Unit 1
Goals And an Informal Synopsis of the Course

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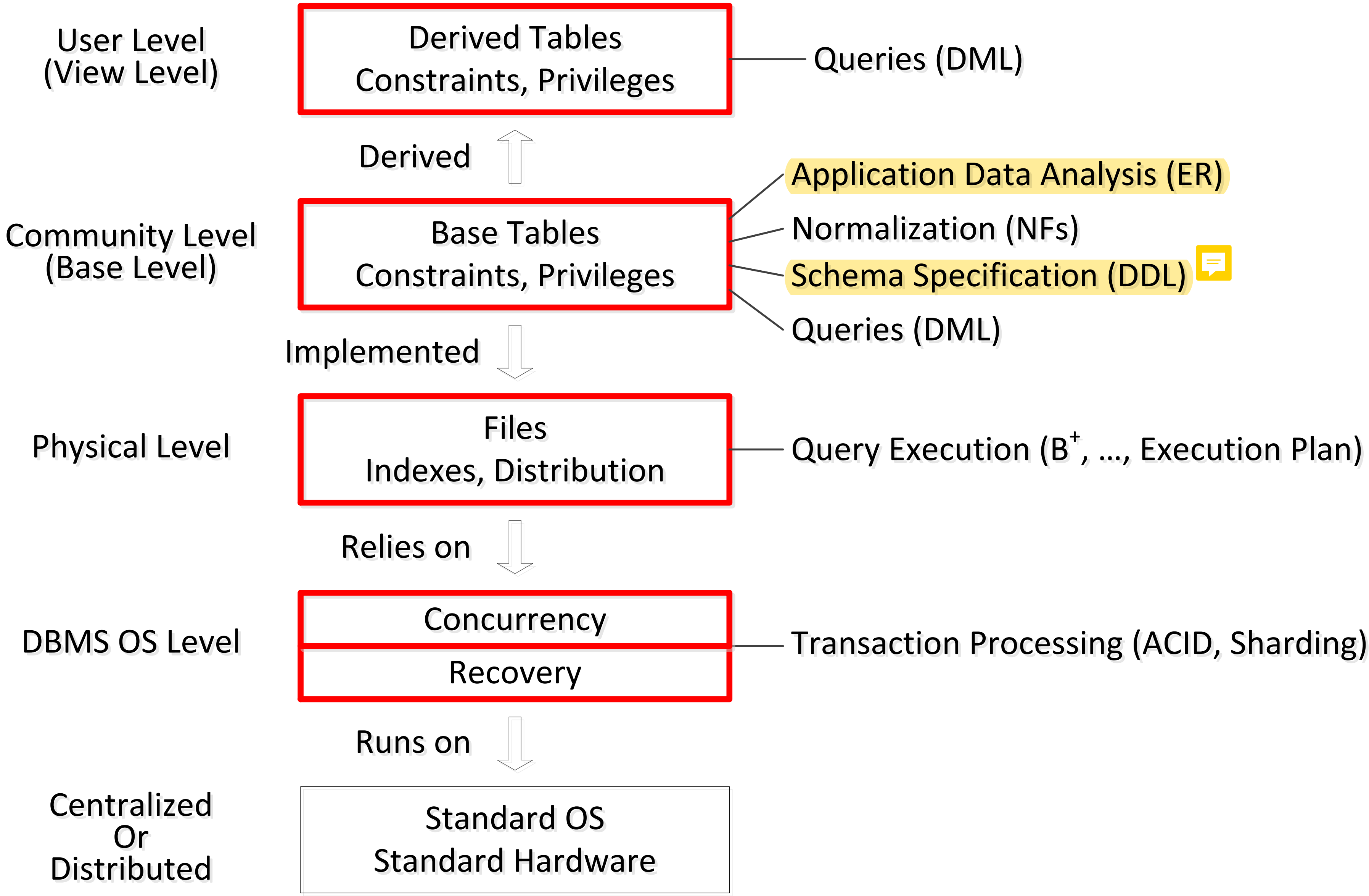
Notes from Prof Zvi Kedem
(modified by Dennis Shasha)

Introduction

Main Material Covered
We Will Understand Soon What This is



Goals of the Course

- To learn fundamental concepts of state-of-the art databases (more precisely called **database management systems**: DBMSs)
- To get to know an open-source tool for database management.
  - MySQL
- To know enough so that it is possible to read/skim a database system manual and
  - Design and implement small databases
  - Manage, query, and update existing databases
- But manuals do not teach you about some important concepts that you must know to be effective
- Understand the ideas behind recent database-like systems, such as MapReduce, Hadoop, MongoDB
- Build your own in-memory time series database system.

Two Main Functions of Databases

- A very large fraction of computer use is devoted to business processing of data using databases
  - Think about what Amazon has to do to manage its operations
- Two main uses of databases
  - ***OLTP*** (Online Transaction Processing):

    The database is used is for entering, modifying, and querying data

    Correctness, at least for entering and modifying data must be assured

    Example: Amazon charges the customer's credit card for the price of the book that the customer ordered
  - ***OLAP*** (Online Analytical Processing)

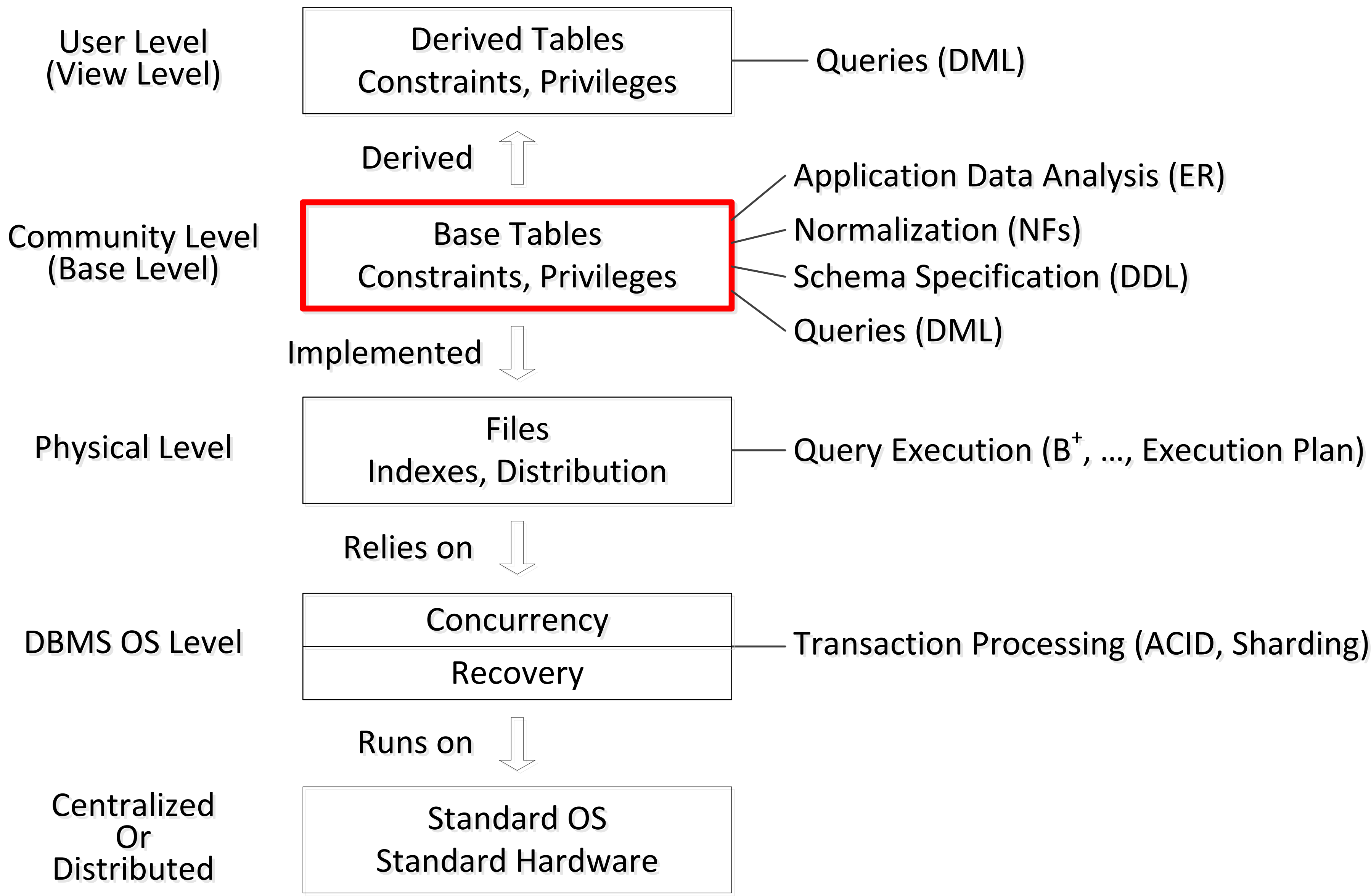
    The database is used for business intelligence, including data mining and machine learning

    Example: Amazon wants to know how many books that cost less than $10 each were sold in New Jersey during July 2019

    Example: Find out which jeans are being sold well in southern California in April.

Informal Synopsis

Topics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Managing the Data of an Enterprise

- We may consider some enterprise (organization) and the totality of the information it maintains.
- We think about managing this information, focusing on OLTP
- Ideally, the information should be stored in a (logically) single (possibly physically distributed) database system
- We start with a very simple example to introduce some concepts and issues to address
- We look at only a very small part of information of the type that an enterprise may need to keep
- We need some way of describing sample data
- We will think, in this unit, of the database as ***a set of tables***, each stored as a ***file on a disk***
- If database supports a language like "SQL", it is a relational database

A Sample Relational Database

Table1

SSN	City	DOB
101	Boston	3498
106	London	2987
121	Portland	2367
132	Miami	3678

Table2

Name	SSN	DOB	Grade	Salary
A	121	2367	2	80
A	132	3678	3	70
B	101	3498	4	70
C	106	2987	2	80

Table3

SSN	Title	Date
132	Python	8976
121	Physics	9003

Table4

SSN	Illness	Date
101	Cold	3498
121	Flu	2987

- The database stores information about employees, titles of books they checked out from the library (and when), and various illnesses they had (and when)

Some Typical Queries

- Some typical queries
  - Give Name of every employee born before 3500
  - Give Name and City for every employee who checked out any Title after 9000
  - Send a notice to every employee who had a flu to come for a checkup
- ***Note that some queries involve a single table, and some involve several tables***
- We would like to have a convenient language, as close as possible to a natural language, to express these queries, and similar ones, ***thinking of tables***, not of lower-level structures (files)
- Some languages
  - ***SQL*** (used to be called Structured Query Language): every relational database supports some version of SQL "close to standard"
  - ***QBE*** (Query By Example); underlying, e.g., Microsoft Access's GUI and some other GUIs

Two Queries in SQL

- The tables have names as shown in a previous slide (as they of course do in SQL)
  - Table1: with columns SSN, City, DOB
  - Table2: with columns Name, SSN, DOB, Grade, Salary
  - Table3: with columns SSN, Title, Date
  - Table4: with columns SSN, Illness, date
- Give Name of every employee born before 3500

```
SELECT Name
FROM Table2
WHERE DOB < 3500;
```

- Give Grade and City for every employee with the name A

```
SELECT Grade, City
FROM Table2, Table1
WHERE Table2.SSN = Table1.SSN AND Table2.Name = ′A′;
```

The Design of The Database Should Reflect the Structure of the Data

- It is important also to think carefully about the correct (or just good!) choice of which tables to use and what should be their structure
- This we should do in order to have good logical design, not worrying (yet) about efficient storage in files
- Our initial design suffers (for pedagogical reasons) from various problems, which we will see next

Redundancy

- A data item appears more than once ***unnecessarily***
  - Assuming that each SSN has only one DOB, the value of DOB appears twice unnecessarily (in two different tables)

    There is a danger that this will be inconsistent
  - Even more dangerous would have been multiple storage of employee's City

    If the employee moves, the City must be changed everywhere it appears
- Note, however, that from an efficiency point of view, it might be useful to replicate information, to speed up access
  - In our example, if frequently we want to correlate DOB with Grade and also DOB with City, it may be good to have it in both tables, and not insist on a "clean" design
- Note that ***it was necessary*** for SSN to appear in two different tables, as otherwise we could not "assemble" information about employees

Storage of Constraints (Business Rules)

- Assume that it is the policy of our enterprise that the value of Salary is determined uniquely by the value of Grade; this is a so-called ***business rule*** (semantic constraint)
  - Thus the fact that the Grade = 2 implies Salary = 80 is written twice in the database
  - This is another type of redundancy, which is less obvious at first
- There are additional problems with this design.
  - We are unable to store the salary structure for a Grade that does not currently exist for any employee.
  - For example, we cannot store that Grade = 1 implies Salary = 90
  - For example, if employee with SSN = 132 leaves, we forget which Salary should be paid to employee with Grade = 3
  - We could perhaps invent a fake employee with such a Grade and such a Salary, but this brings up additional problems, e.g.,

    What is the SSN of such a fake employee? How many employees do we have.
- The business rule specifies a pay scale, which is independent of a particular employee

Handling Storage of Constraints (Motivating Example for Normalization)

- The problem can be solved by replacing

Name	SSN	DOB	Grade	Salary
A	121	2367	2	80
A	132	3678	3	70
B	101	3498	4	70
C	106	2987	2	80

by two tables

Name	SSN	DOB	Grade
A	121	2367	2
A	132	3678	3
B	101	3498	4
C	106	2987	2

Grade	Salary
2	80
3	70
4	70

Handling Storage of Constraints (Example of Normalization)

- And now we can store information more naturally
  - We can specify that Grade 3 implies Salary 70, even after the only employee with this Grade, i.e., employee with SSN 132 left the enterprise
  - We can specify that Grade 1 (a new Grade just established) implies Salary 90, even before any employee with this grade is hired

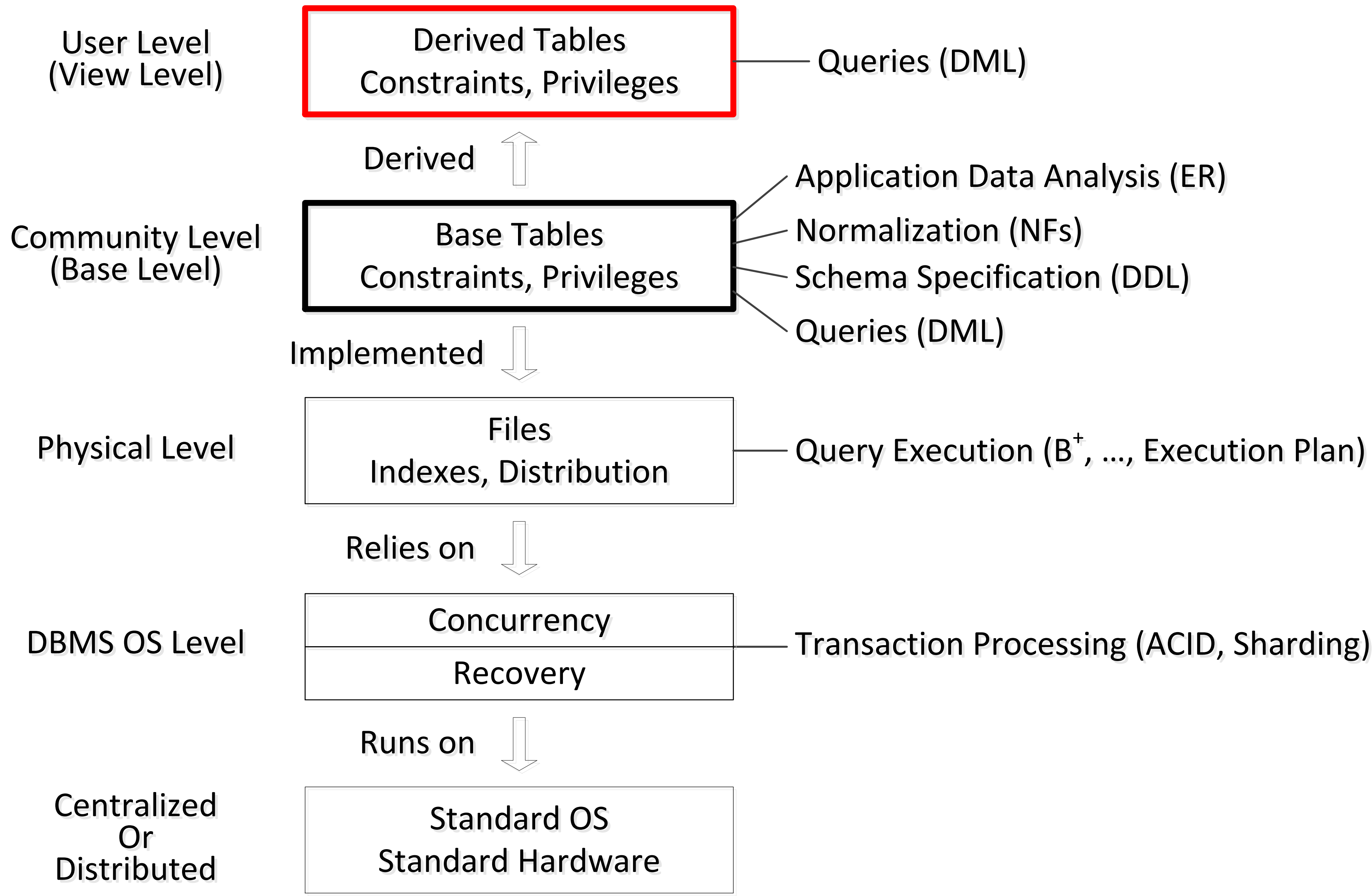
Name	SSN	DOB	Grade
A	121	2367	2
B	101	3498	4
C	106	2987	2

Grade	Salary
1	90
2	80
3	70
4	70

One More Problem

- What if it becomes illegal to use social security numbers for anything other than payroll related matters?
- We will have an incredible mess and enormous amount of work to restructure the database, unless we have designed the application appropriately to begin with
- Of course we did not know that it would become illegal to use social security numbers and it was convenient to do so, so that's what we used
- So how to be able to anticipate potential problems?
- NYU had to spend considerable effort to switch from social security numbers to University ID's
- We will discuss how to "anticipate" such problems, so such switching is painless

Topics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Different Users Need Different Data

- It may be our goal to create a design that best reflects the inherent properties of the data.
  - But, various user groups may need to look at the data assuming different structure (organization) of the data
- For privacy/security reasons we may want to give different users different access privileges to the database
  - The payroll department can see salaries but cannot see diseases.
  - The health department can see diseases but cannot see salaries.
- Users may prefer to look at different aspects of the information.
  - The payroll department may prefer to see the salary in a different currency
  - The health department may prefer to see Age instead of, or in addition to, DOB

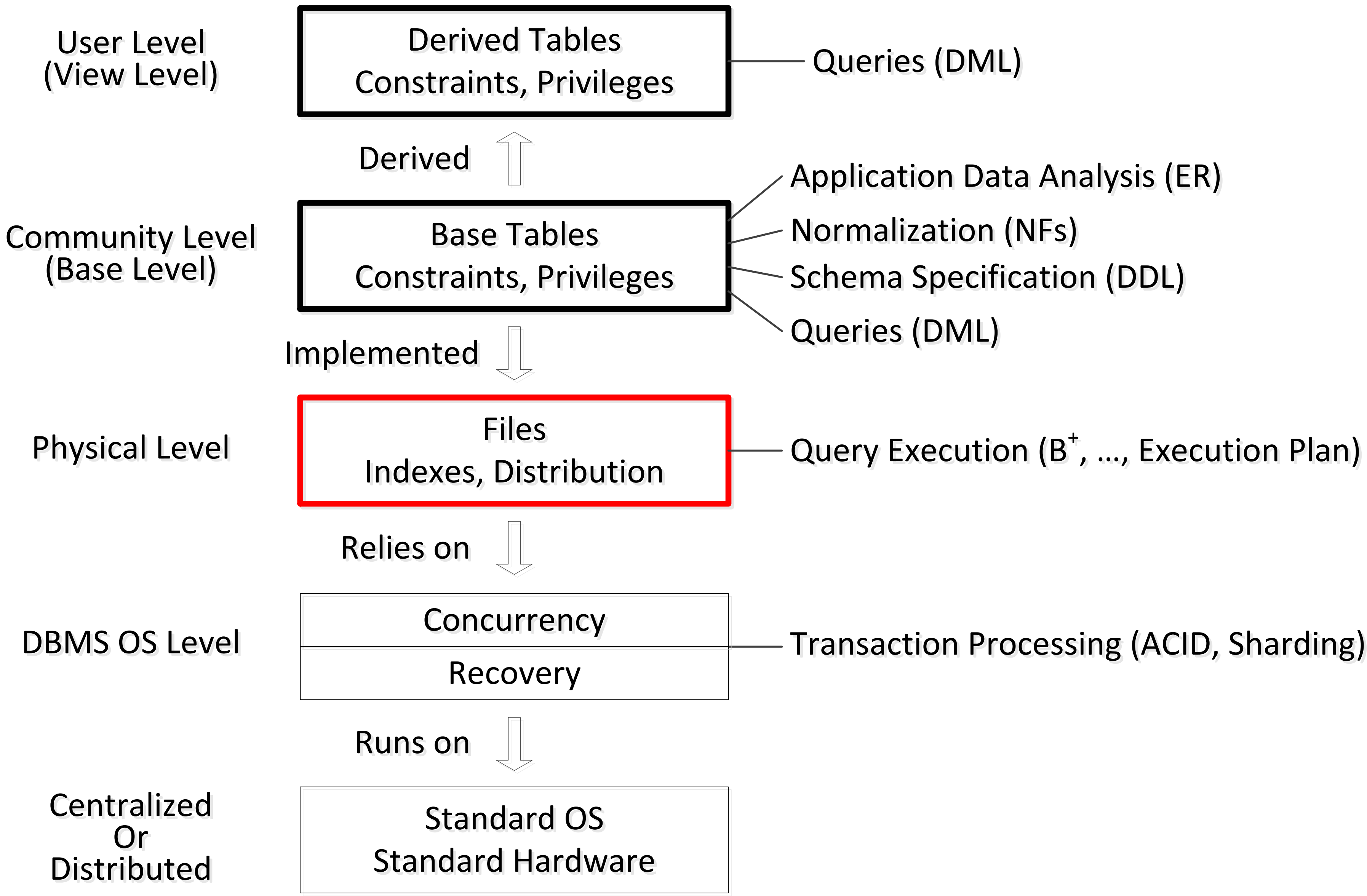
Views (Motivating Example)

- A possible solution: give each user (class of users) privileges to look at a ***view***, that is, informally speaking, a small derived database
- The health department may think that there is a table:

Name	SSN	City	DOB	Age	Illness	Date
A	121	Portland	2367	47	Flu	2987
B	101	Boston	3498	25	Cold	3721

- The database should provide such a view, which is ***computed as needed from the existing tables*** (and the current date), without the user knowing other (prohibited for this user) information
- We need to leave flexibility for unanticipated queries.
  - Some people may later be given the right and want to ask the query: “How are salaries and medical conditions correlated?”

Topics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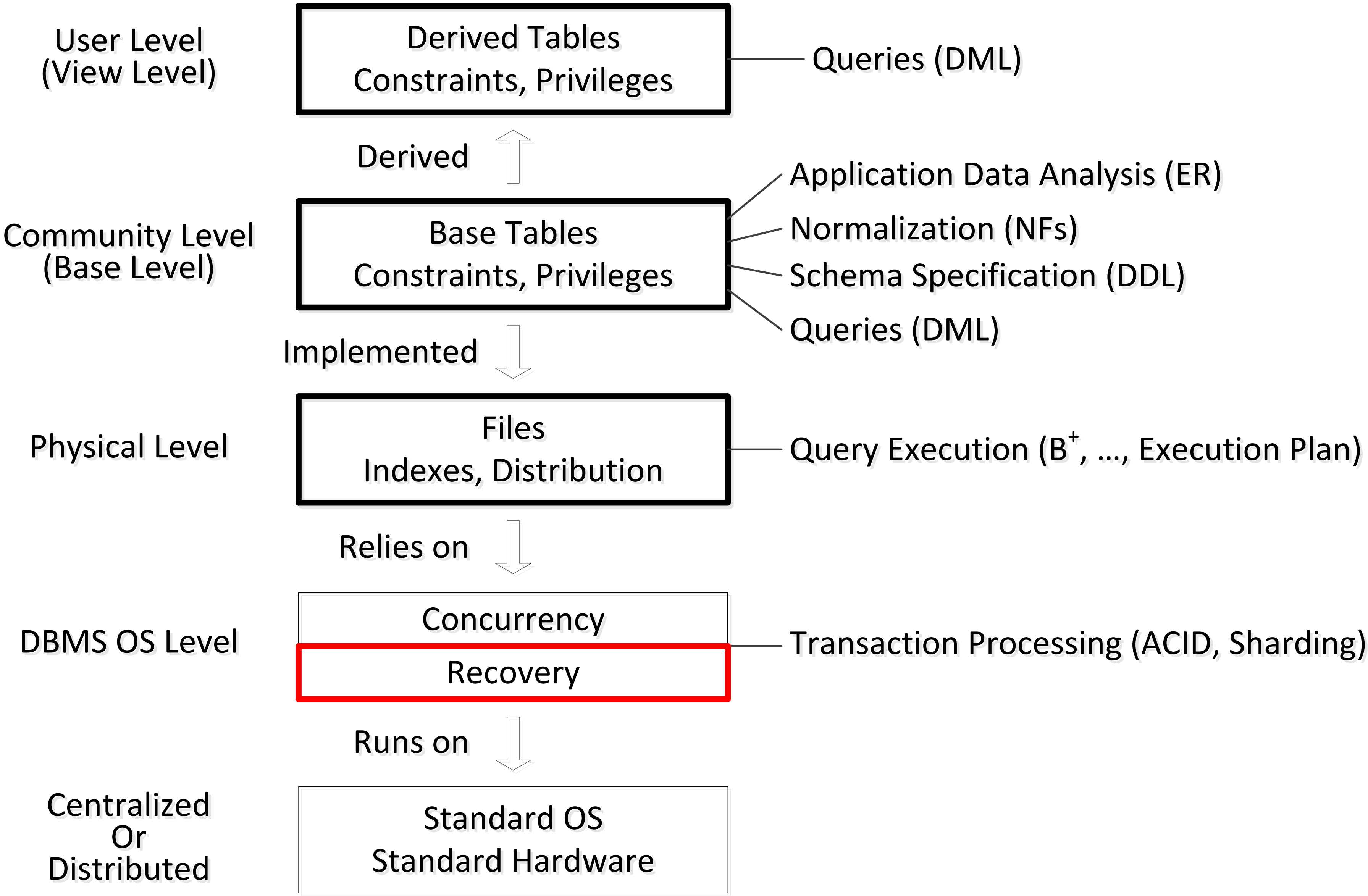
Physical Design (With Motivating Examples)

- The database system must be organized so that it is able to process queries efficiently
- To do this:
  - ***Files must be organized appropriately***
  - ***Indexes may be employed***
- For example, if we frequently want to find the grade for various SSN, perhaps the file should be hashed on SSN, allowing direct access
- But, if we want to print the salaries of all the employees born between 2783 and 2906, maybe the file should be sorted by DOB; actually an index generalizing a 2-3 tree would generally be better
- Physical design of databases deals with such issues (including how to distribute information among various sites), which are also closely related to the optimization of query processing

Topics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Recovery (Motivating Example)

- The database must be resilient (reliable) even though the system is prone to faults.
- Assume one more table, describing employees' accounts in a credit union

SSN	Savings	Checking
101	40	30
106	40	20
121	0	80
132	10	0

- We want to give each employee a bonus of 10 in the savings account.
- To do that, a **transaction** (execution of a user’s program) will sequentially change the values of Savings

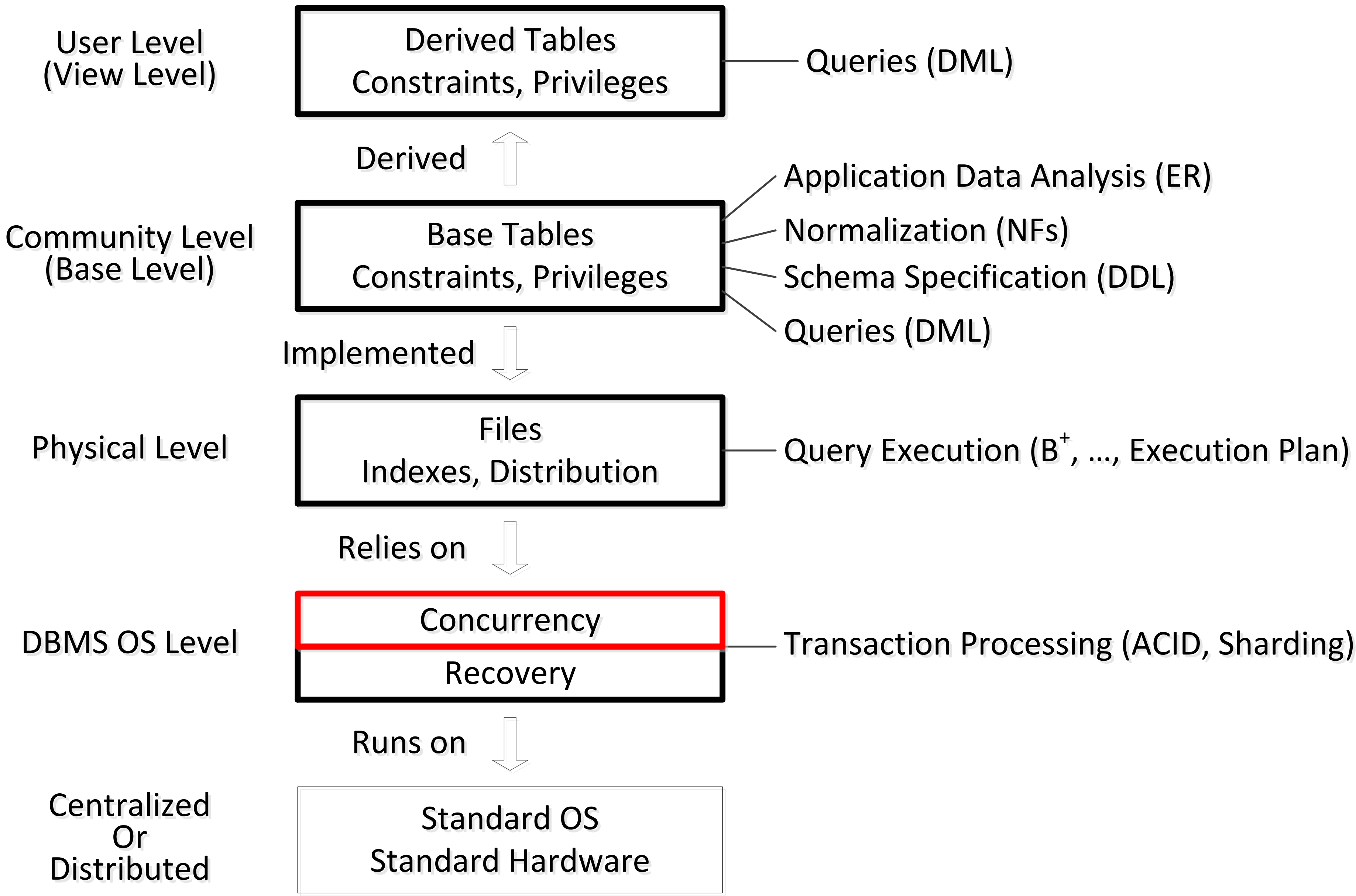
Example of A Problem

- The file describing the table is stored on a disk, values are read into RAM, modified and written out
- If X is a local variable in RAM then we have a trace of the desired execution (in shorthand):

.	
X := Savings[101]	read from disk
X := X + 10	process in RAM
Savings[101] := X	write to disk
.	

- What if the system crashes in the middle, say power goes out? Which records still need to be changed?
- Various techniques exist for managing the execution, so that reliable execution is possible

Topics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Concurrency
(Motivating Example: Updating)

- There may also be problems because of the concurrent execution of several transactions in a system
- Assume one more table, describing employees' accounts in the credit union

SSN	Savings	Checking
101	40	30
106	40	20
121	0	80
132	10	0

- Using transaction T1, we want to multiply the value of each account by 2
- Concurrently, using transaction T2, employee SSN = 121 wants to move 10 from his Checking account (CH[121] for short) to his Savings account (SA[121] for short)

Execution Trace of Two Transactions On Accounts of SSN = 121

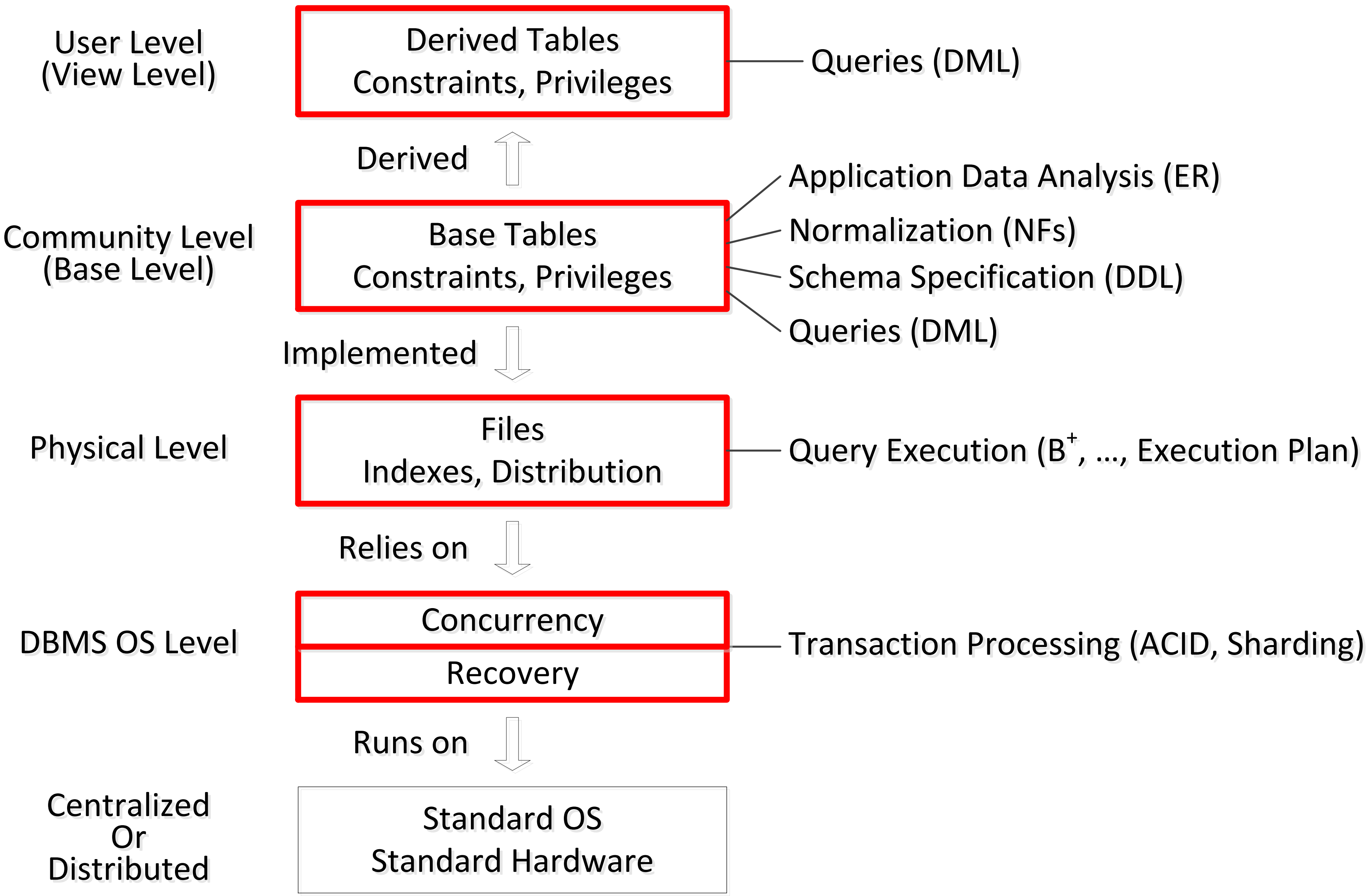
T1	T2
……..	
	Y1 := CH[121] (Y1 = 80)
	Y1 := Y1 − 10 (Y1 = 70)
	CH[121] := Y1 (CH[121] = 70)
X1 := CH[121] (X1 = 70)	
X1 := X1 * 2 (X1 = 140)	
CH[121] := X1 (CH[121] = 140)	
X2 := SA[121] (X2 = 0)	
X2 := X2 * 2 (X2 = 0)	
SA[121] := X2 (S[121] = 0)	
	Y2 := SA[121] (Y2 = 0)
	Y2 := Y2 + 40 (Y2 = 10)
	SA[121] := Y2 (SA[121] = 10)
……..	

- CH[121] + SA[121] = 140 + 10 = 150 and the SSN = 121 has the total of 150 and not 160 as he should have had

Corruption of Database Must Not Be Allowed

- The execution corrupts the database and must not be allowed
- Therefore concurrent execution of transactions must be managed so that the resulting database is correct
- Various methods to do that exists and modules implementing them are part of the system
- But, of course, the topic is not applicable to single-user system, such as Microsoft Access

The Layers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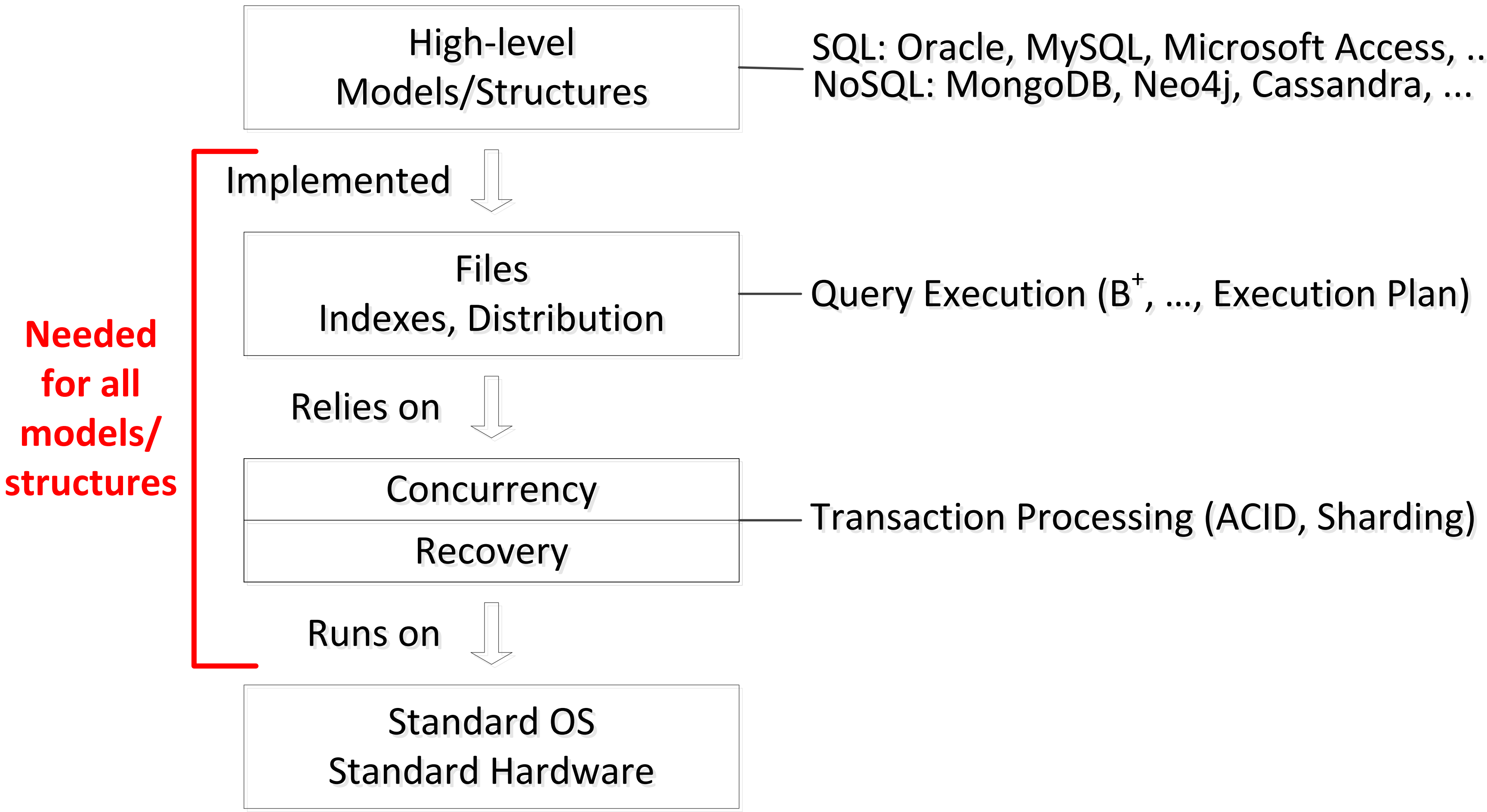
Lower Levels Needed All DBMSs Not Only For Relational DBMSs



The Layers/Levels of the Ideal Database

- It is customary to think of the database as made of several layers or levels, which are not completely standardized
- Different levels have different roles
- We will think of 4 levels:

• **User** (View, External)	Various user views
• **Community** (Base)	Description of the enterprise
• **Physical** (Internal)	Files, access methods, indexes, distribution
• **Database O.S.**	Recovery and concurrency

- The database, in general, does not run on a bare machine
- The Database O.S. (DBOS) runs on top of the O.S., such as Windows or Linux

The Community Level

- The community level is most fundamental as it describes the total information and its structure/meaning
  - to the extent we understand the information and know how to express our understanding
- It is also generally used for manipulating the database, that is querying and modifying it
- The main tools we have:
  - ***Data Definition Language*** (DDL), for specification
  - ***Data Manipulation Language*** (DML), for querying and modifying
- Tables in our example (their structure, not the specific values which change in time) were a kind of DDL
  - They form a ***schema***, a description of the structure.
- Of course, this level changes as the needs of the enterprise change

The User Level

- The user level is seen by various users
- Each view (subschema) is like a small conceptual level.
- It can also change in time.
- A particular view may be modified, deleted, or added even if the community level does not change
  - For example, it may become illegal for some user to see some information

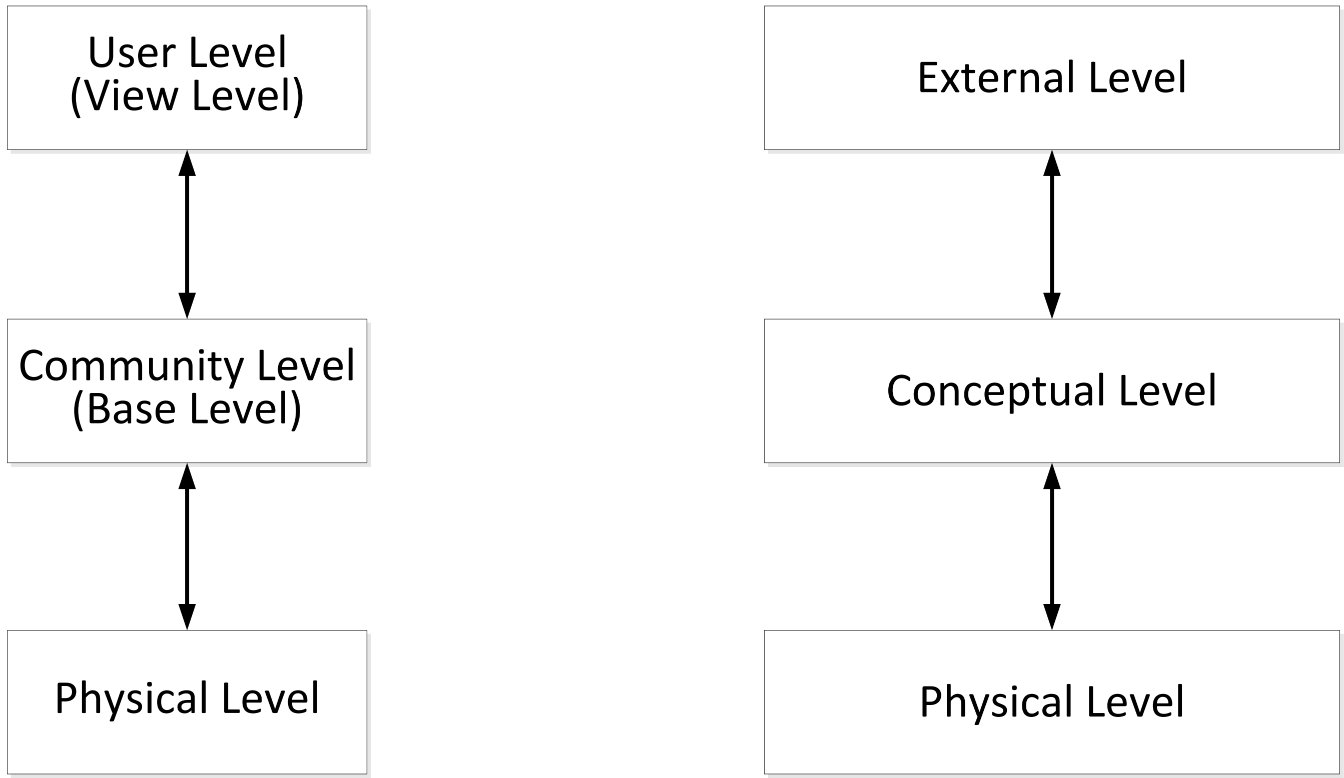
The Physical Level

- The internal level deals with file organization/storage management
- It changes in time too
  - New storage devices are brought
  - Files may have indexes created because some queries have become more frequent
  - The data may be geographically distributed

The Data Base Operating System Level

- The data base operating system level deals with concurrency and recovery
- The data base operating system can change too
- The vendor of the data base may invent better methods to handle recovery/concurrency

Another Way of Naming: Three-Tier Architecture



- Terminologies for the top 3 layers/levels/tiers
- Note that DBOS level is not normally included because once a database management system is deployed in an enterprise, the DBOS level is “not manipulated”
  - But we will still learn the fundamentals of how it works so that you know how to specify levels of correctness, and similar

Independence Among Levels

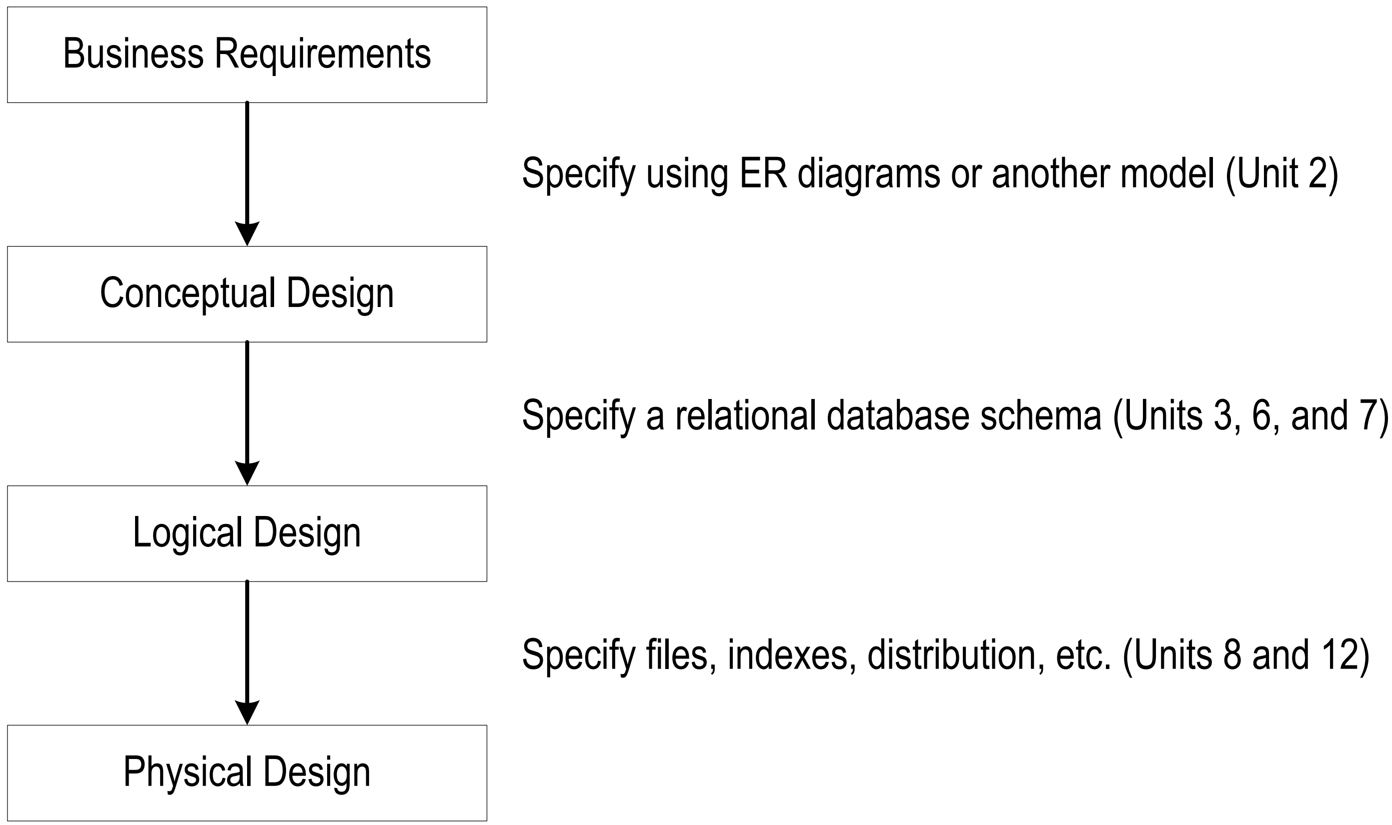
- A very important goal is (Data-) independence between/among levels
- We must make sure that changes in one level disturb as little as possible the other levels (propagate as little as possible)

Who Does What?

- The ***database vendor/implementer*** sends:
  - The database operating system
  - Tools to create and manipulate the three top levels: view, community, and physical
- The ***database designers*** discuss with the users what information the database should contain and its structure
  - A common model (language for describing reality) is needed for them to communicate

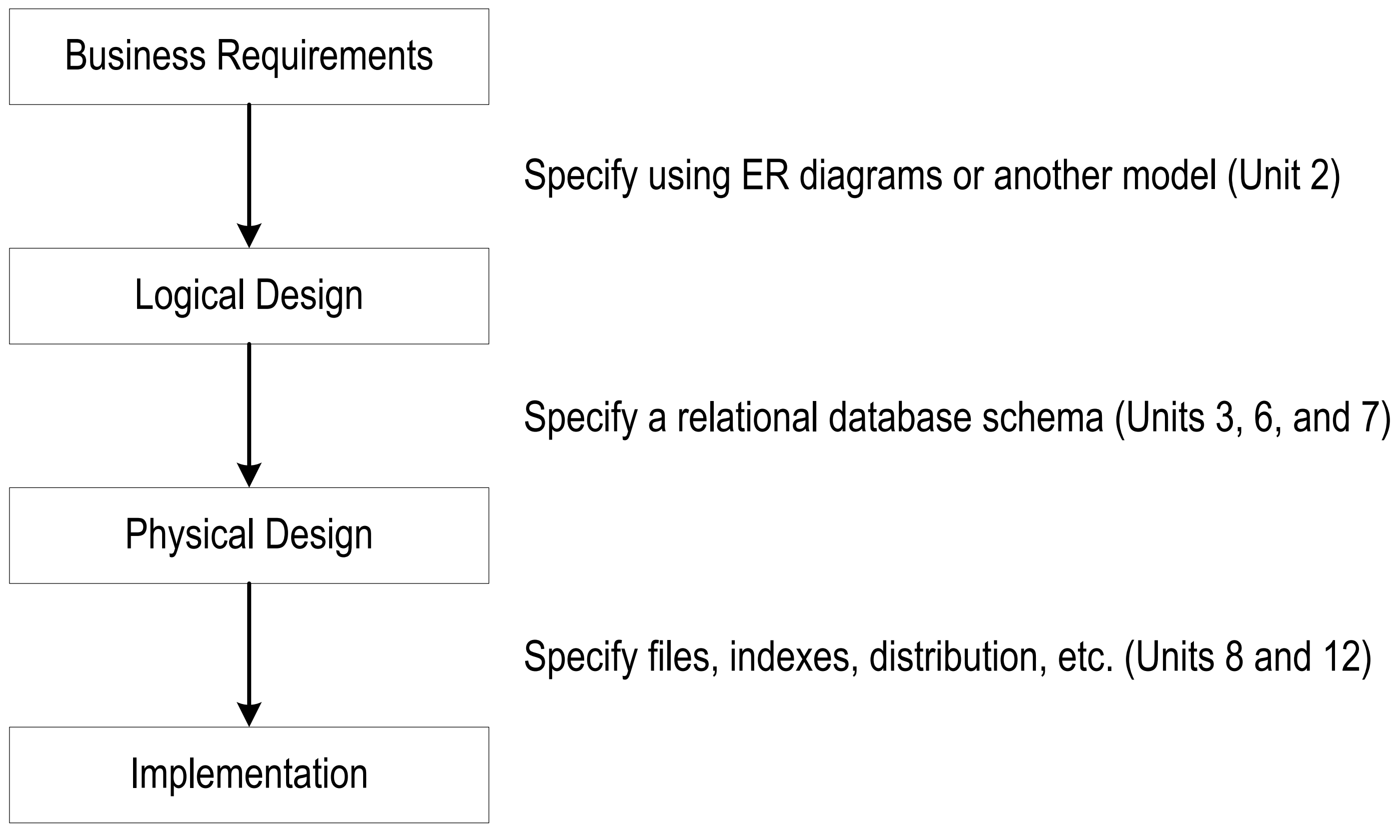
    Entity-relationship model is frequently used
- The ***database application developers*** write the programs (in ***SQL*** and other languages) that specify and manipulate the database
  - Some physical design
- The ***database administrator (DBA)*** maintains the database itself (not the specific application programs), including
  - Loading of data, some physical design, backups, tuning, etc.

Simplified Workflow
Our Terminology



- Of course, we will cover other topics too
  - SQL as Data Manipulation Language
  - DBOS
  - . . .

Simplified Workflow
Another Terminology



Challenges

- We have seen just the tip of the iceberg of what needs to happen for database systems to function as required
- We need
  1. Natural semantics
  2. Convenient syntax
  3. Efficiency
  4. 100% correctness and high reliability
- Enormous effort has been spent since the early 1970s to achieve that
- Most of the effort was on 3 and 4, but it’s not visible as it was “under the hood”

NoSQL: Some Recent Developments

- **Not SQL** or **Not Only SQL**
- Need to handle data that is not easily modeled/stored using tables
- Need much higher processing throughput
  - In tens of microseconds (or even less) for stock trading
- Distribute the computations and data accesses among multiple “nodes” to speed up processing and increase reliability

- However building large, fast, correct, and reliable distributed databases is not practical for the vast majority of applications
- So give up “some” correctness and reliability to gain speed

Material Covered

- Methodology used for modeling a business application during database design process, focusing on entity-relationship model and entity relationship diagrams
- Relational model and implementing an entity relationship diagram in it
- Relational algebra (using SQL syntax)
- SQL as data manipulation language
- SQL as data definition and data control language
- Refining a relational implementation, including the normalization process and the algorithms to achieve normalization

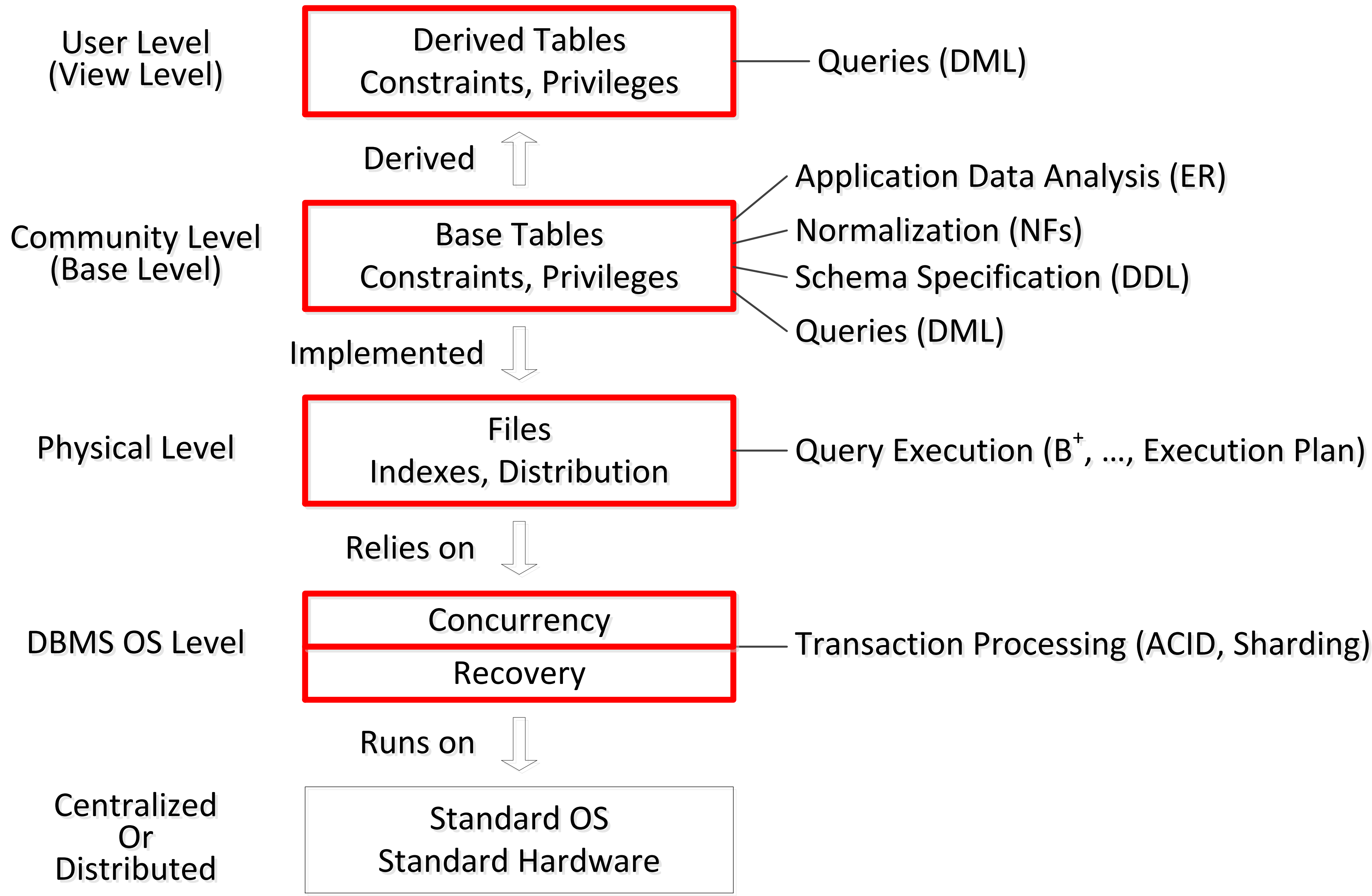
Material Covered

- Physical design of the database using various file organization and indexing techniques for efficient query processing (fundamentals and as implemented)
- Recovery (fundamentals and as implemented)
- Concurrency Control (fundamentals and as implemented)
- Query Execution
- Data warehouses
- Online analytical processing (OLAP)
- New systems

- Power Point presentations will include more material than will be covered in the course
- It will be clearly indicated what has been covered

Recapitulation

We Will Cover the Material In Red Boxes Particularly Stressing the Community Level



An Important Note: Wider Applicability Of Some Of The Material

- The material covered at the levels below the Community Level is applicable to Database Management Systems beyond Relational Database Management Systems, such as NoSQL systems

Key Ideas

Key Ideas

- ***Synopsis*** of the course
- The need for database management systems
- Brief overview of the relational model
- Querying relational database directly and through views
- Need for good logical design
- Need for good physical design
- Recovery
- Concurrency
- Layers of database management systems
- Independence between/among layers
- Various roles of designers, developers, administrators
- NoSQL systems