Chapter 2 The relational Model of data

Relational algebra

Contents

- What is a data model?
- Basics of the relational model

- How to define?
- How to query?
- Constraints on relations

An algebraic query language

- What is an "Algebra"?
- Mathematical system consisting of:
  - *Operands* --- variables or values from which new values can be constructed.
  - *Operators* --- symbols denoting procedures that construct new values from given values.
  - Eg. (x+y) *2

What is Relational Algebra?

- An algebra whose operands are relations or variables that represent relations.
- Operators are designed to do the most common things that we need to do with relations in a database.
  - The result is an algebra that can be used as a *query language* for relations.

Core Relational Algebra

- Union, intersection, and difference.
  - Usual set operations, but *both operands must have the same relation schema*.
- Selection: picking certain rows.
- Projection: picking certain columns.
- Products and joins: compositions of relations.
- Renaming of relations and attributes.

Selection

- $R1 := \sigma_C (R2)$
  - *C* is a condition (as in "if" statements) that refers to attributes of R2.
  - R1 is all those tuples of R2 that satisfy *C*.

Example: Selection

Relation Sells:

bar	beer	price
Joe's	Bud	2.50
Joe's	Miller	2.75
Sue's	Bud	2.50
Sue's	Miller	3.00

JoeMenu := $\sigma_{bar=\text{“Joe's”}}$(Sells):

bar	beer	price
Joe's	Bud	2.50
Joe's	Miller	2.75

Projection

- $R1 := \pi_L (R2)$
  - *L* is a list of attributes from the schema of R2.
  - R1 is constructed by looking at each tuple of R2, extracting the attributes on list *L*, in the order specified, and creating from those components a tuple for R1.
  - Eliminate duplicate tuples, if any.

Example: Projection

Relation Sells:

bar	beer	price
Joe's	Bud	2.50
Joe's	Miller	2.75
Sue's	Bud	2.50
Sue's	Miller	3.00

Prices := $\pi_{beer,price}$(Sells):

beer	price
Bud	2.50
Miller	2.75
Miller	3.00

Extended Projection

- Using the same $\boldsymbol{\pi}_L$ operator, we allow the list L to contain arbitrary expressions involving attributes:
  1. Arithmetic on attributes, e.g., $A+B\text{->}C$.
  2. Duplicate occurrences of the same attribute.

Example: Extended Projection

R =

A	B
1	2
3	4

$\pi_{A+B \to C, A, A}(R) =$

C	A1	A2
3	1	1
7	3	3

Product

- R3 := R1 X R2
  - Pair each tuple t1 of R1 with each tuple t2 of R2.
  - Concatenation t1t2 is a tuple of R3.
  - Schema of R3 is the attributes of R1 and then R2, in order.
  - But beware attribute *A* of the same name in R1 and R2: use R1.*A* and R2.*A*.

Example: R3 := R1 X R2

R1(

A,	B
1	2
3	4

)

R2(

B,	C
5	6
7	8
9	10

)

R3(

A,	R1.B,	R2.B,	C
1	2	5	6
1	2	7	8
1	2	9	10
3	4	5	6
3	4	7	8
3	4	9	10

)

Theta-Join

- $R3 := R1 \bowtie_C R2$
  - Take the product R1 X R2.
  - Then apply σ_C to the result.
- As for σ, C can be any boolean-valued condition.
  - Historic versions of this operator allowed only $A \theta B$, where θ is =, <, etc.; hence the name "theta-join."

Example: Theta Join

Sells(

bar,	beer,	price
Joe's	Bud	2.50
Joe's	Miller	2.75
Sue's	Bud	2.50
Sue's	Coors	3.00

)

Bars(

name,	addr
Joe's	Maple St.
Sue's	River Rd.

)

BarInfo := Sells $\bowtie_{\text{Sells.bar = Bars.name}}$ Bars

BarInfo(

bar,	beer,	price,	name,	addr
Joe's	Bud	2.50	Joe's	Maple St.
Joe's	Miller	2.75	Joe's	Maple St.
Sue's	Bud	2.50	Sue's	River Rd.
Sue's	Coors	3.00	Sue's	River Rd.

)

Natural Join

- A useful join variant (*natural* join) connects two relations by:
  - Equating attributes of the same name, and
  - Projecting out one copy of each pair of equated attributes.
- Denoted R3 := R1 $\bowtie$ R2.

Example: Natural Join

Sells(

bar,	beer,	price
Joe's	Bud	2.50
Joe's	Miller	2.75
Sue's	Bud	2.50
Sue's	Coors	3.00

)

Bars(

bar,	addr
Joe's	Maple St.
Sue's	River Rd.

)

$$\text{BarInfo} := \text{Sells} \bowtie \text{Bars}$$

Note: Bars.name has become Bars.bar to make the natural join "work."

BarInfo(

bar,	beer,	price,	addr
Joe's	Bud	2.50	Maple St.
Joe's	Milller	2.75	Maple St.
Sue's	Bud	2.50	River Rd.
Sue's	Coors	3.00	River Rd.

)

Renaming

- The ρ operator gives a new schema to a relation.
- R1 := $\rho_{R1(A1,\ldots,An)}$(R2) makes R1 be a relation with attributes A1,…,A*n* and the same tuples as R2.
- Simplified notation: R1(A1,…,A*n*) := R2.

Example: Renaming

Bars(

name,	addr
Joe's	Maple St.
Sue's	River Rd.

)

R(bar, addr) := Bars

R(

bar,	addr
Joe's	Maple St.
Sue's	River Rd.

)

Building Complex Expressions

- Combine operators with parentheses and precedence rules.
- Three notations, just as in arithmetic:
  1. Sequences of assignment statements. :=
  2. Expressions with several operators.
  3. Expression trees.

Sequences of Assignments

- Create temporary relation names.
- Renaming can be implied by giving relations a list of attributes.
- Example: R3 := R1 $\bowtie_C$ R2 can be written:

  R4 := R1 X R2

  R3 := σ_C (R4)

Expressions in a Single Assignment

- Example: the theta-join $R3 := R1 \bowtie_C R2$ can be written: $R3 := \sigma_C (R1 \times R2)$
- Precedence of relational operators:
  1. $[\sigma, \pi, \rho]$ (highest).
  2. $[\times, \bowtie]$.
  3. $\cap$.
  4. $[\cup, —]$

Expression Trees

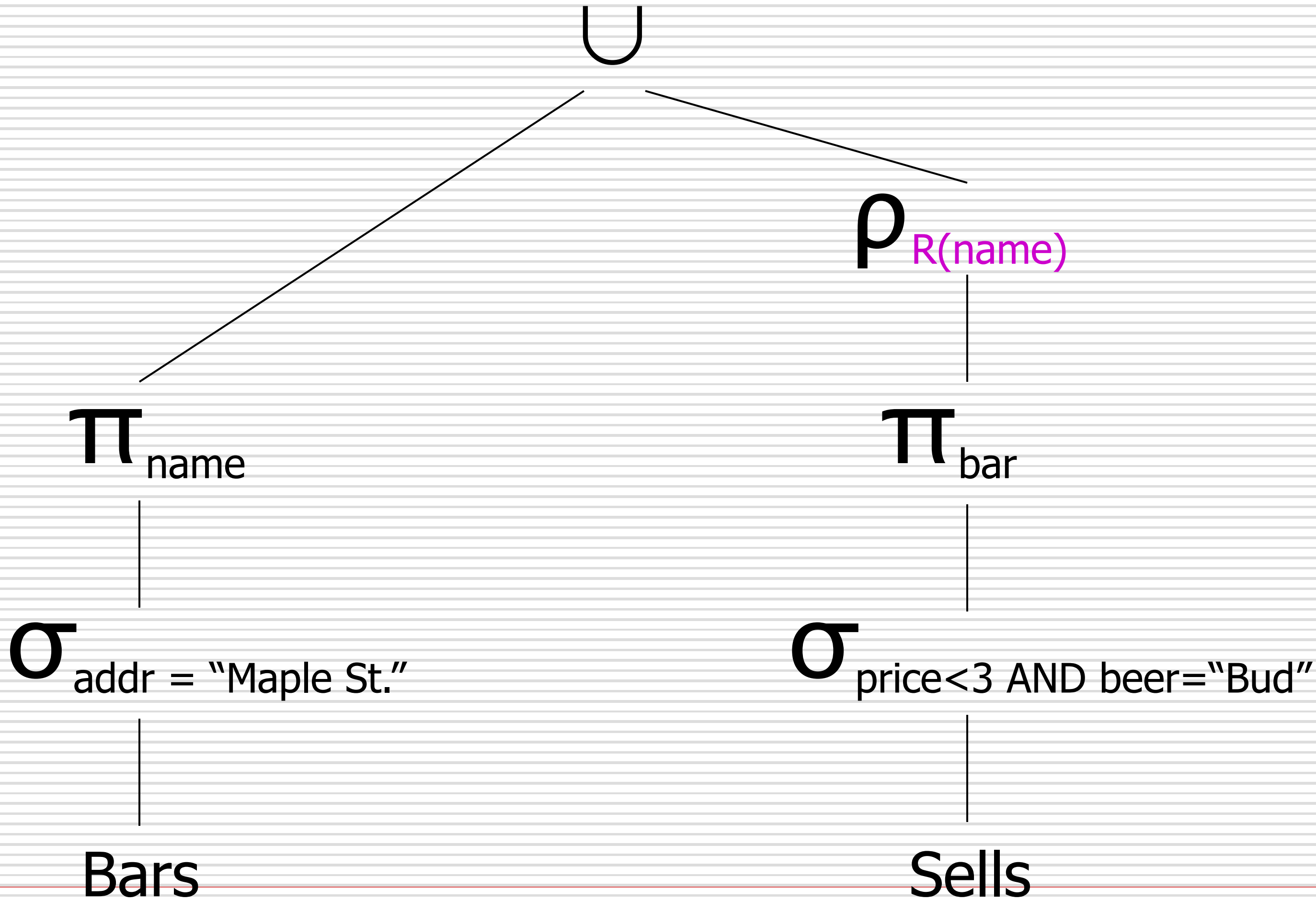
- Leaves are operands --- either variables standing for relations or particular, constant relations.
- Interior nodes are operators, applied to their child or children.

Example: Tree for a Query

- Using the relations Bars(name, addr) and Sells(bar, beer, price), find the names of all the bars that are either on Maple St. or sell Bud for less than $3.

As a Tree:

find the names of all the bars that are either on Maple St. or sell Bud for less than $3.



Example: Self-Join

- Using Sells(bar, beer, price), find the bars that sell two different beers at the same price.

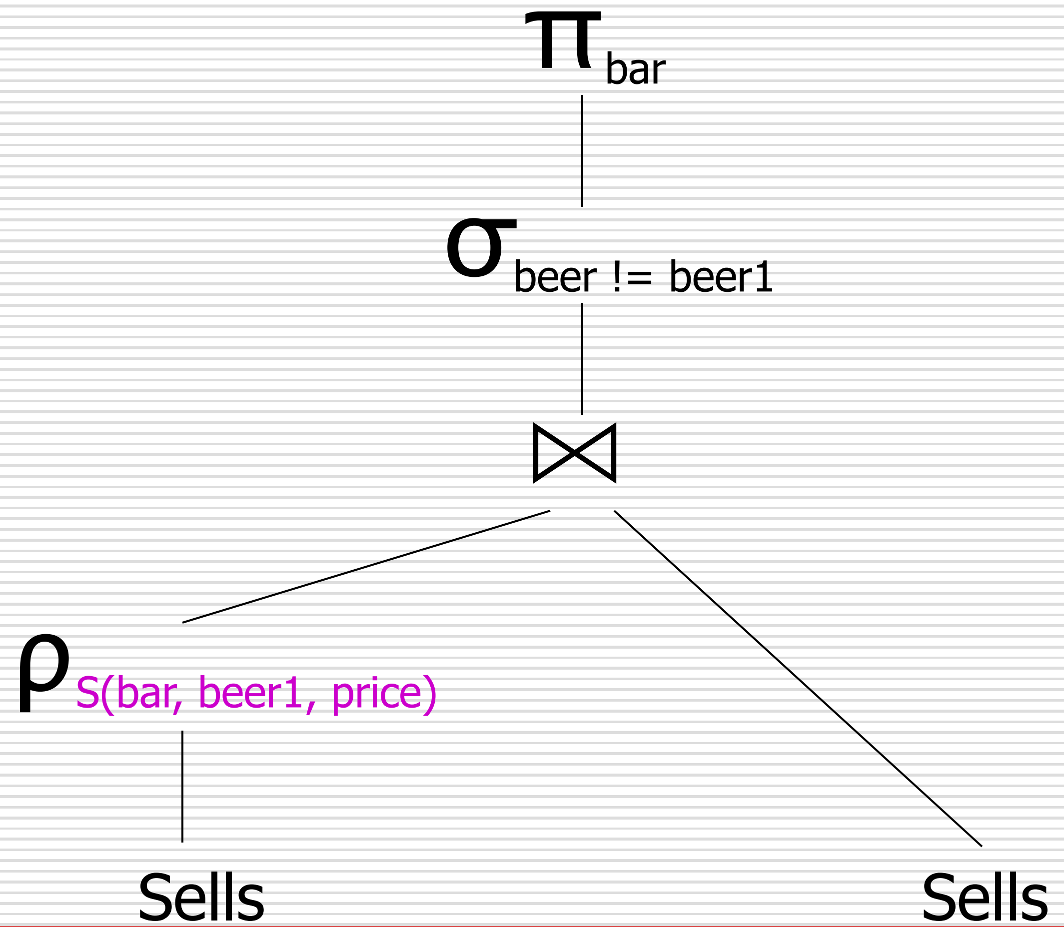
Joe’s	Bud	2.5
Joe’s	Coors	3.0
Joe’s	Miller	2.5
Sue’s	Bud	2.5
Sue’s	Coors	3.5
Marry’s	Miller	2.5

Example: Self-Join (cont.)

- Strategy: by renaming, define a copy of Sells, called S(bar, beer1, price). The natural join of Sells and S consists of quadruples (bar, beer, beer1, price) such that the bar sells both beers at this price.

The Tree

Query: find the bars that sell two different beers at the same price.



The result

Bar	Beer1	price
Joe's	Bud	2.5
Joe's	Coors	3.0
Joe's	Miller	2.5
Sue's	Bud	2.5
Sue's	Coors	3.5
Marry's	Miller	2.5

$\bowtie$

Bar	Beer	price
Joe's	**Bud**	**2.5**
Joe's	**Coors**	**3.0**
Joe's	**Miller**	**2.5**
Sue's	**Bud**	**2.5**
Sue's	**Coors**	**3.5**
Marry's	**Miller**	**2.5**

= ?

Schemas for Results

- Union, intersection, and difference: the schemas of the two operands must be the same, so use that schema for the result.
- Selection: schema of the result is the same as the schema of the operand.
- Projection: list of attributes tells us the schema.

Schemas for Results (cont.)

- Product: schema is the attributes of both relations.
  - Use R.*A*, etc., to distinguish two attributes named *A*.
- Theta-join: same as product.
- Natural join: union of the attributes of the two relations.
- Renaming: the operator tells the schema.

Relational Algebra on Bags

- A *bag* (or *multiset*) is like a set, but an element may appear more than once.
- Example: {1,2,1,3} is a bag.
- Example: {1,2,3} is also a bag that happens to be a set.

Why Bags?

- SQL, the most important query language for relational databases, is actually a bag language.
- Some operations, like projection, are more efficient on bags than sets.

Operations on Bags

- Selection applies to each tuple, so its effect on bags is like its effect on sets.
- Projection also applies to each tuple, but as a bag operator, we do not eliminate duplicates.
- Products and joins are done on each pair of tuples, so duplicates in bags have no effect on how we operate.

Example: Bag Selection

R(

A,	B
1	2
5	6
1	2

)

$\sigma_{A+B<5}$ (R) =

A	B
1	2
1	2

Example: Bag Projection

R(

A,	B)
1	2
5	6
1	2

$\pi_A(R) =$

A
1
5
1

Example: Bag Product

R(

A,	B
1	2
5	6
1	2

)

S(

B,	C
3	4
7	8

)

R X S =

A	R.B	S.B	C
1	2	3	4
1	2	7	8
5	6	3	4
5	6	7	8
1	2	3	4
1	2	7	8

Example: Bag Theta-Join

R(

A,	B)
1	2
5	6
1	2

S(

B,	C)
3	4
7	8

$R \bowtie_{R.B<S.B} S =$

A	R.B	S.B	C
1	2	3	4
1	2	7	8
5	6	7	8
1	2	3	4
1	2	7	8

Bag Union

- An element appears in the union of two bags the sum of the number of times it appears in each bag.
- Example: $\{1,2,1\} \cup \{1,1,2,3,1\} = \{1,1,1,1,1,2,2,3\}$

Bag Intersection

- An element appears in the intersection of two bags the minimum of the number of times it appears in either.
- Example: $\{1,2,1,1\} \cap \{1,2,1,3\} = \{1,1,2\}$.

Bag Difference

- An element appears in the difference $A - B$ of bags as many times as it appears in A, minus the number of times it appears in B.
  - But never less than 0 times.
- Example: {1,2,1,1} – {1,2,3} = {1,1}.

Beware: Bag Laws != Set Laws

- Some, but *not all* algebraic laws that hold for sets also hold for bags.
- Example: the commutative law for union ($R \cup S = S \cup R$) *does* hold for bags.
  - Since addition is commutative, adding the number of times x appears in R and S doesn't depend on the order of R and S.

Example: A Law That Fails

- Set union is *idempotent*, meaning that $S \cup S = S$.
- However, for bags, if x appears n times in S, then it appears $2n$ times in

  $S \cup S$.
- Thus $S \cup S$!= S in general.
  - e.g., {1} ∪ {1} = {1,1} != {1}.

Comparison

Operation	Set model	Bag model
R union S	Elements that are in R or S or both	Sum the times an element appears in the two bags
R intersection S	Elements that are in both R and S	Take the minimum of the number of occurrences in each bag
R difference S	Elements that are in R but not in S	Proper-subtract the number of occurrences in the two bags
Selection $_C$ (R)	Tuples which satisfied the condition C	Tuples which satisfied the condition C
Projection $_L$ (R)	Duplicate tuples eliminated when projecting on L	Duplicate tuples not eliminated when projecting on L
R Join S	Eliminate duplicate tuples	Do not eliminate duplicate tuples
…	….	

Constraints on Relations

- The ability to restrict the data that may be stored in a database.
- Relational algebra: used as a constraint language abstractly.

Two ways to express constraints

R,S: expressions of relational algebra

1. R=0 : “there are no tuples in the result of R” or the value of R must be empty.
2. $R \subseteq S$: “every tuple in the result of R must be in the result of S”

Example 1: Primary Key Constrain

Beers (name, manf)

Bars (name, addr, license)

Sells (bar, beer, price)

Key semantics:

No two tuples agree on the name component in Beers relation.

Does not exist two tuples with the same name and different manf in the Beers relation.

- Primary key constrain:

B1 := Beers

B2 := Beers

$$\sigma_{\mathbf{b1.name=b2.name\ AND\ b1.manf<>b2.manf}}\mathbf{(B1\ X\ B2)=0}$$

Primary Key Constrain (positive example)

Beers (name, manf)

$\sigma_{b1.name=b2.name \text{ AND } b1.manf<>b2.manf}$ (B1 X B2) =0

Bud	Peter’s
Budlit	Peter’s
Miller	A.B.

Name is a key in this table

Bud	Peter’s	Bud	Peter’s
Bud	Peter’s	Budlit	Peter’s
Bud	Peter’s	Miller	A.B.
Budlit	Peter’s	Bud	Peter’s
Budlit	Peter’s	Budlit	Peter’s
Budlit	Peter’s	Miller	A.B.
Miller	A.B.	Bud	Peter’s
Miller	A.B.	Budlit	Peter’s
Miller	A.B.	Miller	A.B.

Primary Key Constrain (negative example)

Beers (name, manf)

$\sigma_{b1.name=b2.name \text{ AND } b1.manf<>b2.manf}$ (B1 X B2) =0

Bud	Petert's
Bud	A.B
Coors	A.B

Name is not a key in this table

Bud	Petert's	Bud	Petert's
Bud	Petert's	Bud	A.B
Bud	Petert's	Coors	A.B
Bud	A.B	Bud	Petert's
Bud	A.B	Bud	A.B
Bud	A.B	Coors	A.B
Coors	A.B	Bud	Petert's
Coors	A.B	Bud	A.B
Coors	A.B	Coors	A.B

Example 2: Other Constrain

Beers (<u>name</u>, manf)

Bars (<u>name</u>, addr, license)

Sells (<u>bar</u>, <u>beer</u>, price)

- Legal value constrain:

  $\sigma_{\text{Price} < 0}$ (Sells)=0 (empty)

Example 3: Referential Integrity Constraint

Beers (<u>name</u>, manf)

Bars (<u>name</u>, addr, license)

Sells (<u>bar</u>, <u>beer</u>, price)

- Referential Integrity constraint:

π_{bar} (Sells) $\subseteq \pi_{name}$(Bars)

π_{beer} (Sells) $\subseteq \pi_{name}$(Beers)

Summary of Chapter 2

- Relational Data models

1. Structure: schemas, relations, keys, how to define structure.
2. Operations: relational algebra as a query language (set and bag), three notations
3. Constraints: Relational algebra as a constraint language (two ways to express)

Classroom exercises (1)

Drinkers(<u>name</u>, addr, phone)

Likes(<u>drinker</u>, <u>beer</u>)

Find names and addresses of all drinkers who like Bud.

Method 1: filter, then concatenate

$\pi_{\text{name, addr}}$

$\sigma_{\text{name=drinker}}$

$\times$

Drinkers $\qquad$ $\sigma_{\text{beer='Bud'}}$

Likes

Method 2: concatenate, then filter

$\pi_{\text{name, addr}}$

$\sigma_{\text{name=drinker}}$ AND beer='Bud'

$\times$

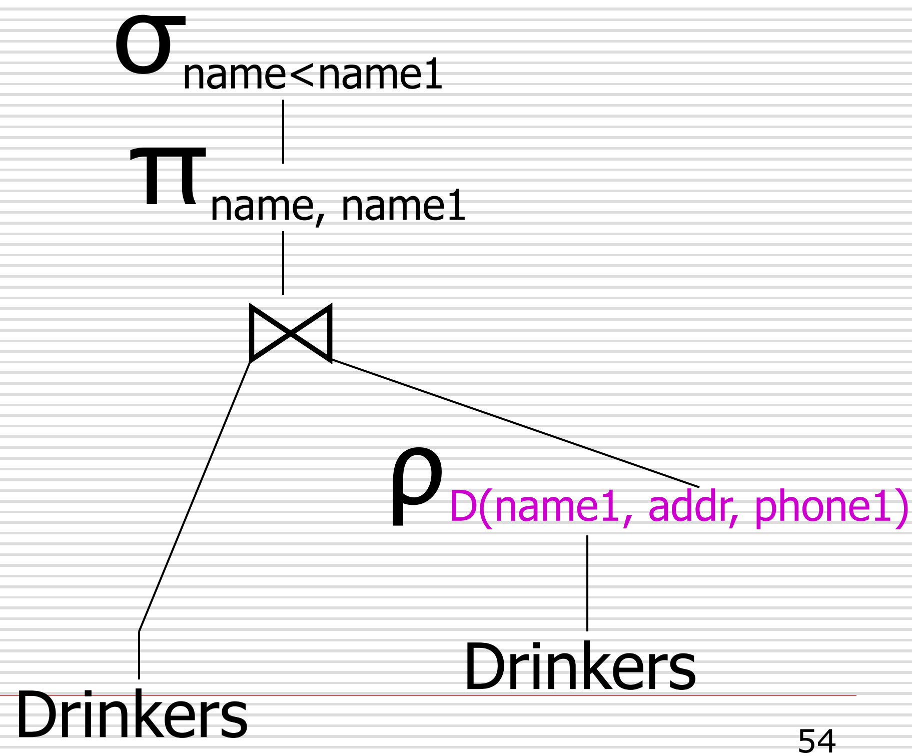
Drinkers $\qquad$ Likes

Classroom exercises (2)

Drinkers(<u>name</u>, addr, phone)

Find names of all pairs of drinkers who live at the same address.

- Comparing drinkers with other drinkers, so reuse and rename
- Natural join contains tuples (name, name1, addr, phone, phone1) such that both drinkers live at this address
- Select condition ensures no duplicates



Classroom Exercise (3)

Drinkers(name, addr, phone)

Likes(drinker, beer)

Sells(bar, beer, price)

Query: find those **beers** that are liked by people living in the Maple street, or that cost less than $5 in everywhere there are sold.

Homework for chapter 2

- Exercise 2.3.1 (DDL)
- Exercise 2.4.1 a), f), h) (DML)
- Exercise 2.5.1 b)