CS 347
Distributed Databases and Transaction Processing
Notes02: Distributed DB Design

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Distributed DB Design

Chapter 5
Ozsu & Valduriez

Top-down approach: - have DB…
- how to split and allocate the sites

Multi-DBs (or bottom-up): - no design issues

Two issues in DDB design:

- Fragmentation
- Allocation

Note: issues not independent,
but will cover separately

Example

Employee relation E (#, name, loc, sal, …)

40% of queries:

Q_A: select *
from E
where loc=S_A
and …

40% of queries:

Q_B: select *
from E
where loc=S_B
and …

Example

Employee relation E (#, name, loc, sal, …)

40% of queries:	40% of queries:
Q_A: select *	Q_B: select *
from E	from E
where loc=S_A	where loc=S_B
and …	and …

Motivation: Two sites: S_A, S_B

$Q_A \rightarrow$ [S_A] [S_B] $\leftarrow Q_B$

- It does not take a rocket scientist to figure out fragmentation...

E

#	NM	Loc	Sal
5	Joe	S_A	10
7	Sally	S_B	25
8	Tom	S_A	15
:			:

F

#	NM	Loc	Sal
5	Joe	S_A	10
8	Tom	S_A	15
:			

At S_A

#	NM	Loc	Sal
7	Sally	S_B	25
:			

At S_B

$$\mathbf{F} = \{ F_1, F_2 \}$$

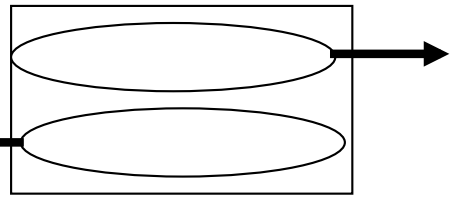
$$F_1 = \sigma_{loc=S_A} E \qquad F_2 = \sigma_{loc=S_B} E$$

$\Rightarrow$ called <u>primary horizontal</u> fragmentation

Fragmentation

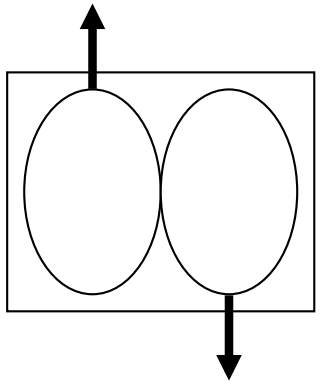
- Horizontal

R



- Vertical

R



- Primary

  depends on local attributes

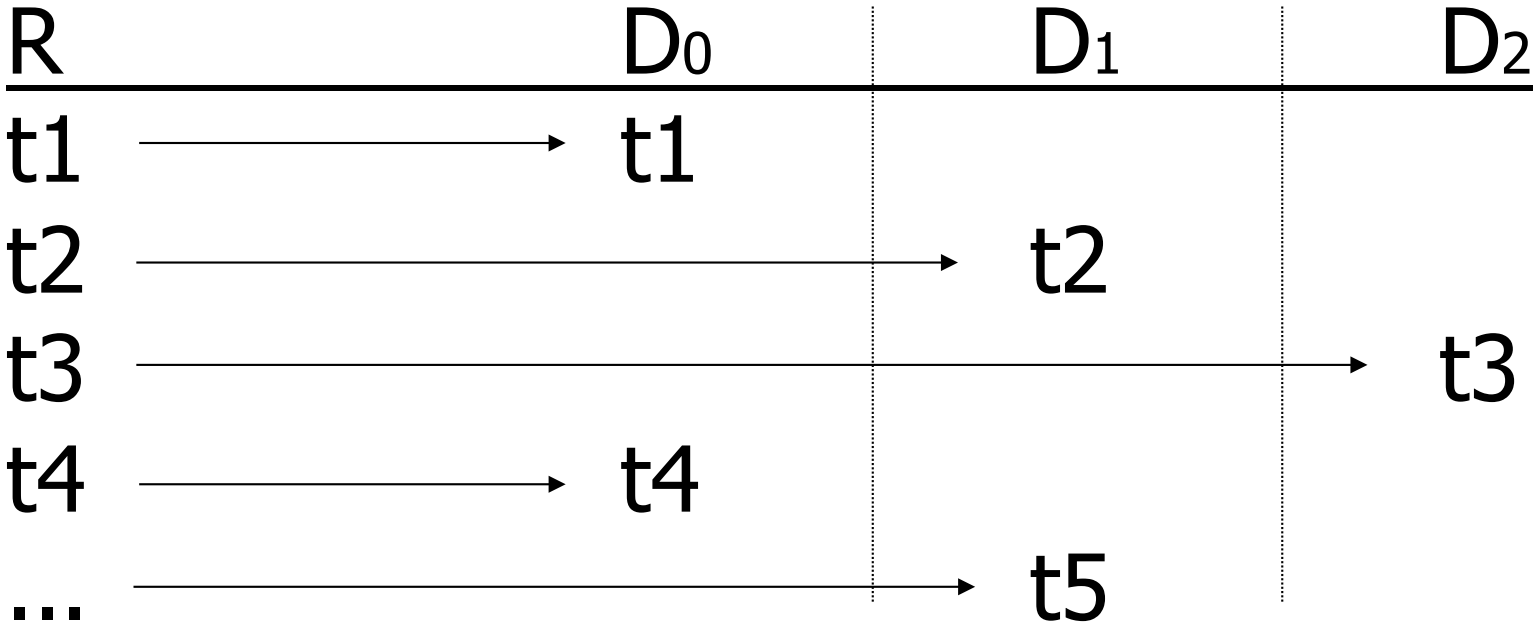
- Derived

  depends on foreign relation

Three common horizontal partitioning techniques

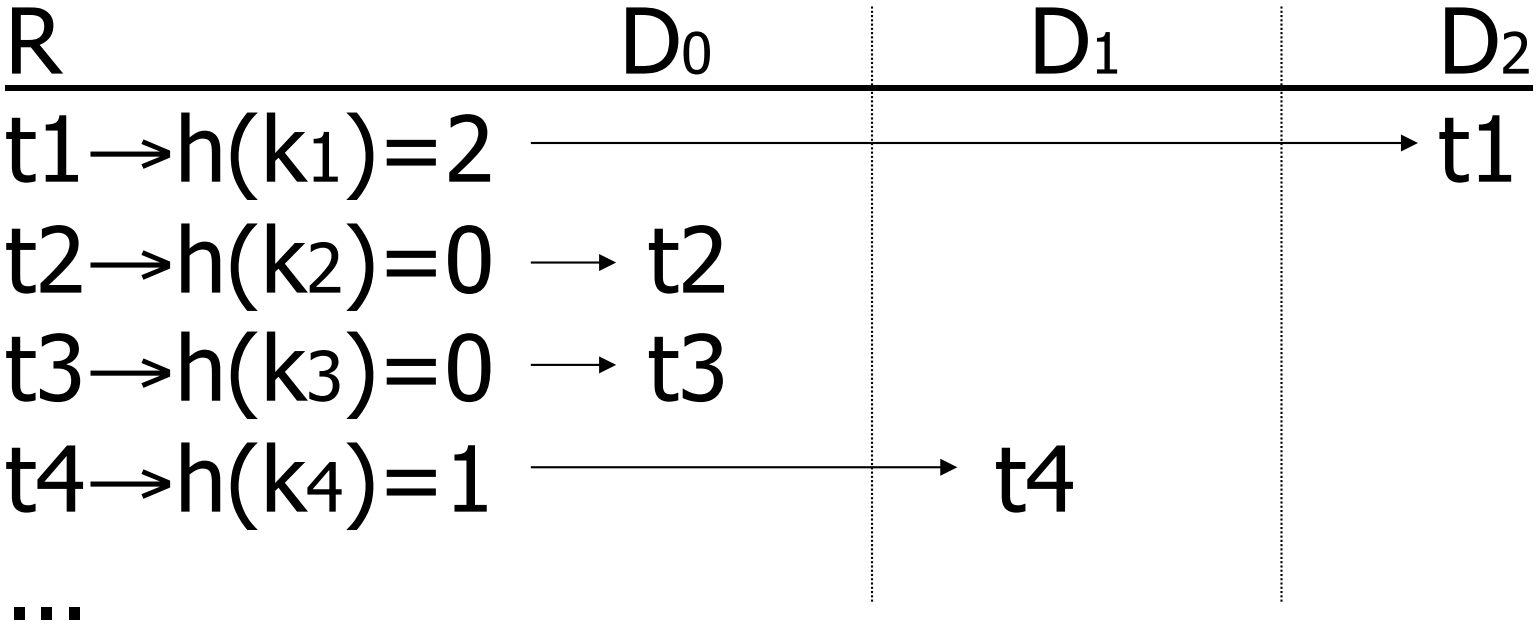
- Round robin
- Hash partitioning
- Range partitioning

- Round robin



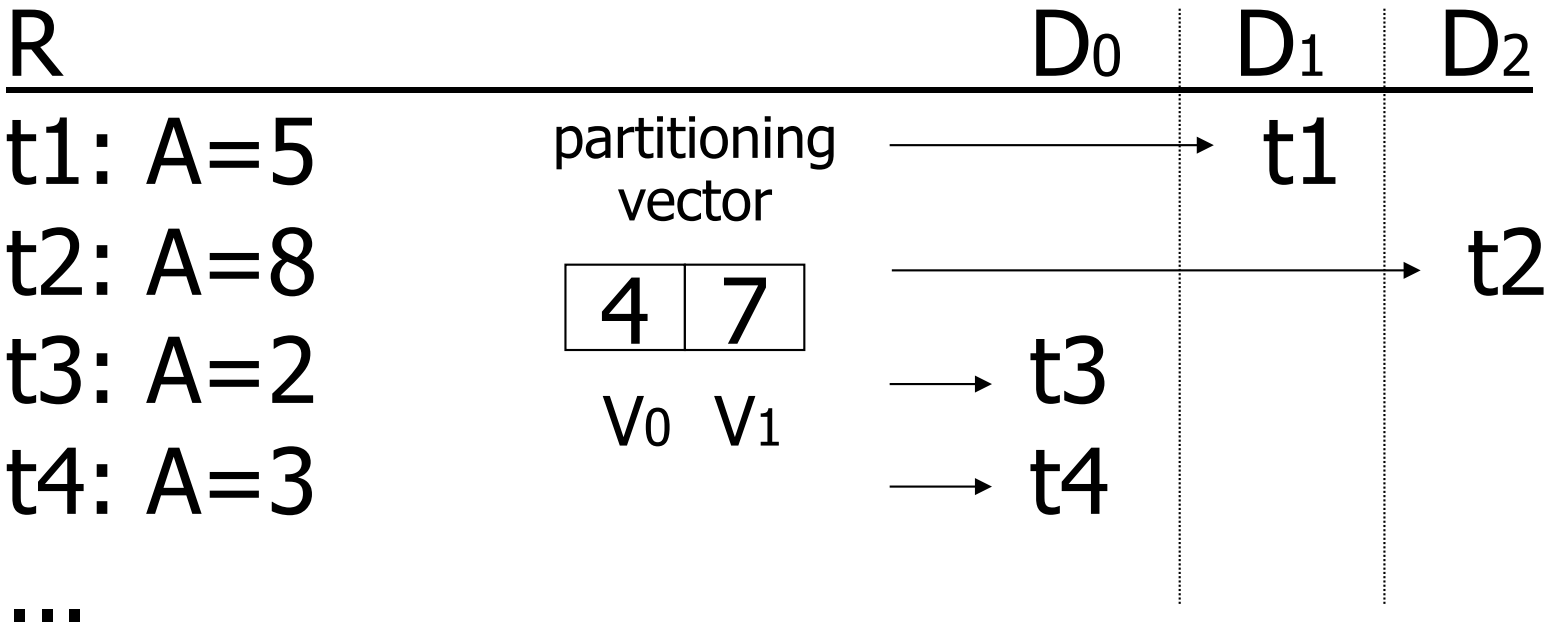
- Evenly distributes data
- Good for scanning full relation
- Not good for point or range queries

- Hash partitioning



- Good for point queries on key; also for joins
- Not good for range queries; point queries not on key
- If hash function good, even distribution

- Range partitioning



- Good for some range queries on A
- Need to select good vector: else unbalanced
  → data skew
  → execution skew

Which are good fragmentations?

Example:

$\mathbf{F} = \{ F_1, F_2 \}$

$F_1 = \sigma_{sal<10} E$ $\qquad$ $F_2 = \sigma_{sal>20} E$

Which are good fragmentations?

Example:

F = { F_1, F_2 }

$F_1 = \sigma_{sal<10} E$ $F_2 = \sigma_{sal>20} E$

Problem: Some tuples lost!

Which are good fragmentations?

Second example:

F = { F_3, F_4 }

$F_3 = \sigma_{sal<10} E$ $\quad\quad$ $F_4 = \sigma_{sal>5} E$

Problem: Tuples with 5 < sal < 10 duplicated!

Prefer to deal with replication explicitly

Example: $\mathbf{F} = \{ F_5, F_6, F_7 \}$

$F_5 = \sigma_{sal \leq 5} E$ $\quad$ $F_6 = \sigma_{5< sal <10} E$

$F_7 = \sigma_{sal \geq 10} E$

☛ Then replicate F_6 if convenient
(part of allocation problem)

Desired properties for horizontal fragmentation

$R \Rightarrow \mathbf{F} = \{ F_1, F_2, \ldots \}$

(1) Completeness

$\forall t \in R, \ \exists F_i \in \mathbf{F}$ such that $t \in F_i$

(2) Disjointness

$\forall t \in F_i$, $\neg \exists F_j$ such that

$t \in F_j$, $i \neq j$, $F_i, F_j \in \mathbf{F}$

How do we get completeness and disjointness?

(1) Check it "manually"!

e.g., $F_1 = \sigma_{sal<10} E$; $F_2 = \sigma_{sal\geq 10} E$

How do we get completeness and disjointness?

(2) "Automatically" generate fragments with these properties

Desired simple predicates $\Rightarrow$ fragments

Example of generation

- Say queries use predicates:

  A<10, A>5, Loc = S_A, Loc = S_B

- Next: - generate "minterm" predicates
  - eliminate useless ones

Minterm predicates (part I)

(1) $A<10 \wedge A>5 \wedge Loc=S_A \wedge Loc=S_B$

(2) $A<10 \wedge A>5 \wedge Loc=S_A \wedge \neg(Loc=S_B)$

(3) $A<10 \wedge A>5 \wedge \neg(Loc=S_A) \wedge Loc=S_B$

(4) $A<10 \wedge A>5 \wedge \neg(Loc=S_A) \wedge \neg(Loc=S_B)$

(5) $A<10 \wedge \neg(A>5) \wedge Loc=S_A \wedge Loc=S_B$

(6) $A<10 \wedge \neg(A>5) \wedge Loc=S_A \wedge \neg(Loc=S_B)$

(7) $A<10 \wedge \neg(A>5) \wedge \neg(Loc=S_A) \wedge Loc=S_B$

(8) $A<10 \wedge \neg(A>5) \wedge \neg(Loc=S_A) \wedge \neg(Loc=S_B)$

Minterm predicates (part I)

$5 < A < 10$

(1) $A<10 \wedge A>5 \wedge Loc=S_A \wedge Loc=S_B$

(2) $A<10 \wedge A>5 \wedge Loc=S_A \wedge \neg(Loc=S_B)$

(3) $A<10 \wedge A>5 \wedge \neg(Loc=S_A) \wedge Loc=S_B$

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(7) $A<10 \wedge \neg(A>5) \wedge \neg(Loc=S_A) \wedge Loc=S_B$

(8) $A<10 \wedge \neg(A>5) \wedge \neg(Loc=S_A) \wedge \neg(Loc=S_B)$

$A \leq 5$

Minterm predicates (part II)

(9) $\neg(A<10) \wedge A>5 \wedge Loc=S_A \wedge Loc=S_B$

(10) $\neg(A<10) \wedge A>5 \wedge Loc=S_A \wedge \neg(Loc=S_B)$

(11) $\neg(A<10) \wedge A>5 \wedge \neg(Loc=S_A) \wedge Loc=S_B$

(12) $\neg(A<10) \wedge A>5 \wedge \neg(Loc=S_A) \wedge \neg(Loc=S_B)$

(13) $\neg(A<10) \wedge \neg(A>5) \wedge Loc=S_A \wedge Loc=S_B$

(14) $\neg(A<10) \wedge \neg(A>5) \wedge Loc=S_A \wedge \neg(Loc=S_B)$

(15) $\neg(A<10) \wedge \neg(A>5) \wedge \neg(Loc=S_A) \wedge Loc=S_B$

(16) $\neg(A<10) \wedge \neg(A>5) \wedge \neg(Loc=S_A) \wedge \neg(Loc=S_B)$

Minterm predicates (part II)

(9) ¬(A<10) ∧ A>5 ∧ Loc=S_A ∧ Loc=S_B

(10) ¬(A<10) ∧ A>5 ∧ Loc=S_A ∧¬(Loc=S_B)

(11) ¬(A<10) ∧ A>5 ∧¬(Loc=S_A) ∧ Loc=S_B

(12) ¬(A<10) ∧ A>5 ∧¬(Loc=S_A) ∧¬(Loc=S_B)

(13) ¬(A<10) ∧¬(A>5) ∧ Loc=S_A ∧ Loc=S_B

(14) ¬(A<10) ∧¬(A>5) ∧ Loc=S_A ∧¬(Loc=S_B)

(15) ¬(A<10) ∧¬(A>5) ∧¬(Loc=S_A) ∧ Loc=S_B

(16) ¬(A<10) ∧¬(A>5) ∧¬(Loc=S_A) ∧¬(Loc=S_B)

$A \geq 10$

Final fragments:

F_2: $5 < A < 10 \quad \wedge \quad Loc = S_A$

F_3: $5 < A < 10 \quad \wedge \quad Loc = S_B$

F_6: $A \leq 5 \quad \wedge \quad Loc = S_A$

F_7: $A \leq 5 \quad \wedge \quad Loc = S_B$

F_{10}: $A \geq 10 \quad \wedge \quad Loc = S_A$

F_{11}: $A \geq 10 \quad \wedge \quad Loc = S_B$

Note: Elimination of useless fragments depends on application semantics:

E.g., if LOC could be $\neq S_A$, $\neq S_B$,
we need to add fragments

F_4: $5 < A < 10 \quad \wedge \quad Loc \neq S_A \wedge Loc \neq S_B$

F_8: $A \leq 5 \quad \wedge \quad Loc \neq S_A \wedge Loc \neq S_B$

F_{12}: $A \geq 10 \quad \wedge \quad Loc \neq S_A \wedge Loc \neq S_B$

Why does this work?

Predicates: $p1 \wedge p2 \wedge p3 \wedge p4$

$p1 \wedge p2 \wedge p3 \wedge \neg p4$

$\vdots$

$\neg p1 \wedge \neg p2 \wedge \neg p3 \wedge \neg p4$

(1) Completeness:

Take $t \in R$, $p_i(t)$ must be T or F!

Say $p_1(t) = T$, $p_2(t) = T$, $p_3(t) = F$, $p_4(t) = F$

Then t is in fragment with predicate

$$p1 \wedge p2 \wedge \neg p3 \wedge \neg p4$$

(2) Disjointness

Say $t \in$ fragment $p_1 \wedge p_2 \wedge \neg p_3 \wedge \neg p_4$

Then

$p_1(t) = T,\ \ p_2(t) = T,\ \ p_3(t) = F,\ \ p_4(t) = F$

$\Rightarrow$ t cannot be in any other fragment!

Summary

- Given simple predicates Pr = { p_1, p_2, ..., p_m } minterm predicates are

$$M=\{ m \mid m = \bigwedge_{p_k \in Pr} p_k^*,\ 1 \le k \le m \}$$

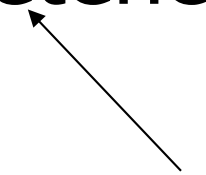
where p_k^* is p_k or is $\neg p_k$

Fragments $\sigma_m R$ for all $m \in M$ are complete and disjoint

Which simple predicates should we use in Pr?

Desired properties of Pr:

- minimality
- completeness



different from COMPLETENESS of fragmentation!

Informal definition

Set of predicates Pr is complete

if for every $F_i \in \mathbf{F}[Pr]$,

every $t \in F_i$ has equal probability of

access by every major application.

Note: $\mathbf{F}[Pr]$ is fragmentation defined by minterm predicates generated by P_r

Informal definition

Set of predicates Pr is minimal if no Pr' $\subset$ Pr is complete

Summary: horizontal fragmentation

- Type: primary, derived
- Properties: completeness, disjointness
- Predicates: minimal, complete

Vertical fragmentation

Example:

E

#	NM	Loc	Sal
5	Joe	Sa	10
7	Sally	Sb	25
8	Fred	Sa	15
…			

E_1

#	NM	Loc
5	Joe	Sa
7	Sally	Sb
8	Fred	Sa
…		

E_2

#	Sal
5	10
7	25
8	15
…	

$$R[T] \Rightarrow \begin{matrix} R_1[T_1] \\ \vdots \\ R_n[T_n] \end{matrix} \qquad T_i \subseteq T$$

- Just like normalization of relations

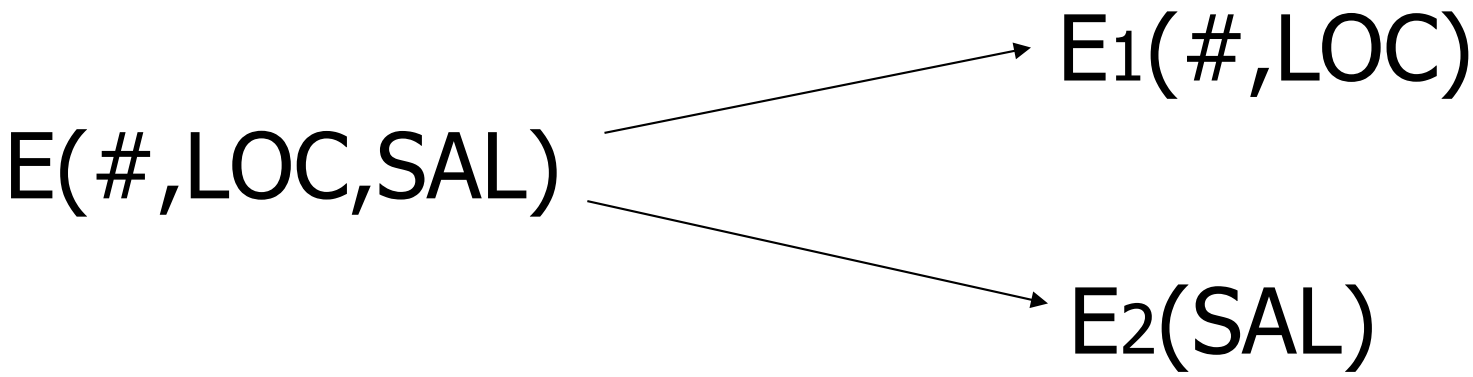
Properties: $R[T] \Rightarrow R_i[T_i]$

(1) Completeness

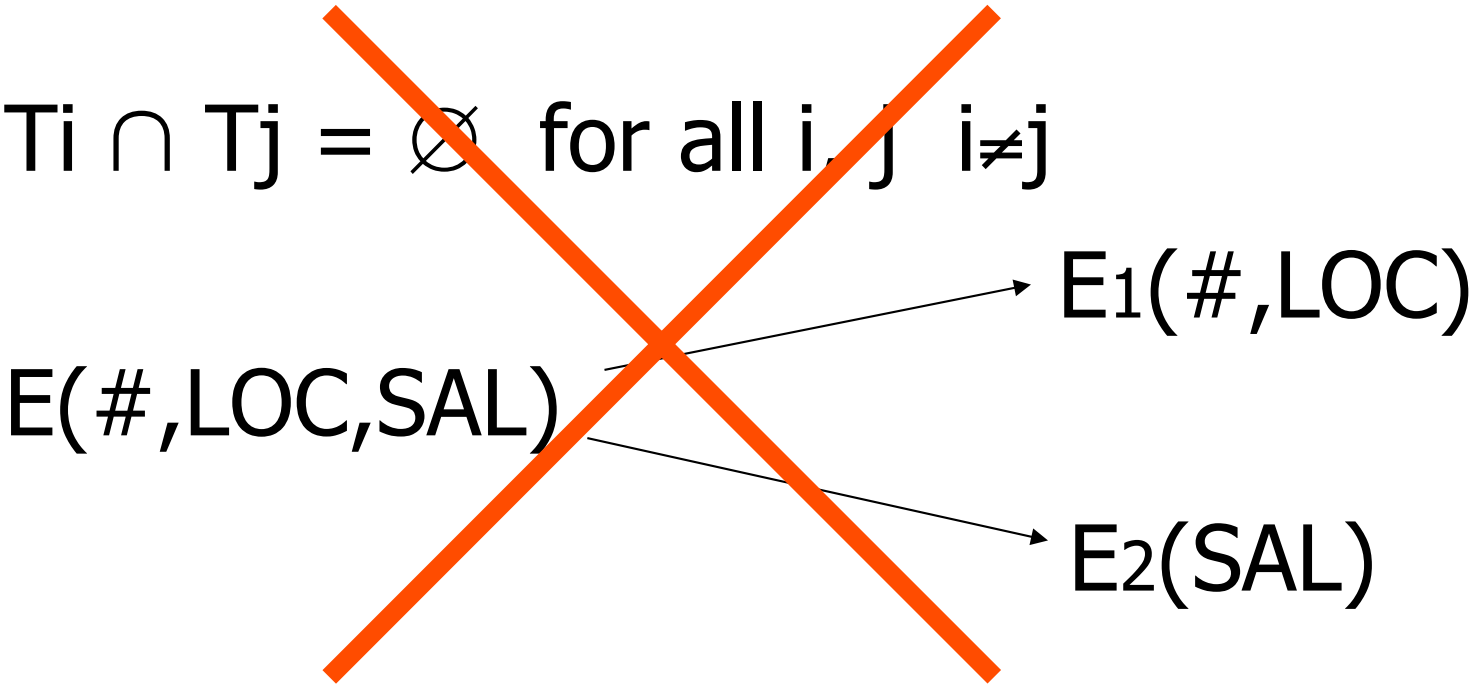
$$\bigcup_{\text{all } i} T_i = T$$

(2) Disjointness

$Ti \cap Tj = \varnothing$ for all i, j $i \neq j$



(2) Disjointness



Not a desirable property!
(could not reconstruct R)

(3) Lossless join

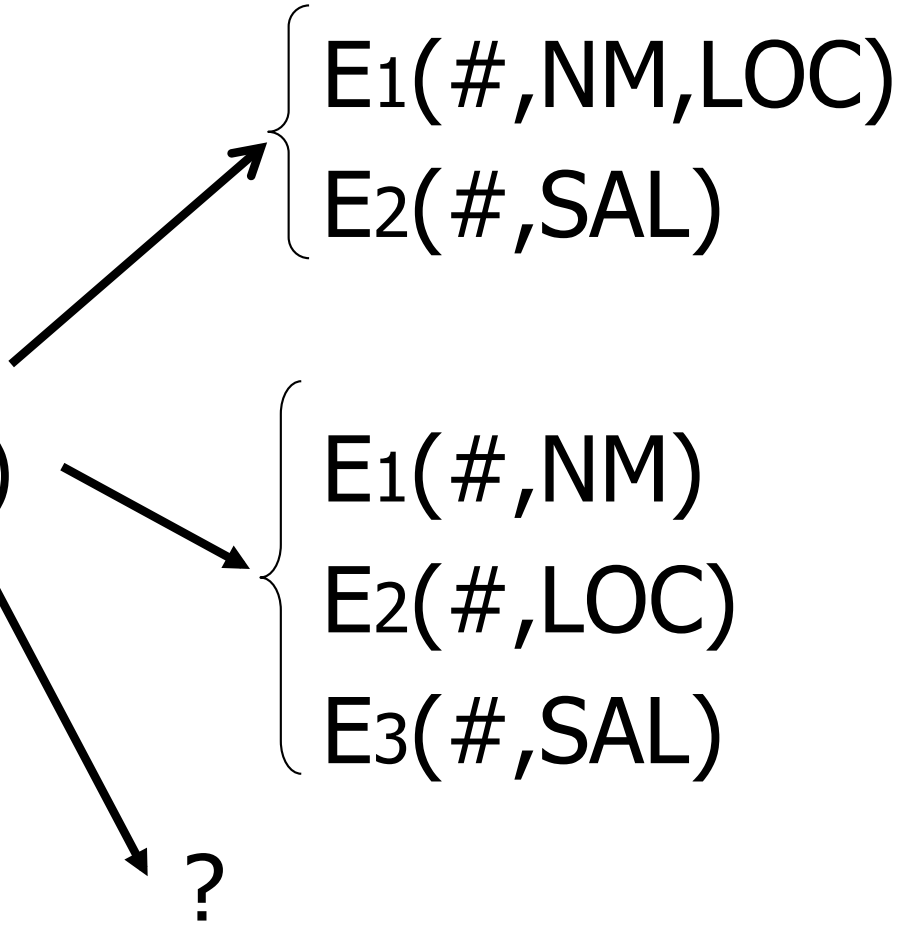
$$\bowtie_{\text{all } i} R_i = R$$

- One way to achieve lossless join: repeat key in all fragments, i.e., key $\subseteq T_i$ for all i

How do we decide what attributes are grouped with which?

Example:

E(#,NM,LOC,SAL)



Attribute affinity matrix

	A_1	A_2	A_3	A_4	A_5
A_1	-	-	-	-	-
A_2	50	-	-	-	-
A_3	45	48	-	-	-
A_4	1	2	0	-	-
A_5	0	0	4	75	-

Attribute affinity matrix

	A_1	A_2	A_3	A_4	A_5
A_1	-	-	-	-	-
A_2	50	-	-	-	-
A_3	45	48	-	-	-
A_4	1	2	0	-	-
A_5	0	0	4	75	-

$R_1[K,A_1,A_2,A_3]$ $R_2[K,A_4,A_5]$

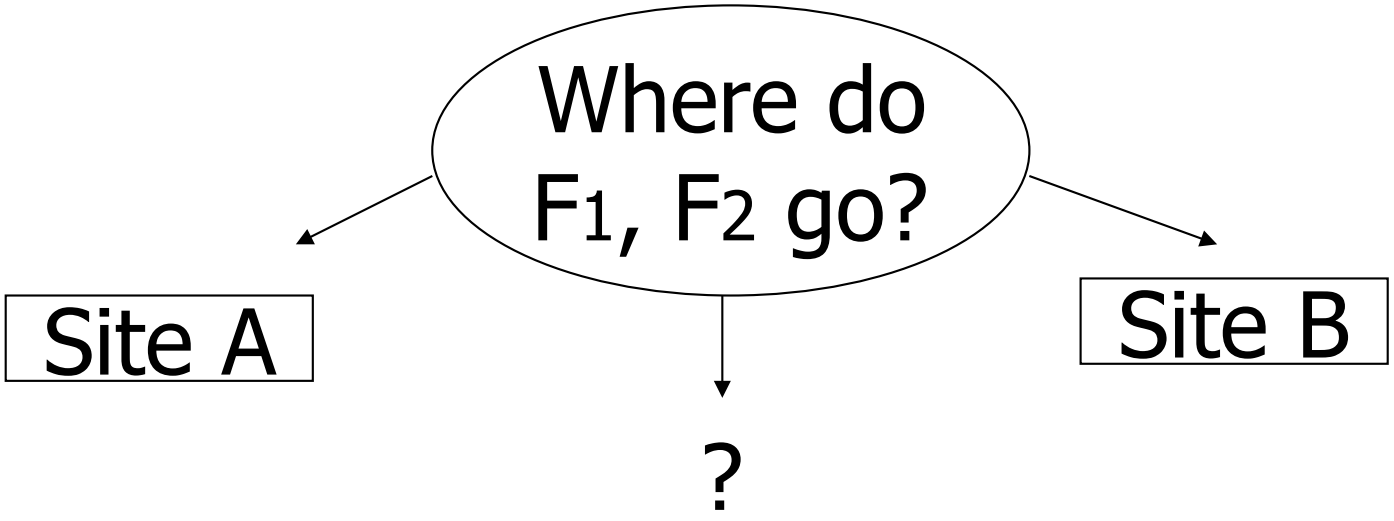
Allocation

Example: E(#,NM,LOC,SAL) $\Rightarrow$

$F_1 = \sigma_{loc=S_A} E$; $F_2 = \sigma_{loc=S_B} E$

Q_A: select … where loc=S_A …

Q_B: select … where loc=S_B …



Issues

- Where do queries originate
- What is communication cost?
  and size of answers, relations, …
- What is storage capacity, cost at sites?
  and size of fragments?
- What is processing power at sites?

More issues

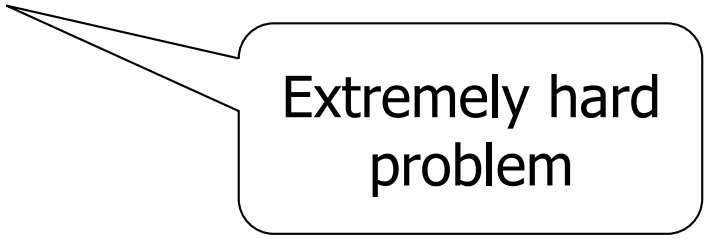
- What is query processing strategy?
  - How are joins done?
  - Where are answers collected?

Do we replicate fragments?

- Cost of updating copies?
- Writes and concurrency control?
- ...

Optimization problem:

- What is best placement of fragments and/or best number of copies to:
  - minimize query response time
  - maximize throughput
  - minimize "some cost"
  - …
- Subject to constraints?
  - available storage
  - available bandwidth, power, …
  - keep 90% of response time below X
  - …



Example: Single fragment F

Read cost: $\sum_{i=1}^{m} [t_i \times \underset{j}{\text{MIN}}\ C_{ij}]$

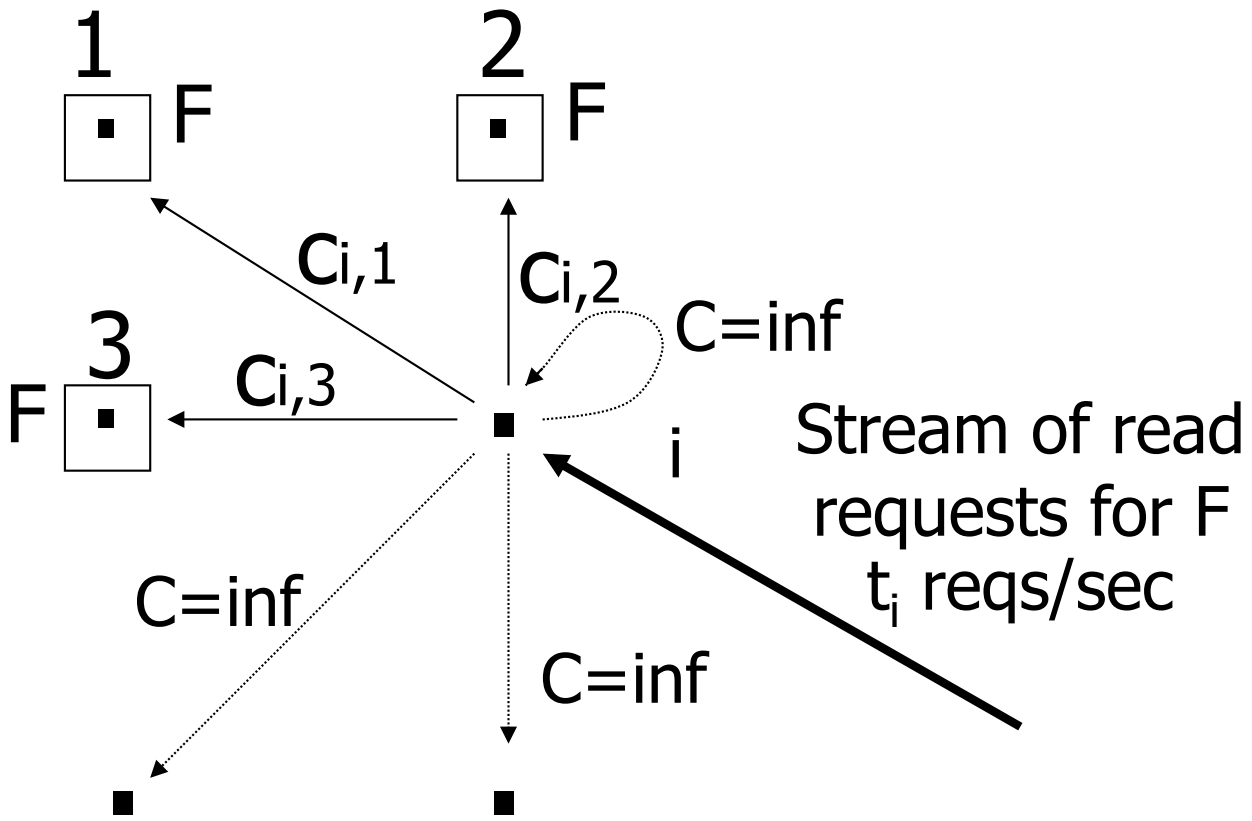
i: Originating site of request (1…m)

t_i: Read traffic at S_i

C_{ij}: Retrieval cost

Accessing fragment F at Sj from Si

Scenario: Read cost



Write cost:

$$\sum_{i=1}^{m} \sum_{j=1}^{m} X_j \, u_i \, C'_{ij}$$

i: Originating site of request

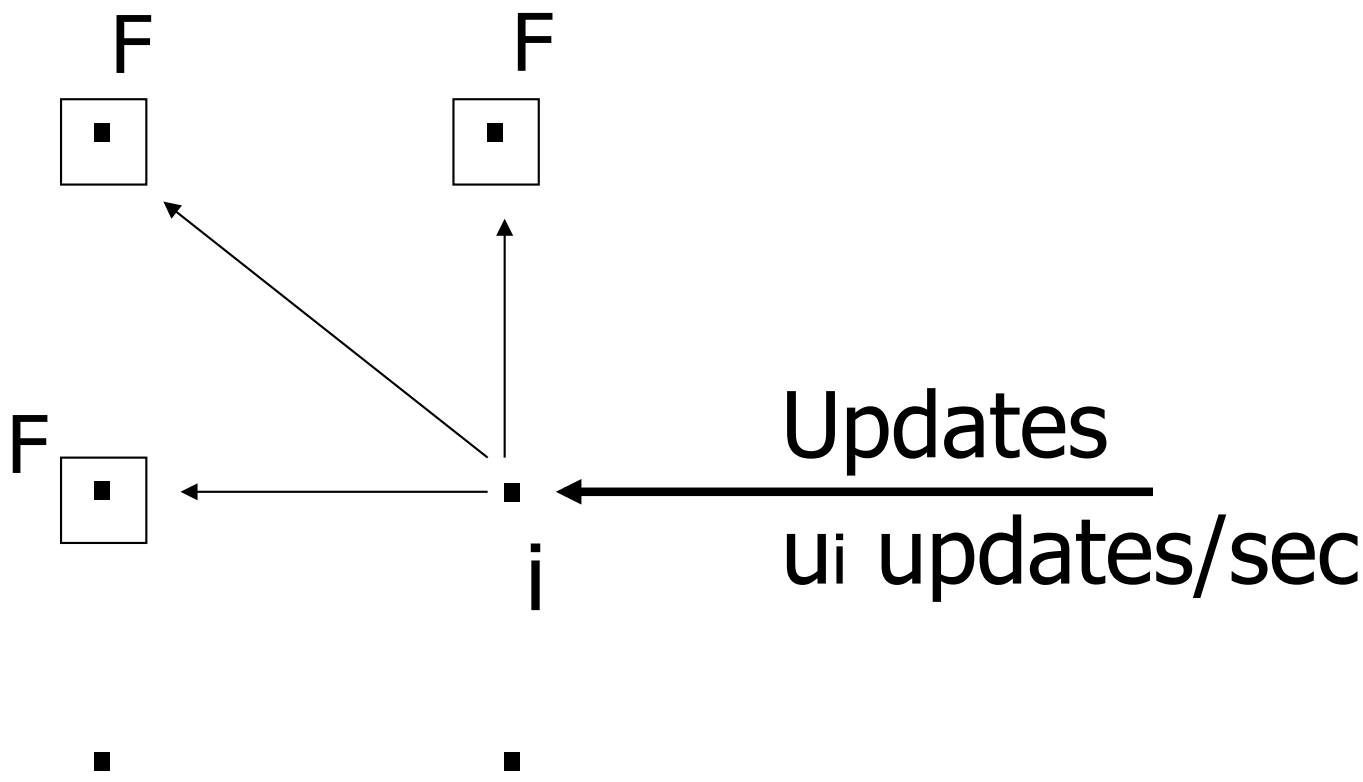
j: Site being updated

X_j: { 0 if F not stored at S_j
1 if F stored at S_j

u_i: Write traffic at S_i

C'_{ij}: Write cost of updating F at S_j from S_i

Scenario: Write cost



Storage cost:

$$\sum_{i=1}^{m} X_i \, d_i$$

X_i: { 0 if F not stored at S_i
1 if F stored at S_i

d_i: storage cost at S_i

Target function:

$$\min \left\{ \sum_{i=1}^{m} \left[t_i \times \min_j C_{ij} + \sum_{j=1}^{m} X_j \times u_i \times C'_{ij} \right] + \sum_{i=1}^{m} X_i \times d_i \right\}$$

over all replication strategies for F, each of which yields particular sets of C, C', X, and d values

Can add more complications:

Examples:

- Multiple fragments
- Fragment sizes
- Concurrency control cost

Summary

- Description of fragmentation
- Good fragmentations
- Design of fragmentation
- Allocation