Name

CWID

Quiz
1

Feb 08, 2023
Due Feb 22, 11:59pm

Quiz 1: CS525 - Advanced Database Organization

Results

Please leave this empty! 1.1 1.2 1.3 1.4 Sum

Instructions

- **You have to hand in the assignment using diderot**
- **This is an individual and not a group assignment**
- **Do not rename the .sql files**
- **The SQL part is autograded, each question gives full points if it returns the expected query answers and 0 points otherwise.**
- Multiple choice questions are graded in the following way: You get points for correct answers and points subtracted for wrong answers. The minimum points for each questions is **0**. For example, assume there is a multiple choice question with 6 answers - each may be correct or incorrect - and each answer gives 1 point. If you answer 3 questions correct and 3 incorrect you get 0 points. If you answer 4 questions correct and 2 incorrect you get 2 points. ...
- For your convenience the number of points for each part and questions are shown in parenthesis.
- There are 4 parts in this quiz
    1. SQL
    2. Relational Algebra
    3. Index Structures
    4. Result Size Estimation

Part 1.1 SQL (Total: 31 + 10 bonus points Points)

Consider the following publication schema and example instance. The example data should not be used to formulate queries. SQL statements that you write should return the correct result for every possible instance of the schema!

Bar

name	city	owner	closedon
Murphys	Chicago	McDonald	NULL
The Elephant	Chicago	Smith	Saturday
Fiesta	Schaumburg	Gordot	Sunday

Drink

drink	type	alcoholperc
Cranberry Juice	juice	0.0
Millers light	beer	3.5
Lagunitas maximus	beer	9.0
Jack Daniels	liquor	38.0
Oban	liquor	45.0
Guiness	beer	6.0

Menu

drink	bname	bcity	price
Cranberry Juice	Murphys	Chicago	3.50
Millers light	Murphys	Chicago	3.00
Oban	Murphys	Chicago	14.50
Guiness	Murphys	Chicago	7.50
Lagunitas maximus	The Elephant	Chicago	6.00
Jack Daniels	The Elephant	Chicago	9.50
Guiness	The Elephant	Chicago	8.30
Lagunitas maximus	Fiesta	Schaumburg	5.50
Jack Daniels	Fiesta	Schaumburg	12.50
Cranberry Juice	Fiesta	Schaumburg	6.50

Receipt

id	patron	bname	bcity	paymentmethod
1	Smitthy	Murphys	Chicago	card
2	Smitthy	The Elephant	Chicago	cash
3	Fran	Murphys	Chicago	card
4	Otto	Murphys	Chicago	cash
5	Schmotto	Fiesta	Schaumburg	cash
6	Potto	Fiesta	Schaumburg	cash

Item

receiptid	drink	quantity
1	Millers light	1
1	Oban	3
2	Guiness	2
3	Guiness	4
3	Cranberry Juice	2
4	Oban	1
5	Lagunitas maximus	1
5	Jack Daniels	1
6	Lagunitas maximus	5

Hints:

- Attributes with black background are the primary key attributes of a relation
- Attribute `Drink` of relation `Menu` is a foreign keys to relation `Drink`.
- Attributes `bname, bcity` of relation `Menu` are a foreign key to relation `Bar`.
- Attributes `bname, bcity` of relation `Receipt` are a foreign key to relation `Bar`.
- Attribute `drink` of relation `item` is a foreign keys to relation `Drink`.

Question 1.1.1 (3 Points)

Write an SQL query that returns names of patrons who have only ordered drinks of type beer. The result schema should be `(patron)`.

Solution

```
SELECT patron
  FROM receipt r1
 WHERE NOT EXISTS (SELECT *
                     FROM receipt r2, item i, drink d
                    WHERE r2.id = i.receiptid
                      AND d.drink = i.drink
                      AND d.type != 'beer'
                      AND r1.patron = r2.patron);
```

Question 1.1.2 (5 Points)

Write an SQL query that returns pairs of patrons that have never ordered the same drink. That is, the first patron never ordered any drink that the second patron has ordered and vice versa. The result schema should be `(patron_1, patron_2)`.

Solution

```
WITH
  patron_drinks AS (
    SELECT DISTINCT patron, drink
      FROM receipt r, item i
     WHERE r.id = i.receiptid
  ),
  patron_pairs AS (
    SELECT DISTINCT p1.patron AS patron_1, p2.patron AS patron_2
      FROM receipt p1, receipt p2
     WHERE p1.patron != p2.patron
  ),
  common_drinks AS (
    SELECT patron_1, patron_2
      FROM  patron_pairs p, patron_drinks p1d, patron_drinks p2d
     WHERE p1d.patron = p.patron_1 AND p2d.patron = p.patron_2 AND p1d.drink = p2d.drink
  )
SELECT DISTINCT patron_1, patron_2
  FROM patron_pairs p
 WHERE (patron_1,patron_2) NOT IN (SELECT * FROM common_drinks);
```

Question 1.1.3 (5 Points)

Write a SQL query that returns for each bar the name of the patron who has spend the most on drinks ordered at this bar. Return the bar name, city where the bar is located, and name of the patron. The result schema should be `(name,city,patron)`.

Solution

```
WITH patron_expenses AS (
  SELECT r.patron, r.bname, r.bcity, sum(price * quantity) AS expense
    FROM receipt r, item i, menu m
   WHERE m.drink = i.drink AND i.receiptid = r.id AND (r.bname,r.bcity) = (m.bname,m.bcity)
   GROUP BY patron, r.bname, r.bcity),
  max_bar AS (
    SELECT patron, bname, bcity, count(1) OVER (PARTITION BY bname, bcity ORDER BY expense DESC)
      FROM patron_expenses)
SELECT bname AS name, bcity AS city, patron
  FROM max_bar
 WHERE pos = 1;
```

Question 1.1.4 (2 Points)

Write a SQL query that returns for each bar the 2 most expensive items on this bar's menu. Return the bar name, city, item (drink), and the drink's price. The result schema should be `(bname, bcity, drink, price)`.

Solution

```
SELECT bname, bcity, drink, price
  FROM (SELECT bname, bcity, drink, price,
               count(1) OVER (PARTITION BY bname, bcity
                              ORDER BY price DESC) AS rank
          FROM menu m) irank
 WHERE rank <= 2;
```

Question 1.1.5 (2 Points)

Write an SQL query that returns all bars sorted in descending order based on their total income (the total dollar amount spend by patrons at this bar). Return the bar name, city where the bar is located, and the total amount. The result schema should be `(bname, bcity, ttl)`.

Solution

```
SELECT bname, bcity, sum(price * quantity) AS ttl
  FROM receipt r NATURAL JOIN menu m, item i
 WHERE r.id = i.receiptid AND m.drink = i.drink
 GROUP BY bname, bcity
 ORDER BY ttl DESC;
```

Question 1.1.6 (3 Points)

Write an SQL query that computes the average price per beverage type and city and returns for each bar the number of drinks that are more than 20% more expensive than the average price for their beverage type in the city the bar is located in. The result schema should be `(bname,bcity,numdrinks)`.

Solution

```
WITH avgprice AS (
  SELECT avg(price) AS avgprice, bcity, type
    FROM drink d NATURAL JOIN menu m
  GROUP BY bcity, type)

SELECT bname, bcity, sum(CASE WHEN price > 1.2 * avgprice THEN 1 ELSE 0 END) AS numdrinks
  FROM (menu m NATURAL JOIN drink d) NATURAL JOIN avgprice
 GROUP BY bname, bcity;
```

Question 1.1.7 (5 Points)

Write an SQL query that computes distances between pairs of patrons (return `patron_1`, `patron_2`, and `distance`). The distance between two patrons is defined as the length of the shortest path between the two patrons in a graph that is defined as follows. The nodes of the graph are the patrons. There is an edge between patron p_1 and patron p_2 if p_1 and p_2 have both visited the same bar. Pairs of patrons that are not connected in the graph should not be returned.

Solution

```
WITH RECURSIVE
  edges AS (SELECT p1.patron AS p1, p2.patron AS p2
              FROM receipt p1, receipt p2
             WHERE (p1.bname,p1.bcity) = (p2.bname,p2.bcity) AND p1.patron != p2.patron),
  distance(p1,p2,d) AS (
    SELECT p1, p2, 1 AS d FROM edges
     UNION ALL
    SELECT p1,p2, min(d)
      FROM (SELECT d.p1, e.p2, d + 1 AS d
              FROM distance d, edges e
             WHERE d.p2 = e.p1
               AND d <= (SELECT count(*) FROM edges)
               AND d.p1 != e.p2) step
     GROUP BY p1, p2)
SELECT p1 as patron_1,p2 AS patron_2, min(d) AS distance
  FROM distance
 GROUP BY p1, p2;
```

Question 1.1.8 (2 Points)

Write an SQL query that returns for each patron how much they have paid in total in cash and using a credit card. The result schema should be `(patron, cashamount, cardamount)`.

Solution

```
SELECT patron,
       sum(CASE WHEN paymentmethod = 'cash' THEN price * quantity ELSE 0 END) AS cashamount,
       sum(CASE WHEN paymentmethod = 'card' THEN price * quantity ELSE 0 END) AS cardmount
  FROM receipt r NATURAL JOIN menu m JOIN item i ON (r.id = i.receiptid)
 WHERE i.drink = m.drink
 GROUP BY patron;
```

Question 1.1.9 (4 Points)

Write an SQL query that returns the number of nodes in the largest clique of the social network graph from question 1.1.7. A clique is a set of nodes such that each pair of nodes from this set is reachable from each other. The result schema should be `cnt` (the number of nodes in the clique).

Solution

```
WITH RECURSIVE
  ps AS (SELECT p1.patron AS p, rank() OVER (order by patron) AS cid
           FROM receipt p1),
  edges AS (SELECT p1.patron AS p1, p2.patron AS p2
              FROM receipt p1, receipt p2
             WHERE (p1.bname,p1.bcity) = (p2.bname,p2.bcity) AND p1.patron != p2.patron),
  clique(p,cid) AS (
    SELECT p, cid FROM ps
     UNION
    SELECT p, min(cid) AS cid
      FROM (SELECT c.p,
                   LEAST(c.cid,p.cid) AS cid
              FROM clique c, edges e, ps p
             WHERE (c.p = e.p1 AND e.p2 = p.p) OR (c.p = e.p2 AND e.p1 = p.p)) step
     GROUP BY p)
SELECT count(DISTINCT p) AS cnt
  FROM clique c
 GROUP BY c.cid
 ORDER BY cnt DESC
 LIMIT 1;
```

Question 1.1.10 Optional Bonus Question (10 Bonus Points)

For this question, you will write a SQL **query** implementing a SAT solver. Given a predicate logic formula, a SAT solver determines whether there exists a satisfying assignment for the formula. That is, can we assign the value true or false to each variable in the formula such that the formula evaluates to true. We assume that the formula is given in conjunctive normal form (CNF), i.e., as a conjunction (`AND`) of disjunctions (`OR`) of terms called clauses. A term is either a variable or its negation. The formula is given as input as a table with schema `formula(clause,var,negated)`. The formula is encoded in this table as follows. Each clause (disjunction) is assigned an id (start with id 0). Each term of a clause with id i is encoded as one row in the table with `clause` equal to i, `var` stores an identifier of the variable (variable identifiers start at 0 and are consecutive) and negated is 0 if the term is not negated and 1 if it is negated. For example, the unsatisfiable formula $(x_0 \vee \neg x_1) \wedge (x_1 \vee x_2)$ would be encoded as

conjunct	var	negated
0	0	0
0	1	1
1	1	0
1	2	0

You query should take such a table as input and return a single row with a single column. The value of this column should be the boolean value `TRUE` if the formula is satisfiable and `FALSE` otherwise.

Solution

```
WITH RECURSIVE maxvar AS (
  SELECT max(var) AS maxvar FROM formula
),
  assignments AS (
    SELECT aid, var, CASE WHEN MOD(aid,POW(2,v+1)::INT) >= POW(2,v)
                          THEN 0
                          ELSE 1
                     END AS val
      FROM maxvar m,
           generate_series(0,POW(2,maxvar+1)::INT - 1) aid(aid),
           generate_series(0,m.maxvar) var(v))
SELECT bool_or(result) AS result
  FROM (SELECT aid, bool_and(cnj) AS result
          FROM (SELECT bool_or(CASE WHEN f.negated = 0
                                    THEN val::bool
                                    ELSE NOT(val::bool)
                               END) AS cnj,
                       aid,
                       clause
                  FROM formula f, assignments a
                 WHERE f.var = a.var
                 GROUP BY aid, clause) clauses
         GROUP BY aid) assign_result;
```

Part 1.2 Relational Algebra (Total: 29 Points)

Question 1.2.1 Relational Algebra (4 Points)

Write a relational (bag semantics) algebra expression over the schema from the SQL part (part 1) that returns bars that have at least 3 items on their menu.

Solution

$$Q_{numitems} = {}_{bname,bcity}\alpha_{count(*)}(menu)$$
$$Q = \pi_{bname,bcity}(\sigma_{count(*)\geq 3}(q_{numitems}))$$

Question 1.2.2 Relational Algebra (3 Points)

Write a relational (bag semantics) algebra expression over the schema from the SQL part (part 1) that returns the maximum alcohol percentage per drink `type`.

Solution

$${}_{max(alcoholperc)}\alpha_{type}(Drink)$$

Question 1.2.3 Relational Algebra (5 Points)

Write a relational (bag semantics) algebra expression over the schema from the SQL part (part 1) that returns bars which have no receipts for patrons.

Solution

$$Q_{hasPatron} = \pi_{bname,bcity}(Menu)$$
$$Q = \pi_{name,city}(Bar) - q_{hasPatron}$$

Question 1.2.4 SQL → Relational Algebra (5 Points)

Translate the SQL query from Question 1.1.1 into relational algebra (bag semantics).

Solution

$$Q_{nonbeerpatrons} = \pi_{patron}(\sigma_{type<>beer}(Drink \bowtie_{drink=idrink} \rho_{receiptid,idrink,quantity}(Item) \bowtie_{receiptid=id} (Receipt)))$$
$$Q = \pi_{patron}(Receipt) - Q_{nonbeerpatrons}$$

Question 1.2.5 SQL → Relational Algebra (6 Points)

Translate the SQL query from question 1.1.2 into relational algebra (bag semantics).

Solution

$$Q_{patrondrink} = \pi_{patron,drink}(Receipt \bowtie_{id=receiptid} Item)$$
$$Q_{shareddrink} = \pi_{p1,p2}(\rho_{p1,drink}(Q_{patrondrink}) \bowtie \rho_{p2,drink}(Q_{patrondrink}))$$
$$Q_{allpairs} = \delta(\rho_{p1}(\pi_{patron}(Receipt))) \times \delta(\rho_{p2}(\pi_{patron}(Receipt)))$$
$$Q = Q_{allpairs} - Q_{shareddrink}$$

Question 1.2.6 SQL → Relational Algebra (6 Points)

Translate the SQL query from question 1.1.4 into relational algebra (bag semantics), but only return the most expensive item per bar.

Solution

$$Q_{maxprice} = {}_{bname,bcity}\alpha_{max(price)}(Menu)$$
$$Q = \pi_{bname,bcity,drink,price}(Menu \bowtie_{price=max(price)} Q_{maxprice})$$

Part 1.3 Index Structures (Total: 30 Points)

Assume that you have the following table:

Item

SSN	name	age
325-63-232	Joe	68
287-07-858	Pete	66
778-48-806	Lily	71
276-34-872	Bob	39
368-11-536	Heinz	20
600-63-751	John	62
788-27-365	Alice	20
306-36-224	Gertrud	32

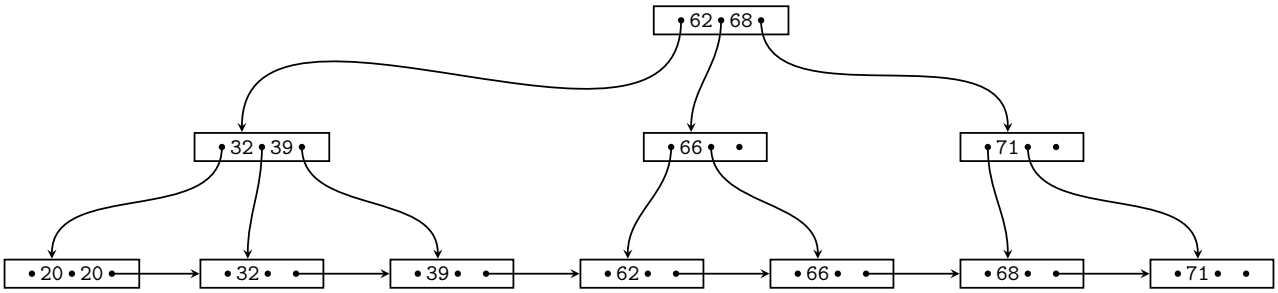
Question 1.3.1 Construction (12 Points)

Create a B+-tree for table *Item* on key *age* with $n = 2$ (up to two keys per node). You should start with an empty B+-tree and insert the keys in the order shown in the table above. Write down the resulting B+-tree after each step.

When splitting or merging nodes follow these conventions:

- **Leaf Split**: In case a leaf node needs to be split during insertion and n is even, the left node should get the extra key. E.g, if $n = 2$ and we insert a key 4 into a node [1,5], then the resulting nodes should be [1,4] and [5]. For odd values of n we can always evenly split the keys between the two nodes. In both cases the value inserted into the parent is the smallest value of the right node.
- **Non-Leaf Split**: In case a non-leaf node needs to be split and n is odd, we cannot split the node evenly (one of the new nodes will have one more key). In this case the "middle" value inserted into the parent should be taken from the right node. E.g., if $n = 3$ and we have to split a non-leaf node [1,3,4,5], the resulting nodes would be [1,3] and [5]. The value inserted into the parent would be 4.
- **Node Underflow**: In case of a node underflow you should first try to redistribute values from a sibling and only if this fails merge the node with one of its siblings. Both approaches should prefer the left sibling. E.g., if we can borrow values from both the left and right sibling, you should borrow from the left one.

Solution

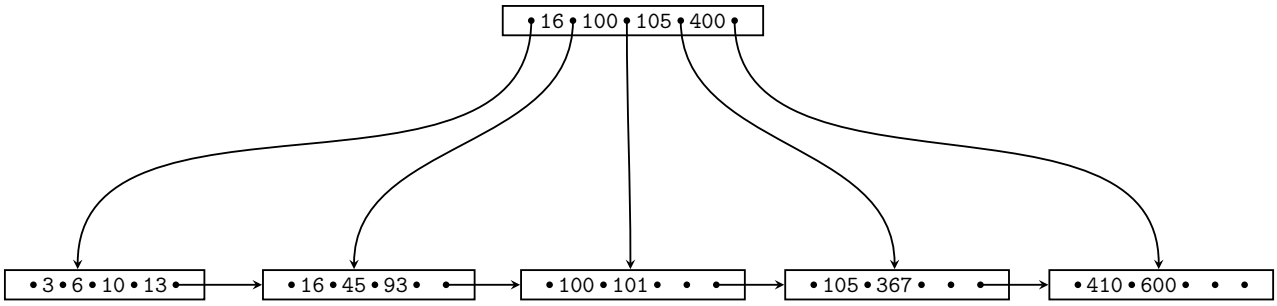


Question 1.3.2 Operations (10 Points)

Consider the B+-tree shown below ($n = 4$). Execute the following operations and write down the resulting B+-tree after each operation:

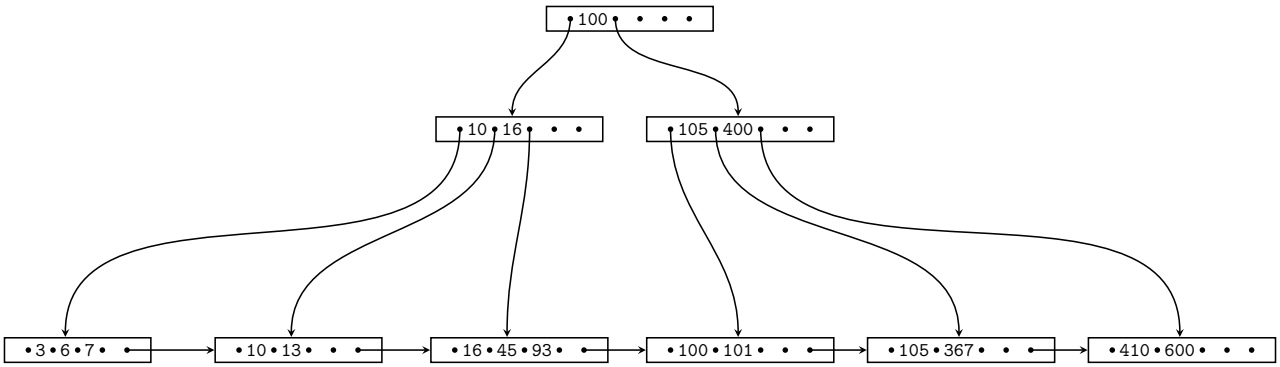
insert(7), insert(8), insert(9), insert(11), delete(101), delete(105)

Use the conventions for splitting and merging introduced in the previous question.

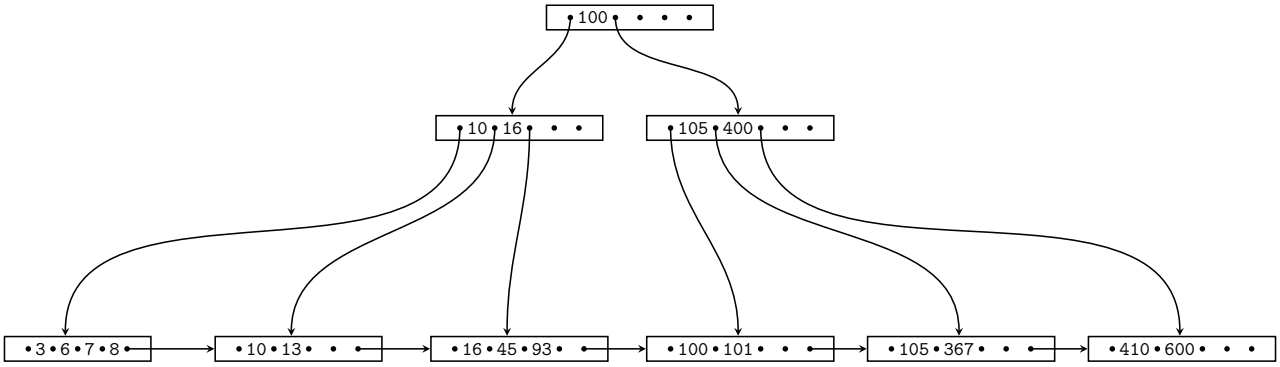


Solution

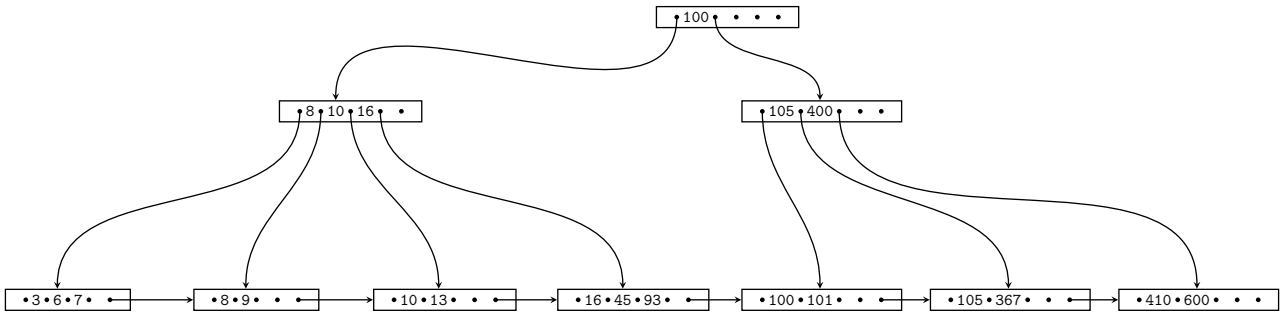
Insert 7



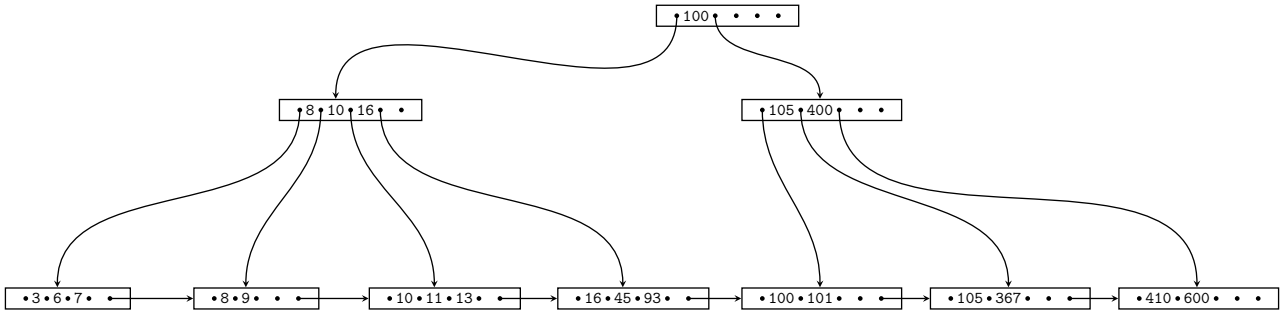
Insert 8



Insert 9

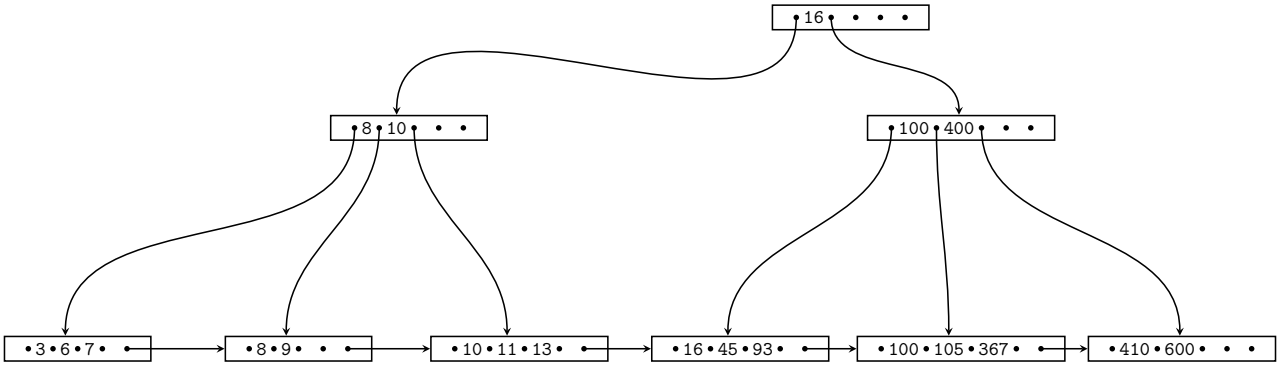


Insert 11

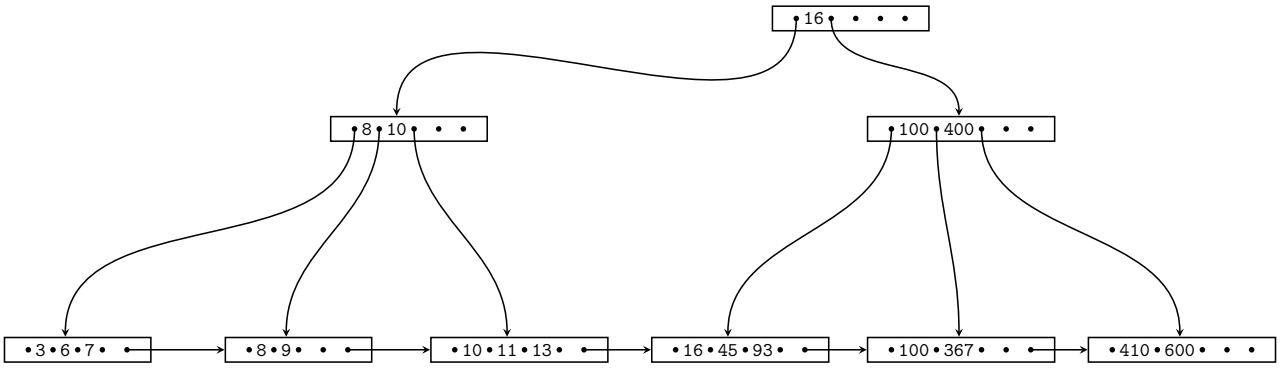


Solution

Delete 101



Delete 105



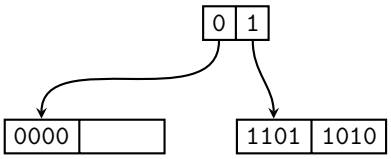
Question 1.3.3 Extensible Hashing (8 Points)

Consider the extensible Hash index shown below that is the result of inserting values 0, 1, and 2. Each page holds two keys. Execute the following operations

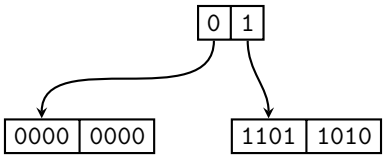
`insert(5),insert(8),insert(0),insert(3)`

and write down the resulting index after each operation. Assume the hash function is defined as:

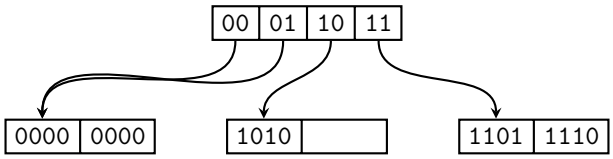
x	h(x)
0	1101
1	0000
2	1010
3	1100
4	0001
5	0000
6	1010
7	0111
8	1110



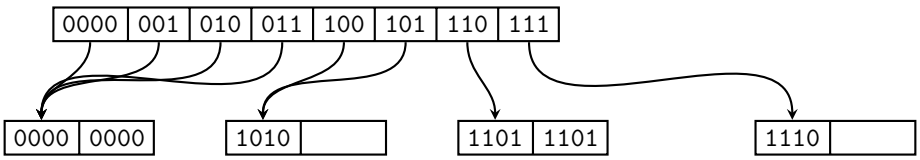
Solution
insert(5)



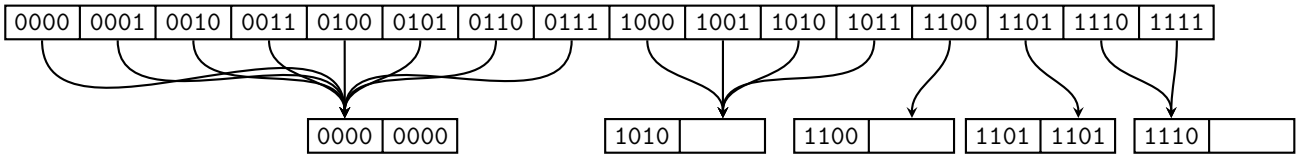
insert(8)



insert(0)



insert(3)



Part 1.4 Result Size Estimations (Total: 10 Points)

Consider a table `lecture` with attributes `title`, `campus`, `topic`, `roomSize`, a table `student` with `name`, `major`, `age`, and a table `attendsLecture` with attributes `student`, `lecture`, and `hoursAttended`. `attendsLecture.student` is a foreign key to `student`. Attribute `lecture` of relation `attendsService` is a foreign key to of relation `lecture`. Given are the following statistics:

$$T(lecture) = 10 \qquad T(student) = 8,000 \qquad T(attendsLecture) = 40,000$$
$$V(lecture, title) = 10 \qquad V(student, name) = 7,500 \qquad V(attendsLecture, student) = 8,000$$
$$V(lecture, campus) = 2 \qquad V(student, major) = 4 \qquad V(attendsLecture, lecture) = 8$$
$$V(lecture, topic) = 3 \qquad V(student, age) = 40 \qquad V(attendsLecture, hoursAttended) = 100$$
$$V(lecture, roomSize) = 5$$

Question 1.4.1 Estimate Result Size (3 Points)

Estimate the number of result tuples for the query $q = \sigma_{age=24}(student)$ using the first assumption presented in class (values used in queries are uniformly distributed within the active domain).

Solution

$$T(q) = \frac{T(student)}{V(student, age)} = \frac{8000}{40} = 200$$

Question 1.4.2 Estimate Result Size (3 Points)

Estimate the number of result tuples for the query $q = \sigma_{hoursAttended>10 \wedge hoursAttended \leq 20}(attendsLecture)$ using the first assumption presented in class. The minimum and maximum values of attribute *hoursAttended* are 0 and 100.

Solution

$$T(q) = \frac{20 - 10}{max(hoursAttended) - min(hoursAttended) + 1} \times T(attendsLecture)$$
$$= \frac{10}{101} \times 40,000 \simeq 3960.40$$

Question 1.4.3 Estimate Result Size (4 Points)

Estimate the number of result tuples for the query q below using the first assumption presented in class.

$$q = (attendsLecture \bowtie_{lecture=title} \sigma_{campus=Mies}(lecture)) \bowtie_{student=name} \sigma_{major=CS \vee major=Math}(student)$$

Solution

$$
\begin{aligned}
q_1 &= \sigma_{campus=Mies}(lecture) \\
T(q_1) &= \frac{T(lecture)}{V(lecture, campus)} = \frac{10}{2} = 5 \\
V(q_1, title) &= min(V(lecture, title), T(q_1)) = 5
\end{aligned}
$$

$$
\begin{aligned}
q_2 &= \sigma_{major=CS \vee major=Math}(student) \\
T(q_2) &= T(student) \cdot (P(major = CS) + P(major = Math)) = 8,000 \cdot (\frac{1}{V(student, major)} + \frac{1}{V(student, major)}) \\
V(q_2, name) &= min(V(student, name), T(q_2)) = 4,000
\end{aligned}
$$

$$
\begin{aligned}
T(q) &= \frac{T(attendsLecture) \times T(q_1) \times T(q_2)}{max(V(attendsLecture, lecture), V(q_1, title)) \times max(V(attendsLecture, student), V(q_2, name))} \\
&= \frac{40,000 \times 5 \times 4,000}{max(8, 5) \times max(8,000, 4,000)} = \frac{8 \times 5 \times 4,000}{8 \times 8,000} \approx 12,500
\end{aligned}
$$