SQL: An Implementation of the Relational Algebra

P.J. McBrien

Imperial College London

SQL

- Relation Model and Algebra proposed by C.J.Codd in 1970
- IBM deleveped a prototype relational database called **System R** with a query language **Structured English Query Language** (**SEQUEL**)
- SEQUEL later renamed **SQL**
- Various commericial versions of SQL launched in late 1970's/early 1980s
  - **DB2**
  - **Oracle**

SQL

- Relation Model and Algebra proposed by C.J.Codd in 1970
- IBM deleveped a prototype relational database called **System R** with a query language **Structured English Query Language** (**SEQUEL**)
- SEQUEL later renamed **SQL**
- Various commericial versions of SQL launched in late 1970's/early 1980s
  - **DB2**
  - **Oracle**

SQL Language Components

Data Definition Language (**DDL**): a relational schema with data
Data Manipulation Language (**DML**): a relational query and update language

SQL DML: Definition of Tables

```
CREATE TABLE branch
(   sortcode INTEGER NOT NULL,
    bname VARCHAR(20) NOT NULL,
    cash DECIMAL(10,2) NOT NULL
)

CREATE TABLE account(
    no INTEGER NOT NULL,
    type VARCHAR(8) NOT NULL,
    cname VARCHAR(20) NOT NULL,
    rate DECIMAL(4,2) NULL,
    sortcode INTEGER NOT NULL
)
```

SQL DML: SQL Data Types

SQL Data Types	
Keyword	Semantics
BOOLEAN	A logical value (TRUE, FALSE, or UNKNOWN)
BIT	1 bit integer (0, 1, or NULL)
INTEGER	32 bit integer
REAL	32 bit floating point number
FLOAT(n)	An n bit mantissa floating point number
DECIMAL(p,s)	A p digit number with s digits after the decimal point
CHAR(n)	A fixed length string of upto n characters
VARCHAR(n)	A varying length string of upto n characters
DATE	A calendar date (day, month and year)
TIME	A time of day (seconds, minutes, hours)
TIMESTAMP	time and day together
ARRAY	A fixed length list of a certain datatype
MULTISET	A variable sized bag of a certain datatype
XML	XML text

SQL DML: Definition of Keys

```
CREATE TABLE account
(   no INTEGER NOT NULL,
    type VARCHAR(8) NOT NULL,
    cname VARCHAR(20) NOT NULL,
    rate DECIMAL(4,2) NULL,
    sortcode INTEGER NOT NULL,
    CONSTRAINT account_pk PRIMARY KEY (no),
    CONSTRAINT account_fk FOREIGN KEY (sortcode)
    REFERENCES branch
)

CREATE TABLE branch
(   sortcode INTEGER NOT NULL,
    bname VARCHAR(20) NOT NULL,
    cash DECIMAL(10,2) NOT NULL
)

ALTER TABLE branch ADD CONSTRAINT branch_pk PRIMARY KEY (sortcod

CREATE UNIQUE INDEX branch_bname_key ON branch(bname)
```

SQL DML: Inserting, Updating and Deleting Data

```
INSERT INTO account
VALUES (100,'current','McBrien, P.',NULL,67),
(101,'deposit','McBrien, P.',5.25,67),
(103,'current','Boyd, M.',NULL,34),
(107,'current','Poulovassilis, A.',NULL,56),
(119,'deposit','Poulovassilis, A.',5.50,56),
(125,'current','Bailey, J.',NULL,56)

UPDATE account SET type='deposit' WHERE no=100

DELETE FROM account WHERE no=100
```

SQL DML: An Implementation of the RA

SQL SELECT statements

$$\begin{array}{ll} \text{SELECT} & A_1, ..., A_n \\ \text{FROM} & R_1, ..., R_m \\ \text{WHERE} & P_1 \\ \text{AND} & ... \\ \text{AND} & P_k \end{array} \Leftrightarrow \pi_{A_1,...,A_n} \sigma_{P_1 \wedge ... \wedge P_k} R_1 \times \ldots \times R_m$$

SQL SELECT implements RA π, σ and $\times$

$\pi_{\text{bname,no}}\, \sigma_{\text{branch.sortcode=account.sortcode} \wedge \text{account.type='current'}}$ branch $\times$ account

```
SELECT  branch.bname,
        account.sortcode
FROM    account, branch
WHERE   account.sortcode=branch.sortcode
AND     account.type='current'
```

Naming columns in SQL

Column naming rules in SQL

- You must never have an ambiguous column name in an SQL statement
- You can use SELECT * to indicate all columns (*i.e.* have no projection)
- You can use tablename.* to imply all columns from a table

✓

```
SELECT  branch.bname,
        account.sortcode
FROM    account, branch
WHERE   account.sortcode=
            branch.sortcode
AND     account.type='current'
```

✗

```
SELECT  bname,
        sortcode
FROM    account, branch
WHERE   account.sortcode=
            branch.sortcode
AND     type='current'
```

✓

```
SELECT  bname,
        account.sortcode
FROM    account, branch
WHERE   account.sortcode=
            branch.sortcode
AND     type='current'
```

✓

```
SELECT  branch.*,
        no
FROM    account, branch
WHERE   account.sortcode=
            branch.sortcode
AND     type='current'
```

sortcode	bname	cash	no
67	'Strand'	34005.00	100
34	'Goodge St'	8900.67	103
56	'Wimbledon'	94340.45	107
56	'Wimbledon'	94340.45	125

Quiz 1: Translating RA into SQL

Which SQL query implements $\pi_{\text{bname,no}}\, \sigma_{\text{type='deposit'}}\, \text{account} \bowtie \text{branch}$?

A

```
SELECT  *
FROM    account, branch
WHERE   type='deposit'
```

B

```
SELECT  bname, no
FROM    account, branch
WHERE   type='deposit'
```

C

```
SELECT  bname, no
FROM    branch, account
WHERE   branch.sortcode=
            account.sortcode
AND     type='deposit'
```

D

```
SELECT  bname, no
FROM    account, branch
WHERE   branch.sortcode=
            account.no
AND     type='deposit'
```

Connectives Between SQL SELECT statements

Binary operators between SELECT statements

- SQL UNION implements RA $\cup$
- SQL EXCEPT implements RA $-$
- SQL INTERSECT implements RA $\cap$

Note that two tables must be **union compatible**: have the same number and type of columns

π_{no}account $-$ π_{no}movement

```
SELECT  no
FROM    account
EXCEPT
SELECT  no
FROM    movement
```

SQL Joins

'Classic' SQL Join Syntax

```
SELECT branch.sortcode, bname, cash, no, type, cname, rate
FROM   branch, account
WHERE  branch.sortcode=account.sortcode
```

Modern SQL Join Syntax

```
SELECT branch.sortcode, bname, cash, no, type, cname, rate
FROM   branch JOIN account ON branch.sortcode=account.sortcode
```

Special Syntax for Natural Join

```
SELECT *
FROM   branch NATURAL JOIN account
```

The above three queries are equivalent

Overview of RA and SQL correspondances

RA and SQL	
RA Operator	SQL Operator
π	SELECT
σ	WHERE
$R_1 \times R_2$	FROM R_1, R_2 *or* FROM R_1 CROSS JOIN R_2
$R_1 \bowtie R_2$	FROM R_1 NATURAL JOIN JOIN R_2
$R_1 \overset{\theta}{\bowtie} R_2$	FROM R_1 JOIN R_2 ON θ
$R_1 - R_2$	R_1 EXCEPT R_2
$R_1 \cup R_2$	R_1 UNION R_2
$R_1 \cap R_2$	R_1 INTERSECT R_2

Try some examples yourself ...

```
medusa-s2(pjm)-4$ psql -h db -U lab -d lab_bank_branch -W
Password:
lab_bank_branch=> SELECT *
lab_bank_branch-> FROM branch NATURAL JOIN account;
```

sortcode	bname	cash	no	type	cname	rate
67	Strand	34005.00	100	current	McBrien, P.	
67	Strand	34005.00	101	deposit	McBrien, P.	5.25
34	Goodge St	8900.67	103	current	Boyd, M.	
56	Wimbledon	94340.45	107	current	Poulovassilis, A.	
56	Wimbledon	94340.45	119	deposit	Poulovassilis, A.	5.50
56	Wimbledon	94340.45	125	current	Bailey, J.	

. . . and find out that not all DBMSs are the same

```
medusa-s2(pjm)-4$ sqsh -S sqlserver -X -U lab -D lab_bank_branch
Password:
[21] sqlserver.lab_bank_branch.1> SELECT *
[21] sqlserver.lab_bank_branch.2> FROM branch NATURAL JOIN account
[21] sqlserver.lab_bank_branch.3> \go
```

```
Msg 102, Level 15, State 1
Server 'DOWITCHER', Line 2
Line 2: Incorrect syntax near 'account'.
```

SQL: Bags and Sets

```
SELECT sortcode
FROM   account
```

$\approx \pi_{\text{sortcode}}$ account

sortcode
34
56
56
56
67
67

```
SELECT DISTINCT sortcode
FROM   account
```

π_{sortcode} account

sortcode
34
56
67

SQL SELECT: Bag semantics

- By default, an SQL SELECT (equivalent to an RA π) does *not* eliminate duplicates, and returns a **bag** (or **multiset**) rather than a set.
- Any SELECT that does not cover a key of the input relation, and requires a set based answer, should use DISTINCT.

SQL: Bags and Sets

```
SELECT ALL sortcode
FROM   account
```

$\approx \pi_{\text{sortcode}}$ account

sortcode
34
56
56
56
67
67

```
SELECT DISTINCT sortcode
FROM   account
```

π_{sortcode} account

sortcode
34
56
67

SQL SELECT: Bag semantics

- By default, an SQL SELECT (equivalent to an RA π) does *not* eliminate duplicates, and returns a **bag** (or **multiset**) rather than a set.
- Any SELECT that does not cover a key of the input relation, and requires a set based answer, should use DISTINCT.

Quiz 2: Correct use of SELECT DISTINCT (1)

branch(sortcode,bname,cash)
key branch(sortcode)
key branch(bname)

Which SQL query requires the use of DISTINCT in order to avoid the possibility of a bag being produced?

A

```
SELECT  *
FROM    branch
WHERE   cash >10000
```

B

```
SELECT  sortcode
FROM    branch
WHERE   cash >10000
```

C

```
SELECT  bname, cash
FROM    branch
```

D

```
SELECT  cash
FROM    branch
WHERE   cash >10000
```

Quiz 3: Correct use of SELECT DISTINCT (2)

branch(sortcode,bname,cash)
account(no,type,cname,rate,sortcode)

key branch(sortcode)
key branch(bname)
key account(no)

Which SQL query requires the use of DISTINCT in order to avoid the possibility of a bag being produced?

A

```
SELECT *
FROM   branch NATURAL JOIN
       account
```

B

```
SELECT branch.sortcode, type, rate
FROM   branch NATURAL JOIN
       account
```

C

```
SELECT branch.sortcode, no
FROM   branch NATURAL JOIN
       account
```

D

```
SELECT branch.sortcode, no, cash
FROM   branch NATURAL JOIN
       account
```

Quiz 4: Operators that might produce bags

If R and S are sets, which RA operator could produce a bag result?

A	B	C	D
σR	$R \cup S$	$R - S$	$R \times S$

Bag and Set operations in SQL

RA Operator	Set Based SQL	Bag Based SQL
$\pi_{A_1,\ldots,A_n}$	SELECT DISTINCT $A_1, \ldots, A_n$	SELECT ALL $A_1, \ldots, A_n$
$R_1 \times \ldots \times R_m$	FROM $R_1, \ldots, R_m$	FROM $R_1, \ldots, R_m$
$\sigma_{P_1,\ldots,P_k}$	WHERE P_1 AND ... AND P_k	WHERE P_1 AND ... AND P_k
$R_1 \cup R_2$	R_1 UNION DISTINCT R_2	R_1 UNION ALL R_2
$R_1 - R_2$	R_1 EXCEPT DISTINCT R_2	R_1 EXCEPT ALL R_2
$R_1 \cap R_2$	R_1 INTERSECT DISTINCT R_2	R_1 INTERSECT ALL R_2

Chosing between set and bag semantics

If you omit DISTINCT or ALL, then the defaults are:
SELECT ALL
UNION DISTINCT
EXCEPT DISTINCT
INTERSECT DISTINCT

No FROM DISTINCT or WHERE DISTINCT?

There is no need for DISTINCT or ALL around FROM ($\times$) and WHERE (σ) cannot introduce any duplicates, and any existing duplicates can be removed in the SELECT

Quiz 5: SQL EXCEPT

```
SELECT   no
FROM     movement
EXCEPT
SELECT   no
FROM     account
```

What is the result of the above SQL query?

A

no
100
101
103
107
119
125

B

no
100
101
103
107
119

C

no
100
100
101
107

D

no

Quiz 6: SQL EXCEPT ALL

```
SELECT   no
FROM     movement
EXCEPT ALL
SELECT   no
FROM     account
```

What is the result of the above SQL query?

A

no
100
101
103
107
119
125

B

no
100
101
103
107
119

C

no
100
100
101
107

D

no

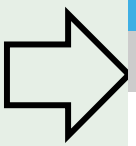
Table Aliases

Table and Column Aliases

The SQL operator AS allows a column or table name to be renamed.
Essential when needing to join a table with itself

List people with a current and a deposit account

```
SELECT current_account.cname,
       current_account.no AS current_no,
       deposit_account.no AS desosit_no
FROM   account AS current_account, account AS deposit_account
WHERE  current_account.cname=deposit_account.cname
AND    current_account.type='current'
AND    deposit_account.type='deposit'
```



cname	current_no	desosit_no
'McBrien, P.'	100	101
'Poulovassilis, A.'	107	119

Worksheet: Translating Between Relational Algebra and SQL

account				
no	type	cname	rate	sortcode
100	'current'	'McBrien, P.'	NULL	67
101	'deposit'	'McBrien, P.'	5.25	67
103	'current'	'Boyd, M.'	NULL	34
107	'current'	'Poulovassilis, A.'	NULL	56
119	'deposit'	'Poulovassilis, A.'	5.50	56
125	'current'	'Bailey, J.'	NULL	56

movement			
mid	no	amount	tdate
1000	100	2300.00	5/1/1999
1001	101	4000.00	5/1/1999
1002	100	-223.45	8/1/1999
1004	107	-100.00	11/1/1999
1005	103	145.50	12/1/1999
1006	100	10.23	15/1/1999
1007	107	345.56	15/1/1999
1008	101	1230.00	15/1/1999
1009	119	5600.00	18/1/1999

movement.no $\longrightarrow$ account.no

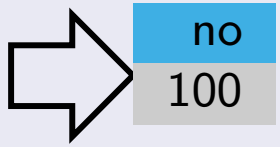
Set Operations: IN

IN operator tests for membership of a set

```
SELECT *
FROM   account
WHERE  type='current'
AND    no IN (100,101)
```

Can use nested SELECT to generate set

```
SELECT no
FROM   account
WHERE  type='current'
AND    no IN (SELECT no
              FROM   movement
              WHERE  amount>500)
```



Quiz 7: SQL Set Membership Testing

```
SELECT  no
FROM    account
WHERE   type='current'
AND     no NOT IN
        ( SELECT no
          FROM   movement
          WHERE  amount>500)
```

What is the result of the above SQL query?

A

no
100
103
107
125

B

no
100
103
107

C

no
103
107
125

D

no
103
107

Quiz 7: SQL Set Membership Testing

```
SELECT no
FROM   account
WHERE  type='current'
AND    no NOT IN
       ( SELECT no
         FROM   movement
         WHERE  amount>500)
```

≠

```
SELECT DISTINCT account.no
FROM   account JOIN movement ON
       account.no=movement.no
WHERE  type='current'
AND    NOT amount>500
```

What is the result of the above SQL query?

A

no
100
103
107
125

B

no
100
103
107

C

no
103
107
125

D

no
103
107

Set Operations: EXISTS

Testing for Existence

- IN can be used to test if some value is in a relation, either listed, or produced by some SELECT statement
- EXISTS can be used to test if a SELECT statement returns any rows

List people without a deposit account

```
SELECT cname
FROM   account
WHERE  cname NOT IN
( SELECT cname
  FROM   account
  WHERE  type='deposit')
```

≡

```
SELECT cname
FROM   account
WHERE NOT EXISTS
( SELECT *
  FROM   account deposit_account
  WHERE  type='deposit'
  AND    account.cname=cname)
```

cname
'Boyd, M.'
'Bailey, J.'

Set Operations: EXISTS

NOT EXISTS and EXCEPT

- Most queries involving EXCEPT can be also written using NOT EXISTS
- EXCEPT relatively recent addition to SQL

π_{no}account $-$ π_{no}movement

```
SELECT no                    SELECT no
FROM   account               FROM   account
EXCEPT                  ≡    WHERE  NOT EXISTS (SELECT no
SELECT no                                       FROM   movement
FROM   movement                                 WHERE  no=account.no)
```

Set Operations: SOME and ALL

Can test a value against members of a set

- V op SOME S is TRUE is there is at least one $V_s \in S$ such that $V = V_s$
- V op ALL S is TRUE is there are no values $V_s \in S$ such that $V \neq V_s$

names of branches that only have current accounts

```
SELECT bname
       FROM   branch
       WHERE  'current'=ALL (SELECT type
                             FROM   account
                             WHERE  branch.sortcode=account.sortcode)
```

names of branches that have deposit accounts

```
SELECT bname
       FROM   branch
       WHERE  'deposit'=SOME (SELECT type
                              FROM   account
                              WHERE  branch.sortcode=account.sortcode)
```

Worksheet: Set Operations

branch		
sortcode	bname	cash
56	'Wimbledon'	94340.45
34	'Goodge St'	8900.67
67	'Strand'	34005.00

movement			
mid	no	amount	tdate
1000	100	2300.00	5/1/1999
1001	101	4000.00	5/1/1999
1002	100	-223.45	8/1/1999
1004	107	-100.00	11/1/1999
1005	103	145.50	12/1/1999
1006	100	10.23	15/1/1999
1007	107	345.56	15/1/1999
1008	101	1230.00	15/1/1999
1009	119	5600.00	18/1/1999

account				
no	type	cname	rate	sortcode
100	'current'	'McBrien, P.'	NULL	67
101	'deposit'	'McBrien, P.'	5.25	67
103	'current'	'Boyd, M.'	NULL	34
107	'current'	'Poulovassilis, A.'	NULL	56
119	'deposit'	'Poulovassilis, A.'	5.50	56
125	'current'	'Bailey, J.'	NULL	56

key branch(sortcode)
key branch(bname)
key movement(mid)
key account(no)
movement(no) $\longrightarrow$ account(no)
account(sortcode) $\longrightarrow$ branch(sortcode)

Null

Several definitions of null have been proposed, including:

1. null represents a something that is not present in the UoD

Null

Several definitions of null have been proposed, including:

1. null represents a something that is not present in the UoD
2. null represents something that might be present in the UoD, but we do not know its value at present

Null

Several definitions of null have been proposed, including:

1. null represents a something that is not present in the UoD
2. null represents something that might be present in the UoD, but we do not know its value at present
3. null represents something that is present in the UoD, but we do not know its value at present

Null

Several definitions of null have been proposed, including:

1. null represents a something that is not present in the UoD
2. null represents something that might be present in the UoD, but we do not know its value at present
3. null represents something that is present in the UoD, but we do not know its value at present

SQL handling of NULL

- SQL uses a three valued logicto process WHERE predicate
- Truth values are TRUE, FALSE, and UNKNOWN
- SQL standard vague, but handling of NULL is nearest to option 2

Quiz 8: SQL handling of NULL (1)

```
SELECT no
FROM   account
WHERE  rate=NULL
```

account

no	type	cname	rate	sortcode
100	'current'	'McBrien, P.'	NULL	67
101	'deposit'	'McBrien, P.'	5.25	67
103	'current'	'Boyd, M.'	NULL	34
107	'current'	'Poulovassilis, A.'	NULL	56
119	'deposit'	'Poulovassilis, A.'	5.50	56
125	'current'	'Bailey, J.'	NULL	56

What is the result of the above SQL query?

A

no
100
101
103
107
119
125

B

no
100
103
107
125

C

no
101
119

D

no

Quiz 9: SQL handling of NULL (2)

```
SELECT no
FROM   account
WHERE  rate=null
OR     rate<>null
```

account

no	type	cname	rate	sortcode
100	'current'	'McBrien, P.'	NULL	67
101	'deposit'	'McBrien, P.'	5.25	67
103	'current'	'Boyd, M.'	NULL	34
107	'current'	'Poulovassilis, A.'	NULL	56
119	'deposit'	'Poulovassilis, A.'	5.50	56
125	'current'	'Bailey, J.'	NULL	56

What is the result of the above SQL query?

A

no
100
101
103
107
119
125

B

no
100
103
107
125

C

no
101
119

D

no

SQL implements three valued logic

P_1 OR P_2		P_2		
		TRUE	UNKNOWN	FALSE
P_1	TRUE	TRUE	TRUE	TRUE
	UNKNOWN	TRUE	UNKNOWN	UNKNOWN
	FALSE	TRUE	UNKNOWN	FALSE

		NOT P_1
P_1	TRUE	FALSE
	UNKNOWN	UNKNOWN
	FALSE	TRUE

P_1 AND P_2		P_2		
		TRUE	UNKNOWN	FALSE
P_1	TRUE	TRUE	UNKNOWN	FALSE
	UNKNOWN	UNKNOWN	UNKNOWN	FALSE
	FALSE	FALSE	FALSE	FALSE

- x=null is UNKNOWN (and not TRUE or FALSE)
  $\therefore$ null=null is UNKNOWN
- x IS NULL returns TRUE if x has a null value
- x IS NOT NULL returns TRUE if x does not have a null value

'Correct' SQL Queries Using null

- Every nullable attribute can be tested to see if it is null:

```
SELECT no
FROM   account
WHERE  rate IS NULL
```

```
SELECT no
FROM   account
WHERE  rate IS NULL OR rate IS NOT NULL
```

- Can test for logical state by IS TRUE, IS NOT TRUE, ...

```
SELECT no
FROM   account
WHERE  (rate=5.50) IS NOT TRUE
```

Quiz 10: SQL 'Might Be'

```
SELECT no
FROM   account
WHERE  (rate=5.25) IS NOT FALSE
```

account

no	type	cname	rate	sortcode
100	'current'	'McBrien, P.'	NULL	67
101	'deposit'	'McBrien, P.'	5.25	67
103	'current'	'Boyd, M.'	NULL	34
107	'current'	'Poulovassilis, A.'	NULL	56
119	'deposit'	'Poulovassilis, A.'	5.50	56
125	'current'	'Bailey, J.'	NULL	56

What is the result of the above SQL query?

A

no
100
101
103
107
125

B

no
100
103
107
119
125

C

no
100
103
107
125

D

no

Worksheet: Null values in SQL

movement			
mid	no	amount	tdate
0999	119	45.00	null
1000	100	2300.00	5/1/1999
1001	101	4000.00	5/1/1999
1002	100	-223.45	8/1/1999
1006	100	10.23	15/1/1999
1008	101	1230.00	15/1/1999
1009	119	5600.00	18/1/1999
1010	null	null	20/1/1999

account				
no	type	cname	rate	sortcode
100	'current'	'McBrien, P.'	null	67
101	'deposit'	'McBrien, P.'	5.25	67
119	'deposit'	'Poulovassilis, A.'	5.50	56
125	'current'	'Bailey, J.'	null	56