Problem 1

1.

- rule-based

$$answer(bar) : -LIKES(Joe, beer), SERVES(bar, beer, cost)$$

- relational algebra

$$\pi_{bar}(\sigma_{drinker='Joe'}(LIKES \bowtie SERVES))$$

2.

- rule-based

$$answer(drinker) : -FREQUENTS(drinker, bar), SERVES(bar, beer, cost), cost < 3$$

- relational algebra

$$\pi_{drinker}(\sigma_{cost<3}(FREQUENTS \bowtie SERVES))$$

3.

- rule-based

$$answer(drinker) : -LIKES(drinker, beer), LIKES('Joe', beer), SERVES(bar, beer, cost), cost > 5$$

- relational algebra

$$\pi_{drinker}(LIKES \bowtie \pi_{beer}(\sigma_{drinker='Joe' \wedge cost>5}(LIKES \bowtie SERVES)))$$

Problem 2

1.

$$\pi_{drinker}(LIKES) - \pi_{drinker}(FREQUENTS \bowtie LIKES)$$

2.

$$\pi_{drinker}(\sigma_{beer='StellaArtois' \vee beer='Warsteiner'}(SERVES \bowtie FREQUENTS))$$

3.

- relational algebra

$$\pi_{bar}(SERVES) - \pi_{bar}(\pi_{bar}(SERVES) \times \pi_{beer}(\sigma_{drinker='Joe'}(LIKES)) - \pi_{bar,beer}(\sigma_{drinker='Joe'}(SERVES \bowtie LIKES)))$$

- relational calculus

$$\{bar \mid \forall beer \exists cost(\neg LIKES('Joe', beer) \vee SERVES(bar, beer, cost))\}$$

Problem 3

- relational algebra

$$\pi_{bar}(\sigma_{drinker='Joe'}(SERVES \bowtie LIKES)) - \pi_{bar}(\sigma_{drinker='Michael'}(SERVES \bowtie LIKES))$$

- relational calculus

$$\{bar \mid \exists b1, cost(LIKES('Joe', b1) \wedge SERVES(bar, b1, cost) \wedge \forall b2(\neg LIKES('Michael', b2) \vee b2 \neq b1))\}$$

- SQL

```
    SELECT DISTINCT bar
    FROM SERVES, LIKES
    WHERE SERVES.beer = LIKES.beer AND LIKES.drinker = 'Joe'
EXCEPT
    SELECT bar
    FROM SERVES, LIKES
    WHERE SERVES.beer = LIKES.beer AND LIKES.drinker = 'Michael'
```

Problem 4

- relational algebra

$$\pi_{drinker}(FREQUENTS \bowtie (\sigma_{(c_1 \leq 3 \vee c_2 \leq 3) \wedge b_1 \neq b_2}($$
$$(\rho_{c_1 \leftarrow cost, b_1 \leftarrow beer}(SERVES \bowtie LIKES)) \bowtie (\rho_{c_2 \leftarrow cost, b_2 \leftarrow beer}(SERVES \bowtie LIKES)))))$$

- relational calculus

$$\{drinker \mid \exists b_1, b_2, bar, c_1, c_2(LIKES(drinker, b_1) \wedge (LIKES(drinker, b_2) \wedge b_1 \neq b_2 \wedge$$
$$FREQUENTS(drinker, bar) \wedge SERVES(bar, b_1, c_1) \wedge SERVES(bar, b_2, c_2) \wedge (c_1 \leq 3 \vee c_2 \leq 3))\}$$

- SQL

```
SELECT DISTINCT F.drinker
FROM Frequents F, Likes L1, Likes L2, Serves S1, Serves S2
WHERE S1.beer <> S2.beer
  AND S1.bar = S2.bar
  AND (S1.cost <= 3 OR S2.cost <= 3)
  AND L1.beer = S1.beer
  AND L2.beer = S2.beer
  AND L1.drinker = F.drinker
  AND L2.drinker = F.drinker
  AND F.bar = S2.bar
```