Distributed DB design

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These slides are a modified version of the slides provided with the book

Özsu and Valduriez, *Principles of Distributed Database Systems* (3rd Ed.), 2011

The original version of the slides is available at: extras.springer.com

Outline (distributed DB)

- Introduction (Ch. 1) *
- Distributed Database Design (Ch. 3) *
  - ➡ Fragmentation
  - ➡ Data distribution (allocation)
- Distributed Query Processing (Ch. 6-8) *
- Distributed Transaction Management (Ch. 10-12) *

* Özsu and Valduriez, *Principles of Distributed Database Systems* (3rd Ed.), 2011

Outline (today)

- Distributed DB design (Ch. 3) ★
  - ➡ Introduction
  - ➡ Top-down (vs. bottom-up) design
  - ➡ Distribution design issues
    - ✦ Fragmentation
    - ✦ Allocation
  - ➡ Fragmentation
    - ✦ Horizontal Fragmentation (HF)
      - ✓ Primary Horizontal Fragmentation (PHF)
      - ✓ Derived Horizontal Fragmentation (DHF)
    - ✦ Vertical Fragmentation (VF)
    - ✦ Hybrid Fragmentation (HyF)
  - ➡ Allocation
  - ➡ Data directory

★ Özsu and Valduriez, *Principles of Distributed Database Systems* (3rd Ed.), 2011

Design Problem

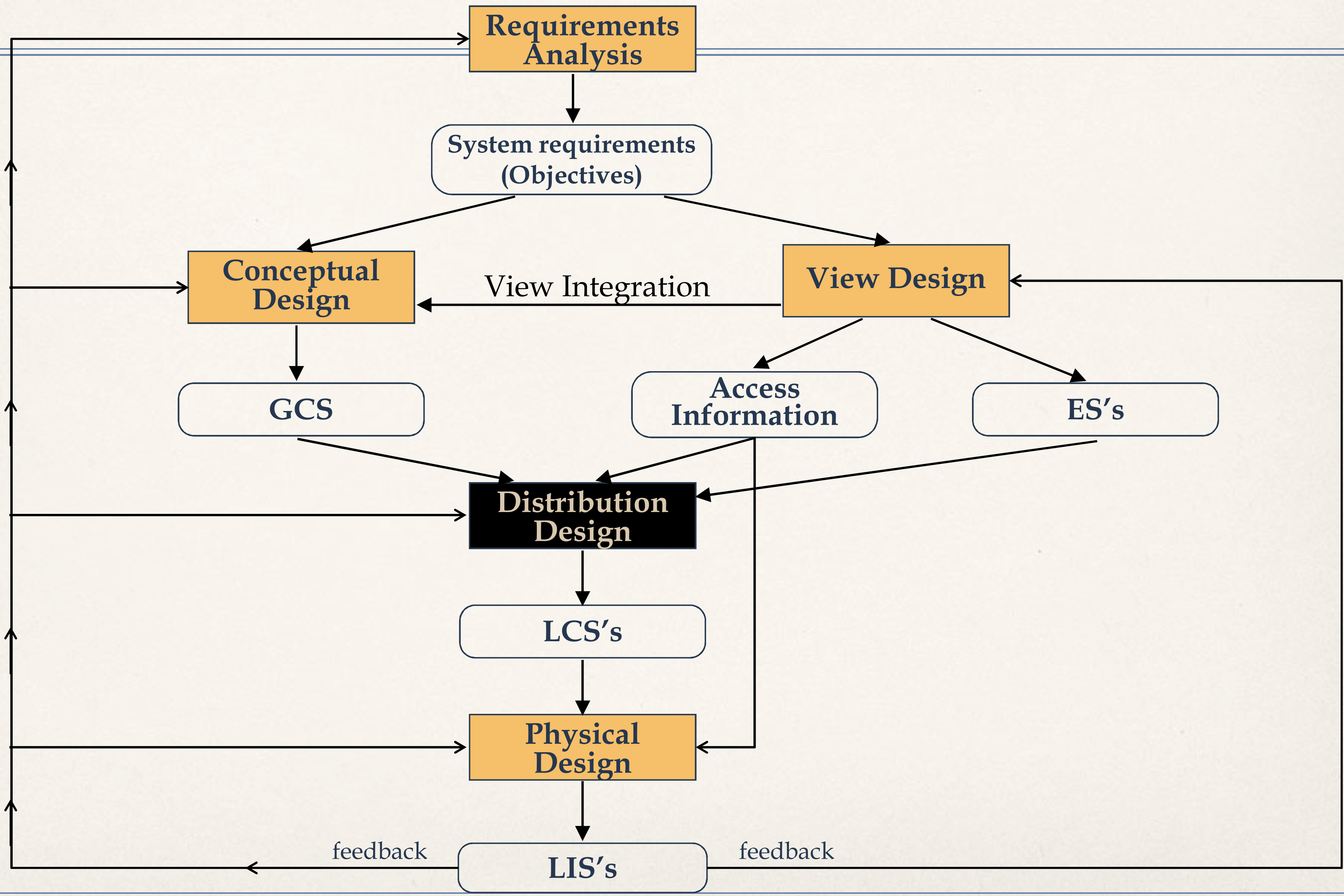
- In the general setting:

  Making decisions about the placement of data across the sites of a computer network as well as possibly designing the network itself

Distribution Design

- Top-down
  - ➡ mostly in designing systems from scratch
  - ➡ mostly in homogeneous systems
  - ➡ applies to fully distributed DBMS (a logical view of the whole DB exists)
- Bottom-up
  - ➡ when the databases already exist at a number of sites
  - ➡ applies to MDBS (we will not treat them)

Top-Down Design



Distribution Design Issues

Distribution design activity boils down to *fragmentation* and *allocation*

❶ Why fragment at all?	[reasons for fragmentation]
❷ How to fragment?	[fragmentation alternatives]
❸ How much to fragment?	[degree of fragmentation]
❹ How to test correctness?	[correctness rules of fragmentation]
❺ How to allocate?	[allocation alternatives]
❻ Information requirements?	[for both fragmentation and allocation]

1. Reasons for Fragmentation

- Can't we just distribute relations (no intrinsic reason to fragment)?
  - ➞ distributed file systems are not fragmented (i.e., distr. unit is the file)
- What is a reasonable unit of distribution?
  - ➞ advantages of fragmentation (why isn't relation the best choice?)
    - ✦ application views are subsets of relations ➔ **locality** allows for finer accesses (applications only access to relevant subsets of relations)
      - ✓ 2 applications accessing different portion of a relation: without fragmentation, either unnecessary data replication or loss of locality (extra communication)
    - ✦ without fragmentation, no **intra-query parallelism**
  - ➞ disadvantages of fragmentation
    - ✦ might cause queries to be executed on more than one fragment (performance degradation, especially when fragments are not disjoint)
    - ✦ semantic data control (especially integrity enforcement) more difficult and costly

2. Fragmentation Alternatives

PROJ

PNO	PNAME	BUDGET	LOC
P1	Instrumentation	150000	Montreal
P2	Database Develop.	135000	New York
P3	CAD/CAM	250000	New York
P4	Maintenance	310000	Paris

Horizontal fragmentation

- $PROJ_1$: projects with budget < \$200,000
- $PROJ_2$: projects with budget ≥ \$200,000

$PROJ_1$

PNO	PNAME	BUDGET	LOC
P1	Instrumentation	150000	Montreal
P2	Database Develop.	135000	New York

$PROJ_2$

PNO	PNAME	BUDGET	LOC
P3	CAD/CAM	250000	New York
P4	Maintenance	310000	Paris

Vertical fragmentation

- PROJ1: information about project budgets
- PROJ2:information about project names and locations

$PROJ_1$

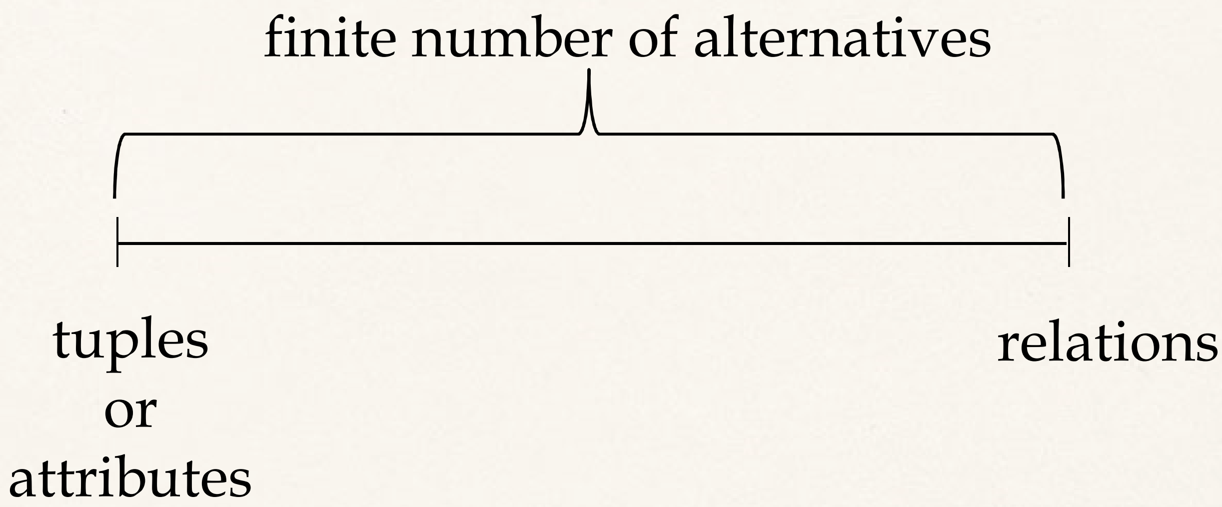
PNO	BUDGET
P1	150000
P2	135000
P3	250000
P4	310000

$PROJ_2$

PNO	PNAME	LOC
P1	Instrumentation	Montreal
P2	Database Develop.	New York
P3	CAD/CAM	New York
P4	Maintenance	Paris

Hybrid fragmentation: obtained by nesting horizontal and vertical fragmentation

3. Degree of Fragmentation



- Finding the suitable level of partitioning within this range
- It depends especially on the applications that will use the DB
- This is the real difficulty of fragmentation

4. Correctness of Fragmentation

- Completeness
  - Decomposition of relation R into fragments R_1, R_2, ..., R_n is complete if and only if each data item in R can also be found in some R_i
- Reconstruction
  - If relation R is decomposed into fragments R_1, R_2, ..., R_n, then there should exist some relational operator ∇ such that

$$R = \nabla_{1 \le i \le n} R_i$$

- Disjointness
  - If relation R is decomposed into fragments R_1, R_2, ..., R_n, and data item d_i is in R_j, then d_i should not be in any other fragment R_k ($k \neq j$).

5. Allocation Alternatives

- Assigning fragments to sites and deciding **whether or not to replicate a fragment**
  - ➡ *partitioned* (aka *non-replicated*): each fragment resides at only one site
  - ➡ *fully replicated*: each fragment at each site
  - ➡ *partially replicated*: each fragment at some of the sites
- Rule of thumb:

  If $\frac{\text{read-only queries}}{\text{update queries}} >> 1$, replication is advantageous,
  otherwise replication may cause problems

- In case of partially replicated DDBS, the number of copies of replicated fragments can either be an input to the allocation algorithm or a decision variable to be computed by the algorithm

6. Information Requirements

- The difficulty of the distributed DB design problem is that too many factor affect the choices towards an optimal design
  - ➡ Logical organization of the DB
  - ➡ Location of DBMS applications
  - ➡ Characteristics of user applications (how they access the DB)
  - ➡ Properties of (computers at) network nodes
  - ➡ …
- Those can be grouped into four categories:
  - ➡ Database information
  - ➡ Application information
  - ➡ Communication network information
  - ➡ Computer system information

} quantitative information, mostly used for allocation, we will not treat them

Fragmentation

- Horizontal Fragmentation (HF)
  - Primary Horizontal Fragmentation (PHF)
  - Derived Horizontal Fragmentation (DHF)
- Vertical Fragmentation (VF)
- Hybrid Fragmentation (HyF)

PHF – Information Requirements

- application information needed for horizontal fragmentation
  - Predicates used in queries
    - 80/20 rule: the most active 20% of user applications account for 80% of accesses
    - **simple predicates**: Given $R[A_1, A_2, \ldots, A_n]$, a **simple predicate** p_j over R is

      $$A_i \ \theta \ Value$$

      where $\theta \in \{=,<,\leq,>,\geq,\neq\}$, $Value \in D_i$ and D_i is the domain of A_i.

      Example:

      PNAME = "Maintenance"

      BUDGET ≤ 200 000
    - **minterms**: Given a set $Pr = \{p_1, p_2, \ldots, p_m\}$ of simple predicates over a relation R, a **minterm** (induced by Pr) is a conjunction

      $$\bigwedge_{p_j \in Pr} p_j^*$$

      where $p_j^* \in \{ p_j , \neg p_j \}$, for all $p_j \in Pr$

      We let $M_{Pr} = \{m_1, m_2, \ldots, m_r\}$ be the set of all minterms induced by a set of simple predicates Pr

PHF – Information Requirements Example

Example

Pr = { PNAME="Maintenance" , BUDGET < 200000 }

$M_{Pr} = \{ m_1 , m_2 , m_3 , m_4 \}$

Where

- m_1: PNAME="Maintenance" $\wedge$ BUDGET < 200000
- m_2: $\neg$(PNAME="Maintenance") $\wedge$ BUDGET < 200000
- m_3: PNAME= "Maintenance" $\wedge$ $\neg$(BUDGET < 200000)
- m_4: $\neg$(PNAME="Maintenance") $\wedge$ $\neg$(BUDGET < 200000)

PHF – Extra Information Requirements

- Application Information
  - ➡ access frequency of queries *(quantitative)*

Primary Horizontal Fragmentation

- Primary horizontal fragmentation (**PHF**) is induced by a set of minterms.
- **Definition:** A set $M = \{ m_1, m_2, \ldots, m_n \}$ of minterm induces the fragmentation

$$F = \{ R_i \mid R_i = \sigma_{m_i}(R),\ m_i \in M \text{, and } R_i \neq \emptyset \}$$

- Therefore, a horizontal fragment R_i of relation R consists of all the tuples of R which satisfy a minterm predicate m_i

⬇

Given a set of minterm predicates M, there are as many horizontal fragments of relation R as there are minterm predicates (some fragments might be empty)

PHF – Example (1)

- Assume there is only 1 application **Q: find projects with budget less than 200 000 €**

$$\sigma_{budget < 200\,000}\,(PROJ)$$

- Then, it makes sense to consider the set of simple predicates S = { BUDGET < 200000 }

  which induces the set of minterms M_S = { BUDGET < 200000, ¬(BUDGET < 200000) }

  which, in turn, induces fragmentation F = { $PROJ_1$, $PROJ_2$ }

- $PROJ_1$ and $PROJ_2$ are the **fragments induced by *S***

PROJ

PNO	PNAME	BUDGET	LOC
P1	Instrumentation	150000	Montreal
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P3	CAD/CAM	250000	New York
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$PROJ_1$

PNO	PNAME	BUDGET	LOC
P1	Instrumentation	150000	Montreal
P2	Database Develop.	135000	New York

$PROJ_2$

PNO	PNAME	BUDGET	LOC
P3	CAD/CAM	250000	New York
P4	Maintenance	310000	Paris

PHF – Example (2)

- Consider now another application **Q′: find projects at a given location** $\sigma_{loc = x}(PROJ)$
  Then, it makes sense to consider the set of simple predicates

$$S' = \{\ LOC = \text{"Montreal"},\quad LOC = \text{"New York"},\quad LOC = \text{"Paris"}\ \}$$

which induces the set of minterms (use abbreviations $\mathbf{L_M}$: LOC = "Montreal", $\mathbf{L_N}$: LOC = "New York", $\mathbf{L_P}$: LOC = "Paris")

$$M_{S'} = \{ \quad L_M \wedge L_N \wedge L_P,\quad L_M \wedge L_N \wedge \neg L_P,\quad L_M \wedge \neg L_N \wedge L_P,\quad L_M \wedge \neg L_N \wedge \neg L_P,$$
$$\neg L_M \wedge L_N \wedge L_P,\quad \neg L_M \wedge L_N \wedge \neg L_P,\quad \neg L_M \wedge \neg L_N \wedge L_P,\quad \neg L_M \wedge \neg L_N \wedge \neg L_P \quad \}$$

PROJ

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P3	CAD/CAM	250000	New York
P4	Maintenance	310000	Paris

PHF – Example (2)

- Consider now another application **Q′: find projects at a given location** $\sigma_{loc = x}(PROJ)$
  Then, it makes sense to consider the set of simple predicates

$$S' = \{\ LOC = \text{“Montreal”},\quad LOC = \text{“New York”},\quad LOC = \text{“Paris”}\ \}$$

which induces the set of minterms (use abbreviations $\mathbf{L_M}$: LOC = “Montreal”, $\mathbf{L_N}$: LOC = “New York”, $\mathbf{L_P}$: LOC = “Paris”)

$M_{S'} = \{$ ~~$L_M \wedge L_N \wedge L_P$,~~ ~~$L_M \wedge L_N \wedge \neg L_P$,~~ ~~$L_M \wedge \neg L_N \wedge L_P$,~~ $L_M \wedge \neg L_N \wedge \neg L_P$,
~~$\neg L_M \wedge L_N \wedge L_P$,~~ $\neg L_M \wedge L_N \wedge \neg L_P$, $\neg L_M \wedge \neg L_N \wedge L_P$, $\neg L_M \wedge \neg L_N \wedge \neg L_P$ $\}$

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which induces the set of minterms (use abbreviations **L_M**: LOC = “Montreal”, **L_N**: LOC = “New York”, **L_P**: LOC = “Paris”)

$M_{S'}$ = { ~~$L_M \wedge L_N \wedge L_P$,~~ ~~$L_M \wedge L_N \wedge \neg L_P$,~~ ~~$L_M \wedge \neg L_N \wedge L_P$,~~ $L_M \wedge \neg L_N \wedge \neg L_P$,
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which reduces to $\{\ L_M \wedge \neg L_N \wedge \neg L_P,\quad \neg L_M \wedge L_N \wedge \neg L_P,\quad \neg L_M \wedge \neg L_N \wedge L_P\ \}$

PROJ

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~~$\neg L_M \wedge L_N \wedge L_P$,~~ $\neg L_M \wedge L_N \wedge \neg L_P$, $\neg L_M \wedge \neg L_N \wedge L_P$, ~~$\neg L_M \wedge \neg L_N \wedge \neg L_P$~~ }

which reduces to $\{ L_M \wedge \neg L_N \wedge \neg L_P,\ \neg L_M \wedge L_N \wedge \neg L_P,\ \neg L_M \wedge \neg L_N \wedge L_P \}$

or, even more succinctly, $\{ L_M,\ L_N,\ L_P \}$

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~~$\neg L_M \wedge L_N \wedge L_P$~~ , $\neg L_M \wedge L_N \wedge \neg L_P$, $\neg L_M \wedge \neg L_N \wedge L_P$, ~~$\neg L_M \wedge \neg L_N \wedge \neg L_P$~~ $\}$

which reduces to $\{ L_M \wedge \neg L_N \wedge \neg L_P ,\ \neg L_M \wedge L_N \wedge \neg L_P ,\ \neg L_M \wedge \neg L_N \wedge L_P \}$

or, even more succinctly, $\{ L_M ,\ L_N ,\ L_P \}$

which, in turn, induces fragmentation $F' = \{ PROJ'_1 , PROJ'_2 , PROJ'_3 \}$

PROJ

PNO	PNAME	BUDGET	LOC
P1	Instrumentation	150000	Montreal
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P3	CAD/CAM	250000	New York
P4	Maintenance	310000	Paris

$PROJ'_1$

PNO	PNAME	BUDGET	LOC
P1	Instrumentation	150000	Montreal

$PROJ'_2$

PNO	PNAME	BUDGET	LOC
P2	Database Develop.	135000	New York
P3	CAD/CAM	250000	New York

$PROJ'_3$

PNO	PNAME	BUDGET	LOC
P4	Maintenance	310000	Paris

Completeness of the Set of Simple Predicates

- Sets of simple predicates (and thus sets of minterms) should be complete and minimal
- Intuitively, *complete* means that all applications (queries) are taken into account
- Definition: a set of simple predicates *Pr* is said to be complete if and only if any two tuples in a fragment induced by *Pr* have the same probability of being accessed by any application

Informal definition (completeness): **in other words**, we have that

every application Q access either **all** or **none** of the tuples of a fragment *F*

(for every fragment *F* induced by *Pr*)

Completeness – Examples

Informal definition (completeness): Q and Q' access either **all** or **none** of the tuples in each fragment

- Only 2 applications Q and Q'
- Q: find projects with budget less than 200 000 €
- Q': find projects based in New York
- Is S' = { LOC = "New York" } complete wrt. appl. Q and Q' ?

PROJ

PNO	PNAME	BUDGET	LOC
P1	Instrumentation	150000	Montreal
P2	Database Develop.	135000	New York
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- Only 2 applications Q and Q'
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- Q': find projects based in New York
- Is S' = { LOC = "New York" } complete wrt. appl. Q and Q' ?
  - it produces F = { $PROJ_1$, $PROJ_2$ }
  - Q only accesses project P2 in fragment $PROJ_1$

$PROJ_1$

PNO	PNAME	BUDGET	LOC
P2	Database Develop.	135000	New York
P3	CAD/CAM	250000	New York

$PROJ_2$

PNO	PNAME	BUDGET	LOC
P1	Instrumentation	150000	Montreal
P4	Maintenance	310000	Paris

PROJ

PNO	PNAME	BUDGET	LOC
P1	Instrumentation	150000	Montreal
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Informal definition (completeness): Q and Q' access either **all** or **none** of the tuples in each fragment

- Only 2 applications Q and Q'
- Q: find projects with budget less than 200 000 €
- Q': find projects based in New York
- Is S' = { LOC = "New York" } complete wrt. appl. Q and Q' ?
  - **NO!**
    - it produces F = { $PROJ_1$, $PROJ_2$ }
    - Q only accesses project P2 in fragment $PROJ_1$

$PROJ_1$

PNO	PNAME	BUDGET	LOC
P2	Database Develop.	135000	New York
P3	CAD/CAM	250000	New York

$PROJ_2$

PNO	PNAME	BUDGET	LOC
P1	Instrumentation	150000	Montreal
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PROJ

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P1	Instrumentation	150000	Montreal
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Completeness – Examples

Informal definition (completeness): *Q* and *Q′* access either **all** or **none** of the tuples in each fragment

- Only 2 applications *Q* and *Q′*
- *Q*: find projects with budget less than 200 000 €
- *Q′*: find projects based in New York
- Is *S′* = { LOC = "New York" } complete wrt. appl. *Q* and *Q′* ?
  - **NO!**
    - it produces *F* = { $PROJ_1$, $PROJ_2$ }
    - *Q* only accesses project P2 in fragment $PROJ_1$

$PROJ_1$

PNO	PNAME	BUDGET	LOC
P2	Database Develop.	135000	New York
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$PROJ_2$

PNO	PNAME	BUDGET	LOC
P1	Instrumentation	150000	Montreal
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- *S″* = {BUDGET < 200000 , LOC = "New York" } is **complete** wrt. appl. *Q* and *Q′*
  - it produces the minterm set (L_N stands for LOC = "New York")

$$M_{S''} = \{ \text{BUDGET} < 200000 \land \neg L_N ,\ \text{BUDGET} \geq 200000 \land \neg L_N ,\ \text{BUDGET} < 200000 \land L_N ,\ \text{BUDGET} \geq 200000 \land L_N \}$$

PROJ

PNO	PNAME	BUDGET	LOC
P1	Instrumentation	150000	Montreal
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Completeness – Examples

Informal definition (completeness): Q and Q' access either **all** or **none** of the tuples in each fragment

- Only 2 applications Q and Q'
- Q: find projects with budget less than 200 000 €
- Q': find projects based in New York
- Is S' = { LOC = "New York" } complete wrt. appl. Q and Q' ?
  - **NO!**
    - it produces F = { $PROJ_1$, $PROJ_2$ }
    - Q only accesses project P2 in fragment $PROJ_1$

$PROJ_1$

PNO	PNAME	BUDGET	LOC
P2	Database Develop.	135000	New York
P3	CAD/CAM	250000	New York

$PROJ_2$

PNO	PNAME	BUDGET	LOC
P1	Instrumentation	150000	Montreal
P4	Maintenance	310000	Paris

- S'' = {BUDGET < 200000 , LOC = "New York" } is **complete** wrt. appl. Q and Q'
  - it produces the minterm set (L_N stands for LOC = "New York")

$M_{S''}$ = { BUDGET < 200000 $\wedge \neg L_N$, BUDGET $\geq$ 200000 $\wedge \neg L_N$, BUDGET < 200000 $\wedge L_N$, BUDGET $\geq$ 200000 $\wedge L_N$, }

PROJ

PNO	PNAME	BUDGET	LOC
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Minimality of the Set of Simple Predicates

- Set of simple predicates (and thus sets of minterms) should be complete and minimal

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- Set of simple predicates (and thus sets of minterms) should be complete and minimal
- Intuitively, *minimal* means that all predicates should be relevant in the set:
  - relevant wrt. to final fragmentation (every predicate produces some fragments *not produced by other predicates in Pr*)
  - relevant wrt. to applications (there is at least one application that benefits from the predicate): guaranteed if the choice of the set of simple predicates is driven by applications

Minimality of the Set of Simple Predicates

- Set of simple predicates (and thus sets of minterms) should be complete and minimal
- Intuitively, *minimal* means that all predicates should be relevant in the set:
  - relevant wrt. to final fragmentation (every predicate produces some fragments *not produced by other predicates in Pr*)
  - relevant wrt. to applications (there is at least one application that benefits from the predicate): guaranteed if the choice of the set of simple predicates is driven by applications
- Definition: a set of simple predicates *Pr* is said to be minimal if and only if every predicates $p \in Pr$ creates a new fragment (i.e., *p* divides fragment *F* into F_1 and F_2) and F_1 and F_2 are accessed differently by at least one application

  In other words: we look for a set of simple predicates *Pr* that is complete and such that every subset of *Pr* is not complete (minimality)

PHF – Algorithm (Intuition)

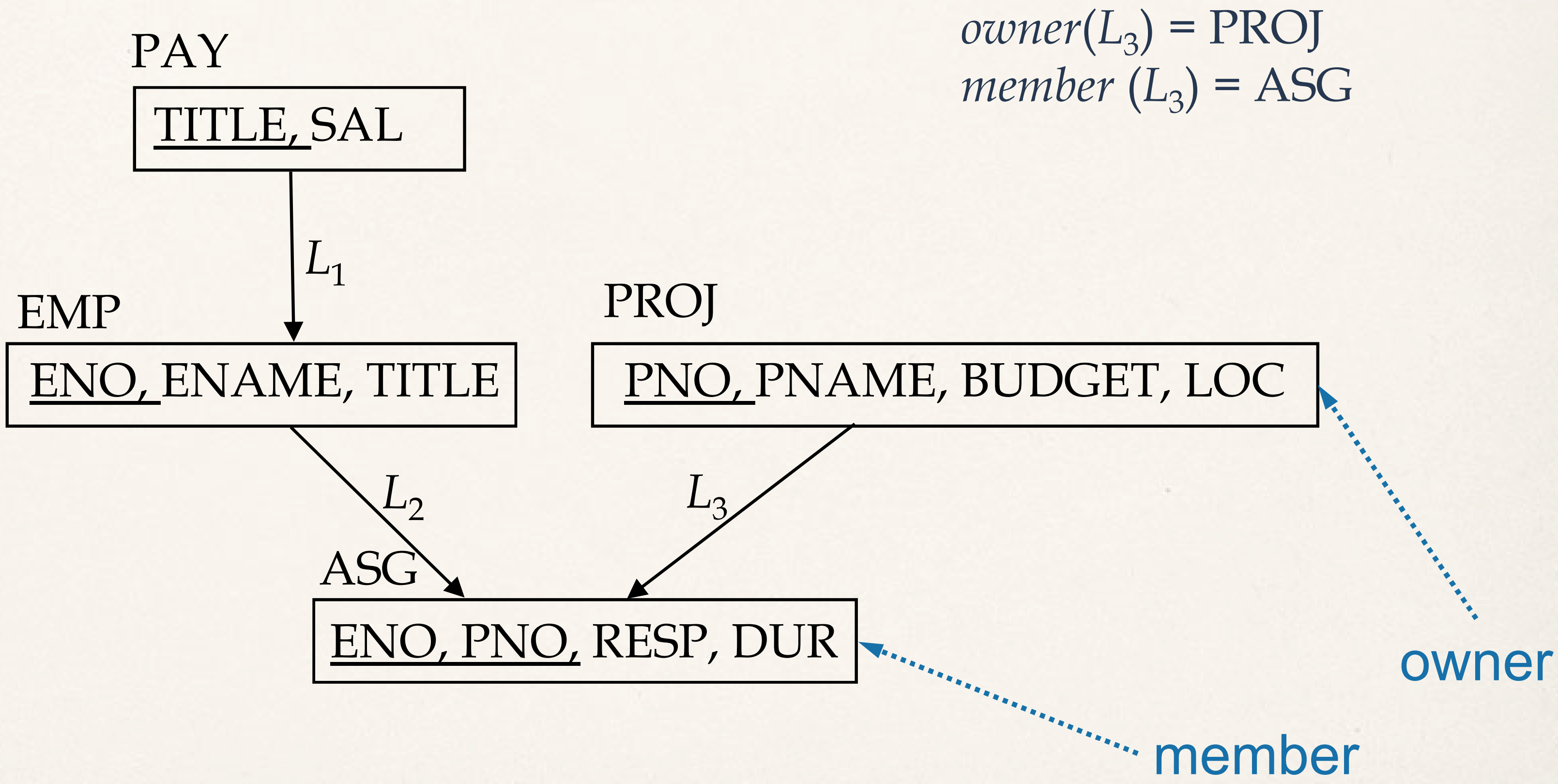
Input: a relation *R*

Output: a fragmentation schema for *R*

```
obtain set S of simple predicates over attributes of R contained in queries
compute set M of minterms induced by S
eliminate contradictory minterms from M            // i.e., minterms that
                                                   // produce empty fragments
return fragmentation F = { Rm = σm(R)| m ∈ M }
```

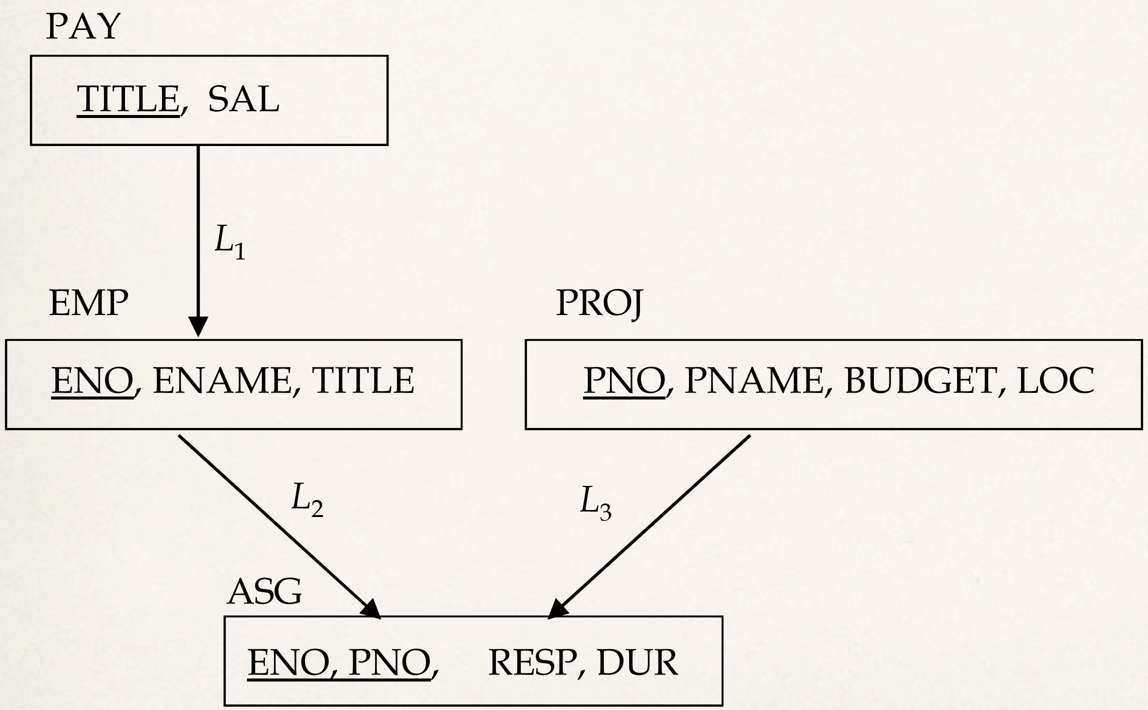
DHF – Information Requirements

- qualitative Database Information
  - relationship



Derived Horizontal Fragmentation

- Derived Horizontal Fragmentation (DHF) is defined on a member relation of a link according to a selection operation specified on its owner (propagated from owner to member)



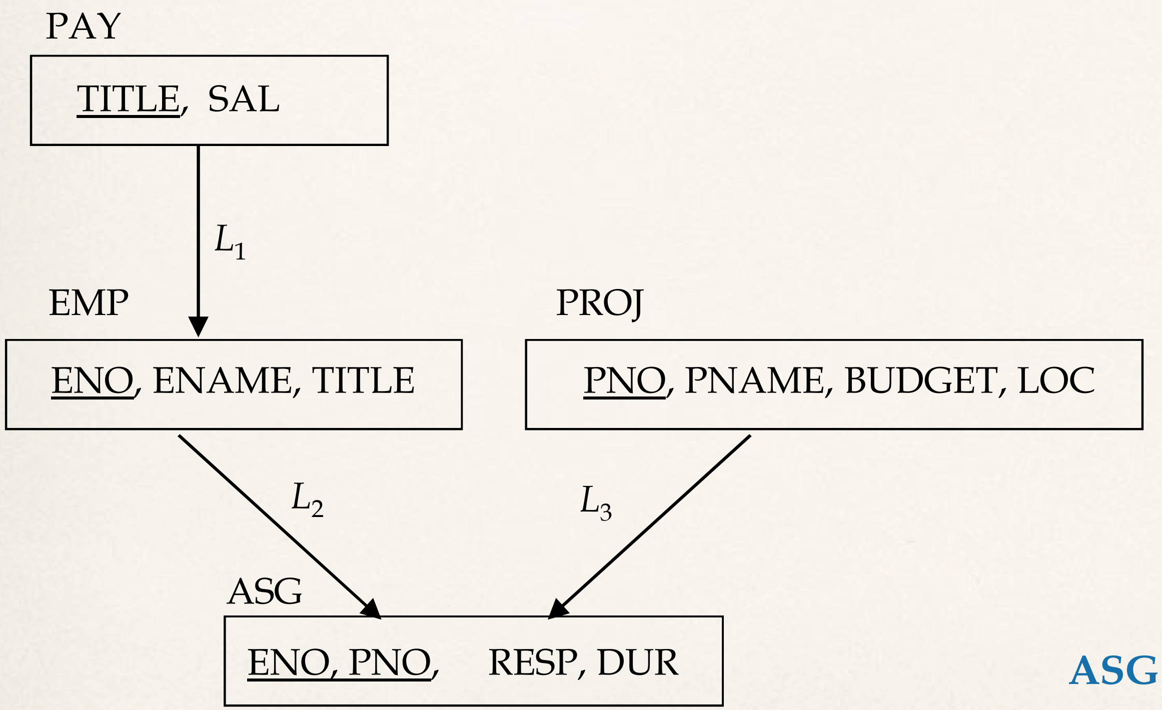
owner(L_1) = PAY
member (L_1) = EMP

owner(L_2) = EMP
member (L_2) = ASG

owner(L_3) = PROJ
member (L_3) = ASG

Derived Horizontal Fragmentation

- Derived Horizontal Fragmentation (DHF) is defined on a member relation of a link according to a selection operation specified on its owner (propagated from owner to member)



$owner(L_1)$ = PAY
$member\ (L_1)$ = EMP

$owner(L_2)$ = EMP
$member\ (L_2)$ = ASG

$owner(L_3)$ = PROJ
$member\ (L_3)$ = ASG

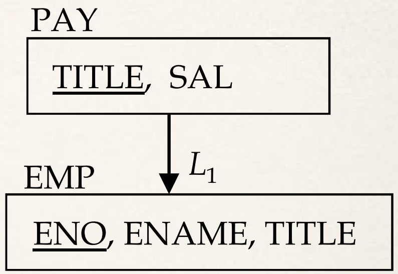
ASG could be fragmented by propagating
either fragmentation on EMP
or fragmentation on PROJ

DHF – Definition

Given

- a relation S fragmented into $F_S = \{ S_1, S_2, \ldots, S_w \}$ and
- a link L where $owner(L)=S$ and $member(L)=R$,

the derived horizontal fragments of R are defined as $R_i = R \ltimes S_i \; (S_i \in F_S)$



PAY

TITLE	SAL
Elect. Eng.	40000
Syst. Anal.	34000
Mech. Eng.	27000
Programmer	24000

EMP

ENO	ENAME	TITLE
E1	J. Doe	Elect. Eng.
E2	M. Smith	Syst. Anal.
E3	A. Lee	Mech. Eng.
E4	J. Miller	Programmer
E5	B. Casey	Syst. Anal.
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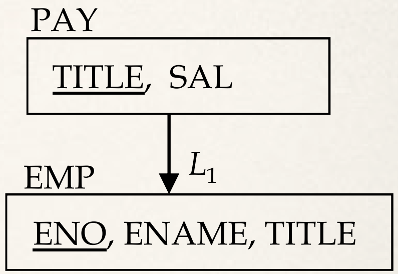

PAY$_1$

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PAY$_2$

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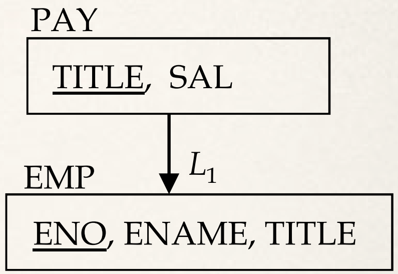

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➔

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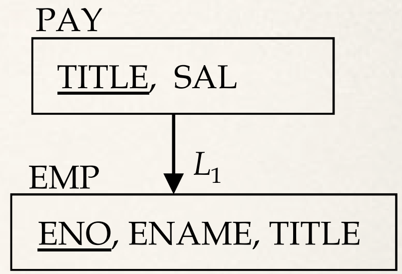

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  - PHF: minterms are **mutually exclusive** by construction
- **Completeness** and **disjointness** for **derived** horizontal fragmentation
  - Both come from **integrity constraints** of foreign keys and from completeness/disjointness of PHF
    - fragmentation propagates from *owner* to *member* following one-to-many associations; thus, each tuple of *member* is associated with exactly 1 tuple of *owner* (collect NULL-valued tuples into a separated fragment); by disjointness and completeness of PHF, such tuple of owner appears in exactly 1 fragment of owner

Vertical Fragmentation

- Has been studied within the centralized context
  - design methodology
  - physical clustering
- Choose a partition $P = \{ P_1, P_2, \ldots, P_n \}$ of the set of attribute of relation. Then,

$$F = \{ R_i \mid R_i = \Pi_{P_i \cup key}(R) \text{ and } P_i \in P \}$$

  where *key* is the (set of) key attribute(s): they are replicated in each fragment
- The problem boils down to finding the best partition
  - Number of elements of the partition
  - Distribution of attributes among elements of the partition
- More difficult than horizontal, because more alternatives exist
  - Number of possible partitions of a set of size n is the Bell's number B_n (its growth rate is more than exponential)
- Two approaches :
  - Grouping (bottom-up) – from single attributes to fragments
  - Splitting (top-down) – from relation to fragments
    - preferable for 2 reasons
      - close to the design approach
      - optimal solution is more likely to be close to the full relation than to the fully fragmented situation

VF – The General Idea

- Partition is guided by a measure of affinity (“togetherness”)
- Affinity measures how much attributes that are accessed together by queries

VF – Information Requirements (Qualitative Application Info)

- The matrix ***use(q, A)*** for attribute usage values
  - ➡ R relation over attributes $A_1, A_2, \ldots, A_n$
  - ➡ $Q = \{q_1, q_2, \ldots, q_q\}$: set of queries that will run on R
    - ✦ (the 80/20 rule can be used here, too: select the most active 20% of queries only)

$$use(q_i, A_j) = \begin{cases} 1 \text{ if attribute } A_j \text{ is referenced by query } q_i \\ 0 \text{ otherwise} \end{cases}$$

VF – Example of $use(q_i,A_j)$

Consider the following 4 queries for relation PROJ

q_1: **SELECT** BUDGET
FROM PROJ
WHERE PNO=Value

q_2: **SELECT** PNAME,BUDGET
FROM PROJ

q_3: **SELECT** PNAME
FROM PROJ
WHERE LOC=Value

q_4: **SELECT** **SUM**(BUDGET)
FROM PROJ
WHERE LOC=Value

use(q, A)

	PNO	*PNAME*	*BUDGET*	*LOC*
q_1	1	0	1	0
q_2	0	1	1	0
q_3	0	1	0	1
q_4	0	0	1	1

VF – Information Requirements (Quantitative Application Info)

- matrix *acc(q)* for the frequency of ***q***
- attribute affinity measure $aff(A_i, A_j)$ between any two attributes A_i and A_j of a relation R with respect to a set of applications Q

$$aff(A_i, A_j) = \sum_{\text{all queries } q} use(q, A_i) * use(q, A_j) * acc(q)$$

we are considering frequencies only of queries q that access both A_i and A_j, i.e., $use(q, A_i) = use(q, A_j) = 1$

use(q, A)	*PNO*	*PNAME*	*BUDGET*	*LOC*
q_1	1	0	1	0
q_2	0	1	1	0
q_3	0	1	0	1
q_4	0	0	1	1

VF – Computation of $aff(A_i, A_j)$

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- Example: affinity between *PNO* and *BUDGET*
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- Also consider the access frequencies: *acc*(***q***)

use(q, A)

	PNO	*PNAME*	*BUDGET*	*LOC*
q_1	1	0	1	0
q_2	0	1	1	0
q_3	0	1	0	1
q_4	0	0	1	1

acc(q)

q_1	45
q_2	5
q_3	75
q_4	3

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***aff*(A_i, A_j)**

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PNO	45	0	45	0
PNAME	0	80	5	75
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- Then, ***aff*(*PNO, BUDGET*)** = 45
- *aff*(. , .) is stored in the **attribute affinity matrix** *AA*
- Any clustering algorithm based on the attribute affinity values
  - Bond energy algorithm
  - Neural network
  - Machine learning
  - **(some details later in the course)**

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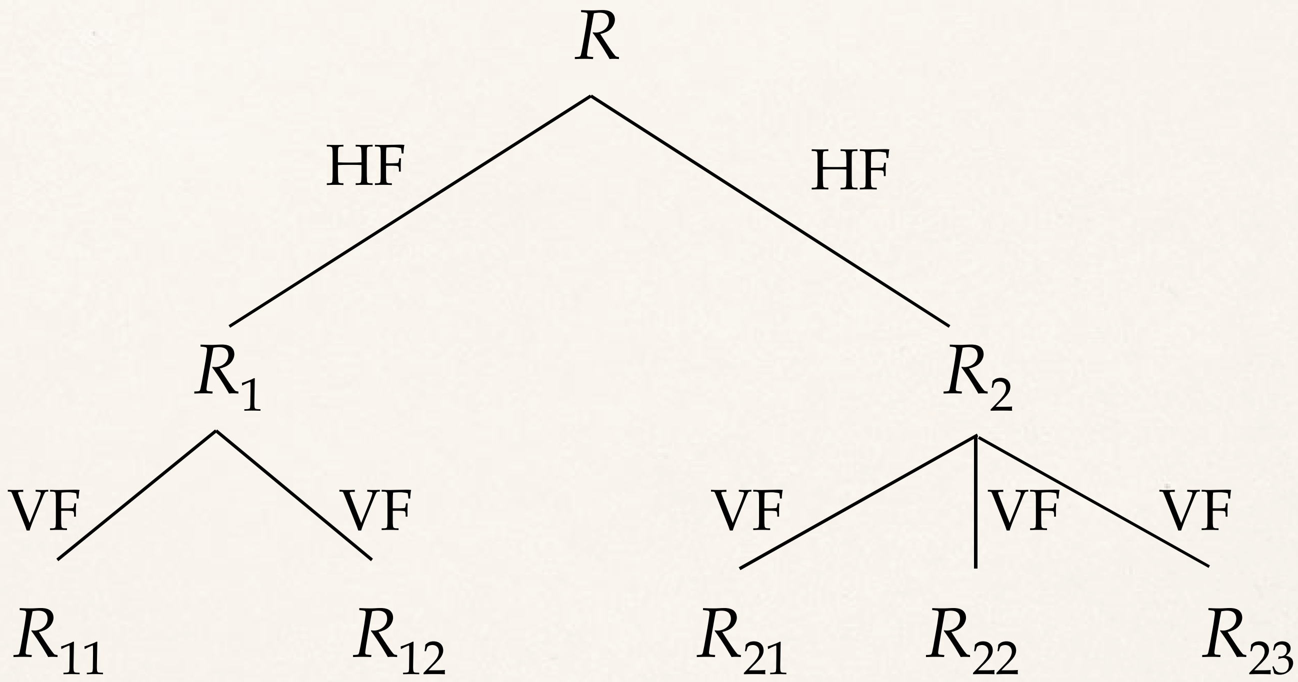
- Reconstruction
  - ➡ Let $F_R = \{R_1, R_2, \ldots, R_n\}$ be the vertical fragmentation obtained for R
  - ➡ R is recovered by joining the fragments

$$R = R_1 \bowtie R_2 \bowtie \ldots \bowtie R_n$$

Hybrid Fragmentation

Hybrid fragmentation, aka *mixed* or *nested fragmentation*



To reconstruct *R*: start from the leaves and move upward applying fragmentation reconstruction methods depending on fragmentation types

Fragment Allocation

- Fragment allocation concerns distribution of resources across network nodes
  - Assignment (possibly with replications) of fragments to sites
- Problem formalization
  - Given

    $F = \{F_1, F_2, \ldots, F_n\}$ fragments

    $S = \{S_1, S_2, \ldots, S_m\}$ network sites

    Qualitative and quantitative information about DB, applications, network, and computer system

    Find the best ("optimal") distribution of fragments in F among sites in S according to information
- Optimality factors
  - Minimal cost
    - Communication, Storage (of F_i at site s_j), Querying (F_i at site s_j , from site s_k), Updating (F_i at all sites where it is replicated, from site s_k)
  - Performance
    - Response time and/or total time
  - Can be formulated as an operations research problem
    - one of the above optimality factors is the cost function to minimize, the others are constraint to satisfy)

```
min (cost function)          e.g., response/total time
s.t. constraints             e.g., storage/communication capacity
```

    - techniques and heuristics from the field of operations research apply (no optimal solution, NP-hard)

Data directory

- Data directory (aka. data dictionary or catalog)
- Both in classic (centralized) and distributed DB, it stores metadata about DB
  - ➡ Centralized context
    - ✦ Schema (relation metadata) definitions
    - ✦ Usage statistics
    - ✦ Memory usage
    - ✦ ...
  - ➡ Distributed context
    - ✦ Info to reconstruct global view of whole DB
    - ✦ What relation/fragment is stored at which site
    - ✦ ...
- It is itself part of the DB, so considerations about fragmentation and allocation issues apply