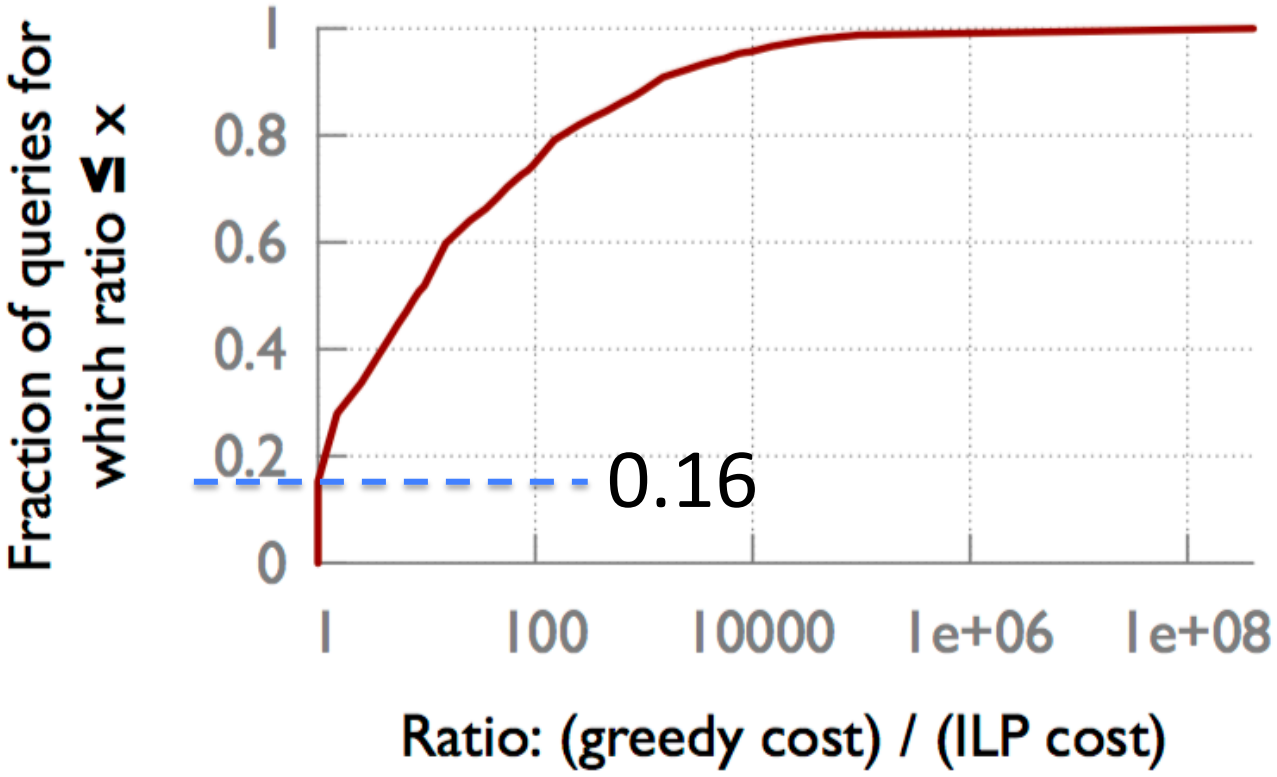
TPC-CH

Bandwidth saving

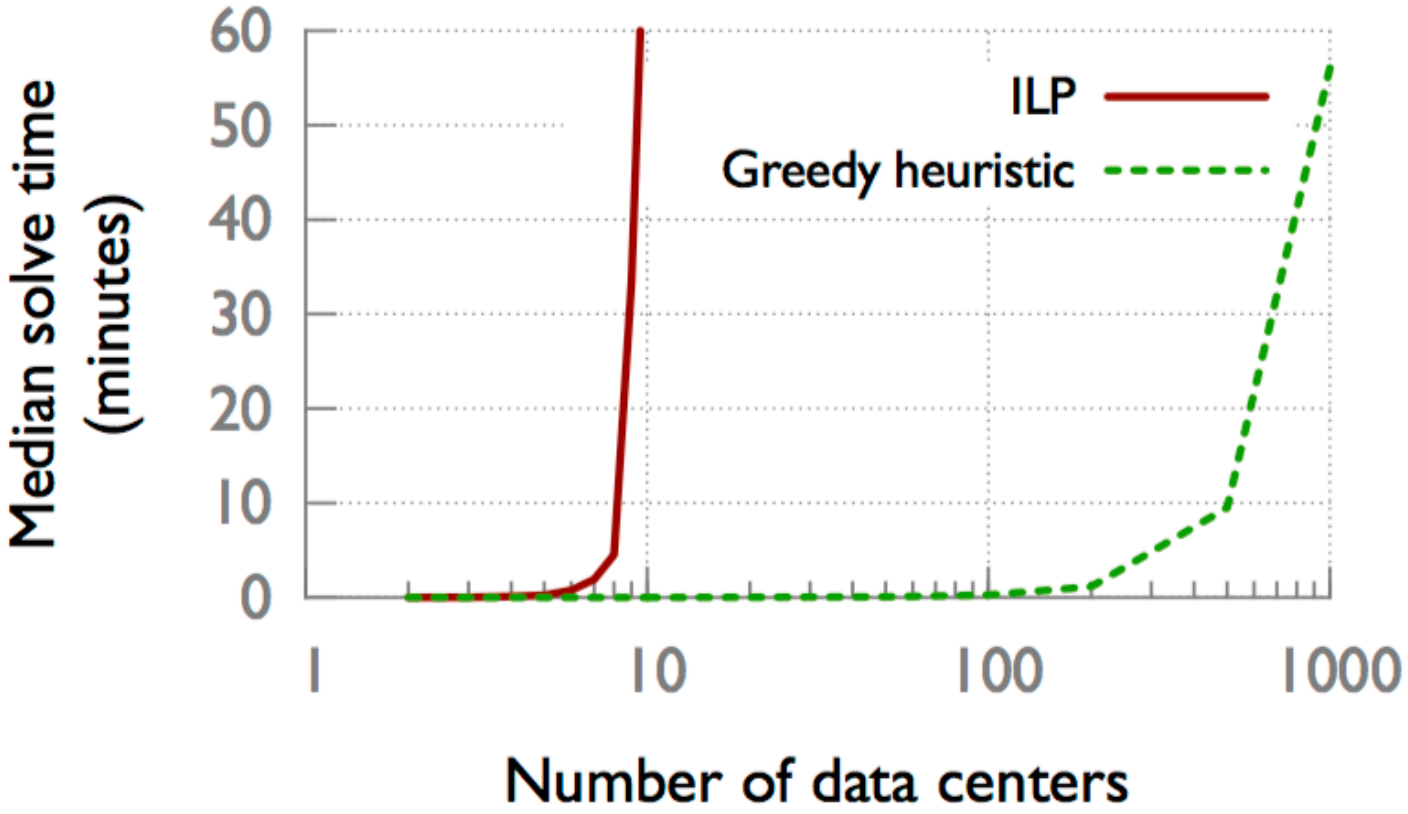


Microsoft production workload

ILP and greedy heuristic comparison



ILP and greedy heuristic comparison



Measurement runtime overhead

- < 20% in runtime

Thank you

Q & A

Potential approximate/online algorithms

- Min-k cut problem (without data replication)
- Uncapacitated facility location problem

$$\text{minimize} \quad \sum_{j=1}^{J} c'_j x_j + \sum_{j=1}^{J}\sum_{i=1}^{I} c_{ij} z_{ij}$$

$$s.t. \quad \sum_{j=1}^{J} z_{ij} \geq 1$$

$$z_{ij} \leq x_j \quad \forall i, j$$

$$x_j, z_{ij} \in \{0, 1\}$$

$$\text{minimize} \quad \sum_{p=1}^{P}\sum_{d=1}^{D} c'_{pd} x_{pd} + \sum_{g \in E}\sum_{d=1}^{D}\sum_{e=1}^{D} c_{gde} y_{gde}$$

$$s.t. \quad \sum_{e=1}^{D} z_{ne} \geq 1 \quad \forall n$$

$$y_{gde} \leq x_{src(g)d} \quad \forall src(g) \in \mathcal{P}, d, e$$

$$y_{gde} \leq z_{src(g),d} \quad \forall src(g) \in \mathcal{N}, e$$

$$z_{ne} = \sum_{d=1}^{D} y_{gde} \quad \forall dst(g) = n, n, e$$