Data Warehousing
View Materialization

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Slides by Toon Calders

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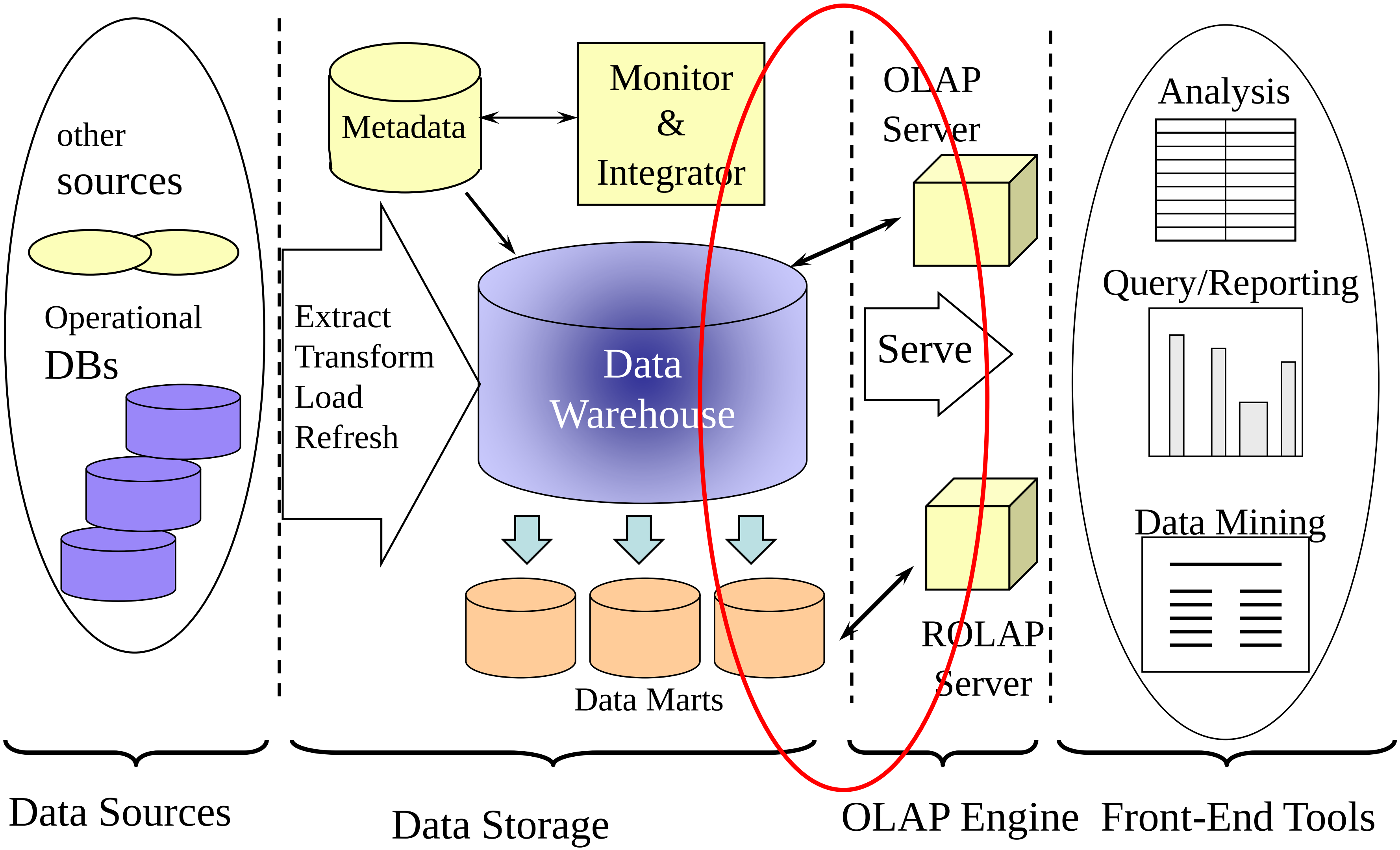
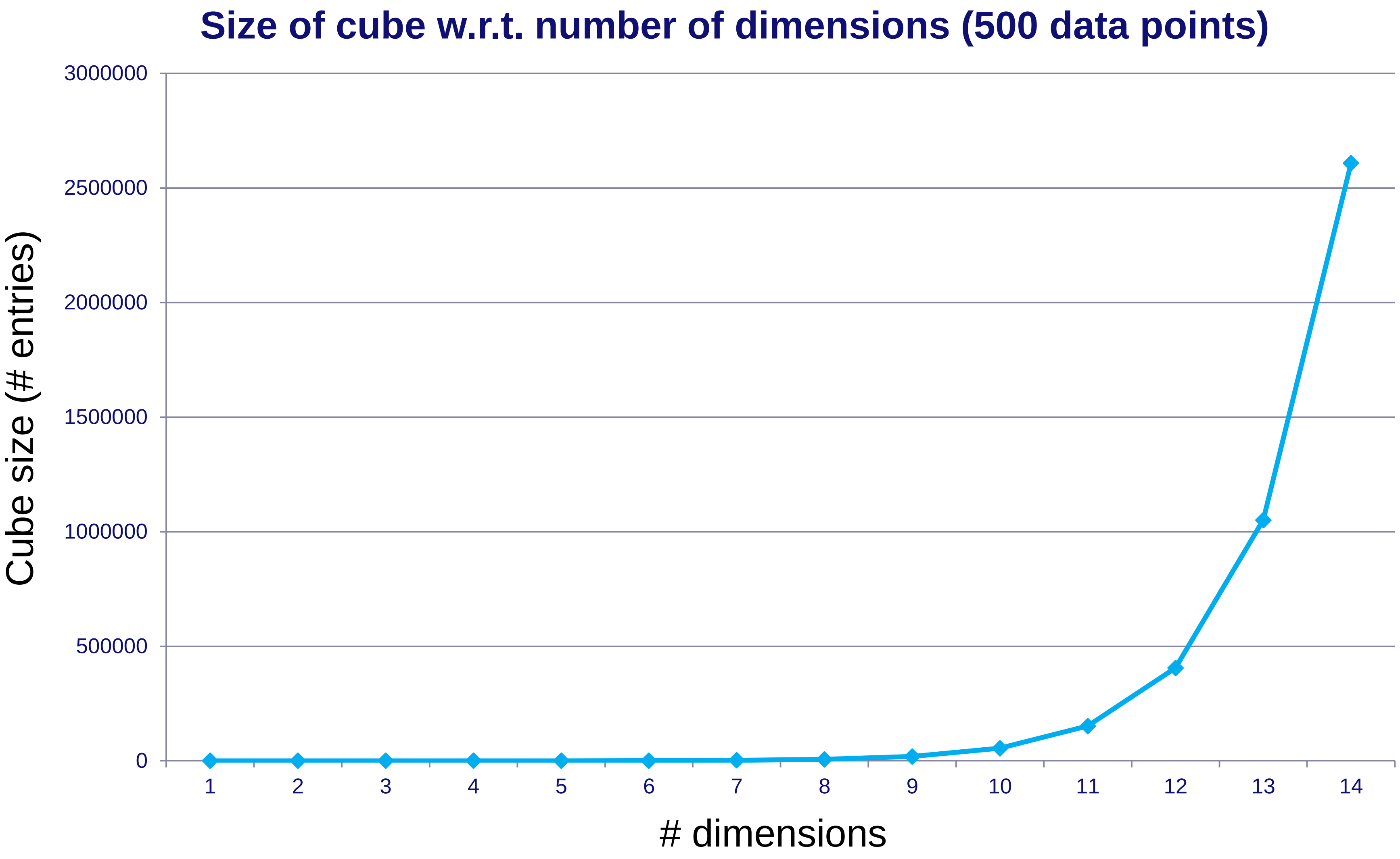
Outline

- Problem statement
- Formal model of computation
  - Partial order on Queries
  - Cost model
- Greedy solution
  - Performance guarantee
- Extensions
- Conclusion

Previous Lecture

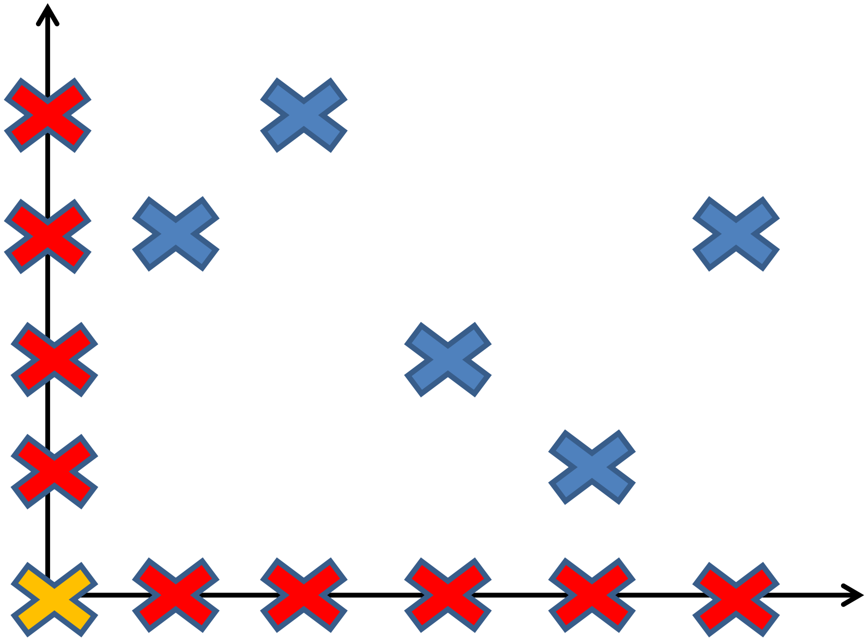


Data Explosion Problem



Data Explosion Problem

Country	Brand	Sales
FR	A	123
NL	B	456
BE	C	678
US	D	254
US	E	134



View materialization

- One of the major optimization techniques for OLAP
- Main question: Which parts to materialize to optimize performance?
  - Explosion problem: Pre-computing everything is impossible

Techniques in this slide set are based upon the following seminal work:

V. Harinarayan, A. Rajaraman, and J. D. Ullman: Implementing data cubes efficiently. In: ACM SIGMOD 1996.

The problem: informally

- Relation Sales
  - Dimensions: part, supplier, customer
  - Measure: sales
  - Aggregation: sum
- The data cube contains all aggregations on part, supplier, customer; e.g.:
  - (p1,s1,<all>,165)
  - (p1,s2,<all>,145)

Queries

- We are interested in answering the following *type* of queries efficiently:

(part, supplier)

```
SELECT part, supplier, sum(sales)
FROM Sales
GROUP BY part, supplier
```

(part)

```
SELECT part, sum(sales)
FROM Sales
GROUP BY part
```

(supplier)

```
SELECT supplier, sum(sales)
FROM Sales
GROUP BY supplier
```

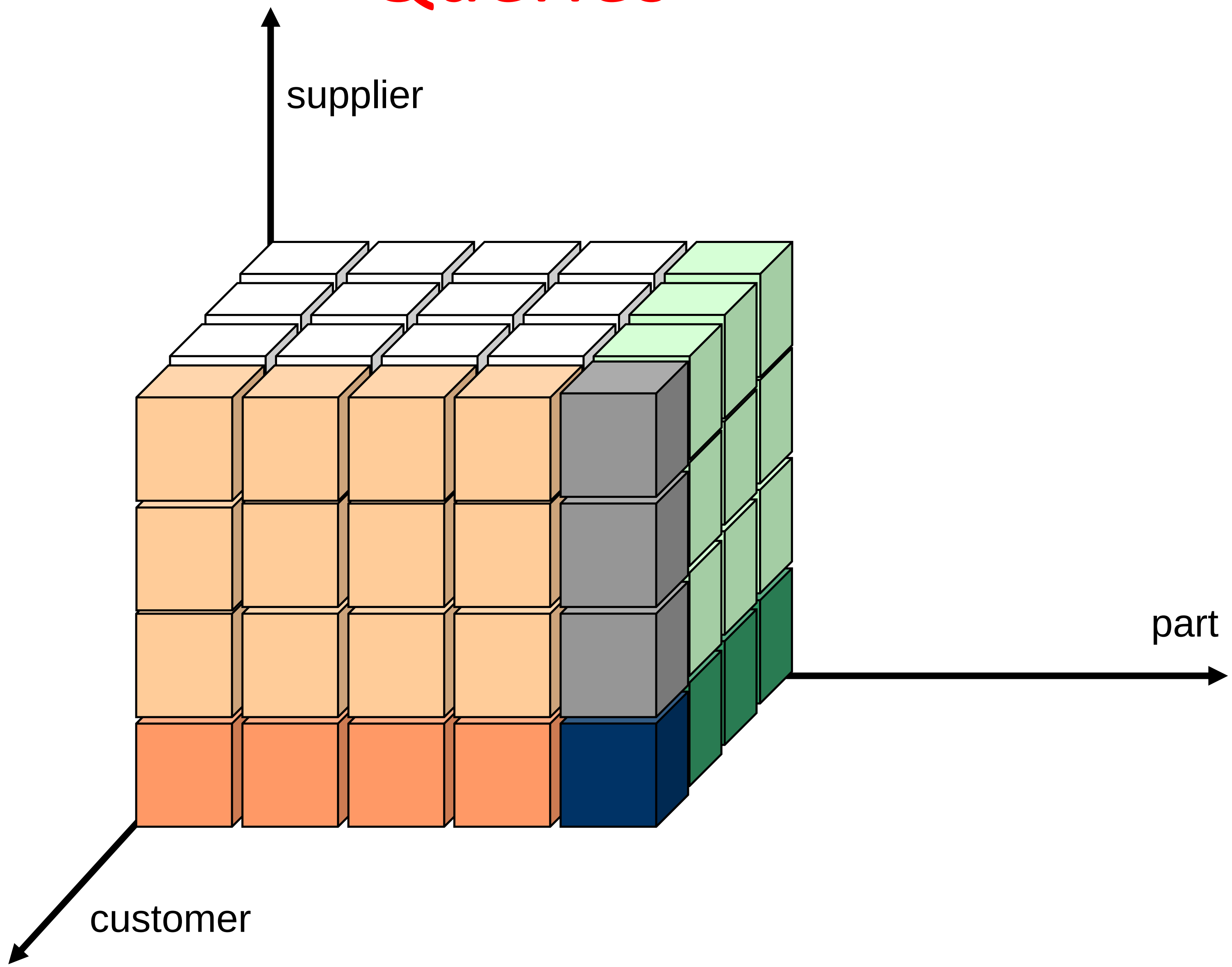
(part, customer)

```
SELECT part, customer, sum(sales)
FROM Sales
GROUP BY part, customer
```

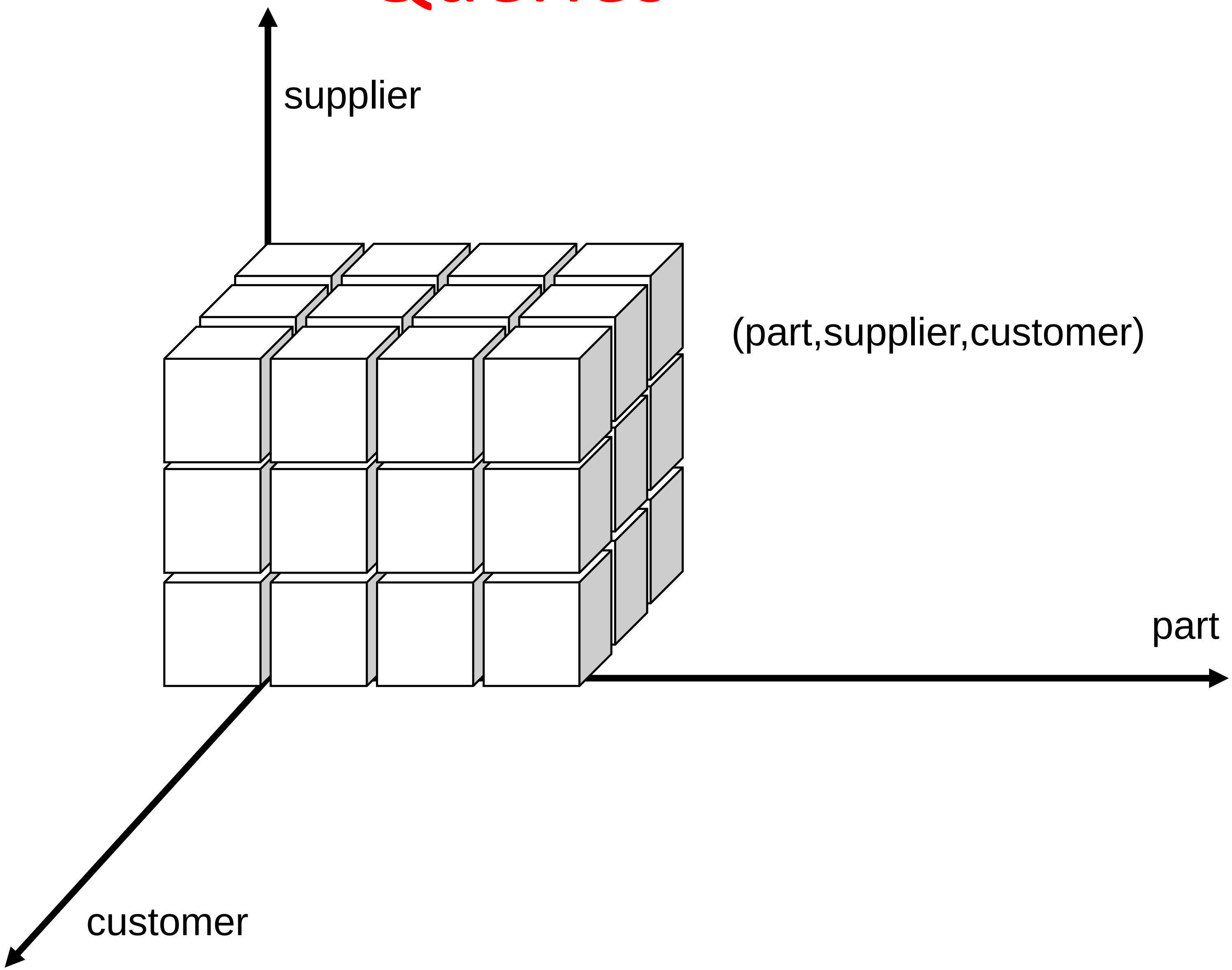
Queries

- The queries are quantified by their *grouping attributes*
- These queries select *disjoint* parts of the cube.
- The *union* of all these queries is the complete cube.

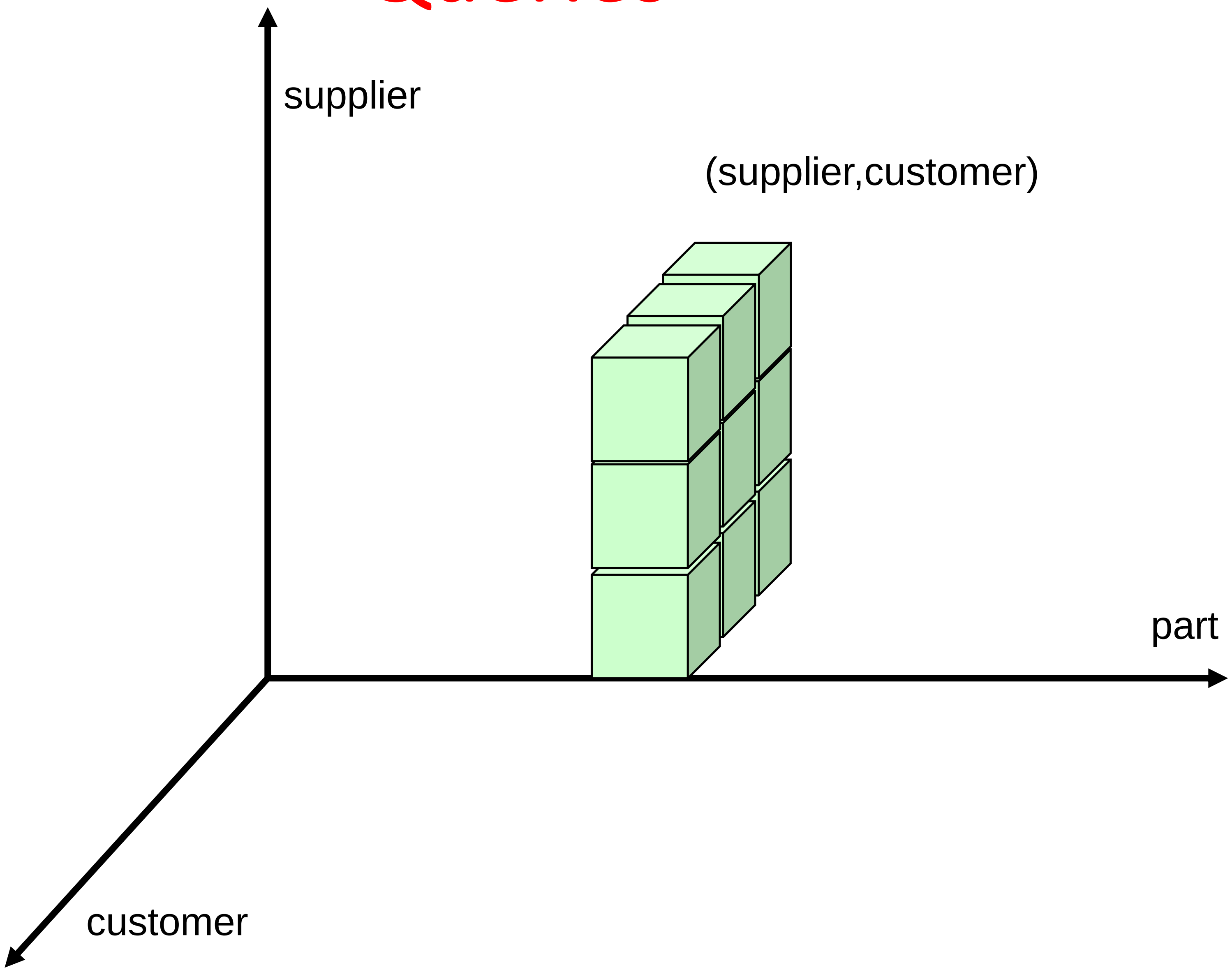
Queries



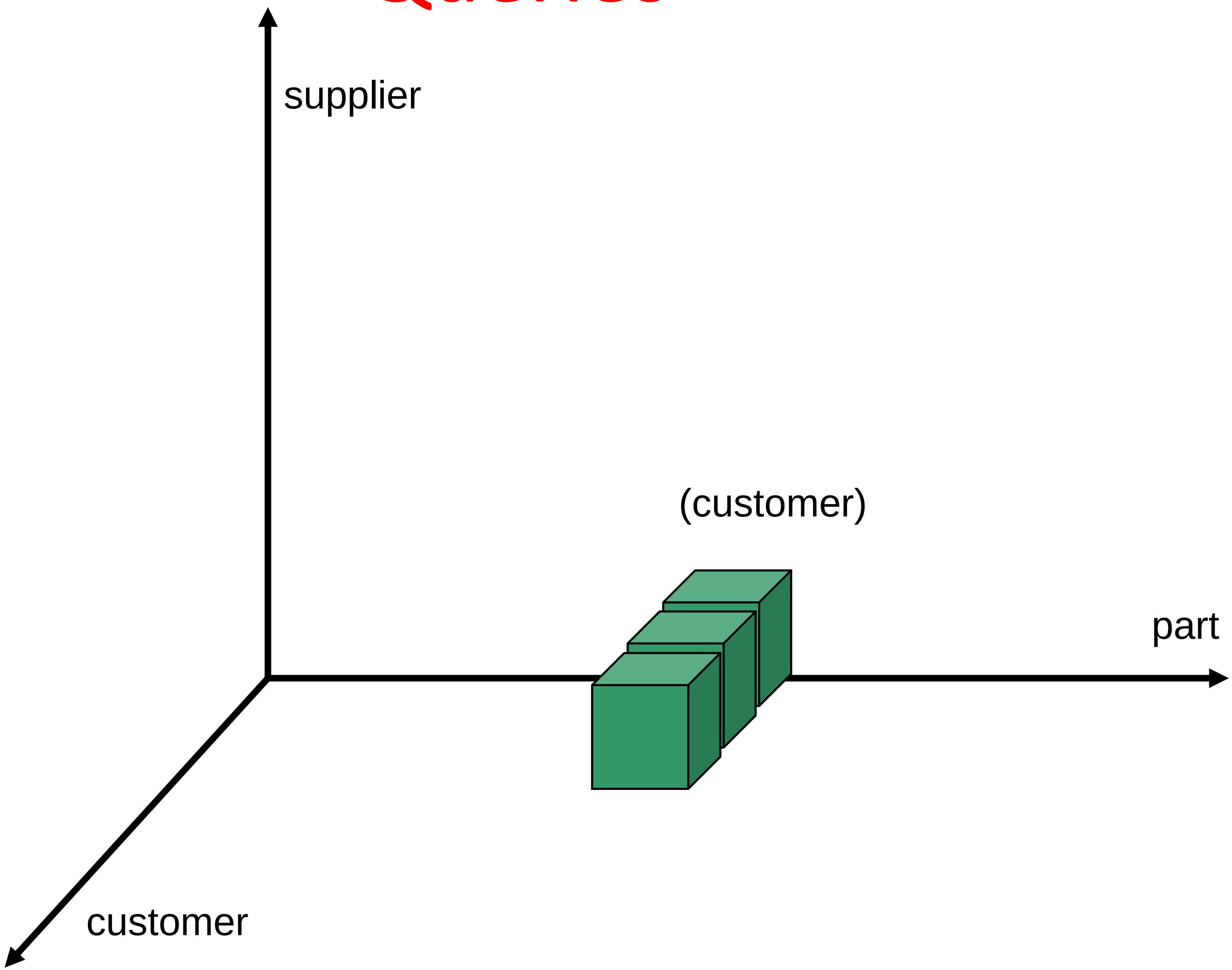
Queries



Queries



Queries



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Materialization

- Materializing everything is impossible
- Cost of evaluating following query directly:

```
SELECT D1, …, Dk, sum(M)
FROM R
GROUP BY D1, …, Dk
```

  – in practice roughly linear in the size of R
  (worst case: |R| log(|R|))
- Materializing *some* queries can help the other queries too

Materialization

Example:

(part, customer)

```
SELECT customer, part, sum(sales)
FROM Sales
GROUP BY customer, part
```

sequential scan is performed
cost is equal to cost of scanning whole tablel

| Sales |

(part)

```
SELECT part, sum(sales)
FROM Sales
GROUP BY part
```

sequential scan is performed
cost is equal to cost of scanning whole tablel

| Sales |

Materialization

Example:

(part, customer)

SELECT customer, part, sum(sales)
FROM Sales
GROUP BY customer, part

materialized as PC

|PC|

(part)

SELECT part, sum(sales)
FROM PC
GROUP BY part

|PC|

Caveat!

- For *additive measures-dimension* pairs and *distributive aggregation operators*
  - Measures that can be aggregated meaningful in any way

  E.g., amount of sales, number of orders
- Careful with semi-additive
  - E.g., inventory level

if workers are working in parallel,
need to find avg
can do sum, count
then do sum of sum and sum of count

- For algebraic aggregation operators: store support measures

Example

Query	Answer
(part,supplier,customer)	6M
(part,customer)	6M
(part,supplier)	0.8M
(supplier,customer)	6M
(part)	0.2M
(supplier)	0.01M
(customer)	0.1M
()	1

Example: nothing materialized

Query	Answer	Cost
• (part,supplier,customer)	6M	6M
• (part,customer)	6M	6M
• (part,supplier)	0.8M	6M
• (supplier,customer)	6M	6M
• (part)	0.2M	6M
• (supplier)	0.01M	6M
• (customer)	0.1M	6M
• ()	1	6M

Total cost: 48M

Example: some materialized

Query	Answer	Cost
• (part,supplier,customer)	6M	
• (part,customer)	6M	
• (part,supplier)	0.8M	
• (supplier,customer)	6M	
• (part)	0.2M	
• (supplier)	0.01M	
• (customer)	0.1M	
• ()	1	

Example: some materialized

Query	Answer	Cost
• (part,supplier,customer)	6M	6M
• (part,customer)	6M	6M
• (part,supplier)	0.8M	0.8M
• (supplier,customer)	6M	6M
• (part)	0.2M	0.8M
• (supplier)	0.01M	0.8M
• (customer)	0.1M	0.1M
• ()	1	0.1M

Total cost: 20.6M

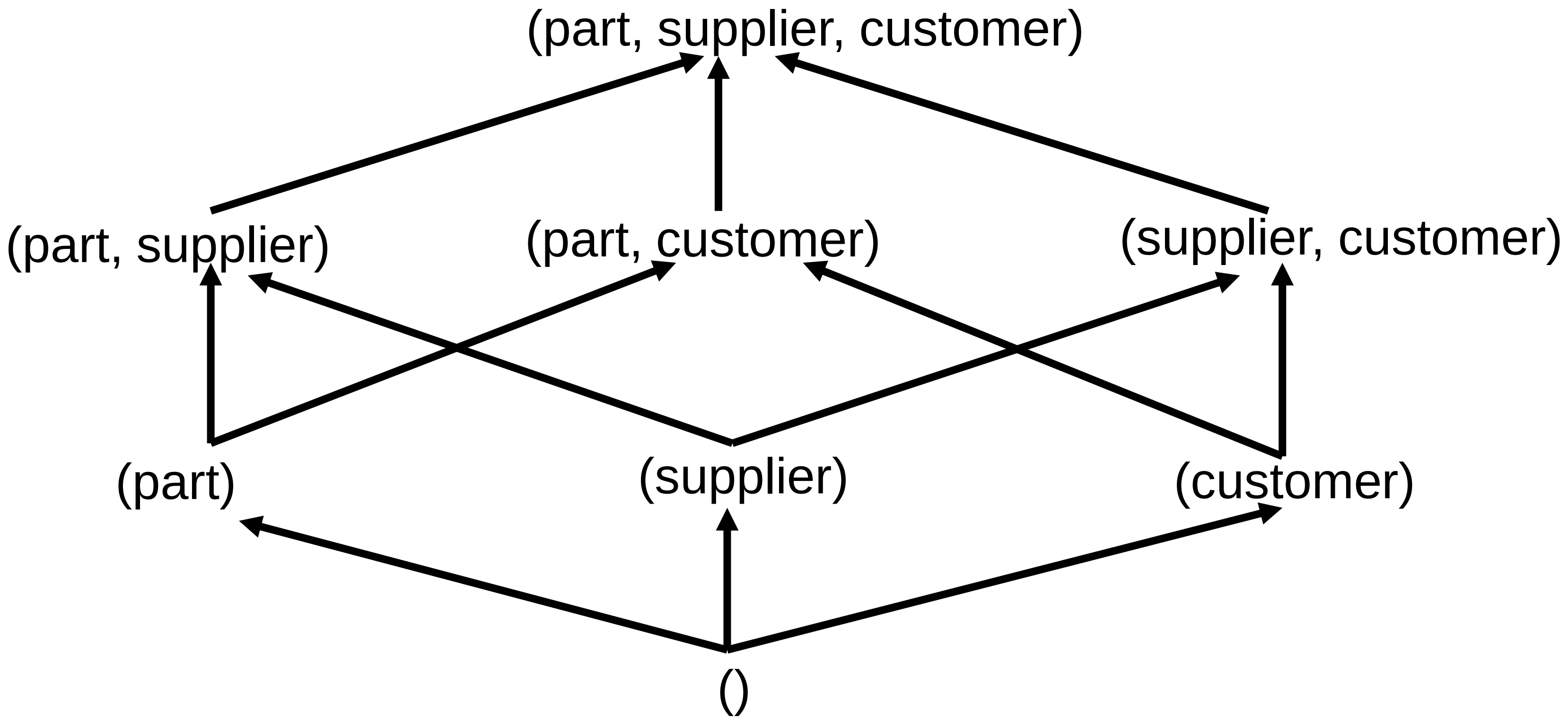
Research Questions

- What is the *optimal set of views* to materialize?
  - *How many views* must we materialize to get reasonable performance?
  - Given bounded space S, what is the *optimal choice* of views to materialize?

- First important step towards a solution: cost model
  - *Estimate* the benefit of materializing a view – associated with an evaluation strategy
  - Often *impossible to know* the sizes of the views without actually computing them

Partial Order on Queries

- partial order on the views: Q1 $\leq$ Q2 :
  - Q1 can be answered using the query results of Q2
  - *materialized view* of Q2 can be used to answer Q1



Partial order on queries

- Can be generalized to hierarchies:

  (product, country, -) $\leq$ (product, city,-)

  (-, country, -) $\leq$ (product, city, -)

  (-, -, -) $\leq$ (product, city, -)

  (-, country, year) $\leq$ (-, city, month)

- This is actually the normal specialization relation of the roll-up lattice

Cost Model

- Hence, given a set of materialized views S
  $S = \{BaseRelation, V_1,\ldots,V_n\}$,

  Unique top element in the lattice

- The *cost of query Q given S* is

  $$cost(Q|S) := \min(\{ |V_i| : i = 1\ldots n, Q \leq V_i \})$$

- The *total cost given S* is:

  $$cost(S) := \sum_Q cost(Q|S)$$

- The *benefit of S* is:

  $$B_S := cost(\{BaseRelation\}) - cost(S)$$

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Greedy Solution for One Variant

- Class of *view selection problems*:

> minimize cost(S) s.t.
> $|S| \leq k$ (bound # views)
> $\sum_{V \in S} |V| \leq M$ (space bound)
> …

- We will treat one particular case:
  – Given: for every view its size, k
  Find: *k* views giving the highest

  This problem is NP-complete

  – greedy algorithm with good guarantees

Greedy algorithm

- Input:
  - Size for every view
  - Relation $\leq$ between views
  - Constant k

"Benefit" of W <u>given S</u>:

$B(W|S) = Cost(S) – Cost(S \cup \{W\})$

$= \sum_Q cost(Q|S) - \sum_Q cost(Q|S \cup \{W\})$

$= \sum_Q [cost(Q|S) - cost(Q|S \cup \{W\})]$

$= \sum_Q B_Q(W|S)$

Greedy:

S = { top level view }

Repeat k times:

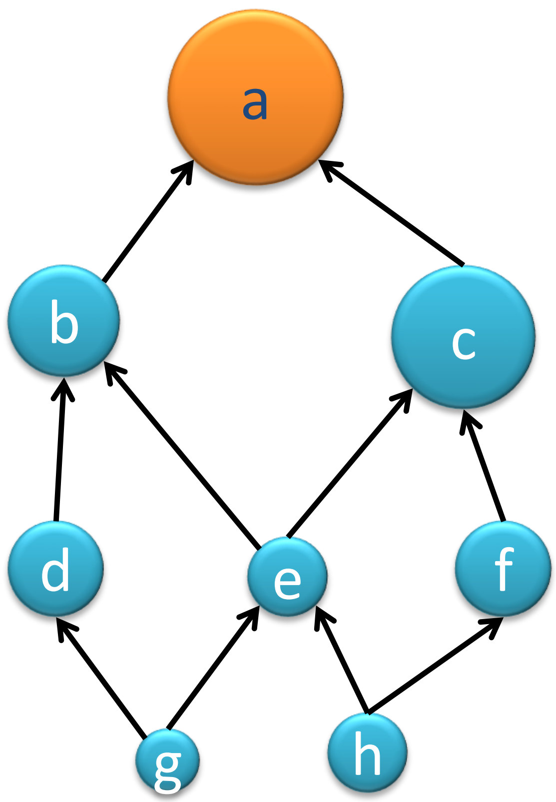
Select W that minimizes cost(S $\cup$ {W})

S := S $\cup$ {W}

Return S

Example

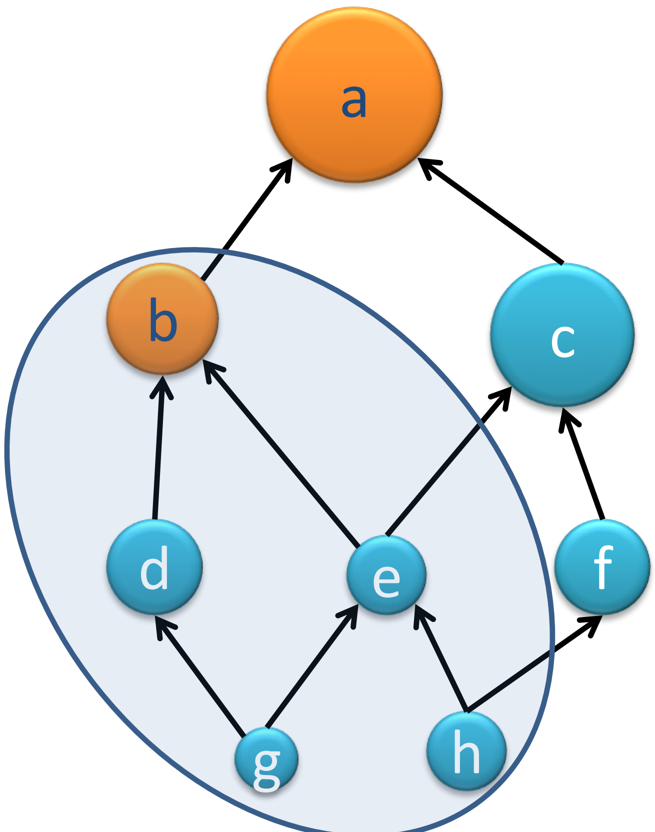
- Only base table a is materialized
  - Total: 8 x 100 = 800



Query	Size	Uses?	Cost
a	100	a	100
b	50	a	100
c	75	a	100
d	20	a	100
e	30	a	100
f	40	a	100
g	1	a	100
h	10	a	100

Example

- Base table a and table b are materialized
  - Total: 3 x 100 + 5 x 50 = 550

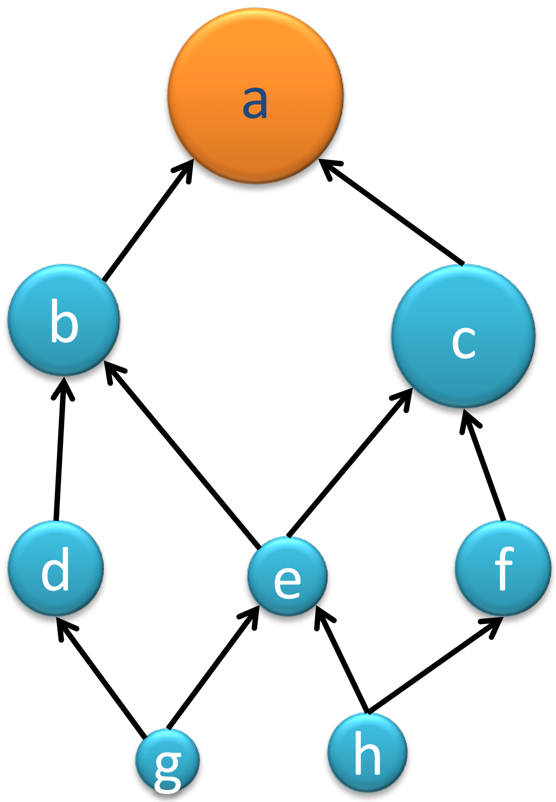


Query	Size	Uses?	Cost	Benefit
a	100	a	100	-
b	50	**b**	**50**	**50**
c	75	a	100	-
d	20	**b**	**50**	**50**
e	30	**b**	**50**	**50**
f	40	a	100	-
g	1	**b**	**50**	**50**
h	10	**b**	**50**	**50**

- Benefit of storing b = 250 = 5 x (100-50)

Example

- Benefit for materializing the other tables:

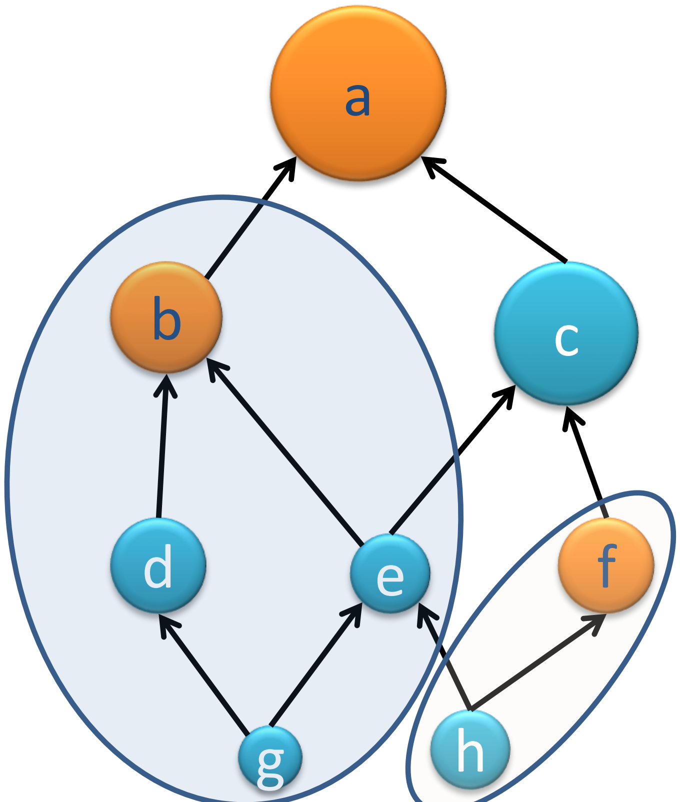


query	Materialized view						
	b	c	d	e	f	g	
a	-	-	-	-	-	-	-
b	**50**	-	-	-	-	-	-
c	-	25	-	-	-	-	-
d	**50**	-	**80**	-	-	-	-
e	**50**	25	-	**70**	-	-	-
f	-	25	-	-	**60**	-	-
g	**50**	25	**80**	**70**	-	**99**	-
h	**50**	25	-	**70**	**60**	-	**90**
Total	**<u>250</u>**	**125**	**160**	**210**	**120**	**99**	**90**

a	100
b	50
c	75
d	20
e	30
f	40
g	1
h	10

Example

- Base table a, table b, and f are materialized
  - Total: 2 x 100 + 4 x 50 + 2 x 40 = 480



Query	Size	Uses?	Cost	Benefit
a	100	a	100	-
b	50	b	50	-
c	75	a	100	-
d	20	b	50	-
e	30	b	50	-
f	40	**f**	**40**	**60**
g	1	b	50	-
h	10	**f**	**40**	**10**

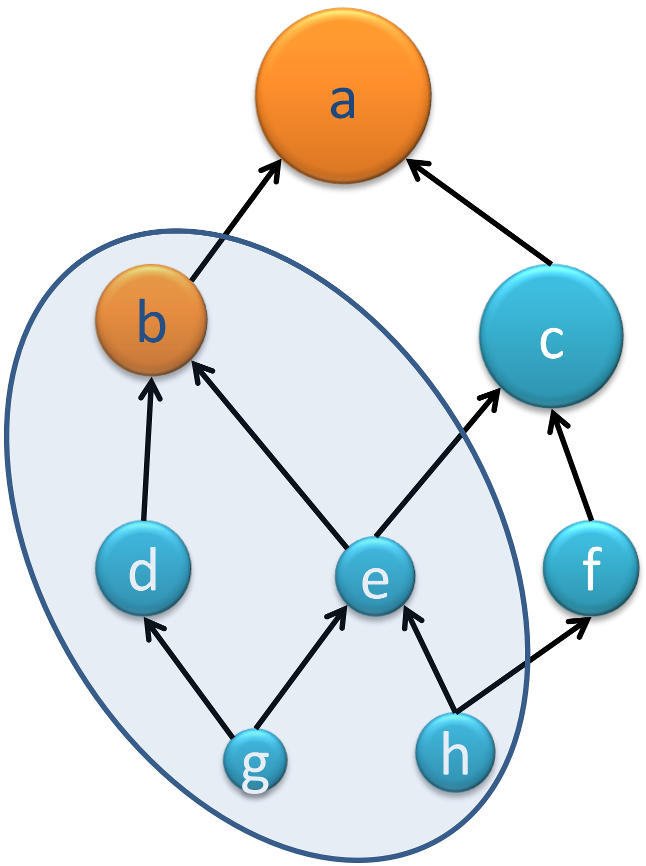
- Additional benefit of materializing f

  = 70 = 1 x (100-40) + 1 x (50-40)

Example

- Benefit for materializing the other tables:

a	100
b	50
c	75
d	20
e	30
f	40
g	1
h	10

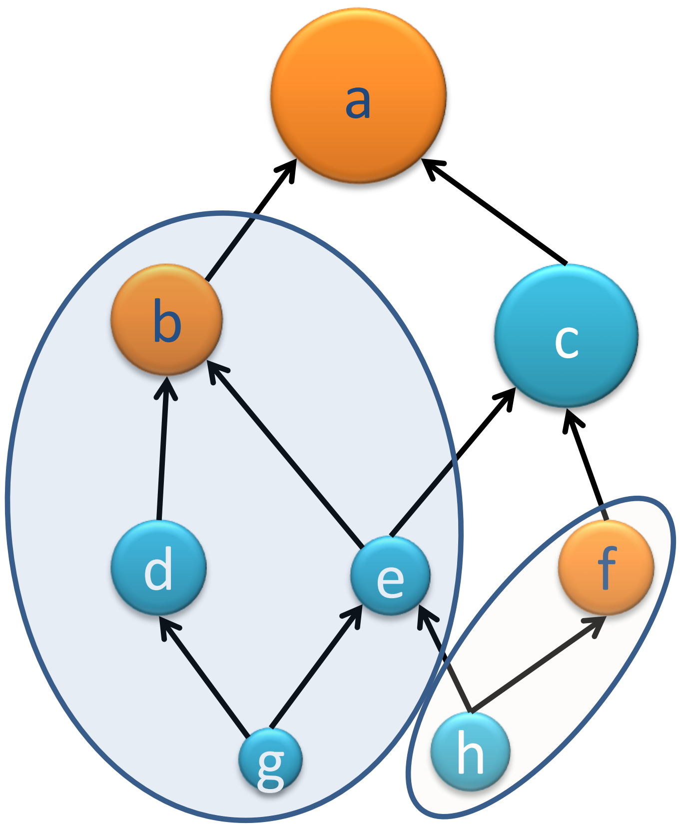


query	Materialized view					
	c	d	e	f	g	h
a	-	-	-	-	-	-
b	-	-	-	-	-	-
c	**25**	-	-	-	-	-
d	-	**30**	-	-	-	-
e	-	-	**20**	-	-	-
f	**25**	-	-	**60**	-	-
g	-	**30**	**20**	-	**49**	-
h	-	-	**20**	**10**	-	**40**
Total	**50**	**60**	**60**	**<u>70</u>**	**49**	**40**

a	100
b	50
c	75
d	20
e	30
f	40
g	1
h	10

Example

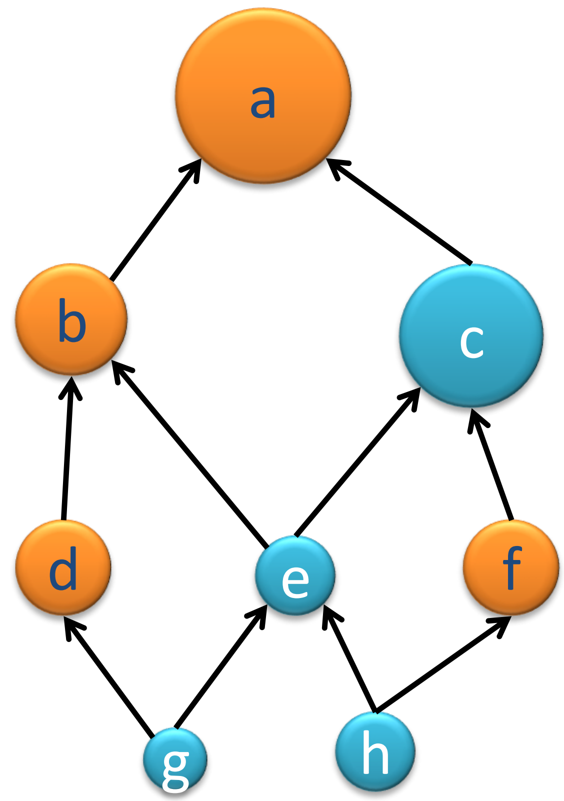
- Benefit for materializing a third table:



query	Materialized view				
	c	d	e	g	h
a	-	-	-	-	-
b	-	-	-	-	-
c	25	-	-	-	-
d	-	**30**	-	-	-
e	-	-	**20**	-	-
f	-	-	-	-	-
g	-	**30**	**20**	**49**	-
h	-	-	**10**	-	**30**
Total	**25**	**<u>60</u>**	**50**	**49**	**30**

Example

- Choice of 3 views according to the Greedy algorithm:
  - Benefit = 250 + 70 + 60 = 380
  - Cost = 420



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Some theoretical results

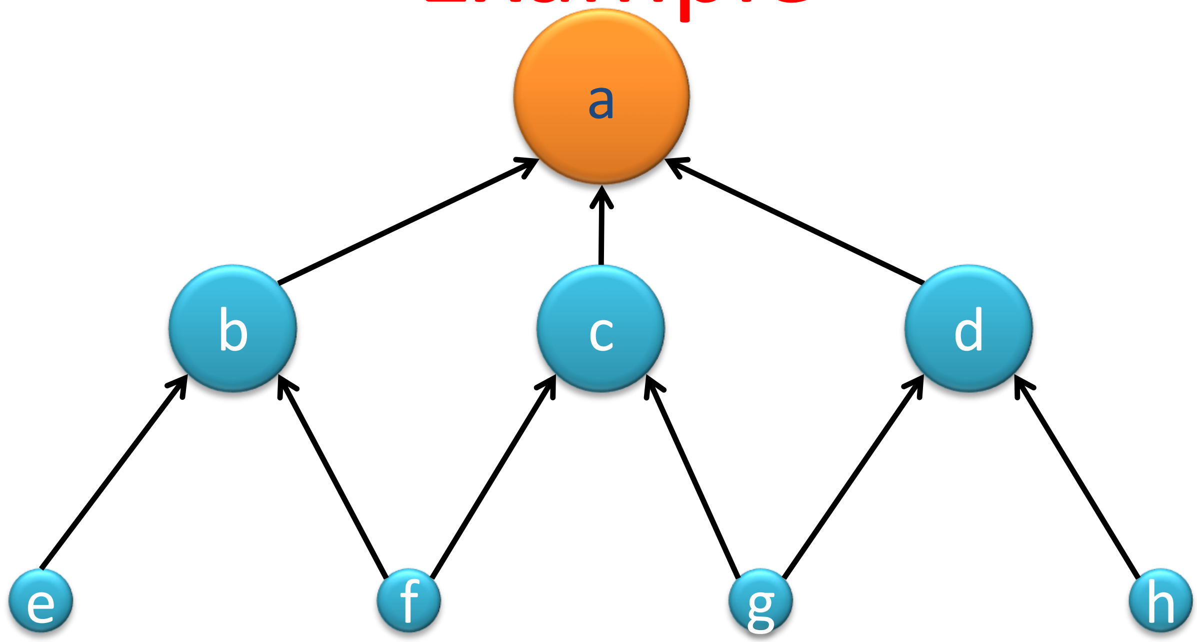
- It can be proved that we can get at least (e – 1) / e (which is about 63%) of the benefit of the optimal algorithm

- When selecting k views, bound is:

$$B_{greedy} / B_{opt} \geq 1 - \left(\frac{k-1}{k}\right)^{k}$$

There are lattices for which this ratio is arbitrarily close to this bound.

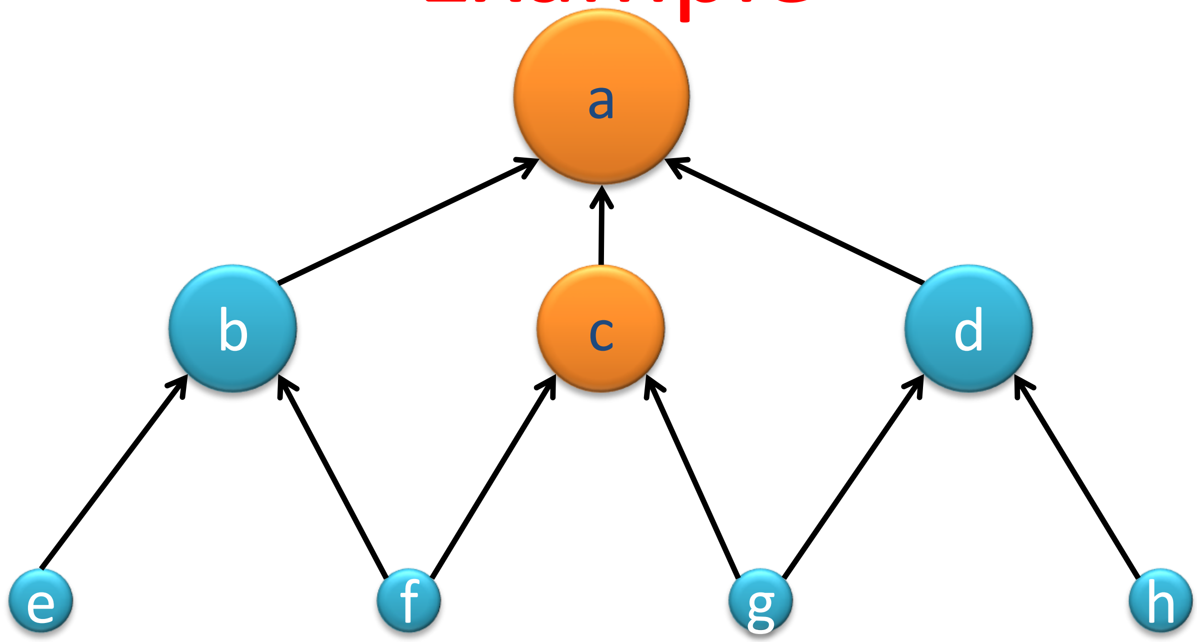
Example



a	200
b	100
c	99
d	100
e	50
f	50
g	50
h	50

Node	Benefit
b, d	3 x (200-100) = 300
c	3x(200-99) = 303
e, f, g, h	1x(200-50) = 150

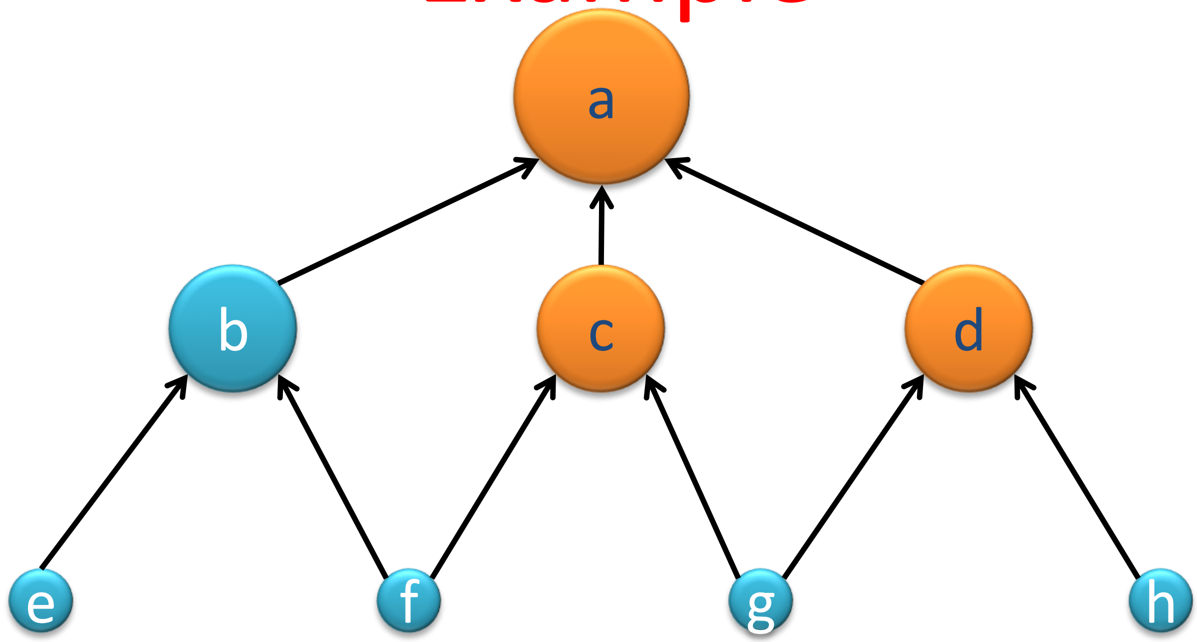
Example



a	200
b	100
c	99
d	100
e	50
f	50
g	50
h	50

Node	Benefit
b, d	2 x (200-100) = 200
e, h	1x(200-50) = 150
f, g	1x(99-50) = 49

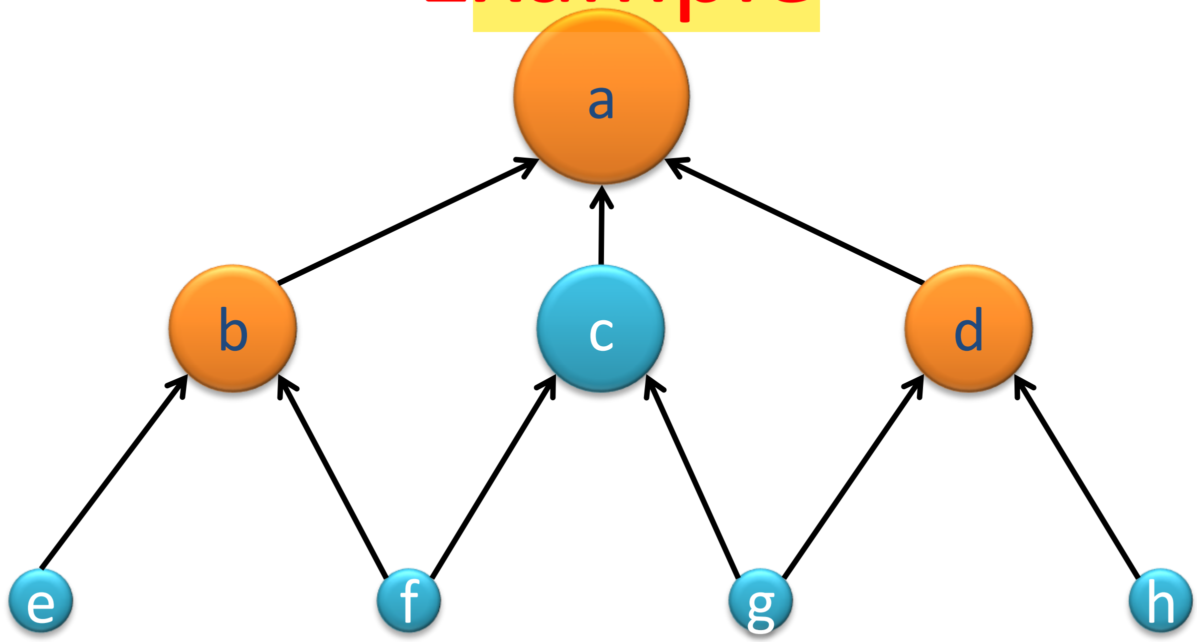
Example



a	200
b	100
c	99
d	100
e	50
f	50
g	50
h	50

- Hence $B_{greedy} = 503$

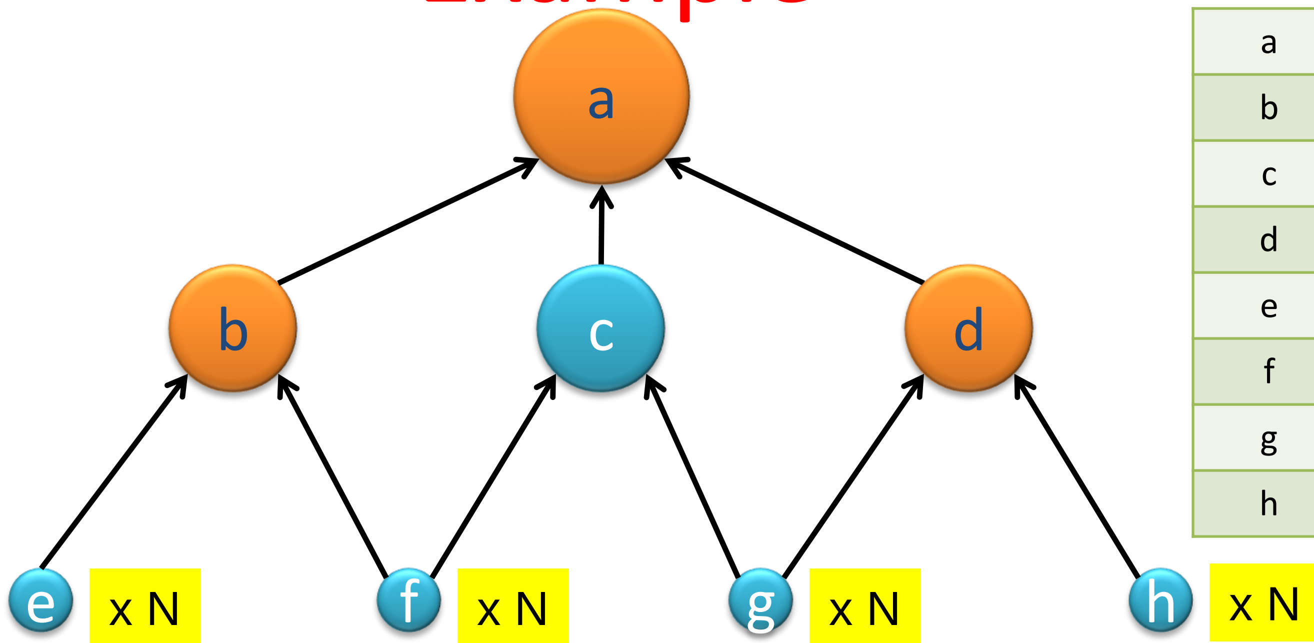
Example



a	200
b	100
c	99
d	100
e	50
f	50
g	50
h	50

- Hence $B_{greedy} = 503$
- $B_{opt} = 6 \times (200\text{-}100) = 600$
- $B_{greedy} / B_{opt} = 503/600 \geq 75\%$

Example



a	200
b	100
c	100-ε
d	100
e	50
f	50
g	50
h	50

- Hence $B_{greedy} = (2N + 1) \times (100+\varepsilon) + (N+1) \times 100$
  $\rightarrow 300N + 200$
- $B_{opt} = (4N+2) \times 100 \rightarrow 400N + 200$
- $B_{greedy} / B_{opt} \rightarrow (3N+2)/(4N+2) \rightarrow 75\%$

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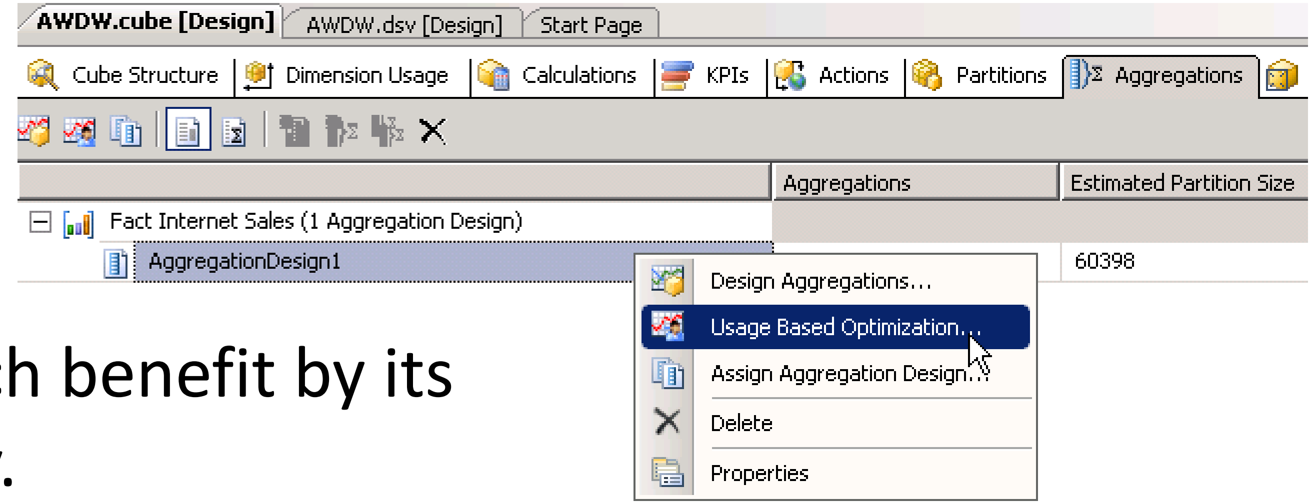
Extensions (1)

- Problem
  - The views in a lattice are unlikely to have the same probability of being requested in a query.



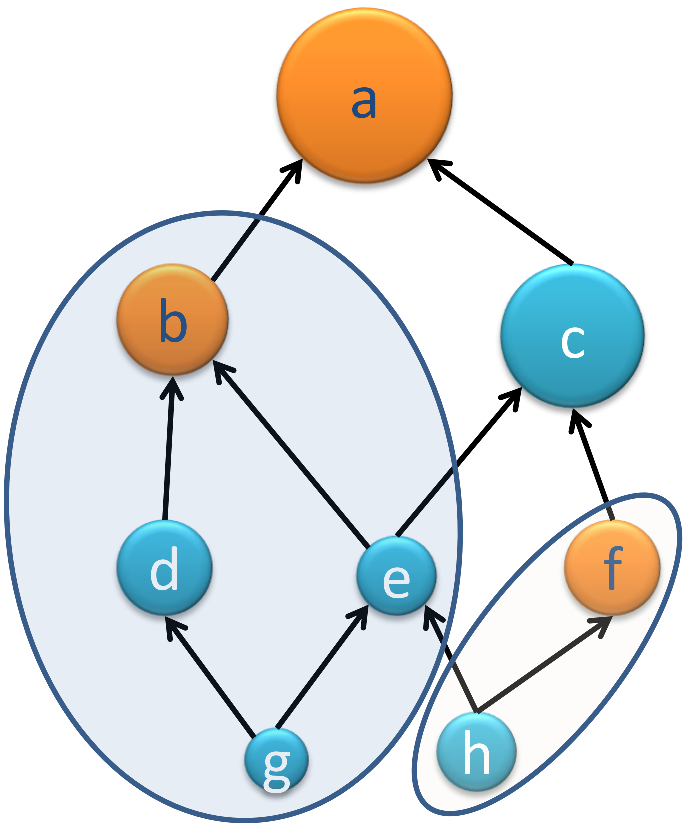
- Solution:
  - We can weight each benefit by its probability.

Example

- Suppose following distribution:

  a: 0%, b: 10%, c:0%, d:10%, e:5%, f:20%, g: 40% , h:15%

a	100
b	50
c	75
d	20
e	30
f	40
g	1
h	10



Query	Uses?	Cost	Exp. Cost
a	a	100	0
b	b	50	5
c	a	100	0
d	b	50	5
e	b	50	2.5
f	f	40	8
g	b	50	20
h	f	40	6
Total			**46.5**

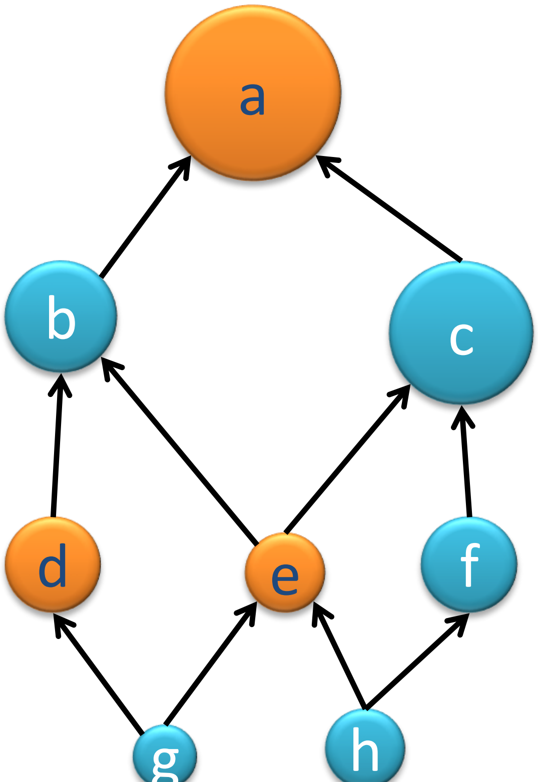
- Expected cost given S = 46.5

Example

- Solution found by greedy:

  a: 0%, b: 10%, c:0%, d:10%, e:5%, f:20%, g: 40% , h:15%

a	100
b	50
c	75
d	20
e	30
f	40
g	1
h	10



Query	Uses?	Cost	Exp. Cost
a	a	100	0
b	a	100	10
c	a	100	0
d	d	20	2
e	e	30	1.5
f	a	100	20
g	d	20	8
h	e	30	4.5
Total			**46**

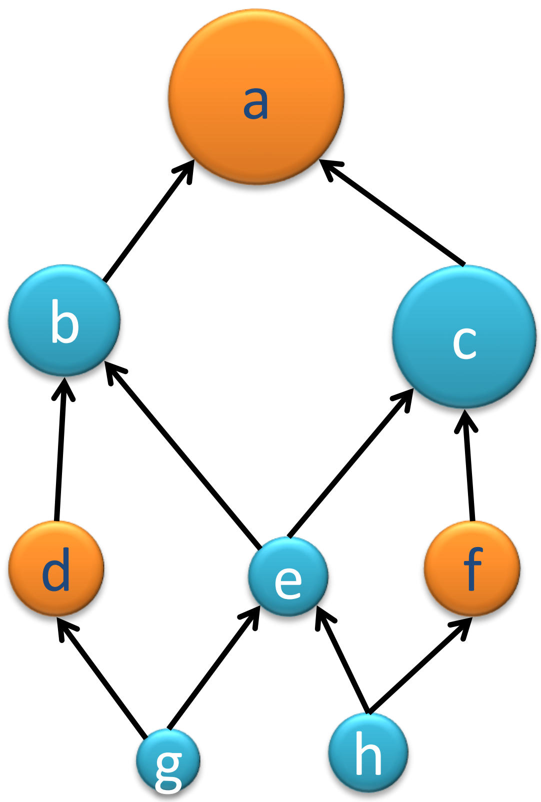
- Expected cost given S = 46

a	100
b	50
c	75
d	20
e	30
f	40
g	1
h	10

Example

- Optimal Solution:

  a: 0%, b: 10%, c:0%, d:10%, e:5%, f:20%, g: 40% , h:15%



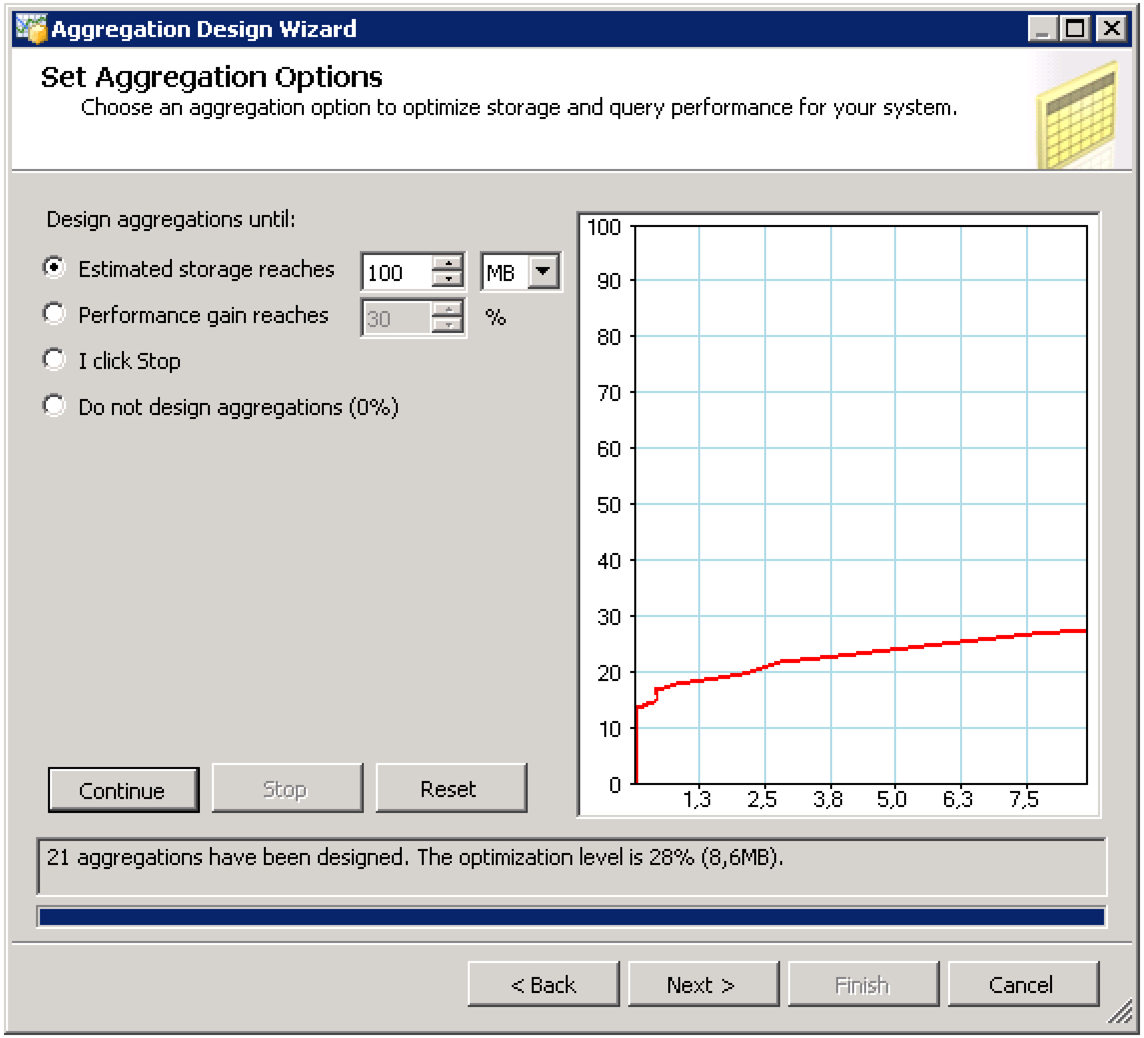
Query	Uses?	Cost	Exp. Cost
a	a	100	0
b	a	100	10
c	a	100	0
d	d	20	2
e	a	100	5
f	f	40	8
g	d	20	8
h	f	40	6
Total			**39**

- Expected cost given S = 39

Extensions (2)

- Problem
  - Instead of asking for some fixed number (k) of views to materialize, we might instead allocate a fixed amount of space to views.
- Solution
  - We can consider the “benefit of each view per unit space”.

View Materialization



Conclusion: View Materialization

- Materialization of views is an essential query optimization strategy for decision-support applications.
  - Finding optimal solution is NP-hard.
- Introduction of greedy algorithm
  - There exists cases which greedy algorithm fails to produce optimal solution
  - Yet, greedy algorithm has a good guarantee
- Expansion of greedy algorithm.