Fundamentals of Physical Design: State of Art

David Toman

D. R. Cheriton School of Computer Science
University of Waterloo

Benefits of Database Technology

1. High-level/declarative DML (query) Languages

Physical Data Independence

Ability to develop/change the physical schema without changing the conceptual (logical) schema.

$\Rightarrow$ essential to fully realize *productivity gains* in development.

2. Transactions and Concurrency Control
3. Recovery
4. . . .

Benefits of Database Technology

1. High-level/declarative DML (query) Languages

Physical Data Independence

Ability to develop/change the physical schema without changing the conceptual (logical) schema.

$\Rightarrow$ essential to fully realize *productivity gains* in development.

2. Transactions and Concurrency Control
3. Recovery
4. . . .

Benefits of Database Technology

1. High-level/declarative DML (query) Languages

   Physical Data Independence

   Ability to develop/change the physical schema without changing the conceptual (logical) schema.

   $\Rightarrow$ essential to fully realize *productivity gains* in development.

2. Transactions and Concurrency Control
3. Recovery
4. ...

Conceptual/Logical vs. Physical Data

IDEA:

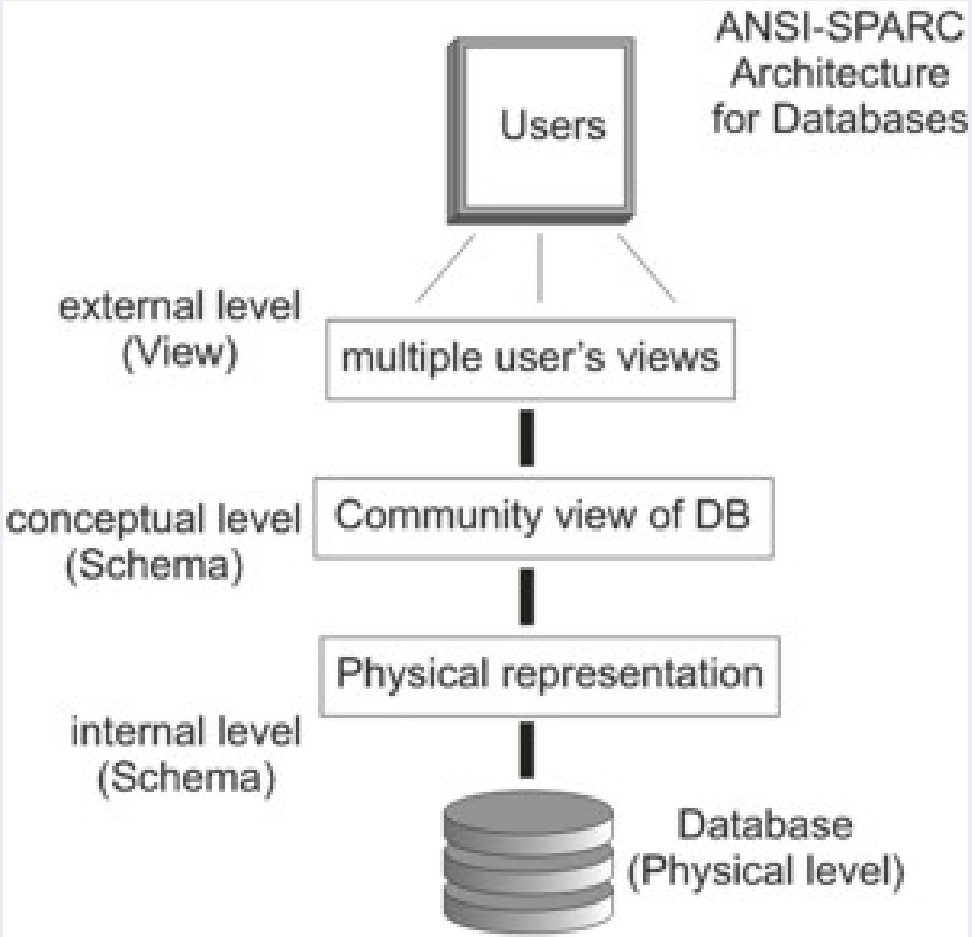
Insulate Users/Applications
from Physical Design issues

. . . essentially ADTs for DATA

Issues:

- DDL Languages?
- How are the schemata
  linked together?
- How to execute
  DML requests?

ANSI SPARC Architecture



Conceptual/Logical vs. Physical Data

IDEA:

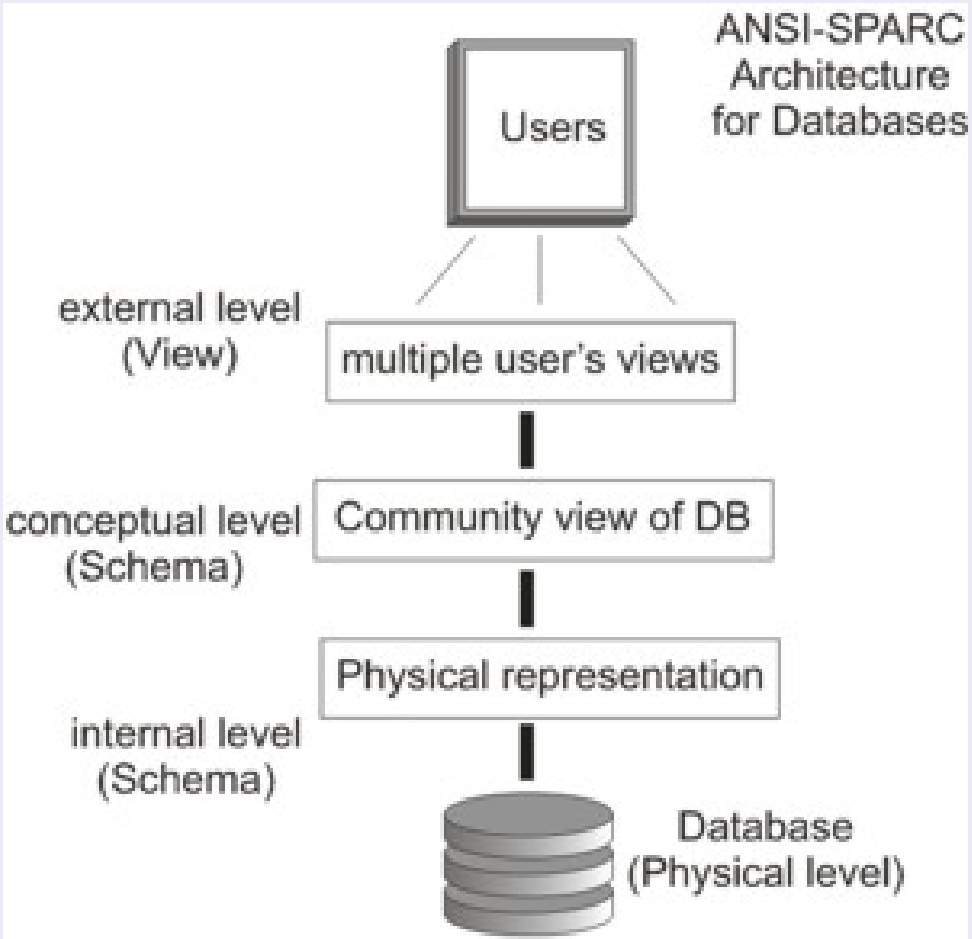
Insulate Users/Applications
from Physical Design issues

. . . essentially ADTs for DATA

Issues:

- DDL Languages?
- How are the schemata
  linked together?
- How to execute
  DML requests?

ANSI SPARC Architecture



Queries vs. Query Processing

(1) User/App Queries:

- formulated w.r.t. the *conceptual/external* schema
- high level (declarative) query languages (SQL, OQL)

logic-based semantics based on satisfaction

"does a database D and a tuple t make a query Q *true*?"

(2) Query PLANS:

- formulated w.r.t. *physical* schema
- low-level iterator-based language (relational algebra)

Problem:

How to get from (1) to (2)?

Queries vs. Query Processing

(1) User/App Queries:

- formulated w.r.t. the *conceptual/external* schema
- high level (declarative) query languages (SQL, OQL)

logic-based semantics based on satisfaction

"does a database D and a tuple t make a query Q *true*?"

(2) Query PLANS:

- formulated w.r.t. *physical* schema
- low-level iterator-based language (relational algebra)

Problem:

How to get from (1) to (2)? Query Optimization!

Queries vs. Query Processing

(1) User/App Queries:

* formulated w.r.t. the *conceptual/external* schema
* high level (declarative) query languages (SQL, OQL)

logic-based semantics based on satisfaction

"does a database D and a tuple t make a query Q *true*?"

(2) Query PLANS:

* formulated w.r.t. *physical* schema
* low-level iterator-based language (relational algebra)

Problem:

How to get from (1) to (2)? Query Optimization!

Standard Approach to Physical Design (and Queries)

First (BAD) IDEA:

Logical schema is closely tied to Physical Schema

. . . this simplifies *Query Optimization* (hence mostly focus on costs)

Example (RDBMS)

The DDL statement `CREATE TABLE`:

1. declares a *new relation* (conceptual; includes keys, . . .)
2. creates a *base file* (physical; includes structure, placement, . . .)

This approach has been followed for $\sim$ 30 years

. . . the IBM DB2's `CREATE TABLE` now has *3 pages of options*.

But there are other related DDL statements:

. . . `CREATE VIEW` (conceptual) and `CREATE INDEX` (physical)

Standard Approach to Physical Design (and Queries)

First (BAD) IDEA:

Logical schema is closely tied to Physical Schema

. . . this simplifies *Query Optimization* (hence mostly focus on costs)

Example (RDBMS)

The DDL statement `CREATE TABLE`:

1. declares a *new relation* (conceptual; includes keys, . . .)
2. creates a *base file* (physical; includes structure, placement, . . .)

This approach has been followed for $\sim$ 30 years

. . . the IBM DB2's `CREATE TABLE` now has *3 pages of options*.

But there are other related DDL statements:

. . . `CREATE VIEW` (conceptual) and `CREATE INDEX` (physical)

Standard Approach to Physical Design (and Queries)

First (BAD) IDEA:

Logical schema is closely tied to Physical Schema

. . . this simplifies *Query Optimization* (hence mostly focus on costs)

Example (RDBMS)

The DDL statement `CREATE TABLE`:

1. declares a *new relation* (conceptual; includes keys, . . .)
2. creates a *base file* (physical; includes structure, placement, . . .)

This approach has been followed for $\sim$ 30 years

. . . the IBM DB2's `CREATE TABLE` now has *3 pages of options*.

But there are other related DDL statements:

. . . `CREATE VIEW` (conceptual) and `CREATE INDEX` (physical)

Common Advice to “DB tuning”

Second (BAD, but practical and expedient) IDEA:

(In closely-tied approaches) Physical Design can be
greatly influenced by *changes to the Conceptual/Logical Schema*

. . . hence we don’t have to change query optimizer

Example (in RDBMS)

1. Denormalization (and NULLs)
2. Horizontal/Vertical Partitioning

Common Advice to “DB tuning”

Second (BAD, but practical and expedient) IDEA:

(In closely-tied approaches) Physical Design can be
greatly influenced by *changes to the Conceptual/Logical Schema*

. . . hence we don’t have to change query optimizer

Example (in RDBMS)

1. Denormalization (and NULLs)
2. Horizontal/Vertical Partitioning

Denormalization

Golden Rule for Conceptual to Logical Mappings

Independent Entities (Relationships) are kept separate

$\Rightarrow$ normal forms (relational: BCNF, 3NF)

. . . makes "complex object reconstruction" harder (joins)

ADVICE:

Settle for lower Normal Form

(i.e., combine multiple entities/relationships into one logical unit).

. . . avoids joins

PROBLEMS:

- update anomalies (often leads to proliferation of NULLs!)
- increase of storage space (in the standard approach)
- queries/updates have to be reformulated

Denormalization

Golden Rule for Conceptual to Logical Mappings

Independent Entities (Relationships) are kept separate

$\Rightarrow$ normal forms (relational: BCNF, 3NF)

. . . makes "complex object reconstruction" harder (joins)

ADVICE:

Settle for lower Normal Form

(i.e., combine multiple entities/relationships into one logical unit).

. . . avoids joins

PROBLEMS:

- update anomalies (often leads to proliferation of NULLs!)
- increase of storage space (in the standard approach)
- queries/updates have to be reformulated

Denormalization

Golden Rule for Conceptual to Logical Mappings

Independent Entities (Relationships) are kept separate

$\Rightarrow$ normal forms (relational: BCNF, 3NF)

. . . makes "complex object reconstruction" harder (joins)

ADVICE:

Settle for lower Normal Form
(i.e., combine multiple entities/relationships into one logical unit).

. . . avoids joins

PROBLEMS:

- update anomalies (often leads to proliferation of NULLs!)
- increase of storage space (in the standard approach)
- queries/updates have to be reformulated

Denormalization

Golden Rule for Conceptual to Logical Mappings

Independent Entities (Relationships) are kept separate

$\Rightarrow$ normal forms (relational: BCNF, 3NF)

. . . makes "complex object reconstruction" harder (joins)

ADVICE:

Settle for lower Normal Form
(i.e., combine multiple entities/relationships into one logical unit).

. . . avoids joins

PROBLEMS:

- update anomalies (often leads to proliferation of NULLs!)
- increase of storage space (in the standard approach)
- queries/updates have to be reformulated

Denormalization: Example

Normalized Design:

```
employee(id, name, dept)
department(dept, address)
```

Denormalization:

```
empdept(id, name, dept, address)
```

Partitioning

ADVICE:

Make *logical units* correspond to frequent requests:

Vertical Partition:

$\Rightarrow$ attributes together in a query form fragments

Horizontal Partition:

$\Rightarrow$ value ranges in queries form fragments

PROBLEMS:

- lossless vs. efficient designs
- queries/updates have to be reformulated

Partitioning

ADVICE:

Make *logical units* correspond to frequent requests:

Vertical Partition:

$\Rightarrow$ attributes together in a query form fragments

Horizontal Partition:

$\Rightarrow$ value ranges in queries form fragments

PROBLEMS:

- lossless vs. efficient designs
- queries/updates have to be reformulated

Problems?

Second (BAD, but practical and expedient) IDEA:

(In closely-tied approaches) Physical Design can be
greatly influenced by *changes to the Conceptual/Logical Schema*

. . . completely breaks Physical Data Independence

- Materialized Views (essentially additional tables)
- Data Cubes (summary tables)

while preserving Physical Data Independence

Physical design $\sim$ changes to logical schema + index selection

Problems?

Second (BAD, but practical and expedient) IDEA:

(In closely-tied approaches) Physical Design can be
greatly influenced by *changes to the Conceptual/Logical Schema*

. . . completely breaks Physical Data Independence

- Materialized Views (essentially additional tables)
- Data Cubes (summary tables)

. . . while preserving Data Integrity?

. . . Physical design $\sim$ changes to logical schema + index selection

Problems?

Second (BAD, but practical and expedient) IDEA:

(In closely-tied approaches) Physical Design can be
greatly influenced by *changes to the Conceptual/Logical Schema*

. . . completely breaks Physical Data Independence

- Materialized Views (essentially additional tables)
- Data Cubes (summary tables)

. . . while preserving Data Integrity?

Physical design $\sim$ changes to logical schema + index selection

Built-in Assumptions: 2-level Storage and Clustering

Additional complications:

- implicit assumption of two-level storage
  - ... most current DBMS assume this
  - ... specialized main-memory DBMS
- impact on data structures (indices)
  - ... primary vs. secondary indices
  - ... clustered vs. unclustered indices

Built-in Assumptions: 2-level Storage and Clustering

Additional complications:

- implicit assumption of two-level storage
  - ... most current DBMS assume this
  - ... specialized main-memory DBMS
- impact on data structures (indices)
  - ... primary vs. secondary indices
  - ... clustered vs. unclustered indices

Goals and Solutions

GOAL 1:

Develop approaches and technology that allow for loose coupling between conceptual/logical designs and physical design.

. . . allows logical design to closely follow the conceptual design

. . . while supporting a wide variety of physical designs

GOAL 2:

Design a small number of primitives that support all of the above.

1. uniform DDL for both conceptual/logical and physical objects
2. capabilities (index) declarations for physical objects
3. integrity constraints to establish links between objects
4. no built-in assumptions (e.g., 2-level store)

Goals and Solutions

GOAL 1:

Develop approaches and technology that allow for loose coupling between conceptual/logical designs and physical design.

. . . allows logical design to closely follow the conceptual design

. . . while supporting a wide variety of physical designs

GOAL 2:

Design a small number of primitives that support all of the above.

1. uniform DDL for both conceptual/logical and physical objects
2. capabilities (index) declarations for physical objects
3. integrity constraints to establish links between objects
4. no built-in assumptions (e.g., 2-level store)

Organization of the Lectures

1. Uniform Approach to Physical Design and Schema Languages
2. How do we execute queries? (take 1: conjunctive queries)
3. How do we execute queries? (take 2: first-order queries)
4. Look into the Future (discussion/seminar)