第三章 关系数据库标准语言

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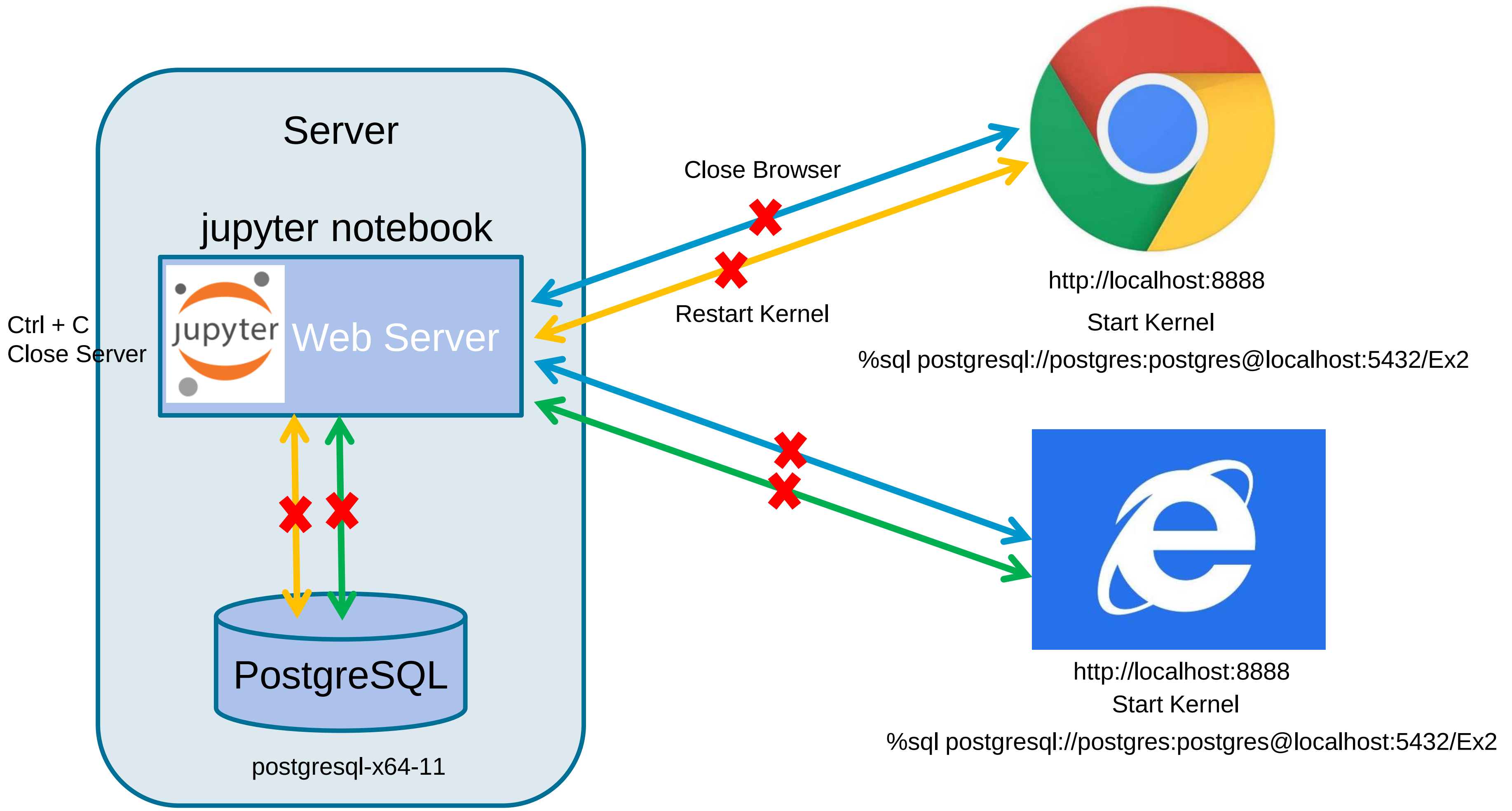
Jupyter Notebook



pgAdmin 4 = Web Server

第一章 地理空间数据库概论回顾

- 关系数据库基本概念
  - 概念数据模型→逻辑数据模型→物理数据模型
  - 逻辑数据模型
    - 层次、网状、关系、面向对象、对象关系
  - 关系模型
    - 模式、内模式、外模式
    - 映像关系
- 地理空间数据库基本概念
  - 矢量数据，栅格数据
  - 特点：空间特征，非结构化特征，空间关系特征，时态特征，多尺度特征
  - 地理空间数据库 = 关系数据库管理系统 + 空间扩展
    - PostgreSQL + PostGIS（空间数据类型、空间分析、空间索引）

第一章 地理空间数据库概论回顾

- 空间数据管理技术的产生与发展
  - 文件系统
  - 文件与关系数据库混合管理系统
  - 空间数据引擎
  - 对象关系型数据库管理系统
- 空间数据库标准
  - SFA SQL
  - SQL/MM
- 空间计算
  - 空间相关性/关联性（因果关系→相关关系）
  - 时空查询

第二章 关系模型回顾

- 基本概念
  - A Database Management System (DBMS) is a piece of software designed to store and manage databases
  - A data model is a collection of concepts for describing data
  - A schema is a description of a particular collection of data, using the given data model
- 什么是逻辑数据模型的数据？
  - 概念数据模型
  - 实体和实体之间的联系
- 如何表达实体之间的联系？
  - 层次模型和网状模型：指针
  - 关系模型：关系/外码

关系模型

- 数据结构
  - 关系：关系名、关系模式和关系实例
    - 基本关系、查询表、视图表
  - 关系模式：$R\,(A_1，A_2，\ldots，A_n)$
  - 逻辑结构：二维表
    - 属性、域、码、元组、分量
- 数据操作
- 完整性约束

关系模型

- 数据结构
- 数据操作
  - 集合操作（输入和输出都是集合）
  - 查询
    - 选择、投影、连接、除、并、交、差
  - 数据更新
    - 插入、删除、修改
  - 关系代数
- 完整性约束

关系模型

- 数据结构
- 数据操作
- 完整性约束 （关系的约束条件）
  - 实体完整性
    - 主码(primary key)，唯一，不能取NULL (unknown or undefined)
  - 参照完整性
    - 外码(foreign key)，取NULL或参照关系中的主码或Unique值
  - 用户定义完整性

sid	Name	GPA
101	Bob	3.2
123	Mary	3.8

Students

Primary Key:
Students: sid
Courses: cid
Enrolled: sid, cid

cid	cname	credits
564	564-2	4
308	417	2

Courses

sid	cid	Grade
123	564	A

Enrolled

关系代数

- 运算符
  - 集合运算符
    - 并∪，交∩，差−，笛卡尔积×
  - 专门的关系运算符
    - 选择σ，投影π，连接 ⋈，除÷
  - 算术比较符
    - $> \ \geq \ < \ \leq \ = \ \neq$
  - 逻辑运算符
    - $\neg \ \wedge \ \vee$
  - 辅助操作
    - 重命名 ρ

关系代数语义

- 关系代数语义
  - set - 标准关系代数 (RA)
    - 并，交，差，选择，投影，连接
    - {1, 2, 3}
  - multiset, bag - 扩展关系代数 (SQL)
    - 重复消除，分组与聚集，排序
    - {1, 1, 2, 3}
- 规则
  - Every paper will assume set semantics
  - Every implementation will assume bag semantics
- A relation or table is a multiset of tuples having the attributes specified by the schema

第三章 关系数据库标准语言

- 3.1 SQL概述
- 3.2 数据定义
- 3.3 数据更新
- 3.4 数据查询

3.1 SQL概述

- SQL (stands for **S**tructured **Q**uery **L**anguage)
  - A standard language for querying and manipulating data
  - A very high-level (optimized) programming language
- Dark times 8 years ago
  - Are databases dead?
  - NoSQL = No SQL
- Now, as before: everyone sells SQL
  - Pig, Hive, Impala
  - NoSQL = Not Only SQL
- “合久必分，分久必合”

SQL的产生与发展

- 1974年由IBM公司的Boyce和Chamberlin提出
- 1986年10月美国国家标准局（American National Standard Institute，简称ANSI）的数据库委员会X3H2批准了SQL作为关系数据库语言的美国标准。同年公布了SQL标准文本（简称SQL-86）
- 1987年国际标准化组织（ISO）也通过了这一标准
- 1989年公布了SQL-89标准
- 1992年公布了SQL-92标准（又称SQL2）
- 1999年公布了SQL-99标准（SQL3）
- 当前版本SQL-2011

SQL内容发展

- SQL92 is a basic set
  - Most systems support at least this
- SQL-1999 Introduced "Object-Relational" concepts
  - Not fully supported yet
- Current standard is SQL-2011
  - 2003 was last major update: XML, window functions, sequences, auto-generated IDs
  - 2008 added x-query stuff, new triggers (instead of)
  - 2011 added temporal data definition and manipulation
  - Also not fully supported yet

注意：不同数据库系统，如Oracle, SQL Server, MySQL, PostgreSQL等，支持SQL标准不同，语法也有所不同。掌握原理，具体数据库参考帮助文档

SQL内容

- Data Definition Language (DDL)
  - Define relational *schemata*
  - Create/alter/delete tables and their attributes
- Data Manipulation Language (DML)
  - Insert/delete/modify tuples in tables
  - Query one or more tables

A **relation** or **table** is a multiset of tuples having the attributes specified by the schema

A **multiset** is an unordered list, {1, 1, 2, 3, 2}

An **attribute** or **column** is a typed data entry present in each tuple in the relation

*Attributes must have an **atomic** type in standard SQL, i.e. not a list, set, etc.*

Product

PName	Price	Manufacturer
iPhone X	￥6349	Apple
Galaxy Note9	￥6569	Sumsung
Mate 20 Pro	￥5399	Huawei
MIX3	￥3299	MI

A **tuple** or **row** or **record** is a single entry in the table having the attributes specified by the schema

SQL特点

- 综合统一
  - 集数据定义语言DDL、数据操纵语言DML、数据控制语言DCL的功能于一体，语言风格统一，可以独立完成数据库生命周期中的全部活动
  - 在关系模型中实体和实体间的联系均用关系表示，数据结构单一性带来了数据操作符的统一，查找、插入、删除、更新等操作都只需一种操作符
- 高度非过程化
  - 非关系数据模型的数据操纵语言是面向过程的语言，在执行一项工作时必须描述“怎么做”
  - SQL语言是非过程语言，使用它进行数据库操作时，只须提出“做什么”，而无须指明“怎么做”

SQL特点

- 综合统一
- 高度非过程化
- 面向集合的操作方式
  - 非关系数据模型采用的是面向记录的操作方式，操作对象是一条记录
  - SQL语言采用集合操作方式，不仅操作对象、查找结果可以是元组的集合，而且一次插入、删除、更新操作的对象也可以是元组的集合

SQL特点

- 综合统一
- 高度非过程化
- 面向集合的操作方式
- 以同一种语法结构提供两种使用方式
  - SQL语言既是自含式语言，又是嵌入式语言
  - 作为自含式语言，它能够独立地用于联机交互的使用方式，用户可以在终端键盘上直接键入SQL命令对数据库进行操作
  - 作为嵌入式语言，SQL语句能够嵌入到高级语言（例如C/C++，Java，C#，Python，JavaScript）程序中，供程序员设计程序时使用

SQL特点

- 综合统一
- 高度非过程化
- 面向集合的操作方式
- 以同一种语法结构提供两种使用方式
- 语言简捷，易学易用

SQL 功 能	动　词
数 据 定 义	CREATE, DROP, ALTER
数 据 查 询	SELECT
数 据 操 纵	INSERT, UPDATE, DELETE
数 据 控 制	GRANT，REVOKE

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3.2 数据定义

- 关系数据库的基本对象是基本表、视图和索引。因此SQL的数据定义功能包括
  - 定义基本表
  - 定义视图
  - 定义索引

注意：
SQL **comands** are case insensitive
(Same: SELECT, Select, select)
Values are not
(Different: ‘iPhone’, ‘iphone’)
Using single quotes for **constants**
(‘abs’ – yes, “abs” – no)

操 作 对 象	操 作 方 式		
	创 建	删 除	修 改
基本表	CREATE TABLE	DROP TABLE	ALTER TABLE
视 图	CREATE VIEW	DROP VIEW	
索 引	CREATE INDEX	DROP INDEX	

定义表

CREATE TABLE <表名>

（<列名> <数据类型>[<列级完整性约束条件>]

[，<列名> <数据类型>[<列级完整性约束条件>]] …

[，<表级完整性约束条件>] ）；

- <表名>：所要定义的基本表的名字
- <列名>：组成该表的各个属性（列）
- <列级完整性约束条件>：涉及相应属性列的完整性约束条件
- <表级完整性约束条件>：涉及一个或多个属性列的完整性约束条件

https://www.postgresql.org/docs/current/static/ddl.html

数据类型

- 定义表的属性时需要指明该属性的域
- 在SQL中域的概念用数据类型来实现
- SQL提供了一些主要的数据类型，在实际使用中要遵照具体的DBMS规定
  - Microsoft Access、MySQL和SQL Server数据类型
    - http://www.w3school.com.cn/sql/sql_datatypes.asp
  - PostgreSQL数据类型
    - https://www.postgresql.org/docs/current/static/datatype.html

数据类型

- Atomic types
  - Characters
    - char(20), varchar(50), text
  - Numbers
    - int, bigint, smallint, float, float8
  - Times
    - date, timestamp
  - Geometries
    - point, line, polygon, box
  - Others
    - bit, bool, serial, memory

Name	Aliases	Description
bigint	int8	signed eight-byte integer
bigserial	serial8	autoincrementing eight-byte integer
bit [(n)]		fixed-length bit string
bit varying [(n)]	varbit	variable-length bit string
boolean	bool	logical Boolean (true/false)
box		rectangular box on a plane
bytea		binary data ("byte array")
character [(n)]	char [(n)]	fixed-length character string
character varying [(n)]	varchar [(n)]	variable-length character string
cidr		IPv4 or IPv6 network address
circle		circle on a plane
date		calendar date (year, month, day)
double precision	float8	double precision floating-point number (8 bytes)
inet		IPv4 or IPv6 host address
integer	int, int4	signed four-byte integer
interval [*fields*] [(p)]		time span
json		textual JSON data
jsonb		binary JSON data, decomposed
line		infinite line on a plane
lseg		line segment on a plane
macaddr		MAC (Media Access Control) address
macaddr8		MAC (Media Access Control) address (EUI-64 format)
money		currency amount
numeric [(p, s)]	decimal [(p, s)]	exact numeric of selectable precision
path		geometric path on a plane
pg_lsn		PostgreSQL Log Sequence Number
point		geometric point on a plane
polygon		closed geometric path on a plane
real	float4	single precision floating-point number (4 bytes)
smallint	int2	signed two-byte integer
smallserial	serial2	autoincrementing two-byte integer
serial	serial4	autoincrementing four-byte integer
text		variable-length character string
time [(p)] [without time zone]		time of day (no time zone)
time [(p)] with time zone	timetz	time of day, including time zone
timestamp [(p)] [without time zone]		date and time (no time zone)
timestamp [(p)] with time zone	timestamptz	date and time, including time zone
tsquery		text search query
tsvector		text search document
txid_snapshot		user-level transaction ID snapshot
uuid		universally unique identifier
xml		XML data

PostgreSQL数据类型

思考：为什么每个属性/列只能是原子类型？

完整性约束

- The schema of a table is the table name, its attributes, and their types
  - Product(Pname: string, Price: float, Category: string, Manufacturer: string)
- 实体完整性：PRIMARY KEY
  - A key is a minimal subset of attributes that acts as a unique identifier for tuples in a relation
    - Product(<u>Pname</u>: string, Price: float, Category: string, <u>Manufacturer</u>: string)
  - A key is an implicit constraint on which tuples can be in the relation
    - i.e. If two tuples agree on the values of the key, then they must be the same tuples
    - multiset → set

完整性约束

- 实体完整性: PRIMARY KEY
  - Students(sid: string, name: string, gpa: float)
    - Q1: Which would you select as a key?
    - Q2: Is a key always guaranteed to exist?
    - Q3: Can we have more than one key?
- 参照完整性：FOREIGN KEY
  - Enrolled(student_id: string, cid: string, grade: string)
    - A student must appear in the Student table to enroll in a class
    - student_id is a foreign key that refers to Students
    - Q4: Which would you select as a key?
  - 基本关系R的任何一个元组在外码上的取值要么是空值，要么是被参照关系S中一个元组的主码值/Unique值
    - Referential integrity = Integrity of references = No “dangling pointer”

完整性约束

注意：由于性能原因，实际应用中不会使用太多数据完整性约束

- 实体完整性：PRIMARY KEY
- 参照完整性：FOREIGN KEY
- 用户定义完整性：NOT NULL
  - NULL = unknown, or undefined
  - 某列不能取空值，如Students关系中的name属性
- 用户定义完整性：UNIQUE
  - 某列或多个列的组合在关系中唯一
  - UNIQUE(name, age)
- 用户定义完整性：DEFAULT
  - 某列有默认值，如当前登录用户，当前时间等
- 用户定义完整性：CHECK
  - Check (age > 0)

完整性约束

- 用CHECK实现NOT NULL限制
  - CREATE TABLE Student(sID INT, sName TEXT, GPA REAL CHECK(GPA is NOT NULL), sizeHS INT);
  - MySQL: accepts but does no enforce
- 用CHECK实现Keys
  - CREATE TABLE T(A int CHECK(
    A not in (SELECT A FROM T)));
  - CREATE TABLE T(A int CHECK(
    (SELECT count(distinct A) FROM T) =
    (SELECT count(*) FROM T)));
  - SQLite, PostgreSQL: several issues
  - MySQL: accepts but does no enforce

完整性约束

- Subqueries in Check Constraints
  - SQLite, PostgreSQL: no subqueries in CHECK constraints
  - MySQL: accepts but does not enforce
  - create table Student(sID int, sName text, GPA real, sizeHS int);
  - create table Apply(sID int, cName text, major text, decision text, check(sID in (select sID from Student)));
  - create table College(cName text, state text, enrollment int, check(enrollment > (select max(sizeHS) from Student)));

注意：不同数据库实现的完整性约束不同

完整性约束

- 域约束
  - SQL语言可以使用CREATE DOMAIN语句定义新的值域
  - 在定义域时声明域的取值范围，如：
  - CREATE DOMAIN GenderDomain CHAR(2)
    CHECK (VALUE IN (‘男’, ’女’));
- 域使用举例：

```
CREATE TABLE S
(Sno     char(7) PRIMARY KEY,
Sname  char(8) NOT NULL,
Ssex     GenderDomain,
Sage     int,
Sdept    char(20));
```

完整性约束

- General assertions
  - SQL standard, but not implemented by any system
  - create assertion Keycheck ((select count(distinct A) from T) = (select count(*) from T)));
  - create assertion ReferentialIntegritycheck (not exists (select * from Apply where sID not in (select sID from Student)));
  - create assertion Sizescheck (not exists (select * from College where enrollment <= (select max(sizeHS) from Student)));
  - create assertion AvgAcceptcheck (3.0 < (select avg(GPA) from Student where sID in (select SID from Apply where decision = 'Y')));

完整性约束

- 约束条件 (CONSTRAINT)
  - NOT NULL 列
  - UNIQUE 列或列集合
  - PRIMARY KEY 列或列集合， 自动获得UNIQUE
  - FOREIGN KEY 列或列集合

    预防破坏表之间连接的动作, 防止非法数据插入外键列
  - CHECK 列或列集合 (attribute, tuple-based)
  - DEFAULT 列

    ALTER COLUMN City SET DEFAULT 'SANDNES‘

Schema and Constraints are how databases understand the semantics (meaning) of data

https://www.postgresql.org/docs/current/static/ddl-constraints.html

思考：一张基本表可以建多少个UNIQUE约束，PRIMARY KEY约束？

数据定义举例

- 创建Students关系

```
CREATE TABLE Students (
    sid    CHAR(10)       PRIMARY KEY,
    name VARCHAR(20) NOT NULL,
    age    INT                    CHECK(age > 0));
```

- 创建Enrolled关系

```
CREATE TABLE Enrolled (
student_id CHAR(10) REFERENCES Students(sid),
cid             CHAR(20),
grade         INT,
PRIMARY KEY(student_id, cid));
```

注意：属性级完整性约束与表级完整性约束的区别

数据定义举例

- 创建Enrolled关系

```
CREATE TABLE Enrolled (
    student_id CHAR(10),
    cid        CHAR(20),
    grade      INT,
    CONSTRAINT pk_En PRIMARY
KEY(student_id, cid),
    CONSTRAINT fk_En FOREIGN KEY
(student_id) REFERENCES Students(sid));
```

- 多属性外键/外码(foreign key)

  foreign key (b, c) references other_table (c1, c2)

修改和删除表

- 修改表

  ALTER TABLE <表名>

  [ADD <新列名> <数据类型> [完整性约束]]

  [DROP <完整性约束名>]

  [MODIFY <列名> <数据类型>];

- 删除表

  DROP TABLE <表名>

  – 基本表删除，则数据、表上的索引都删除
  – 表上的视图往往仍然保留，但无法引用

https://www.postgresql.org/docs/current/static/ddl-alter.html

数据定义举例

- 如何增加属性？

ALTER TABLE Students ADD Scome DATE;

ALTER TABLE Students ALTER COLUMN Scome type timestamp;

ALTER TABLE Students DROP Scome;

- 如何更改列和表的约束条件？

ALTER TABLE Enrolled ADD CONSTRAINT grade_check CHECK(grade >= 0 and grade <= 100);

ALTER TABLE Enrolled DROP CONSTRAINT pk_En;

- 如何删除表？

DROP TABLE Students;

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数据插入

- 语句格式

  INSERT

  INTO <表名> [(<属性列1>[，<属性列2 >] …)]

  VALUES (<常量1> [，<常量2>] …)

- 将新元组插入指定表中

  Insert into Students Values(‘200011’, ‘张三’, 19);

  Insert into Students(sid, age, name)

  Values(‘200012’, 20, ‘李四’);

  Insert into Students(sid, name)

  Values(‘200013’, ‘王五’);

注意：中英文标点符号

https://www.postgresql.org/docs/current/static/dml.html

数据插入

- 在INTO子句中只指出了表名，没有指出属性名，这表示新元组要在表的所有列上都指定值，列的次序同CREATE TABLE中的次序
- 如果数据违反完整性约束？

完整性约束保证的数据一致性

Insert into Students Values(‘200011’, ‘刘晓’, 19);

Insert into Students Values(‘200014’, NULL, 19);

Insert into Students Values(‘200014’, ‘刘晓’, 0);

数据修改

- 语句格式

  UPDATE <表名>

  SET <列名>=<表达式>[，<列名>=<表达式>]…

  [WHERE <条件>]；

- 修改指定表中满足WHERE子句条件的元组

  Update Students Set age = 18 where sid = ‘200011’

  Update Students Set age = 18 where name = ‘王五’

  Update Students Set age = age + 1;

  Update Students Set sid = ‘200012’ where sid = ‘200011’;

思考：上面第二句将会修改多少元组/行记录？如何避免这类操作？

数据删除

- 语句格式

  DELETE

  FROM <表名>

  [WHERE <条件>];

> 注意：Delete from Students删除了Students的所有元组，但保留了表的结构、属性和索引

- 删除指定表中满足WHERE子句条件的元组
- WHERE子句
  - 指定要删除的元组
  - 缺省表示要修改表中的所有元组

Delete From Students where sid = ‘200011’;

Delete From Students where sid = ‘200000’;

Delete From Students;

参照完整性

- Enrolled的属性sid参照关系Students的属性sid，Enrolled的属性cid参照关系Courses的属性cid
- Insert into Enrolled Values(201, 308, NULL);
- Update Enrolled Set cid = 405;
- Update Students Set sid = 102 where sid = 123;
- Delete Students where sid = 123;

sid	Name	GPA
101	Bob	3.2
123	Mary	3.8

Students

sid	cid	Grade
123	564	A

Enrolled

cid	cname	credits
564	564-2	4
308	417	2

Courses

参照完整性

- 关系R的属性A参照关系S的属性B，可能违反参照完整性的修改：
  - Insert into R
  - Delete from S
  - Update R.A
  - Update S.B
- 修改后的操作

思考：哪类数据库用户决定哪类操作？

  - Insert into R, 属性A不在关系S的属性B中
    - Insert is rejected (foreign keys are constraints)!
  - Delete from S / Update S.B
    - Restrict (default): Disallow the delete
    - Cascade: Remove all of the courses for that student
    - Set NULL: SQL allows a third via NULL

参照完整性

- 不同数据库系统在外码实现上的差异
  - SQLite: Everything works after setting PRAGMA foreign_keys = ON;
  - MySQL:
    - Requires varchar type for keys
    - Requires foreign key declarations separate from attributes
    - Requires InnoDB storage engine, Otherwise accepts constraints but does not enforce them
  - PostgreSQL: Everything works
  - SQL Server: Set Null does not work, Cascade does not have a loop 思考：当删除已有同学选课的课程，数据库会怎么处理？

```
Create Table Enrolled (
      student_id char(10) references Students(sid) on delete restrict,
      cid        char(20) references Courses(cid) on update cascade,
      ......);
```

参照完整性

- create table T (A int, B int, C int, primary key (A,B), foreign key (B,C) references T(A,B) on delete cascade); 思考：在SQL Server中上述语句的执行结果是什么？
  - insert into T values (1,1,1);
  - insert into T values (2,1,1);
  - insert into T values (3,2,1);
  - insert into T values (4,3,2);
  - insert into T values (5,4,3);
  - insert into T values (6,5,4);
  - insert into T values (7,6,5);
  - insert into T values (8,7,6);
  - delete from T where A=1;
  - select * from T; 结果是什么？ [PostgreSQL, MySQL]

完整性约束

- CREATE TABLE S(c INT PRIMARY KEY, d INT);
- CREATE TABLE T(a INT PRIMARY KEY, b INT, CHECK(b IN (SELECT c FROM S)));
- 表S的元组包含(2, 10), (3, 11), (4, 12), (5, 13)
- 表T的元组包含(0, 4), (1, 5), (2, 4), (3, 5)
- 下列哪些操作不违反已有的完整性约束？ C

A. Inserting (1, 4) into T　B. Inserting (5, 0) into T

C. Updating (3, 5) in T to be (3, 3)

D. Inserting (4, 6) into T　E. Inserting (3, 1) into S

F. Updating (0, 4) in T to be (0, 0)

参照完整性

- CREATE TABLE S(c INT PRIMARY KEY, d INT);
- CREATE TABLE T(a INT PRIMARY KEY, b INT REFERENCES S(c));
- 表S的元组包含(2, 10), (3, 11), (4, 12), (5, 13)
- 表T的元组包含(0, 4), (1, 5), (2, 4), (3, 5)
- 下列哪些操作不违反已有的完整性约束？DF

A. Inserting (1, 2) into T B. Inserting (2, 5) into T

C. Inserting (4, 4) into S D. Inserting (5, 3) into T

E. Inserting (6, 1) into T F. Inserting (6, 4) into T

参照完整性

- CREATE TABLE R(e INT PRIMARY KEY, f INT)
- CREATE TABLE S(c INT PRIMARY KEY, d INT REFERENCES R(e) ON DELETE CASCADE);
- CREATE TABLE T(a INT PRIMARY KEY, b INT REFERENCES S(c) ON DELETE CASCADE);
- 关系R的元组包含 (1,0), (2,4), (3,5), (4,3), (5,7)
- 关系S的元组包含 (1,5), (2,2), (3,3), (4,5), (5,4)
- 关系T的元组包含 (0,2), (1,2), (2,3), (3,4), (4,4)
- 下列哪些条件delete from R where _AE_ 会使得关系T变为空集？

A. e >= 2 B. f < 6 C. e * f >= 10 D. e + f > 6 E. f > 3

F. e = 5 or f = 5 G. e + f < 8

第三章 关系数据库标准语言

- 3.1 SQL概述
- 3.2 数据定义
- 3.3 数据更新
- 3.4 数据查询
  - 3.4.1 The basic SELECT statement
  - 3.4.2 Using Table and Attribute Variables
  - 3.4.3 Set Operators in SQL
  - 3.4.4 Subqueries in the WHERE clause
  - 3.4.5 Subqueries in the FROM and SELECT
  - 3.4.6 The Join Operators
  - 3.4.7 Aggregation
  - 3.4.8 NULL values

3.4.1 The basic SELECT statement

- 语句格式

SELECT $A_1, A_2, \ldots, A_n$ #3: what to return

FROM $R_1, R_2, \ldots, R_n$ #1: relations to query

WHERE condition #2: combine, filter relations

- SELECT * FROM ... = Select all attributes
- How would you translate this into relational algebra?

$$\pi_{A1, A2, \ldots, An}(\sigma_{condition}(R_1 \times R_2 \times \ldots \times R_n))$$

- The result of a SELECT query is also a relation
  - SQL is a compositional language

https://www.postgresql.org/docs/current/static/queries.html

3.4.1 The basic SELECT statement

- 语句格式

SELECT $A_1, A_2, \ldots, A_n$ #3: what to return

FROM $R_1, R_2, \ldots, R_n$ #1: relations to query

WHERE condition #2: combine, filter relations

- C语言 (顺序很重要，Multiset Union)

```
Answer = {}
for x1 in R1 do
    for x2 in R2 do
        .....
          for xn in Rn do
             if conditions(x1,…, xn)
                then Answer = Answer ∪ {(x1.a1, x1.a2, …, xn.an)}
return Answer
```

思考：上述只是语义上的转换，帮助理解。DBMS的执行顺序取决哪些因素？

3.4.1 The basic SELECT statement

```
SELECT R.A
FROM   R, S
WHERE  R.A = S.B
```

A
1
3

B	C
2	3
3	4
3	5

Cross Product

A	B	C
1	2	3
1	3	4
1	3	5
3	2	3
3	3	4
3	3	5

Apply Selections / Conditions

A	B	C
3	3	4
3	3	5

Apply Projection

Output

A
3
3

3.4.1 The basic SELECT statement

- For all SQL examples, we will be using a simple college admissions database
  - College(cName, state, enrollment)
  - Student(sID, sName, GPA, sizeHS)
  - Apply(sID, cName, major, decision)

- Note: The underlined attributes designate a key for that relation - the values for those attributes must be unique across all rows of that table!

3.4.2 Table and Attribute Variables

SELECT $A_1, A_2, \ldots, A_n$

FROM $R_1, R_2, \ldots, R_n$

WHERE condition

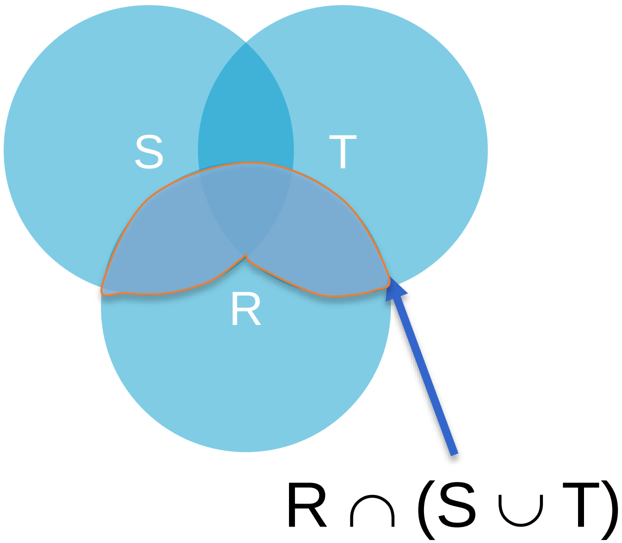
Ambiguity in Joining Multi-Table

- What if attributes have the same name (e.g. $A_1 == A_2$)?
  - $R_1.A_1, R_2.A_2$
- What if we want to query from the same relation multiple times (e.g. $R_1 == R_2$)?
  - Can rename relations (and attributes!) using the "as" keyword
  - Same as the ρ operator in relational algebra

3.4.2 Table and Attribute Variables

- What does it compute?

```
SELECT DISTINCT R.A
FROM   R, S, T
WHERE  R.A=S.A OR R.A=T.A
```



- But what if S = ∅?
- Recall the semantics!
  - Take cross-product
  - Apply selections / conditions
  - Apply projection
- If S = {}, then the cross product of R, S, T = {}, and the query result = {}!

3.4.3 Set Operators in SQL

Relational Algebra	SQL
$\cup$	union
$\cap$	intersect
-	except

- union eliminates duplicates – to preserve duplicates, use "union all"
- Projection does not eliminates duplicates – to eliminate duplicates, use distinct
- intersect and except are supported in SQLite and PostgreSQL, but not MySQL

3.4.3 Set Operators in SQL

- In-Class Exercise: Write a SQL query that returns the IDs of students who applied to CS but not EE

  SELECT sID FROM Apply WHERE major = `CS'

  except

  SELECT sID FROM Apply WHERE major = `EE';

- Follow-up question: MySQL doesn't support the except keyword - can this query be rewritten to work in MySQL?

3.4.4 Subqueries in the WHERE clause

SELECT $A_1, A_2, \ldots, A_n$
FROM $R_1, R_2, \ldots, R_n$
WHERE condition ← nested SELECT statements

- 4 operators (can be inverted using not):
  - in
  - exists
  - all
  - any

s in R
exists R
s > all R
s < any R

- SQL is compositional (extremely powerful)
  - Everything (inputs / outputs) is represented as multisets- the output of one query can thus be used as the input to another (nesting)!

3.4.4 Subqueries in the WHERE clause

- In-Class Exercise: Write a SQL query that returns the IDs of students who applied to CS but not EE

```
SELECT sID FROM Apply WHERE major = `CS'
except
SELECT sID FROM Apply WHERE major = `EE';
```

- But we couldn't (yet) rewrite this without the except keyword! Now, can we do it?

```
SELECT sID FROM Student
WHERE sID in (SELECT sID FROM Apply WHERE major = `CS')
and sID not in (SELECT sID FROM Apply WHERE major = `EE');
SELECT distinct sID FROM Apply A1 WHERE major = ‘CS’ and
        not exists (SELECT * FROM Apply A2 WHERE A1.sID = A2.sID
and major = ‘EE’);
```

3.4.4 Subqueries in the WHERE clause

SELECT $A_1, A_2, \ldots, A_n$

FROM $R_1, R_2, \ldots, R_n$

WHERE condition ← nested SELECT statements

- Support for correlated references: You can also refer to relations listed outside of the subquery. For example:

```
SELECT A1
FROM R1
WHERE A1 in (SELECT A2 FROM R2 WHERE R2.A2 = R1.A1);
```

3.4.4 Subqueries in the WHERE clause

- Nested queries as alternatives to INTERSECT and EXCEPT (MySQL不支持Intersect和Except)

```
(SELECT R.A, R.B
 FROM   R)
INTERSECT
(SELECT S.A, S.B
 FROM   S)
```

```
SELECT R.A, R.B
FROM   R
WHERE EXISTS (
            SELECT *
            FROM S
      WHERE R.A=S.A AND R.B=S.B)
```

```
(SELECT R.A, R.B
 FROM   R)
EXCEPT
(SELECT S.A, S.B
 FROM   S)
```

```
SELECT R.A, R.B
FROM   R
WHERE NOT EXISTS (
            SELECT *
      FROM S
      WHERE R.A=S.A AND R.B=S.B)
```

思考：如果R和S没有重复元组，不是子查询，如何实现上述功能？

3.4.5 Subqueries in the FROM and SELECT clauses

- We can also insert subqueires in the SELECT and FROM clauses, too!

SELECT $A_1, A_2, \ldots, A_n$ ← nested SELECT statements
FROM $R_1, R_2, \ldots, R_n$ ← nested SELECT statements
WHERE condition ← nested SELECT statements

- Be careful! If a subquery is used in the SELECT clause, it must only return a **single** row as its result!
  - Seriously - be careful!! This will throw an error in PostgreSQL and MySQL, but it will "work" in SQLite!!!

3.4.6 The Join Operators

SELECT $A_1, A_2, \ldots, A_n$
FROM $R_1, R_2, \ldots, R_n$ ← explicitly Join tables
WHERE condition

- Instead of taking the cross product, you can also find the natural join or theta-join of two relations, just like in relational algebra

思考：通过判断属性是否相同等，关联不同关系中的记录，扩展到空间关联？

3.4.6 The Join Operators

- Inner Join On condition
  - Same as $\bowtie_{条件}$
- Natural Join
  - Same as $\bowtie$
- Inner Join Using (attributes)
  - Same as $\bowtie$, but common attributes to join on must be explicitly specified
- (Left | Right | Full) Outer Join
  - If join condition don’t match for certain tuples, include those tuples in the result, but pad with NULL values
- These operators don’t add any additional expressive power to SQL

3.4.6 The Join Operators

- By default, Joins in SQL are “Inner Joins”

  select R.A, S.B from R, S where R.A = S.A

  select R.A, S.B from R join S on R.A = S.A
- Outer Join
  - If there is an entry in R with A=3, but none in S with A=3
  - A LEFT OUTER JOIN will return a tuple (a, NULL)!

  select R.A, S.B from R left outer join S on R.A = S.A

R.A	R.B
1	Cat
2	Dog
3	Dog

S.A	S.B
1	Apple
2	Bana
2	Pear

R.A	S.B
1	Apple
2	Bana
2	Pear

R.A	S.B
1	Apple
2	Bana
2	Pear
3	NULL

3.4.6 The Join Operators

- In-Class Exercise: Is the Full Outer Join operator associative? Specifically is

SELECT *

FROM (T1 natural full outer join T2) natural full outer join T3;

equivalent to

SELECT *

FROM T1 natural full outer join (T2 natural full outer join T3);

- No
  - Try testing this out with three sample tables of your own – you should be able to see that they won't necessarily produce the same result!

3.4.6 The Join Operators

- Max/Min value problem
  - Write a SQL query that returns the IDs of students who have the maximum GPA
    - Student(sID, sName, GPA, sizeHS)
  - Solution 0

SELECT sID FROM Student ORDER BY GPA DESC LIMIT 1;如果两个学生GPA一样呢都是max

  - Solution 1 (all/any?)

SELECT sID FROM Student

WHERE GPA >= all (SELECT GPA FROM Student);

  - Solution 2

SELECT sID FROM Student

WHERE GPA = (SELECT max(GPA) FROM Student);

3.4.6 The Join Operators

- Max/Min value problem
  - Write a SQL query that returns the IDs of students who have the maximum GPA
    - Student(sID, sName, GPA, sizeHS)
  - Solution 2

```
SELECT sID FROM Student
WHERE GPA = (SELECT max(GPA) FROM Student);
```

  - Solution 3

```
SELECT sID FROM Student,
    (SELECT max(GPA) as maxGPA FROM Student) as T
WHERE GPA = maxGPA;
```

3.4.7 Aggregation

SELECT $A_1, A_2, \ldots, A_n$ ← "Aggregation" functions
FROM $R_1, R_2, \ldots, R_n$
WHERE condition

- Aggregation functions compute values over multiple rows of the result, such as
  - min, max, sum, avg, and count
  - NULL is special
- Except count, all aggregations apply to a single attribute

3.4.7 Aggregation

SELECT $A_1, A_2, \ldots, A_n$

FROM $R_1, R_2, \ldots, R_n$

WHERE condition

GROUP BY $A_i, A_j, \ldots, A_k$ ⟵ Partition rows into “groups”

- The aggregation functions are computed over each “group” independently
  - For example, average GPA for each college, number of applications per student, the maximum enrollment for each particular state
- Warning: every column in the SELECT clause must either be
  - Also present in the GROUP BY clause AND/OR
  - Used in an aggregation function

3.4.7 Aggregation

- Semantics
  - 1. Compute the FROM and WHERE clauses
  - 2. Group by the attributes in the GROUP BY
  - 3. Compute the SELECT clause: grouped attributes and aggregates
- Example
  - Find total sales after 10/1/2005 per product

```
SELECT   product, sum(price * quantity) as totalsales
FROM     Purchase
WHERE    date > '10/1/2005'
GROUP BY product
```

Product	Date	Price	Quantity
apple	10/21	1	20
banana	10/3	0.5	10
banana	10/10	1	10
apple	10/25	1.5	20

3.4.7 Aggregation

- 1. Compute the FROM and WHERE clauses

```
SELECT   product, sum(price * quantity) as totalsales
FROM     Purchase
WHERE    date > '10/1/2005'
GROUP BY product
```

Product	Date	Price	Quantity
apple	10/21	1	20
apple	10/25	1.5	20
banana	10/3	0.5	10
banana	10/10	1	10

- 2. Group by the attributes in the GROUP BY

```
SELECT   product, sum(price * quantity) as totalsales
FROM     Purchase
WHERE    date > '10/1/2005'
GROUP BY product
```

Product	Date	Price	Quantity
apple	10/21	1	20
	10/25	1.5	20
banana	10/3	0.5	10
	10/10	1	10

3.4.7 Aggregation

- 3. Compute the SELECT clause: grouped attributes and aggregates

```
SELECT   product, sum(price * quantity) as totalsales
FROM     Purchase
WHERE    date > '10/1/2005'
GROUP BY product
```

Product	Date	Price	Quantity
apple	10/21	1	20
	10/25	1.5	20
banana	10/3	0.5	10
	10/10	1	10

Product	TotalSales
apple	50
banana	15

3.4.7 Aggregation

SELECT $A_1, A_2, \ldots, A_n$
FROM $R_1, R_2, \ldots, R_n$
WHERE condition
GROUP BY $A_i, A_j, \ldots, A_k$
HAVING condition ← Filter aggregate results

- The WHERE conditions apply to single rows at a time
- The HAVING conditions apply to the groups generated by the GROUP BY clause
- Warning: Don't use HAVING without GROUP BY!

3.4.7 Aggregation

SELECT $A_1, A_2, \ldots, A_n$

FROM $R_1, R_2, \ldots, R_n$

WHERE C_1

GROUP BY $A_i, A_j, \ldots, A_k$

HAVING C_2

- $A_1, A_2, \ldots, A_n$ = Can ONLY contain attributes $A_i, \ldots, A_k$ and/or aggregates over other attributes
- C_1 = is any condition on the attributes in $R_1,\ldots,R_n$
- C_2 = is any condition on the aggregate expressions

3.4.7 Aggregation

SELECT $A_1, A_2, \ldots, A_n$
FROM $R_1, R_2, \ldots, R_n$
WHERE C_1
GROUP BY $A_i, A_j, \ldots, A_k$
HAVING C_2

- Evaluation steps:
  - Evaluate FROM-WHERE: apply condition C_1 on the attributes in $R_1,\ldots,R_n$
  - GROUP BY the attributes $A_i, \ldots, A_k$
  - Apply condition C_2 to each group (may have aggregates)
  - Compute aggregates in $A_1, A_2, \ldots, A_n$ and return the result

3.4.7 Aggregation

- Group by vs. Nested Query
  - Author(login, name), Wrote(login, url)
  - Question: Find authors who ≥ 10 documents
  - Solution 1: with nested queries

```
SELECT DISTINCT Author.name
FROM Author
WHERE count(
    SELECT Wrote.url
    FROM Wrote
    WHERE Author.login = Wrote.login) >= 10
```

3.4.7 Aggregation

- Group by vs. Nested Query
  - Author(login, name), Wrote(login, url)
  - Question: Find authors who ≥ 10 documents
  - Solution 1: with nested queries
  - Solution 2: SQL style (with GROUP BY)

```
SELECT Author.name
FROM Author, Wrote
WHERE Author.login = Wrote.login
GROUP BY Author.name
HAVING count(Wrote.url) >= 10
```

注意：可能存在多种SQL查询方法，选择查询效率最高，使用Group By效率更高

3.4.7 Aggregation

- In-Class Exercise: Write a SQL query that returns the number of colleges applied to by each student, including 0 for those who applied nowhere

```
SELECT Student.sID, count(distinct cName)
FROM Student, Apply
WHERE Student.sID = Apply.sID
GROUP BY Student.sID
union
SELECT sID, 0
FROM Student
WHERE sID NOT IN (SELECT sID FROM Apply);
```

3.4.7 Aggregation

- Max/Min value problem in aggregation
  - Write a SQL query that returns the name of colleges who have the maximum number of applications
    - Apply(<u>sID, cName, major</u>, decision)
  - Solution

```
SELECT CName
FROM Apply
GROUP BY CName
HAVING count(*) >= ALL
    (SELECT count(*) FROM Apply GROUP BY CName);
```

  - Follow-up question: Write a SQL query that returns the name of colleges who have the maximum number of applicants

3.4.8 NULL values

- We use NULL to represent "unknown" or "undefined" values in our database - the semantic meaning of NULL can vary from situation to situation
- For example, you could use NULL to represent:
  - A student with no middle name
  - A credit card that doesn't expire
  - A car that hasn't been given a license plate yet
  - Or whatever you want it to be!

3.4.8 NULL values

- *For numerical operations,* NULL -> NULL:
  - If x = NULL then 4*(3-x)/7 is still NULL
- *For boolean operations,* in SQL there are three values:

  FALSE = 0

  UNKNOWN = 0.5

  TRUE = 1

  - If x= NULL then x="Joe" is UNKNOWN
  - C1 AND C2 = min(C1, C2)
  - C1 OR C2 = max(C1, C2)
  - NOT C1 = 1 – C1

3.4.8 NULL values

- Will return (1, NULL) in R(A, B)?

  select * from R where B > 1

- Rule in Selection SQL
  - Include only tuples that yield TRUE / 1.0
- Rule in Insert SQL
  - Exclude only tuples that yield FALSE / 0.0

- Can test for NULL explicitly:
  - x IS NULL
  - x IS NOT NULL

3.4.8 NULL values

- NULL values won't necessarily be captured by the appropriate conditions in the WHERE clause. For example, suppose we have the following query:

```
SELECT * FROM Student WHERE GPA >= 3.5 or GPA < 3.5;
```

Will this return every student?

- No! There may be student who have NULL as their GPA! Instead, the query should be

```
SELECT * FROM Student WHERE GPA >= 3.5 or GPA < 3.5
or GPA is NULL;
```

3.4.8 NULL values

- NULL参与的数值或布尔运算，结果都是NULL
- WHERE子句只有条件为true才保留这个记录
- HAVING子句只有条件为true才保留这个GROUP
- JOIN NULL != NULL
- GROUP BY NULL算一个GROUP
- NULL在ORDER BY时默认排序最前面，有语法可以改变顺序
- 对于AGGREGATE函数
  - 如果输入空集，COUNT返回0，其他任何函数返回NULL
  - 如果COUNT(*)，NULL的记录参与计算，COUNT属性，NULL的记录忽略
  - 其他AGGREGATE函数，忽略NULL

Data modification

- Inserting new data
  - INSERT INTO Table
    VALUES $(A_1, A_2, \ldots, A_n)$
  - INSERT INTO Table
    SELECT statement
- Deleting data
  - DELETE FROM Table
    WHERE condition
- Updating existing data
  - UPDATE Table
    SET $A = Expr_1, \ldots, A_n = Expr_n$
    WHERE condition

Expr can a SELECT statement
That return a single value

Other Keywords

- Distinct
  - Eliminates duplicates
- Order by $A_1, A_2, \ldots, A_n$
  - asc/desc
  - Default is asc
- Text comparison
  - s LIKE p: pattern matching on strings
  - % = any sequence of characters
  - _ = any single character
- Between… and …
- With子句，仅在当前事务中能使用的查询表

Multiset

- $\lambda(X)$= “Count of tuple in X”
  - Items not listed have implicit count 0

Multiset X

Tuple
(1, a)
(1, a)
(1, b)
(2, c)
(2, c)
(2, c)
(1, d)
(1, d)

Equivalent Representations of a **Multiset**

Multiset X

Tuple	$\lambda(X)$
(1, a)	2
(1, b)	1
(2, c)	3
(1, d)	2

Note: In a set all counts are {0,1}.

Multiset

Multiset X

Tuple	$\lambda(X)$
(1, a)	2
(1, b)	0
(2, c)	3
(1, d)	0

$\cap$

Multiset Y

Tuple	$\lambda(Y)$
(1, a)	5
(1, b)	1
(2, c)	2
(1, d)	2

$=$

Multiset Z

Tuple	$\lambda(Z)$
(1, a)	2
(1, b)	0
(2, c)	2
(1, d)	0

$$\lambda(Z) = min(\lambda(X), \lambda(Y))$$

For sets, this is **intersection**

Multiset

Multiset X

Tuple	$\lambda(X)$
(1, a)	2
(1, b)	0
(2, c)	3
(1, d)	0

$\cup$

Multiset Y

Tuple	$\lambda(Y)$
(1, a)	5
(1, b)	1
(2, c)	2
(1, d)	2

$=$

Multiset Z

Tuple	$\lambda(Z)$
(1, a)	7
(1, b)	1
(2, c)	5
(1, d)	2

$$\lambda(Z) = \lambda(X) + \lambda(Y)$$

For sets, this is **union**

Multiset

- All RA operations need to be defined carefully on bags
  - σ_C(R): preserve the number of occurrences
  - Π_A(R): no duplicate elimination
  - Cross-product, join: no duplicate elimination
- This is important - relational engines work on multisets, not sets!

第三章 关系数据库标准语言

- 3.1 SQL概述
- 3.2 数据定义
- 3.3 数据更新
- 3.4 数据查询

1. SQL是一个描述型语言，有很多细节(包括语法和DBMS具体实现)，需要理解其中的细微差别
2. 具体问题进行逻辑等价转换，获得容易使用SQL解决的描述 (逻辑思维很重要)
   Find all companies with products all having price < 100
   Find all companies that make only products with price < 100
3. 遇到复杂问题，可以先查询部分结果，再通过嵌套查询、集合操作等进行组合
4. 每个问题可能存在多种SQL解决方案，选择查询效率较高的解决方案 (nested query vs. group by)
5. 多练习，熟能生巧