

The Relational Database Model



Overview

We now have a conceptual model for Monash Software, it is time to move to the second stage and map this to a logical model

For our unit this will involve mapping to the Relational Model in preparation for implementation in a RDBMS

- Relational Model
- Relational Algebra

The Relational Model

- Introduced by CODD in 1970 - the fundamental basis for the relational DBMS
- Basic structure is the mathematical concept of a RELATION mapped to the 'concept' of a table (tabular representation of relation)
 - Relation - abstract object
 - Table - pictorial representation
 - Storage structure - "real thing" - eg. isam file of 1's and 0's
- Relational Model Terminology
 - DOMAIN - set of atomic (indivisible) values
 - specify
 - name
 - data type
 - data format
- Examples:
 - customer_number domain - 5 character string of the form xxxdd
 - name domain - 20 character string
 - address domain - 30 character string containing street, town & postcode
 - credit_limit domain - money in the range \$1,000 to \$99,999

A Relation

- A relation consists of two parts
 - heading
 - body
- **Relation Heading**
 - Also called Relational **Schema** consists of a fixed set of attributes
 - $R (A_1, A_2, \dots, A_n)$
 - R = relation name, A_i = attribute i
 - Each attribute corresponds to one underlying domain:
 - Customer relation heading:
 - CUSTOMER (custno, custname, custadd, credlimit)
 - » $\text{dom}(\text{custno}) = \text{customer_number}$
 - » $\text{dom}(\text{custname}) = \text{name}$
 - » $\text{dom}(\text{custadd}) = \text{address}$
 - » $\text{dom}(\text{credlimit}) = \text{credit_limit}$

custno	custname	custadd	credlimit
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Relation Body

▪ Relation Body

- Also called Relation Instance (state of the relation at any point in time)
 - $r(R) = \{t_1, t_2, t_3, \dots, t_m\}$
 - consists of a time-varying set of n-tuples
 - Relation R consists of tuples $t_1, t_2, t_3 \dots t_m$
 - m = number of tuples = **relation cardinality**
 - each n-tuple is an ordered list of n values
 - $t = \langle v_1, v_2, \dots, v_n \rangle$
 - n = number of values in tuple (no of attributes) = **relation degree**
- In the tabular representation:
 - Relation heading \Rightarrow column headings
 - Relation body \Rightarrow set of data rows

custno	custname	custadd	credlimit
SMI13	SMITH	Wide Rd, Clayton, 3168	2000
JON44	JONES	Narrow St, Clayton, 3168	10000
BRO23	BROWN	Here Rd, Clayton, 3168	10000

Relation Properties

- No duplicate tuples
 - by definition sets do not contain duplicate elements
 - hence tuples must be unique
- Tuples are unordered within a relation
 - by definition sets are not ordered
 - hence tuples can only be accessed by content
- No ordering of attributes within a tuple
 - by definition sets are not ordered

Relation Properties cont'd

- Tuple values are atomic - cannot be divided
 - EMPLOYEE (eid, ename, departno, dependants)
 - not allowed: dependants (depname, depage) multivalued
 - hence no multivalued (repeating) attributes allowed, called the first normal form rule
- COMPARE with tabular representation
 - normally nothing to prevent duplicate rows
 - rows are ordered
 - columns are ordered
 - tables and relations are not the same 'thing'

Q1. Which of the following statements is TRUE according the characteristics of the relational model?

- A. All values in an attribute need to be from the same domain.
- B. Each attribute needs to have a distinct name.
- C. The order of attributes and tuples matters.
- D. Each intersection of a attribute and a tuple represent a single value.
- E. More than one statement is TRUE

Functional Dependency

▪ Functional Dependency:

- A set of attributes A functionally determines an attribute B if, and only if, for each A value, there is exactly one value of B in the relation. It is denoted as $A \rightarrow B$ (A determines B, or B depends on A)
 - $\text{order_no} \rightarrow \text{order_date}$
 - $\text{prod_no} \rightarrow \text{prod_desc}$
 - $\text{order_no}, \text{prod_no} \rightarrow \text{qty_ordered}$

ORDERNO	ORDERDATE
10	01/MAY/19
11	02/MAY/19
12	03/MAY/19
13	04/MAY/19
14	04/MAY/19
15	05/MAY/19
16	06/MAY/19

ORDERNO	PRODNO	QTYORDERED	LINEPRICE
10	101	1	11.98
11	101	1	11.98
11	103	2	123.58
12	104	10	479.8
13	105	2	140.36
14	106	1	31.99
15	107	3	116.73

PRODNO	PRODDISC	PRODUNITPRICE
101	Salmon - Smoked, Sliced	11.98
102	Brocolinni - Gaylan, Chinese	80.75
103	Pasta - Lasagne, Fresh	61.79
104	Melon - Cantaloupe	47.98
105	Wine - Peller Estates Late	70.18
106	Peas - Pigeon, Dry	31.99
107	Pumpkin - Seed	38.91

Relational Model Keys

- A **superkey** of a relation R is an attribute or set of attributes which exhibits only the uniqueness property
 - No two tuples of R have the same value for the superkey (Uniqueness property)
 - $t1[\text{superkey}] \neq t2[\text{superkey}]$
- A **candidate key** CK of a relation R is an attribute or set of attributes which exhibits the following properties:
 - Uniqueness property (as above), *and*
 - No proper subset of CK has the uniqueness property (Minimality or Irreducibility property) ie. a minimal superkey
- One candidate key is chosen to be the **primary key** (PK) of a relation. Remaining candidate keys are termed alternate keys (AK).

Many possible superkeys

Potentially many possible candidate keys

Only ONE primary key
(may be composed of
many attributes - a
composite primary key)

Q2. Given the following relation:

EMPLOYEE (empno, empname, empsalary, emptaxfileno)

empno - employee number

empname - employee name

empsalary - employee salary

emptaxfileno - employee tax file number

Possible superkey(s) are:

- A. empno, empname, empsalary, emptaxfileno
- B. empno
- C. emptaxfileno, empname
- D. empname
- E. B and C
- F. A, B and C
- G. A, B, C and D

Q3. Given the following relation:

EMPLOYEE (empno, empname, empsalary, emptaxfileno)

empno - employee number

empname - employee name

empsalary - employee salary

emptaxfileno - employee tax file number

How many candidates keys exist:

- A. 0
- B. 1
- C. 2
- D. 3
- E. 4

Q4. Given the following relation:

EMPLOYEE (empno, empname, empsalary, emptaxfileno)

empno - employee number

empname - employee name

empsalary - employee salary

emptaxfileno - employee tax file number

How many primary keys exist:

- A. 0
- B. 1
- C. 2
- D. 3
- E. 4

Selection of a Primary key

- **A primary key must be chosen considering the data that *may be added to the table in the future***
 - Names, dates of birth etc are rarely unique and as such are not a good option
 - PK should be free of 'extra' semantic meaning and security compliant, preferably a single attribute, preferably numeric (see Table 5.3 Coronel & Morris)
 - Natural vs Surrogate primary key
 - PATIENT_TREATMENT (patient_id, physician_id, treatment_code, pt_date, pt_time, pt_result)
 - Superkey
 - CK
 - PK
 - Issues with PK?

TABLE 5.3**DESIRABLE PRIMARY KEY CHARACTERISTICS**

PK CHARACTERISTIC	RATIONALE
Unique values	The PK must uniquely identify each entity instance. A primary key must be able to guarantee unique values. It cannot contain nulls.
Nonintelligent	The PK should not have embedded semantic meaning other than to uniquely identify each entity instance. An attribute with embedded semantic meaning is probably better used as a descriptive characteristic of the entity than as an identifier. For example, a student ID of 650973 would be preferred over Smith, Martha L. as a primary key identifier.
No change over time	If an attribute has semantic meaning, it might be subject to updates, which is why names do not make good primary keys. If Vickie Smith is the primary key, what happens if she changes her name when she gets married? If a primary key is subject to change, the foreign key values must be updated, thus adding to the database work load. Furthermore, changing a primary key value means that you are basically changing the identity of an entity. In short, the PK should be permanent and unchangeable.
Preferably single-attribute	A primary key should have the minimum number of attributes possible (irreducible). Single-attribute primary keys are desirable but not required. Single-attribute primary keys simplify the implementation of foreign keys. Having multiple-attribute primary keys can cause primary keys of related entities to grow through the possible addition of many attributes, thus adding to the database workload and making (application) coding more cumbersome.
Preferably numeric	Unique values can be better managed when they are numeric, because the database can use internal routines to implement a counter-style attribute that automatically increments values with the addition of each new row. In fact, most database systems include the ability to use special constructs, such as Autonumber in Microsoft Access, sequence in Oracle, or uniqueidentifier in MS SQL Server to support self-incrementing primary key attributes.
Security-compliant	The selected primary key must not be composed of any attribute(s) that might be considered a security risk or violation. For example, using a Social Security number as a PK in an EMPLOYEE table is not a good idea.

Null in the Relational Model

- NULL is NOT a value - is a representation of the fact that there is *NO VALUE*
- Reasons for a NULL:
 - VALUE NOT APPLICABLE -
 - EMP relation - empno, deptno, salary, commission
 - commission only applies to staff in sales dept
 - VALUE UNKNOWN -
 - Joe's salary is NULL, Joe's salary is currently unknown
 - VALUE DOES NOT EXIST -
 - Tax File Number - is applicable to all employees but Joe may not have a number at this time
 - VALUE UNDEFINED -
 - Certain items explicitly undefined eg. divide by zero
 - Columns Number_of_payments, Total_payments
 - Column Average_payment_made
 - If Number_of_payments = 0 => Average undefined

Writing Relations

- Relations may be represented using the following notation:
 - `RELATION_NAME (attribute1, attribute2,...)`
- The primary key is underlined.
- Example:
 - `STAFF (staffid, surname, initials, address, phone)`

Relational Database

- A relational database is a collection of normalised relations.
- Normalisation is part of the design phase of the database and will be discussed in a later lecture.

Example relational database:

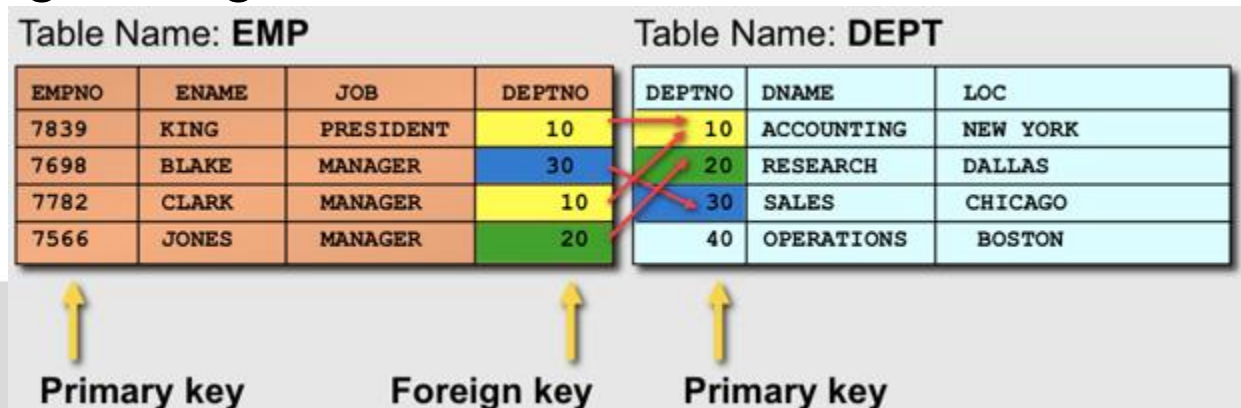
ORDER (order_id, orderdate,)

ORDER_LINE (order_id, product_id, quantity)

PRODUCT (product_id, description, unit_price)

Foreign Key (FK)

- FK: An attribute/s in a relation that exists in the same, or another relation as a Primary Key.
- Referential Integrity
 - A Foreign Key value must either *match the full primary key* in a relation **or be NULL**.
- The pairing of PK and FK creates relationships (**logical connections**) between tables when implemented in a RDBMS. Hence the abstraction away from the underlying storage model.



MANAGER

	PROJECT_MANAGER	MANAGER_PHONE	MANAGER_ADDRESS
▶	Holly B. Parker	904-338-3416	3334 Lee Rd., Gainesville, FL 37123
	Jane D. Grant	615-898-9909	218 Clark Blvd., Nashville, TN 36362
	George F. Dorts	615-227-1245	124 River Dr., Franklin, TN 29185
	William K. Moor	904-445-2719	216 Morton Rd., Stetson, FL 30155

PROJECT

	PROJECT_CODE	PROJECT_BID_PRICE
▶	21-5Z	\$16,833,460.00
	25-2D	\$12,500,000.00
	25-5A	\$32,512,420.00
	25-9T	\$21,563,234.00
	27-4Q	\$10,314,545.00
	29-2D	\$25,559,999.00
	31-7P	\$56,850,000.00

Q5. If the above two tables are to be created in a relational database, in which table would you assign the FK (and using which attribute) to create the logical link? For our supplied scenario a manager may manage many projects and a project can only be managed by one manager. A manager's name (project_manager) and the project_code may be considered to be unique for this example:

- A. MANAGER table using project_manager attribute.
- B. PROJECT table using project_code attribute.
- C. MANAGER table using manager_phone attribute.
- D. PROJECT table using project_manager attribute
- E. None of the above, a relationship is not needed.

Q6. Where are the foreign keys in these two relations?

Note: a supervisor is a staff member

STAFF (staff_id, surname, initials, address, phone, dept_id, supervisor_id)

DEPARTMENT (dept_id, deptname)

- A. dept_id in staff relation.
- B. dept_id in department relation.
- C. staff_id in staff relation.
- D. supervisor_id in staff relation.
- E. More than one answer is correct

Data Integrity

- Entity integrity
 - Primary key value must not be NULL.
 - No duplicate tuple property then ensures that each primary key must be unique
- Referential integrity
 - The values of FK must either match a value of a full PK in the related relation or be NULL.
- Column/Domain integrity
 - All values in a given column must come from the same domain (the same data type and range).

MANAGER

	PROJECT_MANAGER	MANAGER_PHONE	MANAGER_ADDRESS
▶	Holly B. Parker	904-338-3416	3334 Lee Rd., Gainesville, FL 37123
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	George F. Dorts	615-227-1245	124 River Dr., Franklin, TN 29185
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PROJECT

	PROJECT_CODE	PROJECT_MANAGER	PROJECT_BID_PRICE
▶	21-5Z	Holly B. Parker	\$16,833,460.00
	25-2D	Jane D. Grant	\$12,500,000.00
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	25-9T	Holly B. Parker	\$21,563,234.00
	27-4Q	George F. Dorts	\$10,314,545.00
	29-2D	Holly B. Parker	\$25,559,999.00
	31-7P	William K. Moor	\$56,850,000.00

Q7. Suppose that the manager William K. Moor leaves the company and we delete his record from the manager table. Which of the following actions will satisfy the data integrity constraints?

- A. The last row in PROJECT table must be deleted ✓
- B. The PROJECT_MANAGER value in the last row of PROJECT table must be set to NULL (empty) ✓
- C. The PROJECT_MANAGER value in the last row of PROJECT table must be set to any string (e.g., "XYZ") X
- D. The options a and b
- E. All of the above

Relational DMLs

- Relational Calculus
- Relational Algebra
- Transform Oriented Languages (e.g. SQL)
- Graphical Languages
- Exhibit the “closure” property - queries on relations produce relations

Relational Calculus

- Based on mathematical logic.
- Non-procedural.
- Primarily of theoretical importance.
- May be used as a yardstick for measuring the power of other relational languages (“relational completeness”).
- Operators may be applied to any number of relations.

RELATIONAL ALGEBRA

Manipulation of relational data

Relational Algebra

- Relationally complete.
- Procedural.
- Operators only apply to at most two relations at a time.
- 8 basic operations:
 - single relation: selection, projection
 - cartesian product, join
 - union
 - intersection
 - difference
 - division

Relational Operation PROJECT

π

PROJECT_CODE	PROJECT_MANAGER	PROJECT_BID_PRICE
21-5Z	Holly B. Parker	\$16,833,460.00
25-2D	Jane D. Grant	\$12,500,000.00
25-5A	George F. Dorts	\$32,512,420.00
25-9T	Holly B. Parker	\$21,563,234.00
27-4Q	George F. Dorts	\$10,314,545.00
29-2D	Holly B. Parker	\$25,559,999.00
31-7P	William K. Moor	\$56,850,000.00

Relational Operation SELECT

σ

PROJECT_CODE	PROJECT_MANAGER	PROJECT_BID_PRICE
21-5Z	Holly B. Parker	\$16,833,460.00
25-2D	Jane D. Grant	\$12,500,000.00
25-5A	George F. Dorts	\$32,512,420.00
25-9T	Holly B. Parker	\$21,563,234.00
27-4Q	George F. Dorts	\$10,314,545.00
29-2D	Holly B. Parker	\$25,559,999.00
31-7P	William K. Moor	\$56,850,000.00

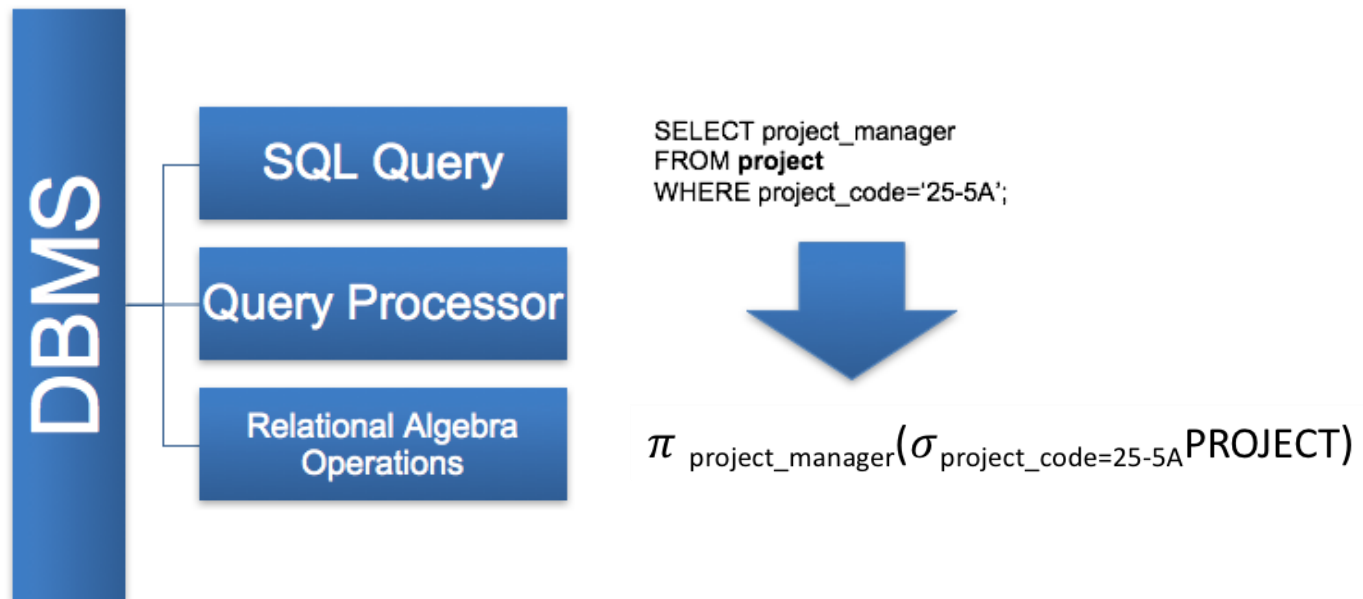
Relational Operation Multiple Actions

2

	PROJECT_CODE	PROJECT_MANAGER	PROJECT_BID_PRICE
	21-5Z	Holly B. Parker	\$16,833,460.00
	25-2D	Jane D. Grant	\$12,500,000.00
1	25-5A	George F. Dorts	\$32,512,420.00
	25-9T	Holly B. Parker	\$21,563,234.00
	27-4Q	George F. Dorts	\$10,314,545.00
	29-2D	Holly B. Parker	\$25,559,999.00
	31-7P	William K. Moor	\$56,850,000.00

$$\text{Result} = \pi_{\text{project_manager}}(\sigma_{\text{project_code}=25-5A} \text{PROJECT})$$

SQL vs Relational Algebra in the Database



STUDENT	course	name	sid	MARK	stude	subj	mark
	BE	Anne	21333		21333	1011	74
	BE	Dave	21876		21333	1021	70
	BSc	John	21531		21333	2011	68
	BSc	Tim	21623		21531	1011	94
					21531	1021	90
					21623	1011	50

Q8. Which of the following statements returns the student ids of the students who got more than 70 marks in the subject 1011.

- A. $\sigma_{\text{mark} > 70} (\pi_{\text{stude}} (\text{MARK}))$
- B. $\sigma_{\text{mark} > 70} (\text{MARK})$
- C. $\sigma_{\text{mark} > 70 \text{ AND } \text{subj} = 1011} (\pi_{\text{stude}} (\text{MARK}))$
- D. $\sigma_{\text{mark} > 70 \text{ AND } \text{subj} = 1011} (\text{MARK})$
- E. $\pi_{\text{stude}} (\sigma_{\text{mark} > 70 \text{ AND } \text{subj} = 1011} (\text{MARK}))$

JOIN

- Join operator used to combine data from two or more relations, based on a common attribute or attributes.
- Different types:
 - theta-join
 - equi-join
 - natural join
 - outer join

THETA JOIN (Generalised join)

$$(\text{Relation_1}) \bowtie_F (\text{Relation_2})$$

- F is a predicate (i.e. truth-valued function) which is of the form $\text{Relation_1}.a_i \theta \text{ Relation_2}.b_j$
 - $\text{CUSTOMER.cust_no} \theta \text{ ORDER.cust_no}$
- θ is one of the standard arithmetic comparison operators, i.e. $<, \leq, =, \geq, >$
- Most commonly, θ is equals ($=$), but can be *any* of the operators
 - $\text{EMPLOYEE.emp_sal} > \text{SALARYSCALE.step_5}$

STUDENT	course	name	sid
	BE	Anne	21333
	BE	Dave	21876
	BSc	John	21531
	BSc	Tim	21623

MARK	stude	subj	mark
	21333	1011	74
	21333	1021	70
	21333	2011	68
	21531	1011	94
	21531	1021	90
	21623	1011	50

Q9. How many rows are generated when the product (Cartesian Product) of the STUDENT and MARK relations is taken? i.e. the number of rows in STUDENT X MARK.

- A. 24
- B. 6
- C. 18
- D. 7
- E. none of the above

STUDENT	course	name	sid
	BE	Anne	21333
	BE	Dave	21876
	BSc	John	21531
	BSc	Tim	21623

MARK	stude	subj	mark
	21333	1011	74
	21333	1021	70
	21333	2011	68
	21531	1011	94
	21531	1021	90
	21623	1011	50

Q10. How many columns are generated when the product (Cartesian Product) of the STUDENT and MARK relations is taken? i.e. the number of columns in STUDENT X MARK.

- A. 9
- B. 6
- C. 5
- D. 7
- E. none of the above

NATURAL JOIN

STUDENT

ID	Name
1	Alice
2	Bob

MARK

ID	Subj	Marks
1	1004	95
2	1045	55
1	1045	90

Step 1: STUDENT X MARK

Step 2: delete rows where IDs do not match (select =)

STUDENT .ID	Name	MARK.ID	Subj	Marks
1	Alice	1	1004	95
1	Alice	2	1045	55
1	Alice	1	1045	90
2	Bob	1	1004	95
2	Bob	2	1045	55
2	Bob	1	1045	90

NATURAL JOIN

STUDENT

ID	Name
1	Alice
2	Bob

MARK

ID	Subj	Marks
1	1004	95
2	1045	55
1	1045	90

Step 1: STUDENT X MARK

Step 2: delete rows where IDs do not match (select =)

Step 3: delete duplicate columns (project away)

STUDENT.ID	Name	MARK.ID	Subj	Marks
1	Alice	1	1004	95
1	Alice	1	1045	90
2	Bob	2	1045	55

NATURAL JOIN

STUDENT			MARK		
ID	Name		ID	Subj	Marks
1	Alice	⋈	1	1004	95
2	Bob		2	1045	55
			1	1045	90

Step 1: STUDENT X MARK

Step 2: delete rows where IDs do not match (select =)

Step 3: delete duplicate columns (project away)

ID	Name	Subj	Marks
1	Alice	1004	95
1	Alice	1045	90
2	Bob	1045	55

A natural join of STUDENT and MARK

STUDENT	course	name	sid
	BE	Anne	21333
	BE	Dave	21876
	BSc	John	21531
	BSc	Tim	21623

MARK	stude	subj	mark
	21333	1011	74
	21333	1021	70
	21333	2011	68
	21531	1011	94
	21531	1021	90
	21623	1011	50

Q11. Which of the following statements returns a natural join of the two relations on the student ids (sid and stude)?

- A. $\sigma_{\text{sid} = \text{stude}} (\text{STUDENT X MARK})$
- B. $\pi_{\text{course, name, sid, subj, mark}} (\sigma_{\text{sid} = \text{stude}} (\text{STUDENT X MARK}))$
- C. $\sigma_{\text{sid} = \text{stude}} (\pi_{\text{course, name, sid, subj, mark}} (\text{STUDENT X MARK}))$
- D. All of the above
- E. None of the above