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Carnegie Mellon Univ.
Dept. of Computer Science
15-415/615 - DB Applications

Lecture #18: Physical Database Design (R&G ch. 20)

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Overview

- Introduction
- Index selection and clustering
- Database tuning (de-normalization etc)
- Impact of concurrency

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Introduction

- After ER design, schema refinement, and the definition of views, we have the *conceptual* and *external* schemas for our database.
- Next step?

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Introduction

- After ER design, schema refinement, and the definition of views, we have the *conceptual* and *external* schemas for our database.
- Next step?
- choose indexes, make clustering decisions, and to refine the conceptual and external schemas (if necessary) to meet performance goals.
- How to decide the above?

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Introduction

- How to decide the above?

Paraphrasing [Sun Tzu / Sun Wu / Sunzi]
Know [the] other,
know [the] self,
hundred battles without danger

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Introduction

- How to decide the above?

Paraphrasing [Sun Tzu / Sun Wu / Sunzi]
Know [the] workload
know [the] Q-opt internals

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Introduction

- We must begin by understanding the **workload**:
  - The most important queries and how often they arise.
  - …………………… updates ………………………..
  - The desired performance for these queries and updates.

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Decisions to Make

- ??

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Decisions to Make

- What indexes should we create?
- For each index, what kind of an index should it be?
- Should we make changes to the conceptual schema?

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Decisions to Make

- What indexes should we create?
  - Which relations should have indexes? What field(s) should be the search key? Should we build several indexes?
- For each index, what kind of an index should it be?
  - Clustered? Hash/tree?
- Should we make changes to the conceptual schema?
  - Consider alternative normalized schemas? (Remember, there are many choices in decomposing into BCNF, etc.)
  - Should we ``undo'' some decomposition steps and settle for a lower normal form? (*Denormalization.*)
  - Horizontal partitioning, replication, views ...

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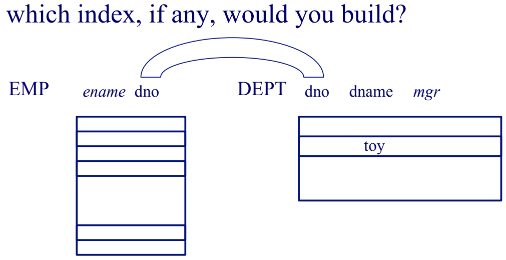
Example 1

```
SELECT E.ename, D.mgr
FROM Emp E, Dept D
WHERE D.dname='Toy' AND E.dno=D.dno
```

- which index, if any, would you build?



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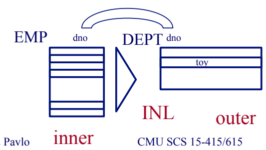
Example 1

```
SELECT E.ename, D.mgr
FROM Emp E, Dept D
WHERE D.dname='Toy' AND E.dno=D.dno
```

- Hash index on *D.dname* supports 'Toy' selection.
  - Given this, index on D.dno is not needed.
- Hash index on *E.dno* allows us to get matching (inner) Emp tuples for each selected (outer) Dept tuple.



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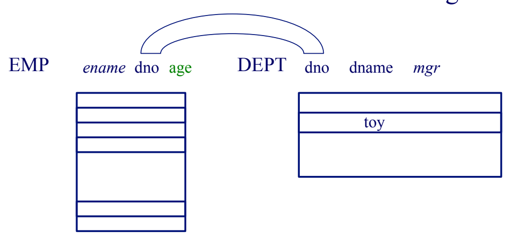
Example 1

```
SELECT E.ename, D.mgr
FROM Emp E, Dept D
WHERE D.dname='Toy' AND E.dno=D.dno
```

- What if WHERE included: `` ... AND E.age=25'' ?



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Example 1

```
SELECT E.ename, D.mgr
FROM Emp E, Dept D
WHERE D.dname='Toy' AND E.dno=D.dno
```

- What if WHERE included: `` ... AND E.age=25'' ?
  - Could retrieve Emp tuples using index on *E.age*, then join with Dept tuples satisfying *dname* selection. Comparable to strategy that used *E.dno* index.
  - So, if *E.age* index is already created, this query provides much less motivation for adding an *E.dno* index.

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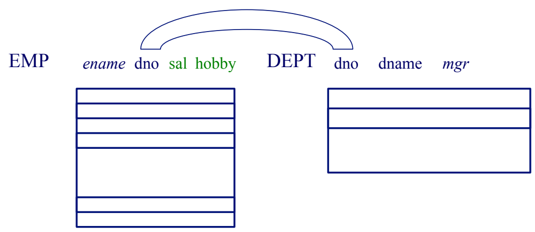
Example 2

SELECT E.ename, D.mgr
FROM Emp E, Dept D
WHERE E.sal BETWEEN 10000 AND 20000
AND E.hobby='Stamps' AND E.dno=D.dno



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Example 2

SELECT E.ename, D.mgr
FROM Emp E, Dept D
WHERE E.sal BETWEEN 10000 AND 20000
AND E.hobby='Stamps' AND E.dno=D.dno

- Emp should be the outer relation – indices for Dept?
  - .
- What index for Emp?

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Example 2

SELECT E.ename, D.mgr
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- Emp should be the outer relation – indices for Dept?
  - hash index on *D.dno.*
- What index for Emp?

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Example 2

```
SELECT E.ename, D.mgr
FROM Emp E, Dept D
WHERE E.sal BETWEEN 10000 AND 20000
  AND E.hobby='Stamps' AND E.dno=D.dno
```

- Emp should be the outer relation – indices for Dept?
  - hash index on *D.dno.*
- What index for Emp?
  - B+ tree on *E.sal*, OR an index on *E.hobby*. Only one is probably enough – whichever has better selectivity.
    - As a rule of thumb, equality selections more selective than range selections.
- Notice: in both examples, the choice of indexes depends on the plan(s) we expect from the optimizer. *Have to understand optimizers!*

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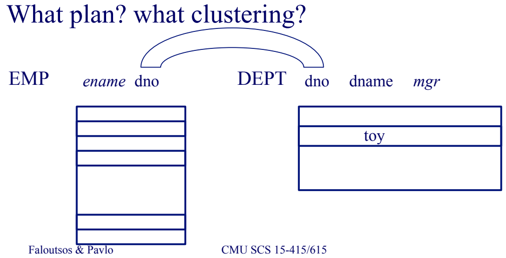
Clustering and Joins

```
SELECT E.ename, D.mgr
FROM Emp E, Dept D
WHERE D.dname='Toy' AND E.dno=D.dno
```

- What plan? what clustering?



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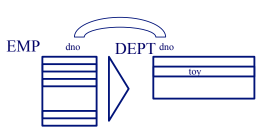
Clustering and Joins

```
SELECT E.ename, D.mgr
FROM Emp E, Dept D
WHERE D.dname='Toy' AND E.dno=D.dno
```

- Index on Emp.dno – clustered or not?



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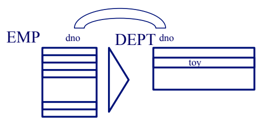
Clustering and Joins

```
SELECT  E.ename, D.mgr
FROM  Emp E, Dept D
WHERE  D.dname='Toy' AND E.dno=D.dno
```

- Index on Emp.dno – clustered or not?
- A: clustered will be much faster



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Overview

- Introduction
- Index selection and clustering
- ➡ Database tuning (de-normalization etc)
- Impact of concurrency

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Tuning the Conceptual Schema

- The choice of conceptual schema should be guided by the workload, in addition to redundancy issues:
  - We may settle for a 3NF schema rather than BCNF.
  - Workload may influence the choice we make in decomposing a relation into 3NF or BCNF.
  - We may further decompose a BCNF schema!
  - We might *denormalize* (i.e., undo a decomposition step), or we might add fields to a relation.
  - We might consider *horizontal decompositions*.

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Tuning the Conceptual Schema

- If such changes are made after a database is in use: called *schema evolution*
- Q: How to mask these changes from applications?

Student ⇨ New_Student

Ssn	name

Ssn	name	year

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Tuning the Conceptual Schema

- If such changes are made after a database is in use: called *schema evolution*
- Q: How to mask these changes from applications?
- A: Views!

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Tuning the Conceptual Schema

- If such changes are made after a database is in use: called *schema evolution*
- Q: How to mask these changes from applications?
- A: Views!

```
create view student as
  select ssn, name
  from new_student
```

student ⇨ new_student

Ssn	name

Ssn	name	year

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Tuning the Conceptual Schema

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Example?

- Q: When would we choose 3NF instead of BCNF?

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Example?

- Q: When would we choose 3NF instead of BCNF?
- A: Student-Teacher-subJect (STJ)

  S J -> T

  T -> J

  and queries ask for all three attributes (select *)

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Tuning the Conceptual Schema

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Decomposition of a BCNF Relation

- Q: Scenario?

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Decomposition of a BCNF Relation

- Q: Scenario?
- A: eg., STUDENT(ssn, name, address, ph#, ...)
- with many queries like

```
select ssn, name
from student
```

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Tuning the Conceptual Schema

- The choice of conceptual schema should be guided by the workload, in addition to redundancy issues:
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  - – We might consider *horizontal decompositions*.

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De-normalization

- Q: Scenario?

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De-normalization

- Q: Scenario?
- A: E.g.,

  STUDENT (ssn, name)
  TAKES (ssn, cid, grade)
  COURSE (cid, cname)

  – and many queries like: ‘class roster for db-apps’
- Q: resulting table(s) and views?

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Tuning the Conceptual Schema

- The choice of conceptual schema should be guided by the workload, in addition to redundancy issues:
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  - ➡ We might consider *horizontal decompositions*.

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Horizontal Decompositions

Sometimes, might want to replace relation by a collection of relations that are *selections.* Eg.,

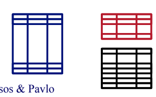
STUDENT (ssn, name, status)

decomposed to

CurrentStudent (ssn, name, status)

Alumni (ssn, name, status)

Q: under what scenario would this help performance?



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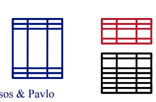

A: most queries on 'current', & too large 'alumni' table

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Horizontal Decompositions

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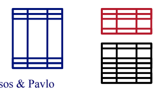
STUDENT (ssn, name, status)

decomposed to

CurrentStudent (ssn, name, status)

Alumni (ssn, name, status)

Q': How to mask the change?



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Masking Conceptual Schema Changes

```
CREATE VIEW  STUDENT(ssn, name, status)
        AS  SELECT  *
             FROM  CurrentStudent
        UNION
             SELECT  *
             FROM  Alumni
```

- Masks change
- But performance-minded users should query the correct table

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Tuning Queries and Views

- If a query runs slower than expected, what to check?

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Tuning Queries and Views

- If a query runs slower than expected, check
  - the plan that is used! (and adjust indices/query/views)

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Tuning Queries and Views

- If a query runs slower than expected, check
  - the plan that is used! (and adjust indices/query/views)
  - whether statistics are too old

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Tuning Queries and Views

- If a query runs slower than expected, check
  - the plan that is used! (and adjust indices/query/views)
  - whether statistics are too old or
  - whether an index needs to be re-built, or

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Tuning Queries and Views

- Sometimes, the DBMS may not be executing the plan you had in mind. Common areas of weakness:

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Tuning Queries and Views

- Sometimes, the DBMS may not be executing the plan you had in mind. Common areas of weakness:
  - Selections involving null values.
  - Selections involving arithmetic or string expressions.
  - Selections involving OR conditions.
  - Lack of evaluation features like index-only strategies or certain join methods or poor size estimation.

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Tuning Queries and Views

- Sometimes, the DBMS may not be executing the plan you had in mind. Common areas of weakness:
  - Selections involving null values.
  - Selections involving arithmetic or string expressions. > 3* salary
  - Selections involving OR conditions. like "%main%"
  - Lack of evaluation features like index-only strategies or certain join methods or poor size estimation.

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Rewriting SQL Queries

- Complicated by interaction of:
  - NULLs, duplicates, aggregation, subqueries
- Guideline: Use only one "query block", if possible.

```
SELECT DISTINCT *
  FROM Sailors S
 WHERE S.sname IN
      (SELECT Y.sname
         FROM YoungSailors Y)
```

= ??

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Rewriting SQL Queries

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```
SELECT DISTINCT *
  FROM Sailors S
 WHERE S.sname IN
      (SELECT Y.sname
         FROM YoungSailors Y)
```

=

```
SELECT DISTINCT S.*
  FROM Sailors S,
       YoungSailors Y
 WHERE S.sname = Y.sname
```


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More Guidelines for Query Tuning

- Minimize the use of DISTINCT: when?

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More Guidelines for Query Tuning

- Minimize the use of DISTINCT: when?
- A1: when duplicates are acceptable, or
- A2: if answer contains a key.

```
SELECT DISTINCT ssn
  FROM Student;
```


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More Guidelines for Query Tuning

- Consider DBMS use of index when writing arithmetic expressions:
- *E.age=2*D.age* will benefit from index on *E.age*, but might not benefit from index on *D.age*!

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More Guidelines for Query Tuning

- Minimize the use of GROUP BY and HAVING:

```
SELECT  MIN (E.age)
FROM  Employee E      →   ??
GROUP BY  E.dno
HAVING  E.dno=102
```

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More Guidelines for Query Tuning

- Minimize the use of GROUP BY and HAVING:

```
SELECT  MIN (E.age)
FROM  Employee E
GROUP BY  E.dno
HAVING  E.dno=102
```

→

```
SELECT  MIN (E.age)
FROM  Employee E
WHERE  E.dno=102
```

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Guidelines for Query Tuning (Contd.)

- Avoid using intermediate relations:

```
SELECT  *  INTO  Temp
FROM  Emp E, Dept D
WHERE  E.dno=D.dno
       AND  D.mgrname='Joe'
```

and

```
SELECT  T.dno, AVG(T.sal)
FROM  Temp T
GROUP BY  T.dno
```

vs. ???

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Guidelines for Query Tuning (Contd.)

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vs.

```
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```

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Guidelines for Query Tuning (Contd.)

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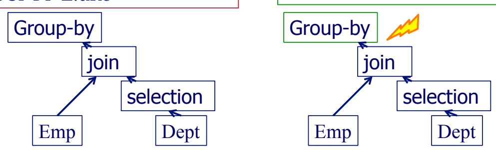

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Guidelines for Query Tuning (Contd.)

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vs.

```
SELECT * INTO Temp
FROM Emp E, Dept D
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```

and

```
SELECT T.dno, AVG(T.sal)
FROM Temp T
GROUP BY T.dno
```

- Does not materialize the intermediate reln Temp.
- If there is a dense B+ tree index on <*dno, sal*>, an index-only plan can be used to avoid retrieving Emp tuples in the second query!

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Concurrency

- Reduce lock durations
- Reduce hot spots

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Concurrency

- Reduce lock durations

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Concurrency

- Reduce lock durations
  - make transactions faster
  - break long transactions in shorter ones (but...)
  - build a data warehouse
  - consider lower isolation level

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Concurrency

- Reduce hot spots

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Concurrency

- Reduce hot spots
  - delay operations on hot spots
  - optimize access patterns
  - partition (batch) operations on hot spots
  - choice of index (root of B-tree -> hot spot)

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Summary

- Database design consists of several tasks: *requirements analysis, conceptual design, schema refinement, physical design* and *tuning.*
  - In general, have to go back and forth between these tasks to refine a database design, and decisions in one task can influence the choices in another task.

Also see the paper by Roussopoulos + Yeh (on the course web site)

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Summary (cont'd)

- *workload* is vital:
  - What are the important queries and updates? What attributes/relations are involved?
- then:
  - refine conceptual schema and views
  - tune queries (indices, clustering, re-writing)

Know the workload
Know the Q-opt internals

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1 of 3

Summary - schema refinement

- May choose 3NF or lower normal form over BCNF.
- May *denormalize*, or undo some decompositions.
- May decompose a BCNF relation further!
- May choose a *horizontal decomposition* of a relation.
- Importance of dependency-preservation based upon the dependency to be preserved, and the cost of the IC check (see text)

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Tuning Queries and Views

- Sometimes, the DBMS may not be executing the plan you had in mind. Common areas of weakness:
  - Selections involving null values. > 3* salary
  - Selections involving arithmetic or string expressions.
  - Selections involving OR conditions. like "%main%"
  - Lack of evaluation features like index-only strategies or certain join methods or poor size estimation.

Summary - Tuning

So, may have to rewrite the query/view: Avoid

- nested queries,
- temporary relations,
- complex conditions, and
- operations like DISTINCT and GROUP BY.