Outline

- Introduction
- Background
- Distributed DBMS Architecture
- Distributed Database Design
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  - Data Location
- Semantic Data Control
- Distributed Query Processing
- Distributed Transaction Management
- Distributed Database Operating Systems
- Open Systems and Interoperability
- Parallel Database Systems
- Distributed Object Management
- Concluding Remarks

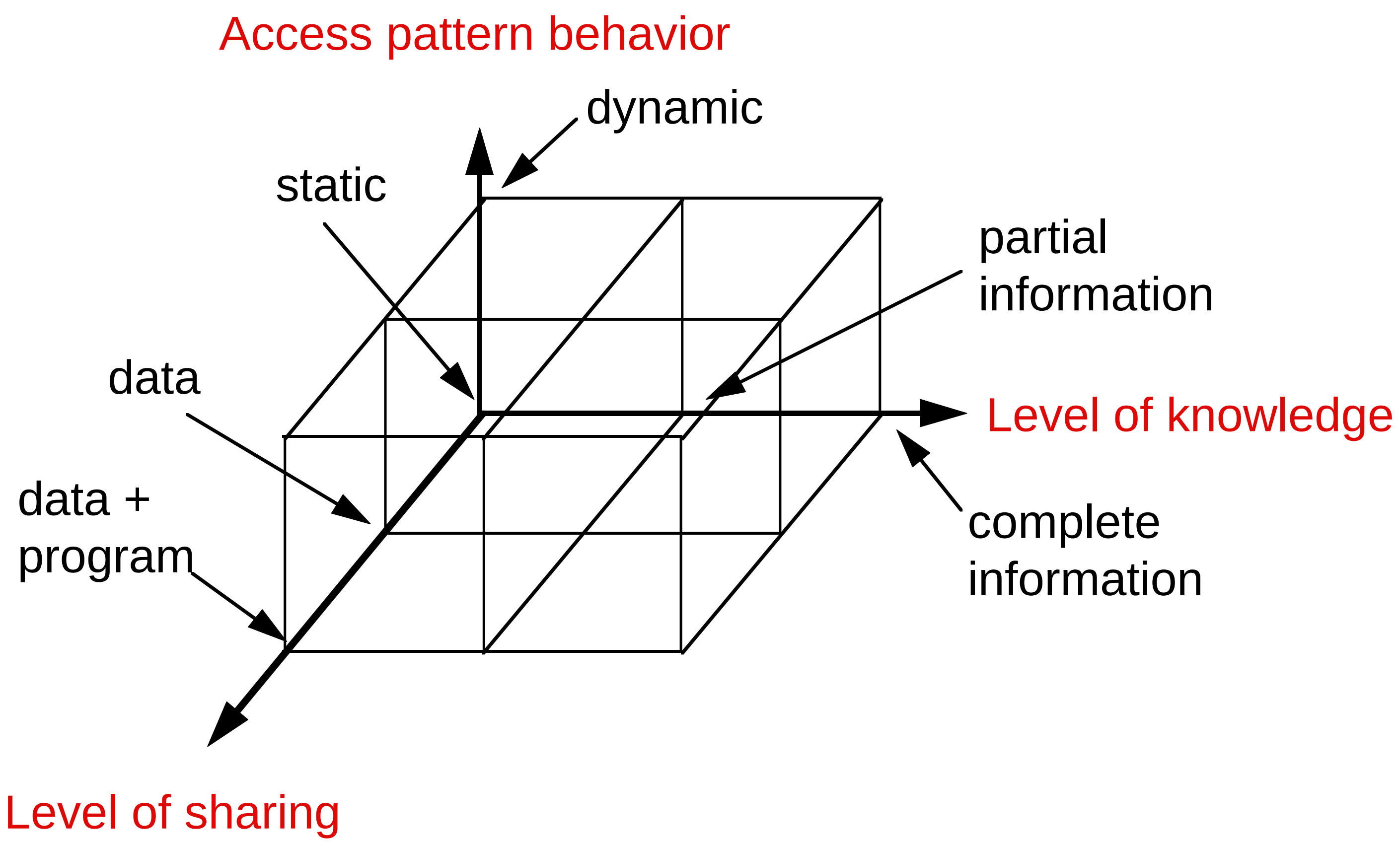
Design Problem

- In the general setting :

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

- In Distributed DBMS, the placement of applications entails
  - placement of the distributed DBMS software; and
  - placement of the applications that run on the database

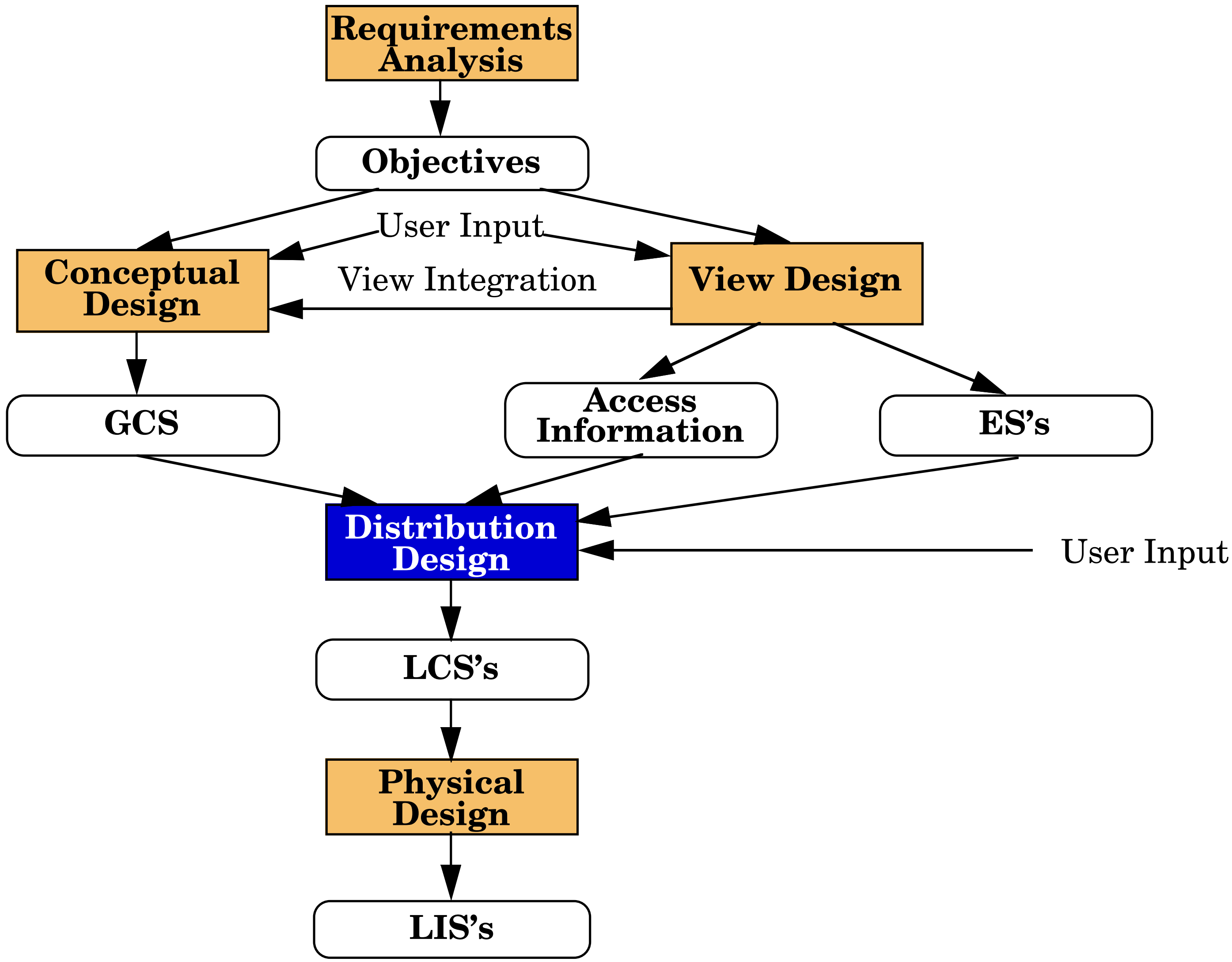
Dimensions of the Problem



Distribution Design

- Top-down
  - mostly in designing systems from scratch
  - mostly in homogeneous systems
- Bottom-up
  - when the databases already exist at a number of sites

Top-Down Design



Distribution Design Issues

❶ Why fragment at all?

❷ How to fragment?

❸ How much to fragment?

❹ How to test correctness?

❺ How to allocate?

❻ Information requirements?

Fragmentation

- Can't we just distribute relations?
- What is a reasonable unit of distribution?
  - relation
    - views are subsets of relations ⇨ locality
    - extra communication
  - fragments of relations (sub-relations)
    - concurrent execution of a number of transactions that access different portions of a relation
    - views that cannot be defined on a single fragment will require extra processing
    - semantic data control (especially integrity enforcement) more difficult

Fragmentation Alternatives – Horizontal

J_1 : projects with budgets less than \$200,000

J_2 : projects with budgets greater than or equal to \$200,000

J

JNO	JNAME	BUDGET	LOC
J1	Instrumentation	150000	Montreal
J2	Database Develop.	135000	New York
J3	CAD/CAM	250000	New York
J4	Maintenance	310000	Paris
J5	CAD/CAM	500000	Boston

J_1

JNO	JNAME	BUDGET	LOC
J1	Instrumentation	150000	Montreal
J2	Database Develop.	135000	New York

J_2

JNO	JNAME	BUDGET	LOC
J3	CAD/CAM	250000	New York
J4	Maintenance	310000	Paris
J5	CAD/CAM	500000	Boston

Fragmentation Alternatives – Vertical

J_1: information about project budgets

J_2: information about project names and locations

J

JNO	JNAME	BUDGET	LOC
J1	Instrumentation	150000	Montreal
J2	Database Develop.	135000	New York
J3	CAD/CAM	250000	New York
J4	Maintenance	310000	Paris
J5	CAD/CAM	500000	Boston

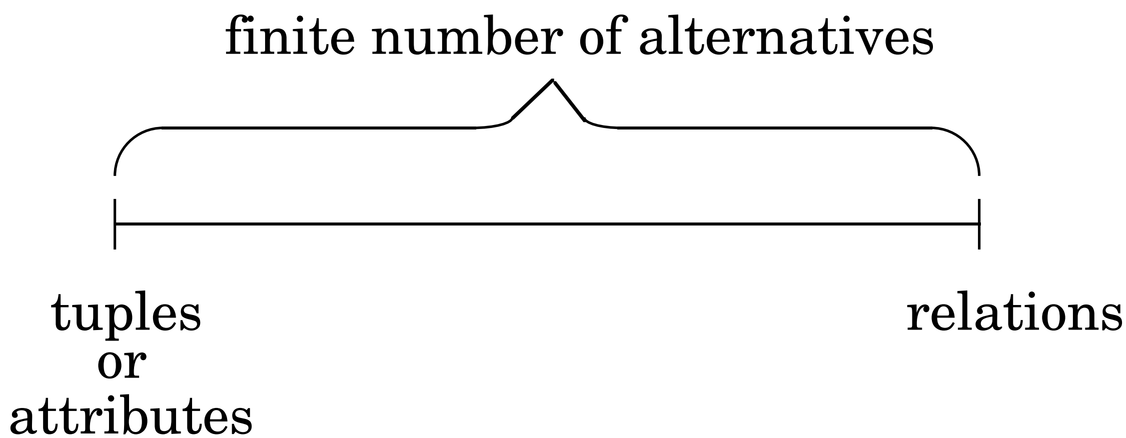
J_1

JNO	BUDGET
J1	150000
J2	135000
J3	250000
J4	310000
J5	500000

J_2

JNO	JNAME	LOC
J1	Instrumentation	Montreal
J2	Database Develop.	New York
J3	CAD/CAM	New York
J4	Maintenance	Paris
J5	CAD/CAM	Boston

Degree of Fragmentation



Finding the suitable level of partitioning within this range

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 $(k \neq j)$.

Allocation Alternatives

- Non-replicated
  - partitioned : each fragment resides at only one site
- Replicated
  - fully replicated : each fragment at each site
  - partially replicated : each fragment at some of the sites
- Rule of thumb:

If $\frac{\text{read - only queries}}{\text{update quries}} \geq 1$ replication is advantageous,

otherwise replication may cause problems

Comparison of Replication Alternatives

	Full-replication	Partial-replication	Partitioning
QUERY PROCESSING	Easy	Same Difficulty	
DIRECTORY MANAGEMENT	Easy or Non-existant	Same Difficulty	
CONCURRENCY CONTROL	Moderate	Difficult	Easy
RELIABILITY	Very high	High	Low
REALITY	Possible application	Realistic	Possible application

Information Requirements

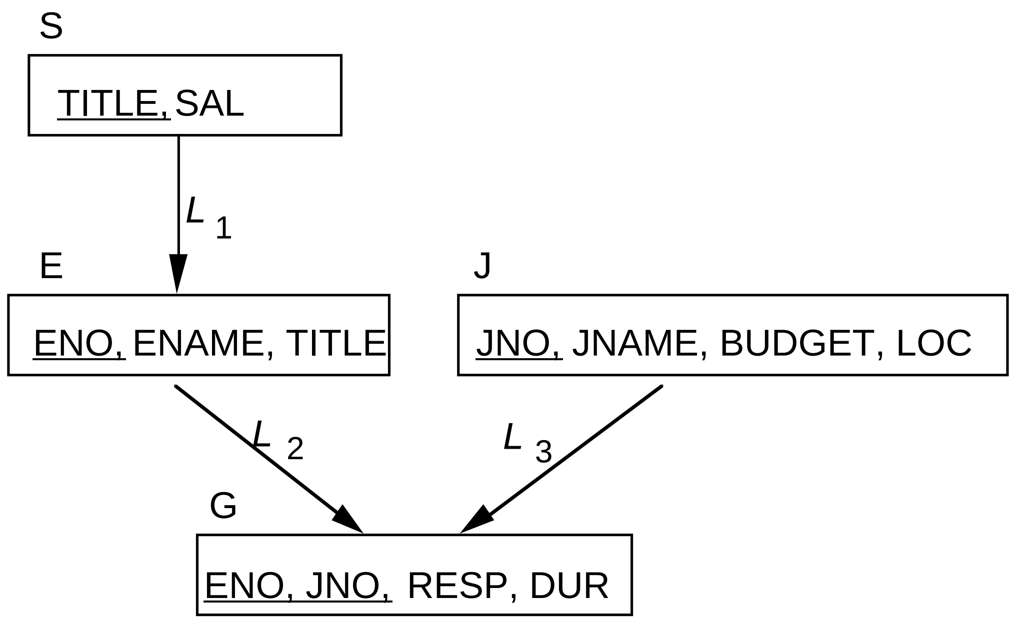
- Four categories :
  - Database information
  - Application information
  - Communication network information
  - Computer system information

Fragmentation

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

PHF – Information Requirements

- Database Information
  - relationship



  - cardinality of each relation: $card(R)$

PHF - Information Requirements

- Application Information
  - **simple predicates** : Given $R[A_1, A_2, \ldots, A_n]$, a simple predicate p_j is

    $$p_j : A_i \ \theta \ Value$$

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

    For relation R we define $Pr = \{p_1, p_2, \ldots, p_m\}$

    Example :

    JNAME = "Maintenance"

    BUDGET ≤ 200000
  - **minterm predicates** : Given R and $Pr=\{p_1, p_2, \ldots, p_m\}$

    define $M=\{m_1, m_2, \ldots, m_r\}$ as

    $$M=\{ m_i \mid m_i = \wedge_{p_j \in Pr} \ p_j^* \}, 1 \leq j \leq m, 1 \leq i \leq z$$

    where $p_j^* = p_j$ or $p_j^* = \neg(p_j)$.

PHF – Information Requirements

Example

m_1: JNAME="Maintenance"$\wedge$ BUDGET$\leq$200000

m_2: NOT(JNAME="Maintenance")$\wedge$ BUDGET$\leq$200000

m_3: JNAME= "Maintenance"$\wedge$ **NOT**(BUDGET$\leq$200000)

m_4: **NOT**(JNAME="Maintenance")$\wedge$ **NOT**(BUDGET$\leq$200000)

PHF – Information Requirements

- Application Information
  - **minterm selectivities**: $sel(m_i)$
    - The number of tuples of the relation that would be accessed by a user query which is specified according to a given minterm predicate *mi*.
  - **access frequencies**: $acc(q_i)$
    - The frequency with which a user application *qi* accesses data.
    - Access frequency for a minterm predicate can also be defined.

Primary Horizontal Fragmentation

Definition :

$$R_j = \sigma_{F_j}(R), \ 1 \leq j \leq w$$

where F_j is a selection formula, which is (preferably) a minterm predicate.

Therefore,

A horizontal fragment R_i of relation R consists of all the tuples of R which satisfy a minterm predicate m_i.

$$\Downarrow$$

Given a set of minterm predicates M, there are as many horizontal fragments of relation R as there are minterm predicates.

Set of horizontal fragments also referred to as *minterm fragments*.

PHF – Algorithm

Given: A relation R, the set of simple predicates Pr

Output: The set of fragments of $R = \{R_1, R_2,\ldots,R_w\}$ which obey the fragmentation rules.

Preliminaries :

- Pr should be *complete*
- Pr should be *minimal*

Completeness of Simple Predicates

- A set of simple predicates *Pr* is said to be *complete* if and only if the accesses to the tuples of the minterm fragments defined on *Pr* requires that two tuples of the same minterm fragment have the same probability of being accessed by any application.

- Example :
  - Assume J[JNO,JNAME,BUDGET,LOC] has two applications defined on it.
  - Find the budgets of projects at each location. (1)
  - Find projects with budgets less than $200000. (2)

Completeness of Simple Predicates

According to (1),

Pr={LOC="Montreal",LOC="New York",LOC="Paris"}

which is not complete with respect to (2).

Modify

Pr ={LOC="Montreal",LOC="New York",LOC="Paris",
BUDGET≤200000,BUDGET>200000}

which is complete.

Minimality of Simple Predicates

- If a predicate influences how fragmentation is performed, (i.e., causes a fragment f to be further fragmented into, say, f_i and f_j) then there should be at least one application that accesses f_i and f_j differently.
- In other words, the simple predicate should be *relevant* in determining a fragmentation.
- If all the predicates of a set Pr are relevant, then Pr is *minimal*.

$$\frac{acc(m_i)}{card(f_i)} \neq \frac{acc(m_j)}{card(f_j)}$$

Minimality of Simple Predicates

Example :

Pr ={LOC="Montreal",LOC="New York", LOC="Paris",
BUDGET≤200000,BUDGET>200000}

is minimal (in addition to being complete).
However, if we add

JNAME = "Instrumentation"

then Pr is not minimal.

COM_MIN Algorithm

Given: a relation R and a set of simple predicates Pr

Output: a *complete* and *minimal* set of simple predicates Pr' for Pr

Rule 1: a relation or fragment is partitioned into at least two parts which are accessed differently by at least one application.

COM_MIN Algorithm

❶ Initialization :

- find a $p_i \in Pr$ such that p_i partitions R according to *Rule 1*
- set $Pr' = p_i$; $Pr \leftarrow Pr - p_i$; $F \leftarrow f_i$

❷ Iteratively add predicates to Pr' until it is complete

- find a $p_j \in Pr$ such that p_j partitions some f_k defined according to minterm predicate over Pr' according to *Rule 1*
- set $Pr' = Pr' \cup p_i$; $Pr \leftarrow Pr - p_i$; $F \leftarrow F \cup f_i$
- if $\exists\, p_k \in Pr'$ which is nonrelevant then

  $Pr' \leftarrow Pr' - p_k$

  $F \leftarrow F - f_k$

PHORIZONTAL Algorithm

Makes use of COM_MIN to perform fragmentation.

Input: a relation R and a set of simple predicates Pr

Output: a set of minterm predicates M according to which relation R is to be fragmented

❶ $Pr' \leftarrow$ COM_MIN (R,Pr)

❷ determine the set M of minterm predicates

❸ determine the set I of implications among $p_i \in Pr$

❹ eliminate the contradictory minterms from M

PHF – Example

- Two candidate relations : S and J.
- Fragmentation of relation S
  - Application: Check the salary info and determine raise.
  - Employee records kept at two sites $\Rightarrow$ application run at two sites
  - Simple predicates

    p_1 : SAL $\leq$ 30000

    p_2 : SAL $>$ 30000

    $Pr = \{p_1,p_2\}$ which is complete and minimal $Pr'=Pr$
  - Minterm predicates

    m_1 : (SAL $\leq$ 30000) $\wedge$ (SAL $>$ 30000)

    m_2 : (SAL $\leq$ 30000) $\wedge$ **NOT**(SAL $>$ 30000)

    m_3 : **NOT**(SAL $\leq$ 30000) $\wedge$ (SAL $>$ 30000)

    m_4 : **NOT**(SAL $\leq$ 30000) $\wedge$ **NOT**(SAL $>$ 30000)

PHF – Example

- Fragmentation of relation S (continued)
  - Implications

$$i_1 : (\text{SAL} \leq 30000) \Rightarrow \textbf{NOT}(\text{SAL} > 30000)$$

$$i_2 : \textbf{NOT}(\text{SAL} \leq 30000) \Rightarrow (\text{SAL} > 30000)$$

$$i_3 : (\text{SAL} > 30000) \Rightarrow \textbf{NOT}(\text{SAL} \leq 30000)$$

$$i_4 : \textbf{NOT}(\text{SAL} > 30000) \Rightarrow (\text{SAL} \leq 30000)$$

  - m_1 is contradictory to i_1, m_4 is contradictory to i_2.

S_1

TITLE	SAL
Mech. Eng.	27000
Programmer	24000

S_2

TITLE	SAL
Elect. Eng.	40000
Syst. Anal.	34000

PHF – Example

- Fragmentation of relation J
  - Applications:
    - Find the name and budget of projects given their no.
      - ✔Issued at three sites
    - Access project information according to budget
      - ✔one site accesses ≤200000 other accesses >200000
  - Simple predicates
  - For application (1)

    p_1 : LOC = "Montreal"

    p_2 : LOC = "New York"

    p_3 : LOC = "Paris"
  - For application (2)

    p_4 : BUDGET ≤ 200000

    p_5 : BUDGET > 200000
  - $Pr = Pr' = \{p_1, p_2, p_3, p_4, p_5\}$

PHF – Example

- Fragmentation of relation J continued
  - Minterm fragments left after elimination

m_1 : (LOC = "Montreal") $\wedge$ (BUDGET $\leq$ 200000)

m_2 : (LOC = "Montreal") $\wedge$ (BUDGET $>$ 200000)

m_3 : (LOC = "New York") $\wedge$ (BUDGET $\leq$ 200000)

m_4 : (LOC = "New York") $\wedge$ (BUDGET $>$ 200000)

m_5 : (LOC = "Paris") $\wedge$ (BUDGET $\leq$ 200000)

m_6 : (LOC = "Paris") $\wedge$ (BUDGET $>$ 200000)

PHF – Example

J_1

JNO	JNAME	BUDGET	LOC
J1	Instrumentation	150000	Montreal

J_2

JNO	JNAME	BUDGET	LOC
J2	Database Develop.	135000	New York

J_4

JNO	JNAME	BUDGET	LOC
J3	CAD/CAM	250000	New York

J_6

JNO	JNAME	BUDGET	LOC
J4	Maintenance	310000	Paris

PHF – Correctness

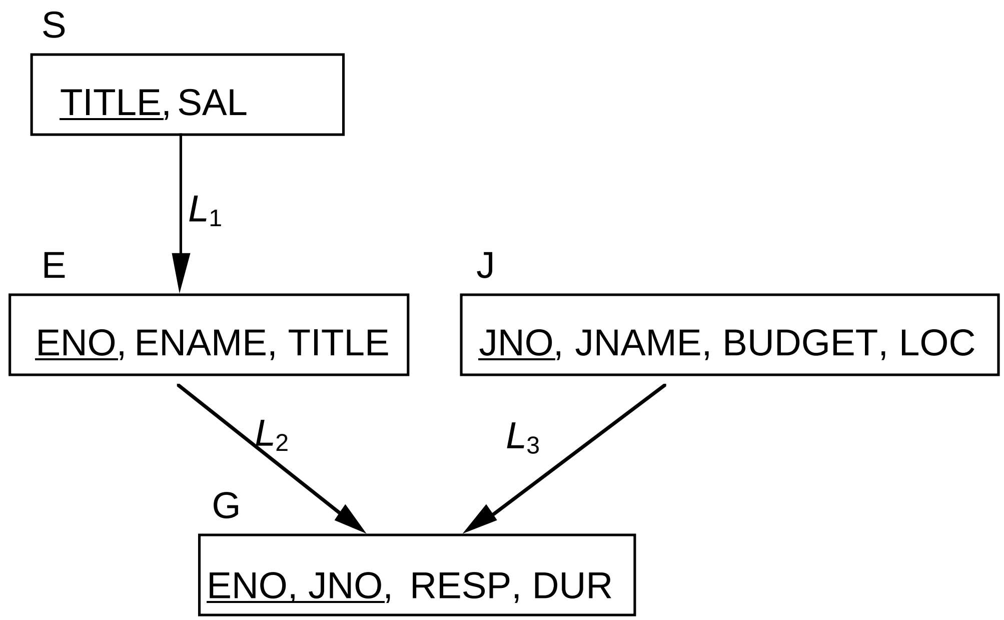
- Completeness
  - Since Pr' is complete and minimal, the selection predicates are complete
- Reconstruction
  - If relation R is fragmented into $F_R = \{R_1, R_2, \ldots, R_r\}$

$$R = \bigcup_{\forall R_i \in F_R} R_i$$

- Disjointness
  - Minterm predicates that form the basis of fragmentation should be mutually exclusive.

Derived Horizontal Fragmentation

- Defined on a member relation of a link according to a selection operation specified on its owner.
  - Each link is an equijoin.
  - Equijoin can be implemented by means of semijoins.



DHF – Definition

Given a link L where $owner(L)=S$ and $member(L)=R$, the derived horizontal fragments of R are defined as

$$R_i = R \ltimes_F S_i,\ 1 \leq i \leq w$$

where w is the maximum number of fragments that will be defined on R and

$$S_i = \sigma_{F_i}(S)$$

where F_i is the formula according to which the primary horizontal fragment S_i is defined.

DHF – Example

Given link L_1 where owner(L_1)=S and member(L_1)=E

$$E_1 = E \ltimes S_1$$

$$E_2 = E \ltimes S_2$$

where

$$S_1 = \sigma_{SAL \leq 30000}(S)$$

$$S_2 = \sigma_{SAL > 30000}(S)$$

E_1

ENO	ENAME	TITLE
E3	A. Lee	Mech. Eng.
E4	J. Miller	Programmer
E7	R. Davis	Mech. Eng.

E_2

ENO	ENAME	TITLE
E1	J. Doe	Elect. Eng.
E2	M. Smith	Syst. Anal.
E5	B. Casey	Syst. Anal.
E6	L. Chu	Elect. Eng.
E8	J. Jones	Syst. Anal.

DHF – Correctness

- Completeness
  - Referential integrity
  - Let R be the member relation of a link whose owner is relation S which is fragmented as $F_S = \{S_1, S_2, ..., S_n\}$. Furthermore, let A be the join attribute between R and S. Then, for each tuple t of R, there should be a tuple t' of S such that

    $$t[A]=t'[A]$$
- Reconstruction
  - Same as primary horizontal fragmentation.
- Disjointness
  - Simple join graphs between the owner and the member fragments.

Vertical Fragmentation

- Has been studied within the centralized context
  - design methodology
  - physical clustering
- More difficult than horizontal, because more alternatives exist.

  Two approaches :
  - grouping
    - attributes to fragments
  - splitting
    - relation to fragments

Vertical Fragmentation

- Overlapping fragments
  - grouping
- Non-overlapping fragments
  - splitting

We do not consider the replicated key attributes to be overlapping.

Advantage:

Easier to enforce functional dependencies

(for integrity checking etc.)

VF – Information Requirements

- Application Information
  - Attribute affinities
    - a measure that indicates how closely related the attributes are
    - This is obtained from more primitive usage data
  - Attribute usage values
    - Given a set of queries $Q = \{q_1, q_2,\dots, q_q\}$ that will run on the relation $R[A_1, A_2,\dots, A_n]$,

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

$use(q_i, \bullet)$ can be defined accordingly

VF – Definition of $use(q_i, A_j)$

Consider the following 4 queries for relation J

q_1: **SELECT** BUDGET
FROM J
WHERE JNO=Value

q_2: **SELECT** JNAME,BUDGET
FROM J

q_3: **SELECT** JNAME
FROM J
WHERE LOC=Value

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

Let A_1= JNO, A_2= JNAME, A_3= BUDGET, A_4= LOC

$$\begin{array}{c c}
 & \begin{array}{cccc} A_1 & A_2 & A_3 & A_4 \end{array} \\
\begin{array}{c} q_1 \\ q_2 \\ q_3 \\ q_4 \end{array} & \begin{bmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 \end{bmatrix}
\end{array}$$

VF – Affinity Measure $aff(A_i,A_j)$

The attribute affinity measure between two attributes A_i and A_j of a relation $R[A_1, A_2, \ldots, A_n]$ with respect to the set of applications $Q = (q_1, q_2, \ldots, q_q)$ is defined as follows :

$$aff\,(A_i, A_j) = \sum_{\text{all queries that access } A_i \text{ and } A_j} (\text{query access})$$

$$\text{query access} = \sum_{\text{all sites}} \text{access frequency of a query} * \frac{\text{access}}{\text{execution}}$$

VF – Calculation of $aff(A_i, A_j)$

Assume each query in the previous example accesses the attributes once during each execution.

Also assume the access frequencies

$$\begin{array}{c c} & \begin{array}{ccc} S_1 & S_2 & S_3 \end{array} \\ \begin{array}{c} q_1 \\ q_2 \\ q_3 \\ q_4 \end{array} & \begin{bmatrix} 15 & 20 & 10 \\ 5 & 0 & 0 \\ 25 & 25 & 25 \\ 3 & 0 & 0 \end{bmatrix} \end{array}$$

Then

$$\begin{aligned} aff(A_1, A_3) &= 15*1 + 20*1+10*1 \\ &= 45 \end{aligned}$$

and the attribute affinity matrix *AA* is

$$\begin{array}{c c} & \begin{array}{cccc} A_1 & A_2 & A_3 & A_4 \end{array} \\ \begin{array}{c} A_1 \\ A_2 \\ A_3 \\ A_4 \end{array} & \begin{bmatrix} 45 & 0 & 45 & 0 \\ 0 & 80 & 5 & 75 \\ 45 & 5 & 53 & 3 \\ 0 & 75 & 3 & 78 \end{bmatrix} \end{array}$$

VF – Clustering Algorithm

- Take the attribute affinity matrix *AA* and reorganize the attribute orders to form clusters where the attributes in each cluster demonstrate high affinity to one another.
- Bond Energy Algorithm (BEA) has been used for clustering of entities. BEA finds an ordering of entities (in our case attributes) such that the global affinity measure

$$AM = \sum_{i} \sum_{j} (\text{affinity of } A_i \text{ and } A_j \text{ with their neighbors})$$

is maximized.

Bond Energy Algorithm

Input: The *AA* matrix

Output: The clustered affinity matrix *CA* which is a perturbation of *AA*

❶ *Initialization*: Place and fix one of the columns of *AA* in *CA*.

❷ *Iteration*: Place the remaining n-i columns in the remaining i+1 positions in the *CA* matrix. For each column, choose the placement that makes the most contribution to the global affinity measure.

❸ *Row order*: Order the rows according to the column ordering.

Bond Energy Algorithm

"Best" placement? Define contribution of a placement:

$$cont(A_i, A_k, A_j) = 2bond(A_i, A_k)+2bond(A_k, A_l) -2bond(A_i, A_j)$$

where

$$bond(A_x,A_y) = \sum_{z=1}^{n} aff(A_z,A_x)aff(A_z,A_y)$$

BEA – Example

Consider the following AA matrix and the corresponding CA matrix where A_1 and A_2 have been placed. Place A_3:

$$AA = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \end{array} \begin{array}{c} \begin{array}{cccc} A_1 & A_2 & A_3 & A_4 \end{array} \\ \begin{bmatrix} 45 & 0 & 5 & 0 \\ 0 & 80 & 5 & 75 \\ 45 & 5 & 53 & 3 \\ 0 & 75 & 3 & 78 \end{bmatrix} \end{array} \qquad CA = \begin{array}{c} \begin{array}{cccc} A_1 & A_2 & & \end{array} \\ \begin{bmatrix} 45 & 0 & & \\ 0 & 80 & & \\ 45 & 5 & & \\ 0 & 75 & & \end{bmatrix} \end{array}$$

Ordering (0-3-1) :

$$cont(A_0,A_3,A_1) = 2bond(A_0\ , A_3)+2bond(A_3\ , A_1)–2bond(A_0\ , A_1)$$
$$= 2*\ 0 + 2*\ 4410 – 2*0 = 8820$$

Ordering (1-3-2) :

$$cont(A_1,A_3,A_2) = 2bond(A_1\ , A_3)+2bond(A_3\ , A_2)–2bond(A_1,A_2)$$
$$= 2*\ 4410 + 2*\ 890 – 2*225 = 10150$$

Ordering (2-3-4) :

$$cont\ (A_2,A_3,A_4) = 1780$$

BEA – Example

Therefore, the *CA* matrix has to form

$$\begin{array}{c} \begin{array}{ccc} A_1 & A_3 & A_2 \end{array} \\ \begin{bmatrix} 45 & 45 & 0 \\ 0 & 5 & 80 \\ 45 & 53 & 5 \\ 0 & 3 & 75 \end{bmatrix} \end{array}$$

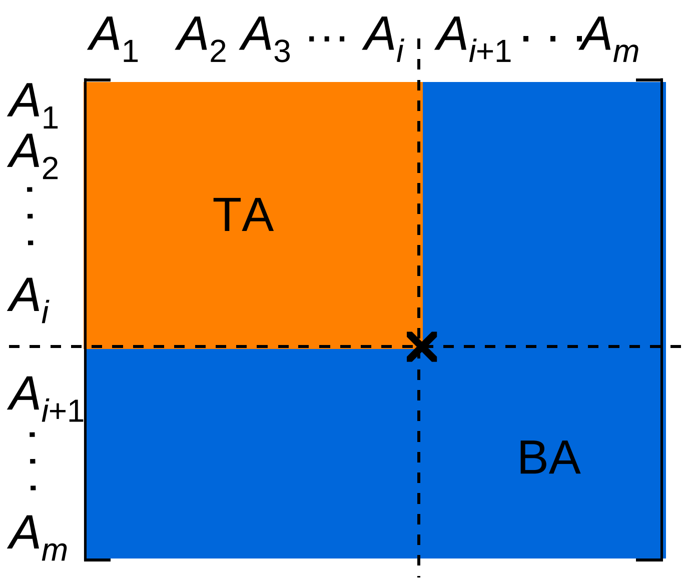
BEA – Example

When A_4 is placed, the final form of the CA matrix (after row organization) is

$$
\begin{array}{c}
 \\ A_1 \\ A_3 \\ A_2 \\ A_4
\end{array}
\begin{array}{c}
\begin{array}{cccc} A_1 & A_3 & A_2 & A_4 \end{array} \\
\left[\begin{array}{cccc}
45 & 45 & 0 & 0 \\
45 & 53 & 5 & 3 \\
0 & 5 & 80 & 75 \\
0 & 3 & 75 & 78
\end{array}\right]
\end{array}
$$

VF – Algorithm

How can you divide a set of clustered attributes $\{A_1, A_2, \ldots, A_n\}$ into two (or more) sets $\{A_1, A_2, \ldots, A_i\}$ and $\{A_i, \ldots, A_n\}$ such that there are no (or minimal) applications that access both (or more than one) of the sets.



VF – ALgorithm

Define

TQ = set of applications that access only TA

BQ = set of applications that access only BA

OQ = set of applications that access both TA and BA

and

CTQ = total number of accesses to attributes by applications that access only TA

CBQ = total number of accesses to attributes by applications that access only BA

COQ = total number of accesses to attributes by applications that access both TA and BA

Then find the point along the diagonal that maximizes

$$CTQ * CBQ - COQ^2$$

VF – Algorithm

Two problems :

❶ Cluster forming in the middle of the *CA* matrix

- Shift a row up and a column left and apply the algorithm to find the "best" partitioning point
- Do this for all possible shifts
- Cost $O(m^2)$

❷ More than two clusters

- m-way partitioning
- try 1, 2, …, m–1 split points along diagonal and try to find the best point for each of these
- Cost $O(2^m)$

VF – Correctness

A relation R, defined over attribute set A and key K, generates the vertical partitioning $F_R = \{R_1, R_2, \ldots, R_r\}$.

- Completeness
  - The following should be true for A:

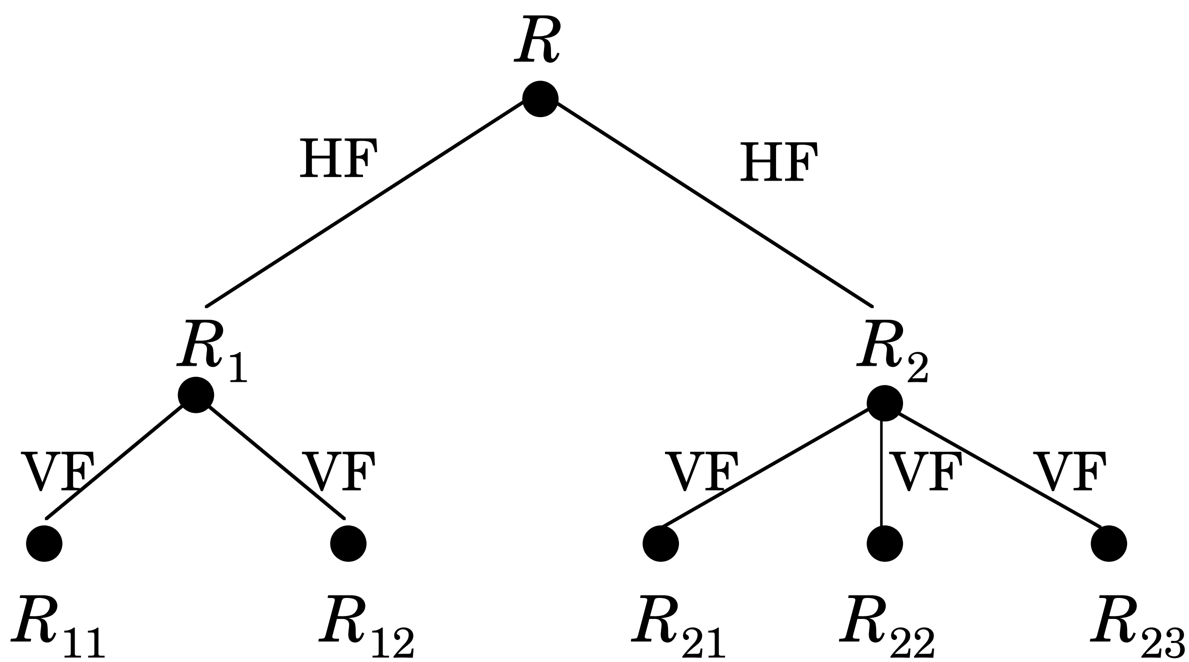
$$A = \cup A_{R_i}$$

- Reconstruction
  - Reconstruction can be achieved by

$$R = \bowtie_K R_i \; \forall R_i \in F_R$$

- Disjointness
  - TID's are not considered to be overlapping since they are maintained by the system
  - Duplicated keys are not considered to be overlapping

Hybrid Fragmentation



Fragment Allocation

- Problem Statement

  Given

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

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

  $Q = \{q_1, q_2, \ldots, q_q\}$ applications

  Find the "optimal" distribution of F to S.

- Optimality
  - Minimal cost
    - Communication + storage + processing (read & update)
    - Cost in terms of time (usually)
  - Performance

    Response time and/or throughput
  - Constraints
    - Per site constraints (storage & processing)

Information Requirements

- Database information
  - selectivity of fragments
  - size of a fragment
- Application information
  - access types and numbers
  - access localities
- Communication network information
  - unit cost of storing data at a site
  - unit cost of processing at a site
- Computer system information
  - bandwidth
  - latency
  - communication overhead

Allocation

File Allocation (FAP) vs Database Allocation (DAP):

- Fragments are not individual files
  - relationships have to be maintained
- Access to databases is more complicated
  - remote file access model not applicable
  - relationship between allocation and query processing
- Cost of integrity enforcement should be considered
- Cost of concurrency control should be considered

Allocation – Information Requirements

- Database Information
  - selectivity of fragments
  - size of a fragment
- Application Information
  - number of read accesses of a query to a fragment
  - number of update accesses of query to a fragment
  - A matrix indicating which queries updates which fragments
  - A similar matrix for retrievals
  - originating site of each query
- Site Information
  - unit cost of storing data at a site
  - unit cost of processing at a site
- Network Information
  - communication cost/frame between two sites
  - frame size

Allocation Model

General Form

min(Total Cost)

subject to

response time constraint

storage constraint

processing constraint

Decision Variable

$$x_{ij} = \begin{cases} 1 \text{ if fragment } F_i \text{ is stored at site } S_j \\ 0 \text{ otherwise} \end{cases}$$

Allocation Model

- Total Cost

$$\sum_{\text{all queries}} \text{query processing cost} +$$

$$\sum_{\text{all sites}} \sum_{\text{all fragments}} \text{cost of storing a fragment at a site}$$

- Storage Cost (of fragment F_j at S_k)

  (unit storage cost at S_k) $*$ (size of F_j) $* x_{jk}$

- Query Processing Cost (for one query)

  processing component + transmission component

Allocation Model

- Query Processing Cost

  Processing component

  access cost + integrity enforcement cost + concurrency control cost

  - Access cost

  $$\sum_{\text{all sites}} \sum_{\text{all fragments}} (\text{no. of update accesses} + \text{no. of read accesses}) * x_{ij} * \text{local processing cost at a site}$$

  - Integrity enforcement and concurrency control costs
    - Can be similarly calculated

Allocation Model

- Query Processing Cost

  Transmission component

  cost of processing updates + cost of processing retrievals

  - Cost of updates

  $$\sum_{\text{all sites}} \sum_{\text{all fragments}} \text{update message cost} \; +$$

  $$\sum_{\text{all sites}} \sum_{\text{all fragments}} \text{acknowledgment cost}$$

  - Retrieval Cost

  $$\sum_{\text{all fragments}} \min_{\text{all sites}} (\text{cost of retrieval command} \; + \; \text{cost of sending back the result})$$

Allocation Model

- Constraints
  - Response Time

    execution time of query $\leq$ max. allowable response time for that query
  - Storage Constraint (for a site)

    $$\sum_{\text{all fragments}} \text{storage requirement of a fragment at that site} \leq \text{storage capacity at that site}$$
  - Processing constraint (for a site)

    $$\sum_{\text{all queries}} \text{processing load of a query at that site} \leq \text{processing capacity of that site}$$

Allocation Model

- Solution Methods
  - FAP is NP-complete
  - DAP also NP-complete
- Heuristics based on
  - single commodity warehouse location (for FAP)
  - knapsack problem
  - branch and bound techniques
  - network flow

Allocation Model

- Attempts to reduce the solution space
  - assume all candidate partitionings known; select the "best" partitioning
  - ignore replication at first
  - sliding window on fragments

Problem –
Separation of Design Steps