Questions about the contents of the final section of the course of Advanced Databases. Version 0.3 of 28/05/2018.

12 Decision support systems

How would you define a Decision Support System? What do OLTP and OLAP stand for? Which are the main differences between these two different kinds of applications? What is a Data Warehouse? What is a business intelligence application? Why running the OLTP and the OLAP applications on the same system may it be a bad idea? Why may it be, in some cases, a good idea? How is a data warehouse populated, according to the standard three-levels approach? Which phase is the most complex and time consuming? Why do we have three distinct stores involved in the project? Which are the constructs of the Dimensional Fact Model? How do we proceed for the conceptual design of a data mart? Which are some examples of facts that one may store in a data mart? What is a measure? What is a dimension? What is the relationship between dimensions and measures? Which of the two is organized in hierarchies? Which operation of the data cube is related to the hierarchies? Where do measures and dimensions appear in typical SQL query?

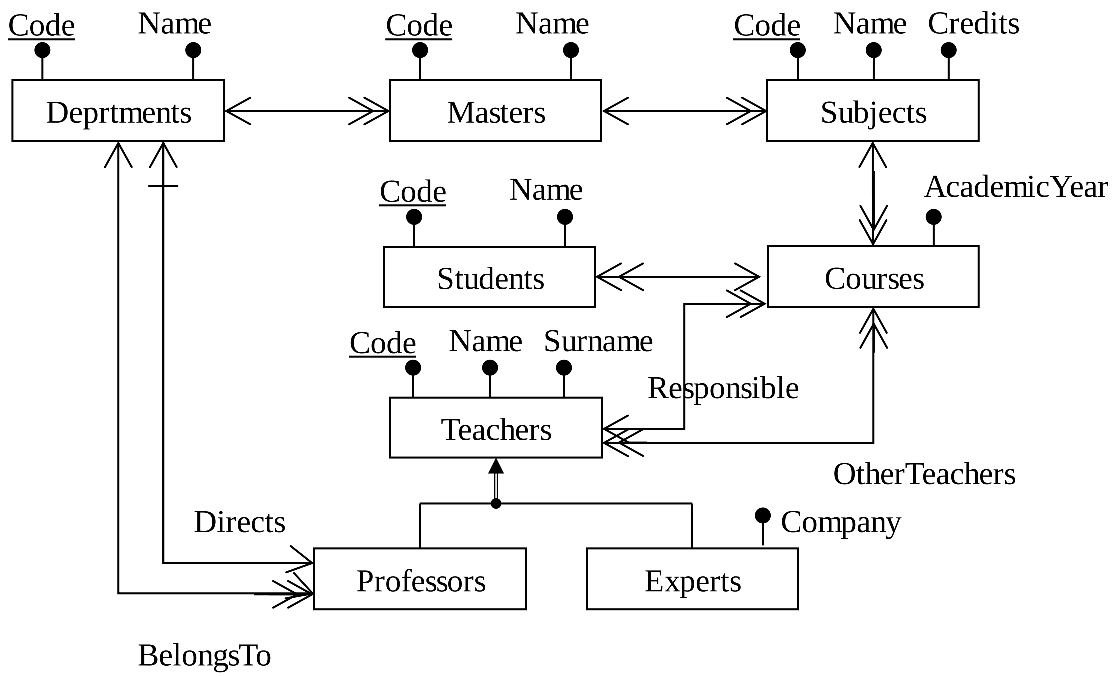
How is a Dimensional Fact Table represented in the relational model? What is a star schema e what is a snowflake schema? The star schema is in Boyce Codd Normal Form? Why? And the snowflake schema? Why is the star schema generally preferred? What is a constellation schema?

What is the multidimensional data model? What is the relationship between a relational table and a cube? We say that a cube of persons whose dimensions are ‘name, surname, age’ is sparse, while a cube of sales whose dimensions are ‘shop, date, product’ is dense. What do we mean? Which algebraic operators correspond to the cube operators – slice, dice, roll-up, drill-down? Which SQL queries? What about the pivot operator? If we have a 3D cube with dimensions Date,Shop,Product, what is the ‘extended cube’? Consider two different cubes C1 and C2 that have been both obtained by rolling-up, in different ways, the same cube C. When is it the case that C1 can be computed from C2? Distinguish the case when dimensions have no hierarchies and the case when dimensions have hierarchies.

The engine that supports OLTP applications must be different from one designed to support OLAP applications. Why?

Exercise

1. Consider the following schema



Consider the following business questions:
For each AcademicYear, we want to know the total number of courses that are taught
For each Master and for each AcademicYear, we want to know the total number of courses that are taught and the total number of students and professors involved. If a student or professor is involved in two different courses, she is counted twice.
For each AcademicYear and for each department, the total credits and the average credits.

How would you define the fact table for these questions? Which would be a minimal set of dimensions, with which attributes each, and which a minimal set of measures?
Define a star schema representation of the dimensional fact table. Consider the natural relational representation of the schema above and write a SQL query to populate the fact table and the dimension tables.

2. Consider a cube Sales with dimensions Date,Shop,Product and consider the following cubes:
   2.1. Sales slice-for 2000 < Date < 2001 roll-up on Date
   2.2. Sales roll-up on Shop slice-for 2000 < Date < 2001 roll-up on Date Date
   2.3. Sales slice-for 2000 < Date < 2001 roll-up on Shop
   2.4. Sales roll-up on Shop
   2.5. Sales roll-up on Date

   Translate each expression into an algebraic expression. Translate each expression into a SQL expression. Consider the order c1 ≤ c2 defines by ‘c1 can be computed from c2’ and give a graphic representation of the order among the 5 expressions above

13 Column databases

Which are the reasons behind the success of column databases? Which have been the changes in the applicative scenario and in the technological scenario? Which are the strongest advantages of a column store over a traditional DB when we have an OLAP application? What are the problems? Why are update operations especially expensive with a column store?

In the traditional Decomposition StorageModel, a ‘column’ is actually a binary table. Can you explain this notion? Is that the same in a column store, that is do we store the RID-Value pairs, or do we just store the values? How is a tuple identified, in this case?

There two possible choices for column order – which are they? Which are the advantages of each possibility?

What is a join index? What is a projection? How many different projections may we have on the same table? Two projections that include the same columns may be different?

Consider a table Sales(FKCust,FKProd,Date,TotPrice), in a traditional DB, sequentially organized by Date, and consider the projection (FKCust,FKProd,Date,TotPrice | Date). What is the difference among the two? Are they stored in the same way?

Why do column stores compress better than traditional databases?

What does it mean to execute an access plan ‘one tuple at a time’ or ‘one operator at a time’? Why do traditional databases prefer ‘one tuple at a time’? What is the problem of that approach with modern architectures? Which intermediate approach is particularly good for modern architectures? Consider the select operator of the binary algebra. Do we need to need to decompress and RLE-encoded column in order to apply Select? What if it is compressed as a bitmap or with a sorted dictionary?

Consider a table that is stored by columns, and all columns are sorted by RID. What must be done in order to rebuild the original table? How much would that cost – including the cost to read the input and to write the result? Assume that, instead, it is stored as a set of projections and we have two projections such that (a) they have the same order and (b) their union covers the entire table. What is the cost, in this case? Is it higher or lower? Assume now that the two projections have different orders, that B*B is bigger than 2*NPag for each of them, and that we have a join index. What is the cost of rebuilding the entire table?

What are the Binary Algebra operators that we have seen? Can you give a formal definition of each of them, apart the Group operator? Can you give an example of application of the group operator?

Consider a join query that returns a single column such as SELECT R.A FROM R, S WHERE R.B=S.B and R.A = 12 and S.C > 10. Can you write a binary algebra access plan that expresses this query? How can you represent a BAT where the first column is a list of consecutive integers? How can the result of a Select operator be represented? What is the advantage of including a range and a bitmap in the representation of a BAT? How can a select operation be implemented in this case? How can a Reconstruct operation be implemented in this case? What is the cost of a Jive Join? Does this cost include the initial reading and writing? Under which assumptions on memory size? What is the cost of a Hash Join under the same assumptions? Why is Jive Join less expensive than Hash Join? Would you use a Jive Join in a traditional database? Why? Can you insert a Jive Join into a traditional access plan that is executed one-tuple-at-a-time? How is typically executed a group-by in a column database? Why is tuple insertion/deletion/update expensive in a column store? What is the solution to this problem? Many column systems give a different differential store to different transactions. Why? What are the Read Store and the Write Store of a columnar data store? Which is the motivation for this approach? How can we exploit the existence of RS and WS to implement transactions? Why do not have we indexes in a column store? Explains these two sentences: “A sorted column A with a join index corresponds to a traditional index A”, “A projection { A, B, C | C } may be considered as an index on C that allows one to rapidly access A and B, with an IndexOnly plan”.

Assume that we try and simulate a column store by building, in a traditional store, one index for every different column. Would that work? Would that have some advantage wrt a traditional design? Would that suffer from some specific problem? Assume that we try and simulate a column store by decomposing a table, in a traditional store, according to the DSM, and organizing every table as a B+-tree over the RID field. Would that work? Would that have some advantage wrt a traditional design? Would that suffer from some specific problem?

Exercises

1) Consider the following tables:

   Sales(Date,FKShop,FKCust,FKProd,UnitPrice,Q,TotPrice)
   Shops(PKShop,Name,City,Region,State)
   Customer(PKCust,Nome,FamName,City,Region,State,Income)
   Products(PKProd,Name,SubCategory,Category,Price)

With the following size:

> Sales: NRec: 100.000.000, Npag: 1.000.000; Shops: 500, 2; Customers: 100.000, 1.000;
> Products: 10.000, 100

Consider the following query:

> SELECT Sh.Region, Month(S.Date),Sum(TotPrice)
> FROM Sales S join Shops Sh on FKShops=PKShops
> GROUP BY Sh.Region, Month(S.Date)

Propose a data organization based on this query, where the function Month returns ‘month-year’, not just month: Month(18/05/2018)=‘05/2018’ (not ‘05’).
Consider both primary organization and indexes. Consider the possibility of denormalization and vertical partitioning.
Compute the cost of an optimal access plan based on this organization.
Add a condition: WHERE 1/1/2017 < Date.
Assume that we want to optimize some variants as well (where the SELECT clause changes according to the GROUP BY)
…GROUP BY Sh.City, Year(S.Date)
…GROUP BY S.Date
…GROUP BY Sh.Region, S.FKCust

2) Define a projection that is optimal to answer the following queries (one projection for both queries):

SELECT Sh.Region, Month(S.Date),Sum(TotPrice)
FROM Sales S join Shops Sh on FKShops=PKShops
GROUP BY Sh.Region, Month(S.Date)

SELECT Date, count(*)
FROM Sales S join Shops Sh on FKShops=PKShops
WHERE Date > 1/1/2016

GROUP BY Date

3) Assume you have a sorted column whose values are 16 bytes strings, with NKey = 1000 and NRec=100.000. How many bits do you need to store it with no compression? How many with RLE? How many with bitmap encoding, without compressing the bitmap? How many with bitmap encoding, where the bitmap is RLE encoded? How many with dictionary encoding? Do all computations in bits, assuming that words do not need to be byte-aligned.

4) Assume you have a unsorted column whose values are 16 bytes strings, with NKey = 100 and NRec=100.000. How many bits do you need to store it with no compression? How many with RLE? How many with bitmap encoding, without compressing the bitmap? How many with bitmap encoding, where the bitmap is RLE encoded? How many with dictionary encoding? Words do not need to be byte-aligned.

5) Assume you have an unsorted column whose values are 16 bytes strings, with NKey = NKey and NRec=NRec. How many bits do you need to store it with no compression? How many with RLE? How many with bitmap encoding, without compressing the bitmap? How many with dictionary encoding?

6) Consider query

SELECT Sh.Region, Month(S.Date),Sum(TotPrice)
FROM Sales S join Shops Sh on FKShops=PKShops
GROUP BY Sh.Region, Month(S.Date)

Of exercise (1). Can we answer it using an access plan where every leaf is ‘IndexOnlyFilter’? Do we need new operator if we want to have such a plan? Assume that Sales and Shops are stored using the DSM approach. Draw an access plan for this query.

14 Parallel and Distributed Databases

Which are the fundamental tasks of any database, including a distributed database? Which are the central issues in a parallel (distributed) database? How would you define a parallel (distributed) database?
What are the models of parallelism? What is the different between Shared Memory/Shared Disk/Shared Nothing? What is the problem of a SM machine, and what is the advantage? Whenever possible, we do not send a tuple-at-a-time, but we collect as many tuples as we can, before sending a message of a bigger size. Why?
Describe different techniques to (horizontally) partition data in a parallel system,
Considering the following techniques for the horizontal partitioning: Range partitioning, Hash partitioning, round-robin, block partitioning, co-located partitioning. What is an advantage of each? Specify some reasons to partition data in a parallel or distributed setting.
In a parallel system, do we execute access plans one-tuple-at-a-time or we usually execute one entire operator before moving to the next one? Why?
How would you execute union / intersection / difference / distinct on a parallel machine? How would you evaluate group-by and join? Can you estimate the time to complete the operation? How does that

depend on the size of the buffer of the machines? What about *filter*? What is the relation between the way *filter* is executed and the technique to partition data?
If the system has 100 nodes, would you expect it to be 100 times faster, when executing one operation, with respect to a one-CPU system, or somehow less efficient than that? Or even better than that? We assume here that executing an operation includes reading the initial data from disk and writing the result on disk.
When data partitioning is very skewed, does this fact affect the efficiency of the system? Why?
What are the main differences between parallel shared-nothing systems and distributed systems? Which are the similarities? Which is the most expensive operation in a distributed system? What may you say about failures?
What is 'data distribution design'? How can we design the data distribution? Which are the decisions to take, and which are the goal? What should we know in order to accomplish this task?
Data fragmentation is based on horizontal partitioning, vertical partitioning, or both? Which are the differences between this phase in a parallel database and in a distributed database?
How would you describe the problem of the distributed commit?
Assume a transaction with participants p1, p2, p3 and coordinator c. Assume that everybody is ready to commit. Which sequence of actions – log writing and messages – would take place during a normal commit process? Assume you are a participant, you receive a message (prepare T) from the coordinator, and, later, you receive another identical message. Why? What may be happened? How will you react? When is the last moment when a participant may autonomously decide to rollback a transaction?
When is the last moment when the coordinator may decide to rollback a transaction?
Assume you are a participant. You receive 'prepare', you answer 'ready' but then, for a long time, you do not get any more message from the coordinator. Why is that a problem for you (excuse the anthropomorphism of the discussion)? What can (and should) you do if the wait time gets too long?
In some implementations of the protocol, the message 'don't commit' is broadcasted to all participants, rather than being sent to the coordinator only. Why may that be useful?
Consider a participant Pi that restarts after a failure, and the last log record says 'ready,T'. Do we know what is the last message that Pi received? Do we know what is the last messages that it sent? Do we know whether that message has been received or not? Assume that the participant decides to rollback T. Is this decision safe? Assume that it decides to send a message 'don't commit', is that safe? Assume that it decides to send a message '(ready T)' to the coordinator, is that safe? Assume that it decides not to send any message, is that safe? In order to answer these questions, it is necessary to reason by cases: what if Pi already sent a message before crashing? What if it did not? What may the others have done, while Pi was down?
Assume that, at restart, Pi sees that the last log record was 'don't commit,T'. Consider which of the following choices are safe: rollback the transaction? send a message (don't commit T)? do not send any message?
Assume that, at restart, the coordinator C sees that the last log record was 'Prepare,T'. Which was the last massage the C has sent (list all the possibilities)? Consider which of the following choices are safe: do not do anything, send a message (Prepare T), send a message (Abort T), send a message (Commit T) (writing a log record if needed).
Assume that, at restart, the coordinator C sees that the last log record was 'Abort,T'. Which was the last massage the C has sent (list all the possibilities)? Consider which of the following choices are safe: do not do anything, send a message (Prepare T), send a message (Abort T), send a message (Commit T) (writing a log record if needed).
Assume that, at restart, the coordinator C sees that the last log record was 'Commit,T'. Which was the last massage the C has sent (list all the possibilities)? Consider which of the following choices are safe:

do not do anything, send a message (Prepare T), send a message (Abort T), send a message (Commit T) (writing a log record if needed).
Assume that we want to implement a distributed lock protocol that ensures that no two processes may hold two conflicting locks over the same logical entity. Which possibilities exist? Which are the advantages and the problems of a centralized solution? May we adopt a solution where every logical object has one specific lock manager but the lock managers do not communicate the ones with the others? In a situation of data replication, is it possible to devise a solution where every process only communicates with a lock manager that is on the same node as the process? Describe the write-locks-all and the majority-lock approaches. Which are the advantages of one and of the other? Is it necessary that the lock managers are in the same nodes as the managed objects? Is that useful? Define the quorum approach. What is the relationship between the primary copy, the write-locks-all, the majority-lock, and the quorum approaches? Can ones be described as a special case of another?
If we adopt the lock protocol – that is, only write or read on data after you got the necessary locks – may we run into consistency problems, such as non-repeatable read, or reading two different values from two different nodes? Is distributed deadlock a problem? Is it possible to keep a global wait-for graph? Is it complicated? Can we generalize the prevention approaches – such as wait-die or would-wait 2PL – to the distributed setting?

Consider a participant Pi that restarts after a failure, and the last log record says 'don't commit'. Do we know what is the last message that Pi received? Do we know what is the last messages that it sent? Do we know whether that message has been received or not? Assume that the participant decides to rollback T. Is this decision safe? Assume that it decides to send a message 'don't commit', is that safe? Assume that it decides not to send any message, is that safe? In order to answer this questions, it is necessary to reason by cases: what if Pi already sent that message before crashing, what if

Exercises

1) Assuming that you have k nodes, connected in a Shared-Noting network, that you take time 10ms to read 4KB of data, that you send data in blocks of 4KB which need 30 ms each to be transmitted. Assume that R and S both measure 10 GB, that R is hash-distributed around nodes 1-100 according to h1(R.A), while S is hash-distributed around nodes 1-50 according to h2(S.B). Describe how would you proceed to compute R Intersect S. Is it possible to parallelize the operations of reading data from disks and sending messages? The result must be written on disk, and you may leave it distributed on the disks of the different machines in any way. Compute the elapsed total time of the computation, including reading data, distributing it for computation, and storing the result.

2) Assume you have relation R(X,Y) at site@R of size NPag(R) and relation S(Y,Z) at site @S of size NPag(S). Assume that sf(SJ(S,R)) is the selectivity factor of SJ(S,R), that is NRec(SemiJoin(S,R))/NRec(S), L(Y) is the size if the Y attribute, and LRec(S) (respectively LRec(R)) is the size of a record of S (resp. R). Write a formula for the amount of data communication that is needed in order to compute the following plan:

O1@R = TableScan(R)@R
O2@S = Send(O1,@S)
O3@S = TablesScan((S)@S
O4@S = SemiJoin(O2,O3)
O5@R = Send(O4,@R)
O6@R = TableScan(R)@R

O7@R = Join(O5,O6)@R

3) Assume that a group of three participants and one coordinator must perform a 2PC. At the beginning every node may fail at every moment, but it is guaranteed to restart after 10 seconds, and, after the first failure, to stay up for at least one second, which is enough to do any *sequence* of read/write log or send/receive message, if the send/receive partner is up. Under this hypothesis, try and find the longest possible delay for protocol termination. We assume that no partner ever gives up and that, when an expected message is not received, all partners request a re-send at random intervals never longer than 2 seconds.

15 Big Data and NoSql

Explain the notion of impedance mismatch. Why have object oriented databases been proposed? What is a BigData applicative problem? What do we mean by Volume, Velocity, Variety? Which problems have traditional DBMSs with Volume, Velocity, and Variety? What is a NoSQL system? What distinguishes it from a traditional SQL database? What does it miss and what does it add? Which are the main types of NoSQL databases? Is it possible to represent a set of key-value pairs in a traditional DBMS? How does that differ from a key-value NoSQL system? Which are the main reasons of the success of NoSQL systems? May you define the 'aggregate data model'? What are the advantages and disadvantages of this model with respect to the relational data model? Which kinds of applicative situations may benefit from the aggregate data model and which situations are better faced using a traditional non-aggregate data model? Which aggregate data models do you know? How is the graph data model described? Is that regarded as an aggregate data model? How is data structured in a key-value store? How is it structured in a document store? How in a column-family store?
What is a schemaless database? Which are the advantages of a schemaless database? Which are the disadvantages?
Which are the main advantages of NoSQL systems? Which are their main limitations?