CS 348 Introduction to Database Systems (Fall 2012)

Final Exam
(Sections 001 and 003)
Instructor: M. Tamer Özsu

19 December 2012
Start: 7:30PM End: 10:00PM Duration: 150 minutes

Student Id: ____________________

Student Name: ____________________

Instructions:

1. This is a closed book examination. No additional materials are allowed.
2. Answer all the questions.
3. Answer each question in the space provided.
4. You can use the back of the sheets for rough work.
5. The exam consists of 7 questions and 12 (twelve) pages; make sure you have all of the pages.

Question	Points	Score
1	10	
2	10	
3	10	
4	6	
5	4	
6	4	
7	6	
Total:	50	

Q1. (10 points)

Answer the following questions with a few sentences (no longer than the allocated space).

(a) What are the three major steps of the database design (data modeling) process? Define each by ***one*** sentence.

Solution:

- Conceptual modeling: The process of identifying the entities, their properties, and the relationships among these entities that are part of the environment that the information system models. In our case, we used E-R model for conceptual modeling.
- Logical modeling: The process of mapping the conceptual model to the primitives of the data model that is used. In the case of relational DBMSs, this is the process of defining the relational schema.
- Physical modeling: The process of defining the physical organization characteristics (e.g., indexes, file structure) of the database.

(b) What types of participation constraints can you have in an E-R model? Define each by ***one*** sentence.

Solution: Two types:

1. Total participation constraint: If entity type E1 is in total participation in relation R with entity type E2, then every entity instance of E1 has to participate via relation R to an entity instance of entity type E2.
2. Partial participation constraint: If, in the above situation, it is acceptable that some instances of E1 participate in relationship R with instances of E2,while others do not have to, then we have a partial participation constraint.

(c) Given relation R(A, B, C, D, E) where (A,B) is the key, and the functional dependencies (A, B) $\rightarrow$ (C, D, E) and B $\rightarrow$ D, is R in Boyce-Codd Normal Form (BCNF)? Justify your answer with one sentence.

Solution: Relation R is not in BCNF, because D is functionally dependent on part of the key (B) and not the full key.

(d) What is the main difference between relational calculus and relational algebra?

Solution: Relational calculus is a declarative language that requires the user to specify the predicates that need to be satisfied by all the tuples in the result relation. Relational algebra, on the other hand, is procedural where the user specifies how to execute the query by means of relational algebraic operators.

(e) What is the difference between logical data independence and physical data independence?

Solution: Logical data independence refers to the immutability of the application programs and users to changes in the logical schema of the database (and vice versa) whereas the physical data independence refers to the immutability of the application programs and users to the changes in the physical schema of the database (and vice versa).

(f) What is referential integrity? How do you represent it in relational model?

Solution: Referential integrity refers to the relationship between two entities such that if there is a referential integrity from entity E1 to entity E2, an instance of E2 has to exist for an instance of E1 to exist. In the relational model, this is represented by foreign keys.

(g) What are insertion, deletion, and update anomalies?

Solution: These anomalies exist when relations are not normalized properly. Insertion anomaly refers to the condition where it is not possible to insert into the database information about a new fact unless (a) a certain relationship is established, or (b) null values are inserted for some key attributes. Deletion anomaly occurs when the deletion of a fact from the database forces the deletion of another fact that we wish to remain in the database. Update anomaly is the case where the modification of one value in a relation cascades to modifications to a number of tuples due to information repetition.

(h) When writing application programs using C and embedded SQL standard, what is the role of a cursor?

Solution: Cursors assist with the *impedance mismatch* between SQL and the host language C. SQL queries return set-oriented results, but there is no C construct to hold these results. A cursor over the result of an SQL query will return each tuple of the result one-by-one to the host C program.

(i) What is the main difference between discretionary access control and mandatory access control?

Solution: From your book "Discretionary access control is based on the concept of rights, or privileges, and mechanism for giving users such privileges. ... Mandaroy access control is based on systemwide policies that cannot be changed by individual users." The fundamental point is that in the first case, the granting of rights to objects are at the discretion of users who already hold rights to those objects, while in the latter case, this is done systemwide.

(j) What are ACID properties of transactions. Explain each by one sentence.

Solution: **Atomicity:** All actions of a transaction are atomic and either they are all performed or none of the actions are performed.

Consistency: Each transaction, when run alone, must preserve the consistency of the database.

Isolation: Each transaction is isolated (protected) from the effects of other concurrently running transactions.

Durability: Once a transaction successfully completes (commits), its effects on the database will survive any future crashes.

Q2. (10 points)
You are designing a database for KW Humane Society. The result is the following set of relations where the type of each relations attribute is given following the attribute (e.g., ID: integer):

> Animals(<u>ID: `integer`</u>, Name: `string`, PrevOwner: `string`, DateAdmitted: `date`, Type: `string`)
> Adopter(<u>SIN: `integer`</u>, Name: `string`, Address: `string`, OtherAnimals: `integer`)
> Adoption(<u>AnimalID: `integer`, SIN: `integer`</u>, AdoptDate: `date`, chipNo: `integer`)

where

(a) The primary keys are underlined.

(b) Animals stores information about the animals currently at the Humane Society. Each is given an ID, and their names together with the SIN of their previous owners (attribute PrevOwner), and their date of admission is recorded. Type refers to the type of animal (dog, cat, etc).

(c) Adopter is the relation that holds information about animal adopters. The attributes are self-descriptive, except OtherAnimals which records the number of other animals that the adopter currently has at home.

(d) AnimalID in Adoption refers to the ID of Animals. Similarly, SIN in Adoption refers to the SIN of Adopter. Attribute chipNo stores the number on the microchip that is implanted on the animal for tracking. Owner in Animals refers to the SIN of Adopter (in this case the previous adopter).

Formulate the following queries in SQL; each one is worth 2 points:

(a) Retrieve the total number of dogs that were brought to the Humane Society on 18 April 2000.

Solution:

```sql
SELECT  COUNT(*)
FROM    Animals
WHERE   Type = ''dog''
AND     DateAdmitted = ''18/04/2000''
```

(b) List the name of the adopter who has adopted every type of animal.

Solution:

```sql
SELECT  Name
FROM    Adopter
WHERE   NOT EXISTS
        (SELECT *
        FROM    Animals A1
        WHERE   NOT EXISTS
```

```
(SELECT *
FROM    Adoption, Animals A2
WHERE   AnimalID = A2.ID
AND     A2.Type = A1.Type
AND     Adoption.SIN = Adopter.SIN))
```

(c) For each animal type, list the animal type and total number of adoptions on 14 June 1999.

Solution:

```
SELECT   Type, COUNT(*)
FROM     Animals, Adoption
WHERE    AdoptDate = ''14/06/1999''
AND      Animals.ID = Adoption.AnimalID
GROUP BY Type;
```

(d) List the types of animals who have not had any adoptions.

Solution:

```
SELECT DISTINCT Type
FROM     Animals
WHERE    NOT EXISTS
          (SELECT *
          FROM     Adoption
          WHERE    Adoption.AnimalID = Animals.ID)
```

(e) For each adopter who has made at least two adoptions, list their names and addresses.

Solution:

```
SELECT   Name, Address
FROM     Adopter, Adoption
WHERE    Adopter.SIN = Adoption.SIN
GROUP BY Adoption.SIN
HAVING   COUNT(SIN) > 1;
```

Note: Some of you were confused with the semantics of the Animals relation (did the entry for an animal get deleted from this table when they are adopted) and I think our answers during the exam did not help. So, we marked (b) and (d) lightly to account for that.

Q3. (10 points)
Given relation R(A, B, C, D, E, F, G) and the set of functional dependencies F={BCD → A, BC → E, A → F, F→G, C→D, A→G}, decompose R into 3NF. Show your steps. Is this decomposition also BCNF? Why or why not?

Note: This requires you to first determine the key(s) of R.

Solution: The key of this relation is (B,C). The argument is simple.

BC→E
C→D, by augmentation BC→DC, by decomposition BC→D
BC→D and BCD→A, by pseudotransitivity BC→A
BC→A and A→F, by transitivity BC→F
BC→F and F→G, by transitivity BC→G
Thus, BC→ADEFG and there is (are) no other attribute(s) that functionally determine all attributes of R.

Now we apply the 3NF Synthesize algorithm.

Step 1. We start with result = $\emptyset$

Step 2. Compute minimal cover for F.

1. The right-hand sides are single attributes, so this step is not necessary.
2. Consider BCD→A

   $(CD)^+$ = C,D
   $(BD)^+$ = B,D
   $(BC)^+$ = A, B,C

   Since A is in $(BC)^+$, we replace BCD→A by BC→A
   Now consider BC→E

   C^+ = C,D
   B^+ = B

   So, nothing happens.
3. Now consider each FD:

   Consider A→F; A^+ w.r.t. G−(AF) = {A, G}
   Consider F→G; F^+ w.r.t. G−(FG) = {F}
   Consider C→D; C^+ w.r.t. G−(CD) = {C}
   Consider A→G; A^+ w.r.t. G−(AG) = {A, F, G}

   Therefore A→G is redundant.

Thus, the minimal cover F' = {BC→A, BC→E, A→F, F→G, C→D}.

Step 3. For each $X \to Y \in F'$, create a relation:

R1(B, C, A, E)
R2(A, F)
R3(F, G)
R4(C, D)

This decomposition is also in BCNF. There are a number of ways to reason about this:

1. You can do a BCNF decomposition to show that you can get a decomposition that is the same as this one. However, note that the BCNF decomposition is not unique, so you have to be careful with the particular decomposition – you may need to try a few.
2. You can show that the decomposition is lossless and has no redundancy by showing that elimination of any one of the decomposed relations will make it lossy. Remember that BCNF is guaranteed to be lossless, but not dependency preserving while the 3NF decomposition will be lossless and dependency preserving at the cost of (potentially) adding redundancy. If you can show that there is no redundancy in the resulting decomposition, then it would also be in BCNF.
3. You can get a BCNF decomposition ***from*** the 3NF decomposition. This is based on the understanding that 3NF eliminates transitive dependencies on the superkey, but not partial dependencies (at the same time) while BCNF eliminates both of these (see slide 28). So, if you have a 3NF decomposition, and you can show that there are no partial dependencies in F in that decomposition, the resulting decomposition would be in BCNF.

Note that this decomposition (which is BCNF) is also dependency preserving. If you take the projection of F over R1, R2, R3, and R4 and then take their union, the following FDs will be missing: BCD→A and A→G. However, if you take the closure of the union, BCD→A will be included due to augmentation and decomposition, and A→G will be included due to transitivity. Therefore the closure of the union is equal to the closure of the original FD and thus it is dependency preserving.

Q4. (6 points)
Consider the ER model given in Figure 1. This model represents the operations of a pharmacy chain. Please answer the following questions regarding this model.

(a) (1 point) Can a pharmaceutical company have multiple phone numbers? If not, what do you need to do to allow this?

Solution: Yes, the pharmaceutical company can have multiple phone numbers. This is because the Phone attribute is defined as a multivalued one.

(b) (1 point) If we delete from the database the pharmaceutical company that manufactures a drug, what happens to the drugs that the company manufactures? Justify (in one or two sentences only) your argument.

Solution: All information about these drugs are deleted from the database as well. This is due to the fact that Drug is a weak entity of Pharmaceutical Co. entity and instances of Drug cannot exist without the existence of their strong entity instance.

(c) (1 point) Similar to part (b), but instead of deleting the pharmaceutical company, what if we delete the pharmacy that sells the drug. Do we have to delete the drug too? Why or why not?

Solution: In this case nothing happens, i.e., we do not have to delete the drug. This is because there is no weak entity-strong entity relationship between Drug and Pharmacy. Instances of these entity types can exist on their own..

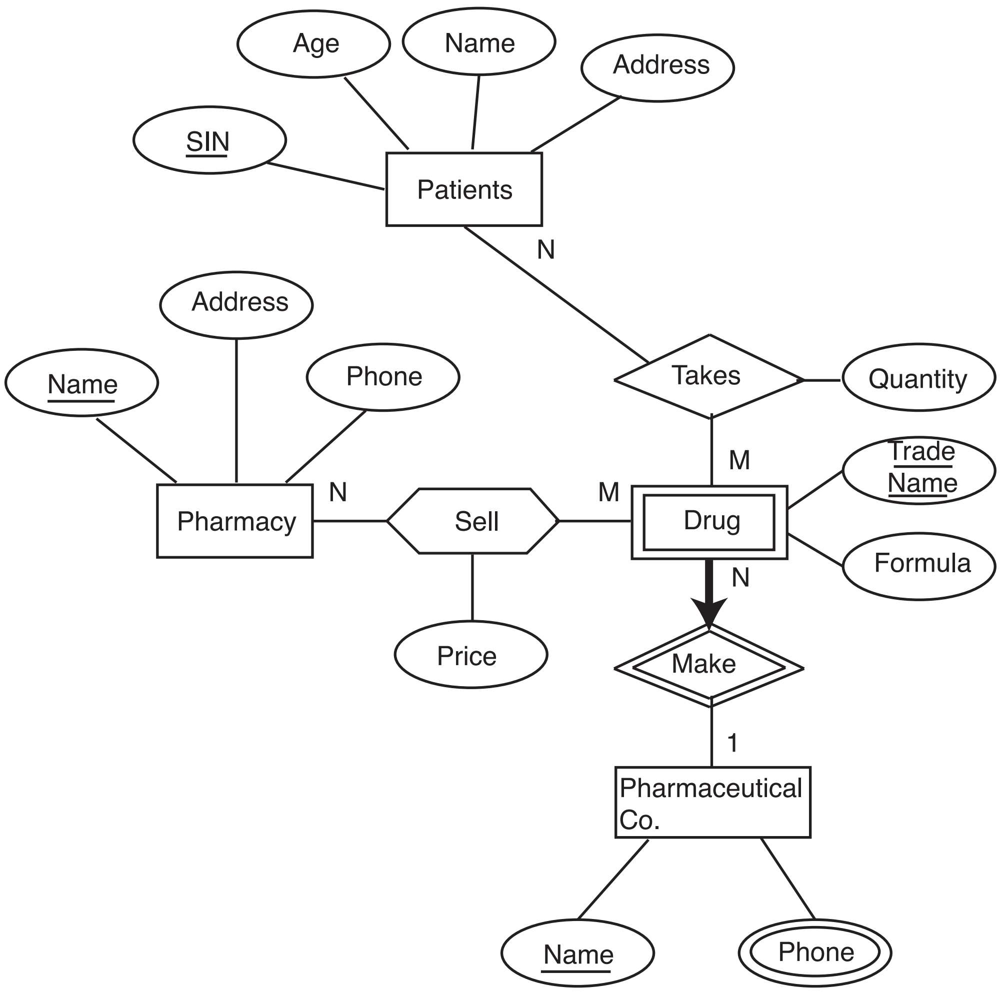


Figure 1: Figure for Question 4

(d) (3 points) Modify the model (by adding to Figure 1, ***not*** by drawing another figure) so that you can represent the following

- Each patient has to have one and only one primary physician. Each physician has at least one patient. We want to know at least the specialty and the date of entry into the profession of each physician.
- Instead of modeling only the fact that a patient takes certain drugs, model the fact that a patient takes certain drugs that are prescribed by a physician and the prescription date.
- Pharmaceutical companies have long-term contracts with pharmacies. A pharmaceutical company can contract with several pharmacies, and a phar-

macy can contract with several pharmaceutical companies. For each contract we want to store a start date, an end date.

Solution: See Figure 2

Note: Some of you reasoned that since there is not a double line from "Pharmaceutical Co." to "Phone", the latter would not be considered multi-valued attribute. The missing line was my error, and I was not looking for this as part of the answer. However, we did accept that correction as part of the solution.

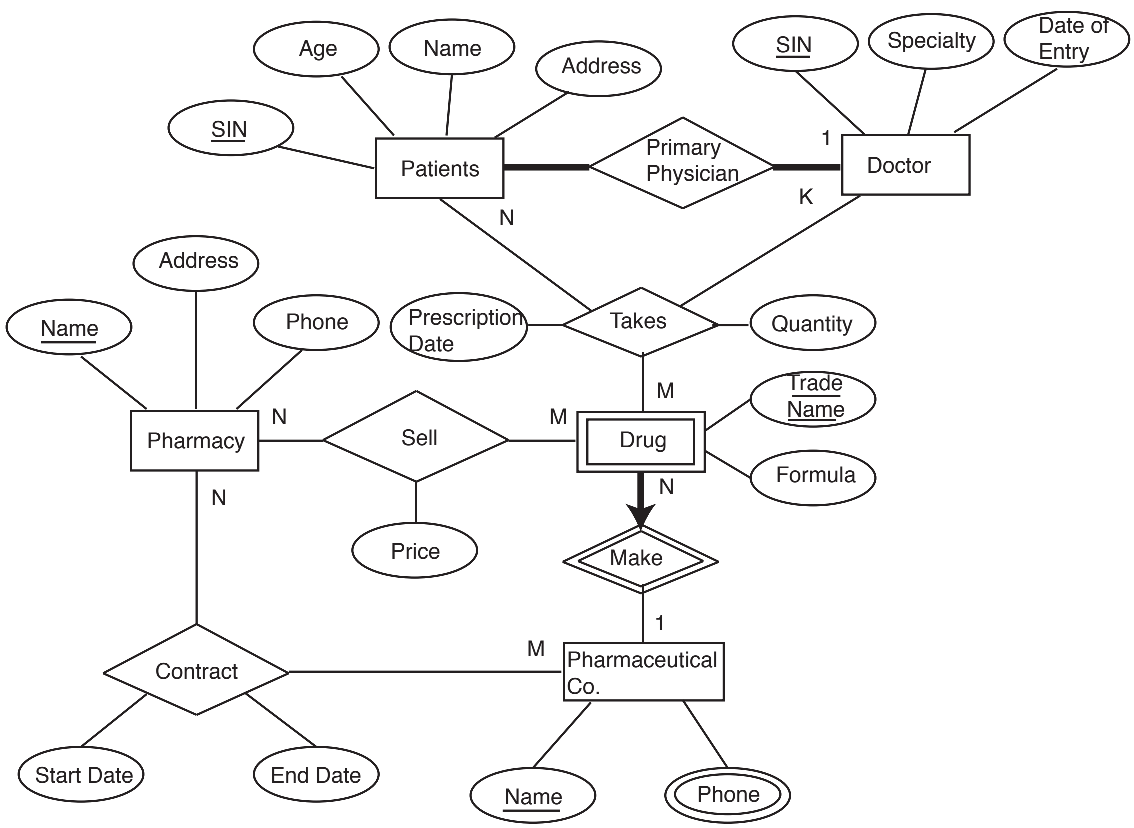


Figure 2: Solution to Question 4d

Q5. (4 points)

Consider histories H_1 and H_2 given below:

$$H_1 = r_1(x), r_2(z), r_1(z), r_3(x), r_3(y), w_1(x), w_3(y), r_2(y), w_2(z), w_2(y)$$
$$H_2 = r_1(x), r_2(z), r_3(x), r_1(z), r_2(y), r_3(y), w_1(x), w_2(z), w_3(y), w_2(y)$$

These histories are generated by the following transactions:

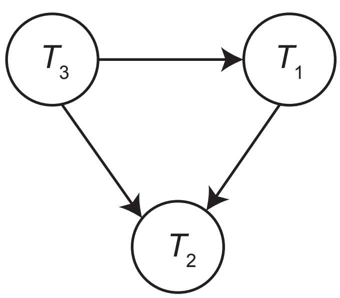
$$T_1 = r_1(x), r_1(z), w_1(x)$$
$$T_2 = r_2(z), r_2(y), w_2(z), w_2(y)$$
$$T_3 = r_3(x), r_3(y), w_3(y)$$

(a) (2 points) Draw the serialization graph for H_1 and state whether or not it is serializable. If it is serializable, give the equivalent serial history.

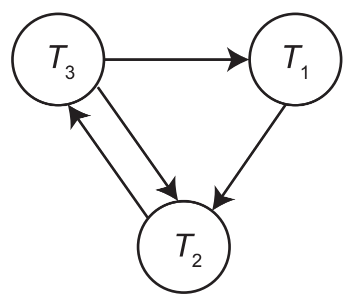
Solution: The serialization graph for H_1 is given in Figure 3a. H_1 is serializable and the serialization order is $T_3 \rightarrow T_1 \rightarrow T_2$.

(b) (2 points) Draw the serialization graph for H_2 and state whether or not it is serializable. If it is serializable, give the equivalent serial history.

Solution: The serialization graph for H_2 is given in Figure 3b. Since there is a cycle in the graph, H_2 is not serializable.



(a) Solution to Question 5a



(b) Solution to Question 5b

Figure 3: Solutions to Question 5b

Q6. (4 points)

Consider the following schema:

Suppliers(<u>sid: `integer`</u>, sname: `string`, address: `string`)
Parts(<u>pid: `integer`</u>, pname: `string`, colour: `string`)
Catalog(<u>sid: `integer`, pid: `integer`</u>, cost: `real`)

The Catalog relation lists the prices charged for parts by Suppliers.

For each of the following transactions state the SQL isolation level that you would use and explain why you chose it.

(a) (1 point) A transaction that adds a new part to a supplier's catalog.

Solution: First note that this is Question 16.8 in your book and it is very similar to the problem that you solved in Assignment 4.

Because we are inserting a new row in the table Catalog, we do not need any lock on the existing rows. So it may appear that using READ UNCOMMITTED would be sufficient. However, note that this isolation level is only allowable for read-only queries. Therefore, READ COMMITTED would need to be used.

(b) (1 point) A transaction that increases the price that a supplier charges for a part.

Solution: Because we are updating one existing row in the table Catalog, we need an exclusive access to the row which we are updating. So we would use READ COMMITTED.

(c) (1 point) A transaction that determines the total number of items for a given supplier.

Solution: To prevent other transactions from inserting or updating the table Catalog while we are reading from it (known as the phantom problem), we would need to use SERIALIZABLE.

(d) (1 point) A transaction that shows, for each part, the supplier that supplies the part at the lowest price.

Solution: Same as (c).

Q7. (6 points)
Consider the following BCNF relational schema for a portion of a university database (type information is not relevant to this question and is omitted):

Prof(sin, pname, office, age, sex, specialty, dept_did)
Dept(did, dname, budget, num_majors, chair_sin)

Suppose you know that the following queries are the five most common queries in the workload for this university and that all five are roughly equivalent in frequency and importance:

- List the names, ages, and offices of professors of a user-specified sex (male or female) who have a user-specified research specialty (e.g., recursive query processing). Assume that the university has a diverse set of faculty members, making it very uncommon for more than a few professors to have the same research specialty.
- List all the department information for departments with professors in a user-specified age range.
- List the department id, department name, and chairperson name for departments with a user-specified number of majors.
- List the lowest budget for a department in the university.

- List all the information about professors who are department chairpersons.

These queries occur much more frequently than updates, so you should build whatever indexes you need to speed up these queries. However, you should not build any unnecessary indexes, as updates will occur (and would be slowed down by unnecessary indexes). Given this information, design a physical schema for the university database that will give good performance for the expected workload. In particular, decide which attributes should be indexed and whether each index should be a clustered index or an unclustered index. Assume that both B+ trees and hashed indexes are supported by the DBMS and that both single- and multiple-attribute index search keys are permitted.

Specify your physical design by identifying the attributes you recommend indexing on, indicating whether each index should be clustered or unclustered and whether it should be a B+ tree or a hashed index.

Solution: Note that this is question 20.2 in your book.

- We should create an unclustered hash index on ⟨specialty, sex⟩ on the Prof relation. This will enable us to efficiently find professors of a given specialty and sex for the first query. It is likely that just having the index on "specialty" would be enough since there are only two sexes. This may in fact be better since the index is smaller. (On the other hand, it is unlikely that "sex" will be updated often).

- We should create a dense clustered B+ tree index on ⟨age, dept_did⟩ on the Prof relation along with an unclustered hash index on "did" in the department relation. We can then find the department with professors in a specified age range efficiently with an index only search and then hash into the Dept relation to get the information we need for the second query.

- We should create an unclustered hash index on "num_majors" in the Dept relation, in order to efficiently find those departments with a given number of majors for the third query.

- We should create a dense clustered B+ tree index on "budget" in the Dept relation so we can efficiently find the department with the smallest budget for the fourth query.

- We should create a dense unclustered B+ tree index on "chair_sin" for the Dept relation along with a dense unclustered hash index on "sin" for the Prof relation so we can find the sin of all chairpersons and then find information about them efficiently by doing an equality search on sin on Prof. The scan on Dept can be made index only for increased efficiency.