CSIT115 Data Management and Security

Data Integrity

Dr Janusz R. Getta

School of Computing and Information Technology -
University of Wollongong

Data Integrity

Outline

- Data integrity ? What is it ?
- Consistency constraints
- ROLLBACK and COMMIT statements
- Backup and recovery

Data integrity ? What is it ?

A term data integrity refers to the overall completeness, accuracy and consistency of data

This can be indicated by the absence of alteration between two instances or between two updates of a data record, meaning data is intact and unchanged (https://www.techopedia.com/definition/811/data-integrity-databases)

A term data integrity refers to maintaining and assuring the accuracy and consistency of data over its entire life-cycle, and is a critical aspect to the design, implementation and usage of any system which stores, processes, or retrieves data (https://en.wikipedia.org/wiki/Data_integrity)

Data integrity is the opposite of data corruption, which is a form of data loss

The overall intent of any data integrity technique is the same: ensure data is recorded exactly as intended and upon later retrieval, ensure the data is the same as it was when it was originally recorded

Data integrity ? What is it ?

In short, data integrity aims to prevent unintentional changes to information (https://en.wikipedia.org/wiki/Data_integrity)

Data Integrity

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- Backup and recovery

Consistency constraints

Consistency constraint is a property which is always valid in a fragment of the real world modelled by a database

Consistency constraint is a condition that must be satisfied by every persistent state of a database

For example:

- an attribute student-number uniquely identifies each student
- a budget of a small ARC grant cannot exceed 10K
- a value of attribute date-of-birth can be unknown
- an employee is a member of precisely one department
- a salary of full professor is in a range from x to y

Consistency constraints

Key constraint: primary and candidate key constraint

Relational schema

```
STUDENT(snum, first-name, last-name, date-of-birth, medicare-num, degree )
primary key= (snum)
candidate key 1 = (first-name, last-name, date-of-birth)
candidate key 2 = (medicare-num)
```

Relational schema

```
SUBJECT(code, title, credits)
primary key = (code)
candidate key = (title)
```

Consistency constraints

Referential integrity constraint: foreign key

Relational schema

```
ENROLMENT(snum, code, edate)
primary key = (snum, code, edate)
foreign key 1 = (snum) references STUDENT(snum)
foreign key 2 = (code) references SUBJECT(code)
```

Relational schema

```
COUNTRY(name)
primary key = (name)
CUSTOMER(cnum, first-name, last-name, country-name)
primary key: (cnum)
foreign key country-name references COUNTRY(name)
```

Consistency constraints

NULL/NOT NULL constraint

NULL/NOT NULL constraint

```
STUDENT(snum, first-name, last-name, date-of-birth, medicare-num, degree )
degree    ...    NOT NULL
```

Attribute type constraint

Attribute type constraint

```
STUDENT(snum, first-name, last-name, date-of-birth, medicare-num, degree )
snum   DECIMAL(7)  ...
```

Domain constraint

Relational schema

```
SUBJECT(code, title, credits)
credits IN (6, 12)
```

Consistency constraints

Other constraints

- Numerical constraint: total number of rows in a table `EMPLOYEE` is less than 1000
- Exclusion constraint: a student cannot be in the same moment undergraduate and postgraduate student
- Distributed (multitable) referential integrity constraint:

Distributed referential integrity constraint

```
UNDERGRADUATE-STUDENT(snum, first-name, last-name, date-of-birth)
POSTGRADUATE-STUDENT(snum, first-name, last-name, date-of-birth)
SCHOLARSHIP(snum, amount)
SCHOLARSHIP.snum references either UNDERGRADUATE-STUDENT.snum or
                                   POSTGRADUATE-STUDENT.snum
```

- Subset constraint:

Subset constraint

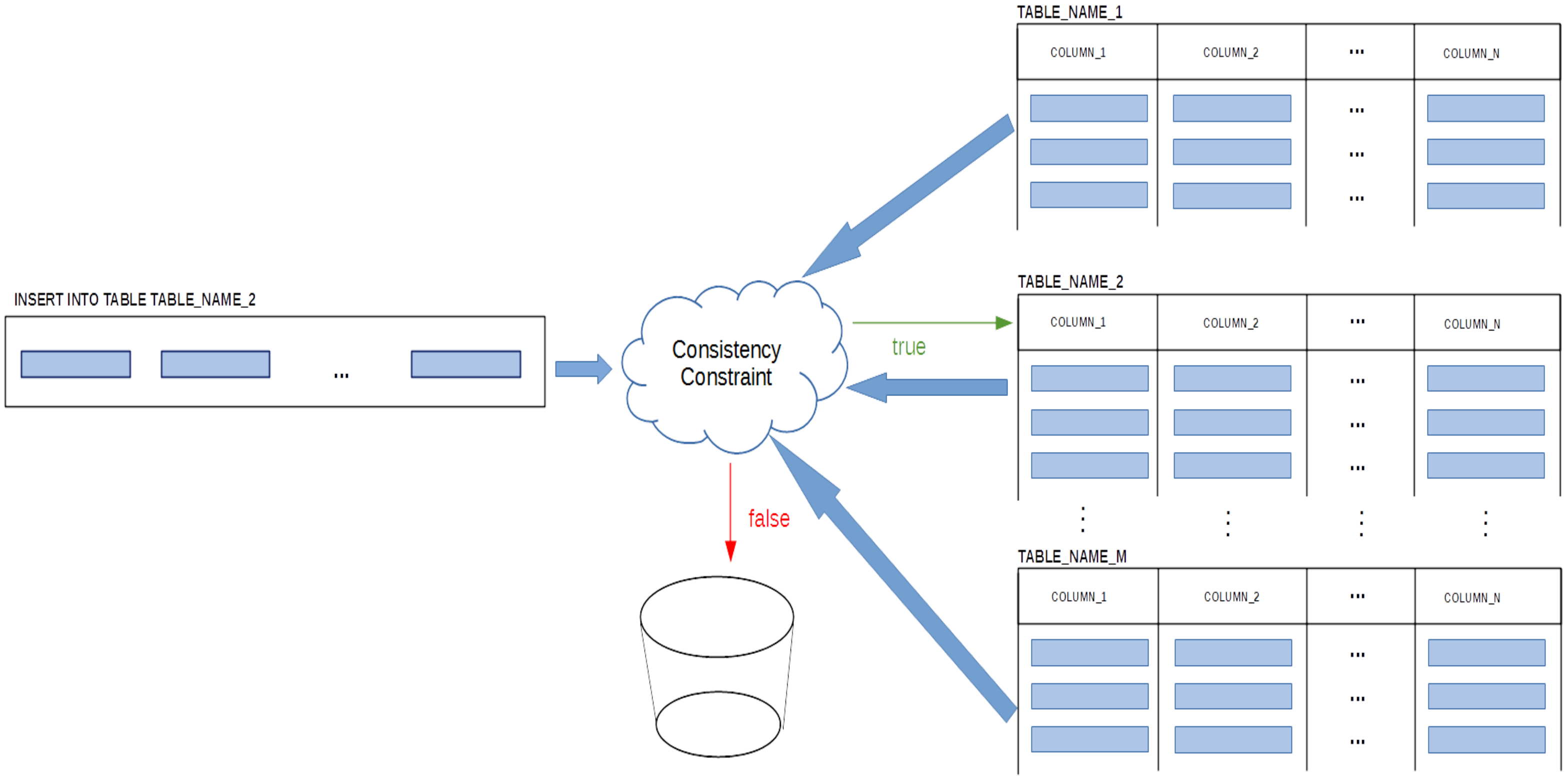
```
EMPLOYEE( enum, ... , city, ... )
PROJECT(pnum, ... , city, ... )
PROJECT.city is included in EMPLOYEE.city
```

- ... and many, many other constraints

Consistency constraints

How do we enforce consistency constraints ?

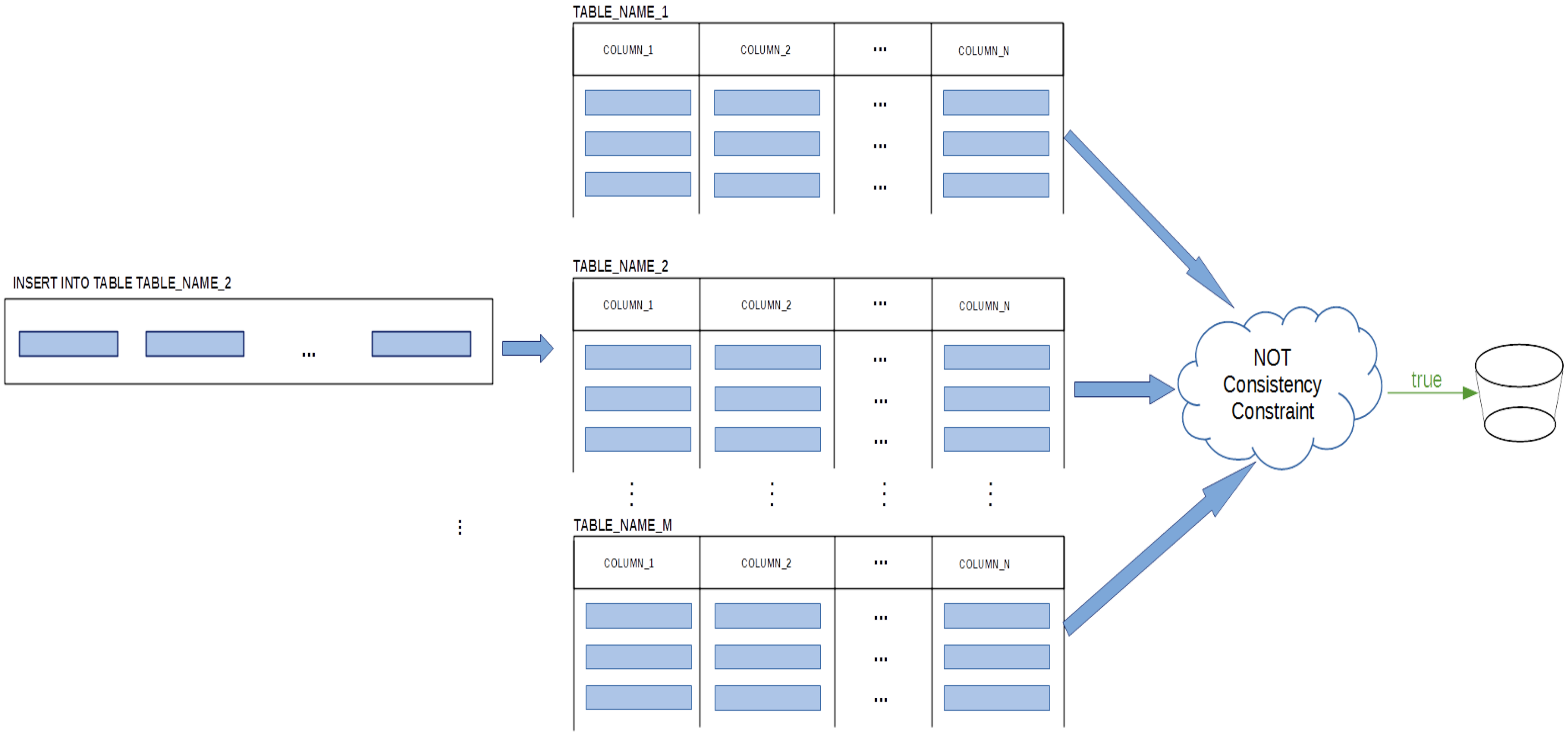
- Define consistency constraints in `CREATE TABLE` statement; in such a case verification is performed by a database server



Consistency constraints

How do we enforce consistency constraints ?

- Implement verification of consistency constraint as SQL script reporting violation of consistency constraints and process the script from time to time; in such a case verification is performed by a database server



Consistency constraints

How do we enforce consistency constraints ?

- Implement verification of consistency constraints within a database application, for example Java application accessing a relational database through Java DataBase Connectivity (JDBC) ; in such a case verification is performed by a database application
- Implement verification of consistency constraints within a stored procedure or stored function; in such a case verification is performed by a database server
- Implement verification of consistency constraints as a servlet, php code, etc; in such a case verification is performed by a Web server
- Implement verification of consistency constraints as a database trigger; in such a case verification is performed by a database server

Consistency constraints

Verification of consistency constraint through SQL scripts

Assume that a relational table EMPLOYEE contains information common to all employees and relational table DRIVER and ADMIN contains information specific to drivers and administration people

We would like to enforce a multitable constraint saying that a table EMPLOYEE must contain only information about drivers and admin people, i.e. if a person is recorded in EMPLOYEE table then/he/she must be recorded in ADMIN or DRIVER

The following SELECT statement included in SQL script verifies the constraint and lists all rows in EMPLOYEE table that violate the constraint

SELECT statement

```
SELECT 'Multitable constraint failed, employee' AS "Constraint",
       enum, 'is not included in either DRIVER or ADMIN tables' AS "Condition"
FROM EMPLOYEE
WHERE enum NOT IN (SELECT enum
                   FROM DRIVER)
and
enum NOT IN (SELECT enum
                   FROM ADMIN);
```

Consistency constraints

The following SELECT statement

SELECT statement that verifies a consistency constraint

```
SELECT 'Multitable constraint failed, employee' AS "Constraint",
       enum, 'is not included in either DRIVER or ADMIN tables' AS "Condition"
FROM EMPLOYEE
WHERE enum NOT IN (SELECT enum
                   FROM DRIVER)
and
enum NOT IN (SELECT enum
                   FROM ADMIN);
```

may return the following results

Sample results from SELECT statement above

```
+-----------------------------------------+------+---------------------------------------------------+
| Constraint                              | enum | Condition                                         |
+-----------------------------------------+------+---------------------------------------------------+
| Multitable constraint failed, employee |   20 | is not included in either DRIVER or ADMIN tables |
+-----------------------------------------+------+---------------------------------------------------+
```

Consistency constraints

Verification of consistency constraint through stored routines (functions and procedures)

Stored routine is a piece of code whose logic is usually implemented in a general purpose procedural language (host language) including embedded SQL statements to communicate with a database server

Stored routine is stored in a data dictionary (data repository) of a database management system, for example information_system database on MySQL

A stored procedure `country_hos`

A stored procedure

```
CREATE PROCEDURE country_hos
(IN con CHAR(20))
BEGIN
  SELECT Name, HeadOfState FROM Country
  WHERE Continent = con;
END;
```

Consistency constraints

A stored procedure `country_hos` is invoked using `CALL` statement in the following way

Calling a stored procedure

```
CALL country_hos('Europe');
```

The following call to a stored procedure `insert_employee` can be used instead of `INSERT` statement to verify the consistency constraints within the procedure

Calling a stored procedure

```
CALL insert_employee(123456, 'James', 'Bond', '1960-12-12', 'MI6');
```

A stored procedure does not have to return a value and it can modify its parameters for a later inspection by the caller

A stored procedure can also generate result sets to be returned to the client program through one of its parameters

Consistency constraints

A stored function can be used much like a built-in row function

A stored function can be invoked in an expression and it returns a value during expression evaluation

Stored function

```
CREATE FUNCTION CustomerLevel(p_creditLimit double) RETURNS VARCHAR(10)
    DETERMINISTIC
BEGIN
    DECLARE lvlvarchar(10);

    IF p_creditLimit> 50000 THEN
        SET lvl = 'PLATINUM';
    ELSEIF (p_creditLimit<= 50000 AND p_creditLimit>= 10000) THEN
        SET lvl = 'GOLD';
    ELSEIF p_creditLimit< 10000 THEN
        SET lvl = 'SILVER';
    END IF;

RETURN (lvl);
END;
```

Then it can be used in `SELECT` statement in the following way

Calling a stored function

```
SELECT customerName, CustomerLevel(creditLimit)
FROM customers
GROUP BY customerName;
```

Consistency constraints

Verification of consistency constraints through database triggers

A trigger is a named database object associated with a table and such that it activates when a particular event occurs for the table

Some uses for triggers are to evaluate consistency constraints after the modifications or to perform the calculations of the values of derived attributes

Triggers can also be used to enforce sophisticated database security constraints and/or to audit suspicious database activities, like for example an update to a column `SALARY` performed on Sunday

A trigger is created through `CREATE TRIGGER` statement

A trigger is activated when a statement inserts, updates, or deletes rows in the associated table

Consistency constraints

For example, rows can be inserted by `INSERT` statements, and then insert trigger is activated for each inserted row

A trigger can be also activated either before or after the trigger event

We can activate a trigger before each row is inserted into a table or after each row that is updated.

For example:

CREATE TRIGGER statement

```
CREATE TRIGGER upd_check BEFORE UPDATE ON account
FOR EACH ROW
BEGIN
  IF NEW.amount < 0 THEN
    ROLLBACK;
  END IF;
END;
```

Consistency constraints

In another application a trigger is used to audit updates on EMPLOYEE table

CREATE TRIGGER statement

```
CREATE TRIGGER before_employee_update
BEFORE UPDATE ON employees
FOR EACH ROW
BEGIN
  INSERT INTO employees_audit( SETaction='update',
                               employeeNumber=OLD.employeeNumber,
                               lastname=OLD.lastname, changedat=NOW() );
END;
```

Data Integrity

Outline

Data integrity ? What is it ?

Consistency constraints

ROLLBACK and COMMIT statements

Backup and recovery

ROLLBACK and COMMIT statements

Database system allow for the immediate reversals of the recent modifications with `ROLLBACK` statement

On the other side, `COMMIT` statement makes all modifications performed since the beginning of a session or since the latest processing of `COMMIT` statement permanent in a database and it also makes reversal of such modification with `ROLLBACK` statement impossible

All modifications performed since the latest `COMMIT` statement or the beginning of a sesson can be reversed with `ROLLBACK` statement

A system variable `AUTOCOMMIT` can be used to control making the database modifications permanent

- If `AUTOCOMMIT = 'ON'` then all data manipulation statements like `INSERT, UPDATE, DELETE` are immediately and automatically committed at the end of processing of a data manipulation statement

ROLLBACK and COMMIT statements

A system variable `AUTOCOMMIT` can be used to control making the database modifications permanent

- If `AUTOCOMMIT = 'OFF'` then all modifications to a database are either committed by either `COMMIT` statement or any data definition statement like `CREATE`, `ALTER`, `DROP`
- End of a session, i.e. `exit` statement does not commit the modifications

Be default a variable `AUTOCOMMIT` is set to `'ON'` at the beginning of a session

ROLLBACK and COMMIT statements

We use a sample database that consists of the following tables

CREATE TABLE statement

```
CREATE TABLE DEPARTMENT(
name               VARCHAR(50)        NOT NULL,
code               CHAR(5)            NOT NULL,
total_staff_number DECIMAL(2)         NOT NULL,
chair              VARCHAR(50)            NULL,
budget             DECIMAL(9,1)       NOT NULL,
  CONSTRAINT dept_pkey PRIMARY KEY(name),
  CONSTRAINT dept_ckey1 UNIQUE(code),
  CONSTRAINT dept_ckey2 UNIQUE(chair),
  CONSTRAINT dept_check1 CHECK (total_staff_number BETWEEN 1 AND 50) );
```

CREATE TABLE statement

```
CREATE TABLE COURSE(
cnum               CHAR(7)           NOT NULL,
title              VARCHAR(200)      NOT NULL,
credits            DECIMAL(2)        NOT NULL,
offered_by         VARCHAR(50)           NULL,
  CONSTRAINT course_pkey PRIMARY KEY(cnum),
  CONSTRAINT course_check1 CHECK (credits IN (6, 12)),
  CONSTRAINT course_fkey1 FOREIGN KEY(offered_by)
                        REFERENCES DEPARTMENT(name)  );
```

ROLLBACK and COMMIT statements

Assume, that we would like to delete a department of Arts and `AUTOCOMMIT = 'ON'`

First, we delete all courses offered by a department of Arts

DELETE statement

```
DELETE FROM COURSES WHERE offered_by = 'Arts';
```

With `AUTOCOMMIT = 'ON'` such statement is immediately committed and the results of deletion are available to other user of the same database

Assume that at this point another user executes `SELECT` statements that find the total number of departments and the total number of courses offered by each department

SELECT statement

```
SELECT COUNT(*) FROM DEPARTMENT;
```

SELECT statement

```
SELECT offered_by, count(*) FROM COURSE GROUP BY offered_by;
```

The user querying a database gets incorrect information that a department of Arts still exists and it offers no courses !

ROLLBACK and COMMIT statements

Now, assume, that we would like to delete a department of Arts and `AUTOCOMMIT = 'OFF'`

First we delete all courses offered by a department of Arts

```
DELETE FROM COURSES WHERE offered_by = 'Arts';
```

DELETE statement

With `AUTOCOMMIT = 'OFF'` such statement is not immediately committed and the results of deletion are not available to other users of the same database

Assume that at this point another user executes `SELECT` statements that find the total number of departments and the total number of courses offered by each department

```
SELECT COUNT(*) FROM DEPARTMENT
```

SELECT statement

```
SELECT offered_by, count(*) FROM COURSE GROUP BY offered_by
```

SELECT statement

Another user gets correct information because the deletions have not been committed yet and another user does not see the deletions

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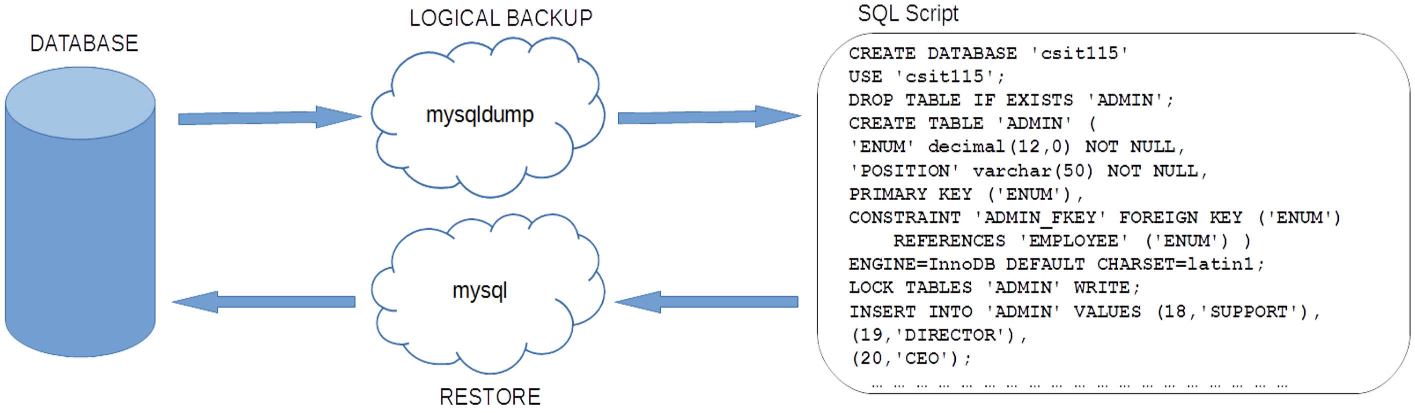
Backup and recovery

Physical backup versus Logical backup

- Physical backup consists of raw copies of the directories and files that store database contents
- Physical backup is suitable for large, important databases that need to be recovered quickly when problems occur
- Logical backup saves information represented as logical database structure (`CREATE DATABASE, CREATE TABLE` statements) and content (`INSERT` statements or delimited-text files)



```
CREATE DATABASE 'csit115'
USE 'csit115';
DROP TABLE IF EXISTS 'ADMIN';
CREATE TABLE 'ADMIN' (
'ENUM' decimal(12,0) NOT NULL,
'POSITION' varchar(50) NOT NULL,
PRIMARY KEY ('ENUM'),
CONSTRAINT 'ADMIN_FKEY' FOREIGN KEY ('ENUM')
    REFERENCES 'EMPLOYEE' ('ENUM') )
ENGINE=InnoDB DEFAULT CHARSET=latin1;
LOCK TABLES 'ADMIN' WRITE;
INSERT INTO 'ADMIN' VALUES (18,'SUPPORT'),
(19,'DIRECTOR'),
(20,'CEO');
  … … … … … … … … … … … … … … … … … … …
```

Backup and recovery

Logical backup is suitable for smaller amounts of data where you might edit the data values or table structure, or recreate the data on a different machine architecture

Backup and recovery

Physical backup versus Logical backup

- Physical backup more compact than logical backup
- Application of physical backup are faster than logical backup because it involves only copying files without any conversion
- Physical backup can be performed while the MySQL server is not running; if the server is running, it is necessary to perform appropriate locking so that the server does not change database contents during the backup
- Logical backup is done by querying the MySQL server to obtain database structure and content information.
- Logical backup is slower than physical methods because the server must access database information and convert it to logical format
- Output from logical backup is larger than for physical backup, particularly when saved in text format
- Granularity of logical backup and restore is available at the server level (all databases), database level (all tables in a particular database), or table level
- Logical backup is performed with the MySQL server running and the server is not taken offline

Backup and recovery

Logical backup with `mysqldump` program

`mysqldump` program produces two types of output, depending on whether the `--tab` option is used

- Without `--tab` option `mysqldump` writes SQL statements to the standard output
- This output consists of `CREATE` statements to create dumped objects (databases, tables, stored routines, and so forth), and `INSERT` statements to load data into the tables
- The output can be saved in a file and reloaded later using `mysql` to recreate the dumped objects
- Options are available to modify the format of the SQL statements, and to control which objects are dumped

Backup and recovery

Logical backup with `mysqldump` program

`mysqldump` program produces two types of output, depending on whether the `--tab` option is used

- With `--tab` option `mysqldump` produces two output files for each dumped table
- The server writes one file as tab-delimited text, one line per table row
- This file is named `tbl_name.txt` in the output directory
- The server also sends a `CREATE TABLE` statement for the table to `mysqldump`, which writes it as a file named `tbl_name.sql` in the output directory

Backup and recovery

Examples of logical backup with `mysqldump` program without `--tab` option, i.e. with output directly to single SQL script file

By default, `mysqldump` writes information as SQL statements to the standard output that can be saved in a file with `file-name`

Starting 'mysqldump' program

```
mysqldump [arguments] > file-name
```

Example 1: `mysqldumpp` connects as a user `root`, prompts about password, use `verbose` mode, performs `lock all` dumped tables, to prevent data inconsistencies, take backup of `all databases` and save it in a file `dump.sql`

Starting 'mysqldump' program with parameters

```
mysqldump --user root --password --verbose --lock_tables
          --all-databases > dump.sql
```

Backup and recovery

Example 2: `mysqldump` connects as a user `root`, prompts about password, use `verbose` mode, performs `lock all` dumped tables to prevent data inconsistencies, takes backup of `csit115` database and save it in a file `csit115dump.sql`

Starting 'mysqldump' program with parameters

```
mysqldump --user root --password --verbose --lock_tables
          --databases csit115 > csit115dump.sql
```

Backup and recovery

Sample contents of a file `csit115dump.sql`

Sample contents of logical backup

```
CREATE DATABASE /*!32312 IF NOT EXISTS*/ 'csit115' /*!40100 DEFAULT CHARACTER SET latin1 */;
USE 'csit115';
DROP TABLE IF EXISTS 'ADMIN';
CREATE TABLE 'ADMIN' (
  'ENUM' decimal(12,0) NOT NULL,
  'POSITION' varchar(50) NOT NULL,
  PRIMARY KEY ('ENUM'),
  CONSTRAINT 'ADMIN_FKEY' FOREIGN KEY ('ENUM') REFERENCES 'EMPLOYEE' ('ENUM')
) ENGINE=InnoDB DEFAULT CHARSET=latin1;
LOCK TABLES 'ADMIN' WRITE;
INSERT INTO 'ADMIN' VALUES (18,'SUPPORT'),(19,'DIRECTOR'),(20,'CEO');
UNLOCK TABLES;
DROP TABLE IF EXISTS 'DRIVER';
CREATE TABLE 'DRIVER' (
  'ENUM' decimal(12,0) NOT NULL,
  'LNUM' decimal(8,0) NOT NULL,
  'STATUS' varchar(10) NOT NULL,
  PRIMARY KEY ('ENUM'),
  UNIQUE KEY 'DRIVER_UNIQUE' ('LNUM'),
  CONSTRAINT 'DRIVER_FKEY' FOREIGN KEY ('ENUM') REFERENCES 'EMPLOYEE' ('ENUM')
) ENGINE=InnoDB DEFAULT CHARSET=latin1;
LOCK TABLES 'DRIVER' WRITE;
INSERT INTO 'DRIVER' VALUES (1,10001,'AVAILABLE'),(2,10008,'ON LEAVE'),(3,10002,'AVAILABLE'),
(4,10004,'AVAILABLE'),(5,10003,'ON LEAVE'),(6,10012,'AVAILABLE'),(7,20002,'BUSY'),
(8,20003,'BUSY'),(9,30005,'BUSY'),(10,40002,'BUSY'),(11,20045,'AVAILABLE');
UNLOCK TABLES;
... ... ...
```

Backup and recovery

Restore a database `csit115`: connect as a user `csit115`

Connecting as 'csit115' user

```
mysql -u csit115 -p -v
```

Drop a database `csit115` and exit `mysql`

Dropping a database

```
DROP DATABASE csit115;
exit;
```

Connect as a user `csit115` and restore a database `csit115`

Restoring a database from a logical backup

```
mysql -u csit115 -p -v < csit115dump.sql
```

Backup and recovery

Example 3: mysqldump connects as a user csit115 , prompts about password, uses verbose mode, performs lock all dumped tables, to prevent data inconsistencies, take backup of EMPLOYEE and DRIVER tables located in csit115 database and save it in a file empdriv.sql

Taking a logical backup of selected relational tables

```
mysqldump csit115 EMPLOYEE DRIVER --user csit115 --password
                                   --verbose --lock_tables > empdriv.sql
```

Restore the tables EMPLOYEE and DRIVER: connect as a user csit115

Connecting as 'csit115' user

```
mysql -u csit115 -p -v
```

Drop the tables EMPLOYEE and DRIVER and exit mysql

Dropping foreign key constraints and relational tables

```
ALTER TABLE TRIP DROP FOREIGN KEY trip_fkey1;
ALTER TABLE ADMIN DROP FOREIGN KEY admin_fkey;
DROP TABLE DRIVER;
DROP TABLE EMPLOYEE;
exit;
```

Backup and recovery

Re-create and restore tables `DRIVER` and `EMPLOYEE` from a backup file `empdriv.sql`

Restoring the relational tables from a logical backup

```
mysql csit115 -u root -p <  empdriv.sql
```

Recreate referential integrity constraints

Recreating foreign key constraints

```
ALTER TABLE ADMIN ADD CONSTRAINT admin_fkey
                      FOREIGN KEY(ENUM) REFERENCES EMPLOYEE(ENUM);
ALTER TABLE TRIP ADD CONSTRAINT trip_fkey1
                     FOREIGN KEY (LNUM) REFERENCES DRIVER(LNUM);
```

References

MySQL 5.7 Reference Manual, 14.3.1 START TRANSACTION, COMMIT, and ROLLBACK Syntax

MySQL 5.7 Reference Manual, 8.4 Using mysqldump for Backup