COMP9120

Week 7: Introduction to Database Application Development

Semester 2, 2022

Today's content will not be covered in exam or quiz. It is only for assignment 2.

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Contents developed by Dr Lijun Chang

Acknowledgement of Country

I would like to acknowledge the Traditional Owners of Australia and recognise their continuing connection to land, water and culture. I am currently on the land of the Gadigal people of the Eora nation and pay my respects to their Elders, past, present and emerging.

I further acknowledge the Traditional Owners of the country on which you are on and pay respects to their Elders, past, present and future.

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Outline

- **Introduction to Database Application Development**
- DB Application Development in Java and Python
- Error Handling in Java and Python
- Security and SQL Injection
- Stored Procedure

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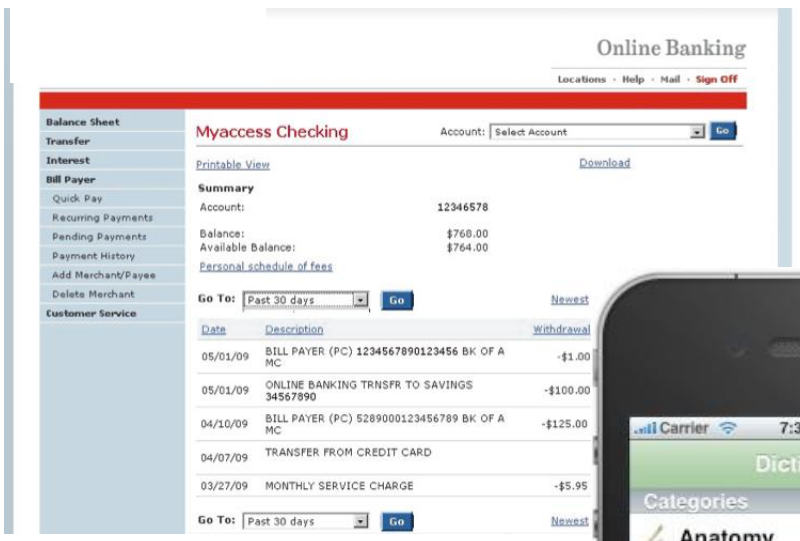
Interactive vs. Non-Interactive SQL

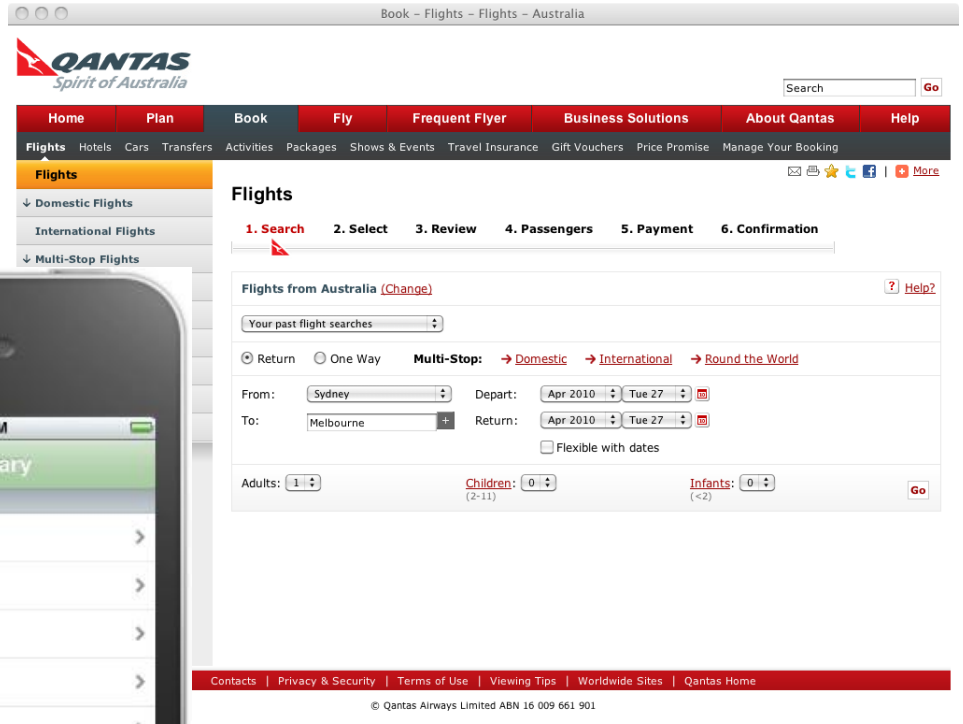
- *Interactive SQL*: SQL statements input from terminal; DBMS outputs to screen
  - Inadequate for most uses
    - It may be necessary to process the data before output
    - Amount of data returned not known in advance
    - SQL has limited expressive power

- *Non-interactive SQL*: SQL statements are included in a database application program written in a host language, like C++, Java, Python, PHP

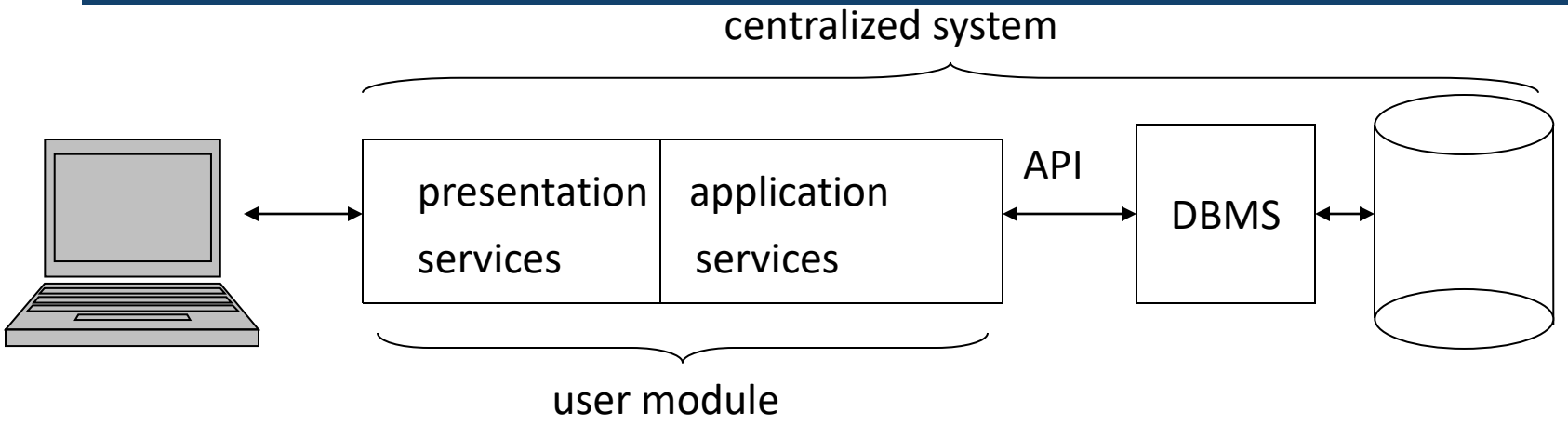
- *Client-side* vs. *Server-side* application development
  - Client-side: database application program
  - Server-side: stored procedures and triggers

Database Applications





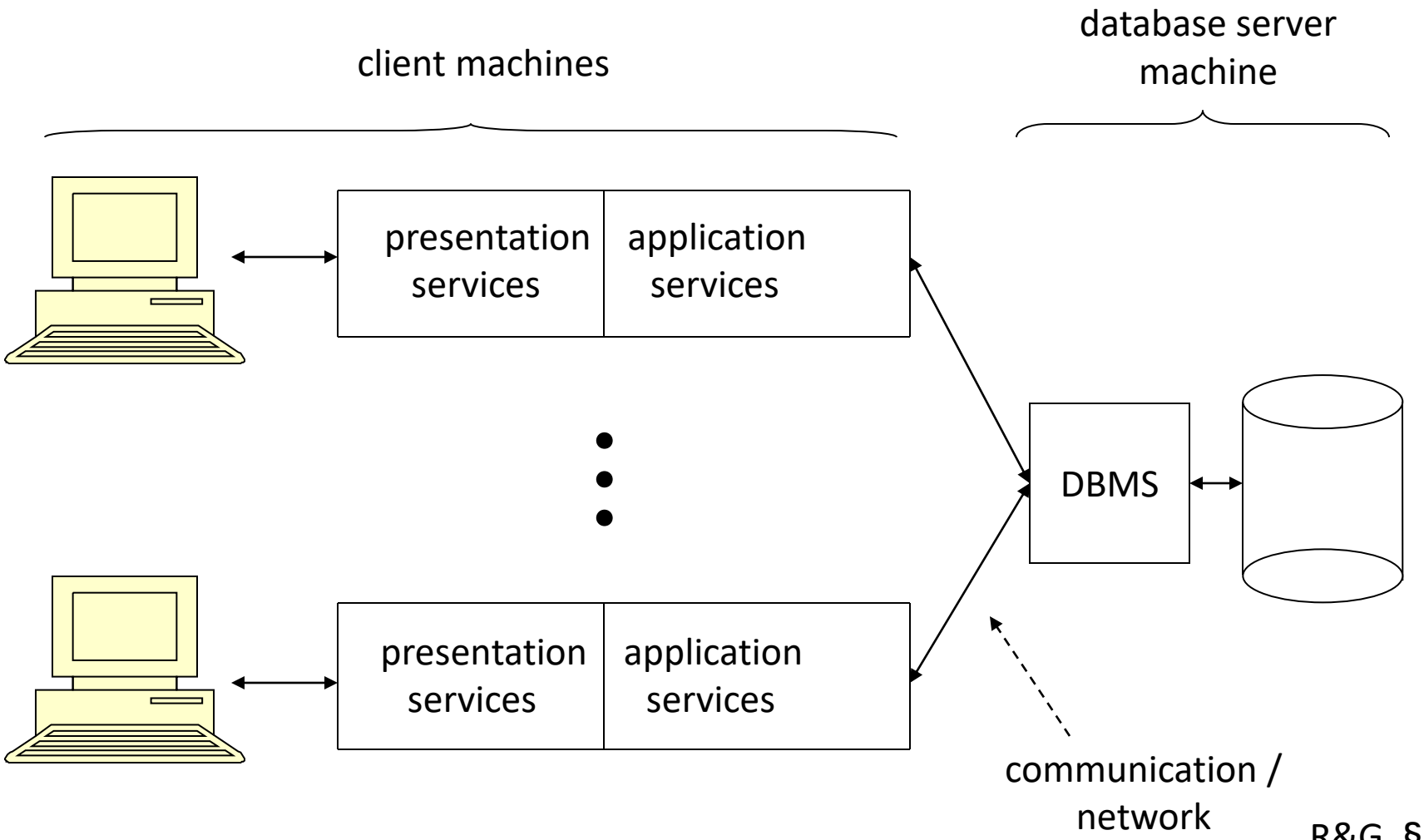
1-Tier Architecture: Centralized System



- *Presentation Services* - displays forms, handles flow of information to/from screen
- *Application Services* - implements user request, interacts with DBMS
- *DBMS* handles user requests – retrieves and returns results of queries or handles user requests for inserts/updates/deletes of data.
- Examples: Any application with integrated DB
  - MS Access systems
  - SQLite, esp. Smartphone apps

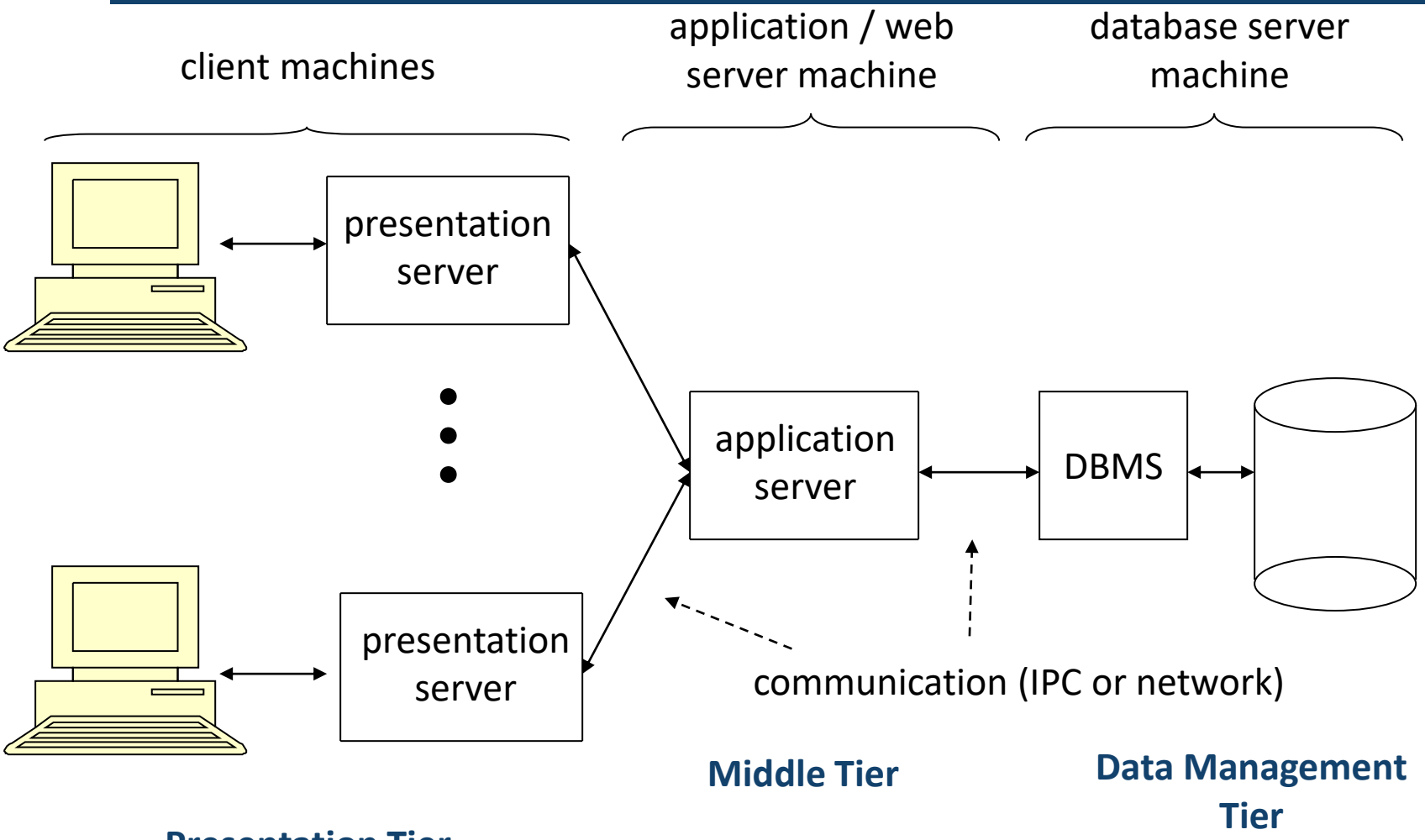
R&G § 7.5

2-Tier Architecture: Client - Server Model



R&G § 7.5

3-Tiered Architecture



R&G § 7.5

SQL in Application Code

- SQL commands can be called from within a *host language* (e.g., C++, Java, PHP, Python) program
  - SQL statements can refer to host variables
  - Must include a statement to *connect* to the right database

```
int userInput = takeUserInput();

SELECT *
FROM student
WHERE sid = userInput
```

- Two main integration approaches
  - Statement-level interface (SLI)
    - Embed SQL in the host language (Embedded SQL in C, SQLJ)
  - Call-level interface (CLI)
    - Create special API to call SQL commands (ODBC, JDBC, PHP-PDO, etc.)
    - SQL statements are passed as arguments to host language (library) procedures / APIs

R&G § 6.1

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- **DB Application Development in Java and Python**
- Error Handling in Java and Python
- Security and SQL Injection
- Stored Procedure

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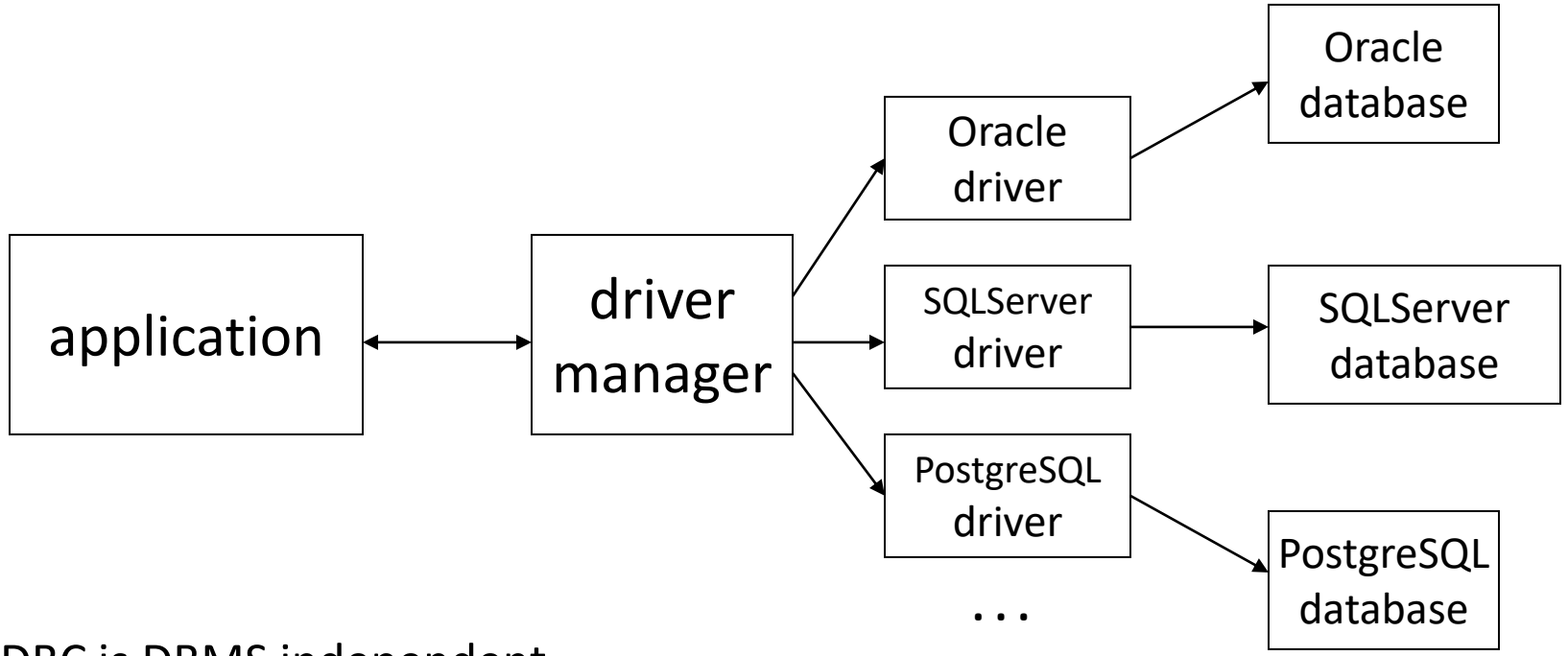
JDBC - “Java Database Connectivity”

- JDBC is a **Java API** for communicating with database systems supporting SQL
- JDBC supports a variety of features for querying and updating data, and for retrieving query results

- Model for communicating with the database:
  - Acquire a connection
  - Create a “Statement” object
  - Execute queries using the Statement object to send queries and fetch results
  - Exception mechanism to handle errors

JDBC Run-Time Architecture



- JDBC is DBMS independent
  - JDBC functions are generic
  - DriverManager allows to connect to specific driver
    - Even to different databases from the same program

JDBC Connection: Connecting to a database

- A session with a data source is started through the creation of a **Connection** object
  - example with PostgreSQL

```
PGSimpleDataSource source = new PGSimpleDataSource();
source.setServerName(myHost);
source.setDatabaseName(myDB);
source.setUser(userid);
source.setPassword(passwd);
Connection conn = source.getConnection();
```

  - Always release resource with conn.**close**();

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JDBC Statement: Executing a query

- SQL operations are conducted using **java.sql.Statement**
  - Constructed from a Connection object:

    Statement stmt = conn.**createStatement**();
  - Execute a SQL query:

    stmt.**executeQuery**("**SELECT** ... ");
  - Execute a DML statement (INSERT/UPDATE/DELETE)

    stmt.**executeUpdate**("**INSERT INTO** ... ");
  - Release resource with stmt.**close**();

- Two other ways (will be covered later)
  - *PreparedStatement* (semi-static SQL statements)
  - *CallableStatement* (stored procedures)

JDBC ResultSet: Retrieving results

› stmt.**executeQuery** returns data, encapsulated in a **ResultSet** object (a cursor)

```
ResultSet rs = stmt.executeQuery(sql);
while(rs.next()) {

   //Iterate through records
  // process the data

   rs.getString("name");
}
rs.close() // Release resources
```

› A **ResultSet** can be a very powerful cursor:

- **previous**(): moves one row back
- **absolute**(**int** num): moves to the row with the specified number
- **relative**(**int** num): moves forward or backward
- **first**() and **last**(): jump to ends
- **wasNull**(): dealing with NULL values

Matching Java and SQL Types

SQL Type	Java class	ResultSet get method
BIT	Boolean	getBoolean()
CHAR	String	getString()
VARCHAR	String	getString()
DOUBLE	Double	getDouble()
FLOAT	Double	getDouble()
INTEGER	Integer	getInt()
REAL	Double	getFloat()
DATE	java.sql.Date	getDate()
TIME	java.sql.Time	getTime()
TIMESTAMP	java.sql.TimeStamp	getTimestamp()

For python matching example: http://initd.org/psycopg/docs/usage.html#adaptation-of-python-values-to-sql-types

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Python Database API (DB-API)

- **Python's API (DB-API)** for communicating with database systems supporting SQL
  - Specific *modules* for each db engine (eg: Oracle, Postgres, IBM DB2, etc) provide an implementation for common DB-API functionality

- Model for communicating with the database:
  - Acquire a connection
  - Create a "cursor" object
  - Execute queries using the cursor object to send queries and fetch results
  - Exception mechanism to handle errors

Python DB-API Connection/Cursor

```
import psycopg2

try:
   # fetch connection object to connect to the database
   conn = psycopg2.connect(database="postgres",user="test",password="secret", host="host")

   # fetch cursor prepare to query the database
   curs = conn.cursor()

   # execute a SQL query
   curs.execute("SELECT name
                 FROM Student NATURAL JOIN Enrolled
                WHERE uos_code = 'COMP9120'")

   # can loop through the resultset
   for result in curs:
       print (" student: " + result[0])

   # for illustrating close methods – calling close() on cursor and connection
   # objects will release their associated resources.
   curs.close()
   conn.close()

except Exception as e: # error handling
   print("SQL error: unable to connect to database or execute query")
   print(e)
```

Some common Python DB-API Cursor Object methods

- **execute**(operation[,parameters])
  - Execute a query or a command with the sql provided as the operation argument;
  - the sql query parameter values provided in the parameters argument.
- **executemany**(operation[,parameters])
  - Can execute the same query (operation) multiple times, each time with a different parameter set
- **fetchone**()
  - Fetch the next row of a query result set, or returns None if no more data is available
- **fetchmany**([size=cursor.arraysize])
  - Return multiple rows from the result set for a given query, where one can specify the desired number of rows to return (where they are available)
- **fetchall**()
  - fetch all remaining rows
- **close**()
  - Release cursor resources

Reference: http://initd.org/psycopg/docs/cursor.html

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Python DB-API Connection/Cursor

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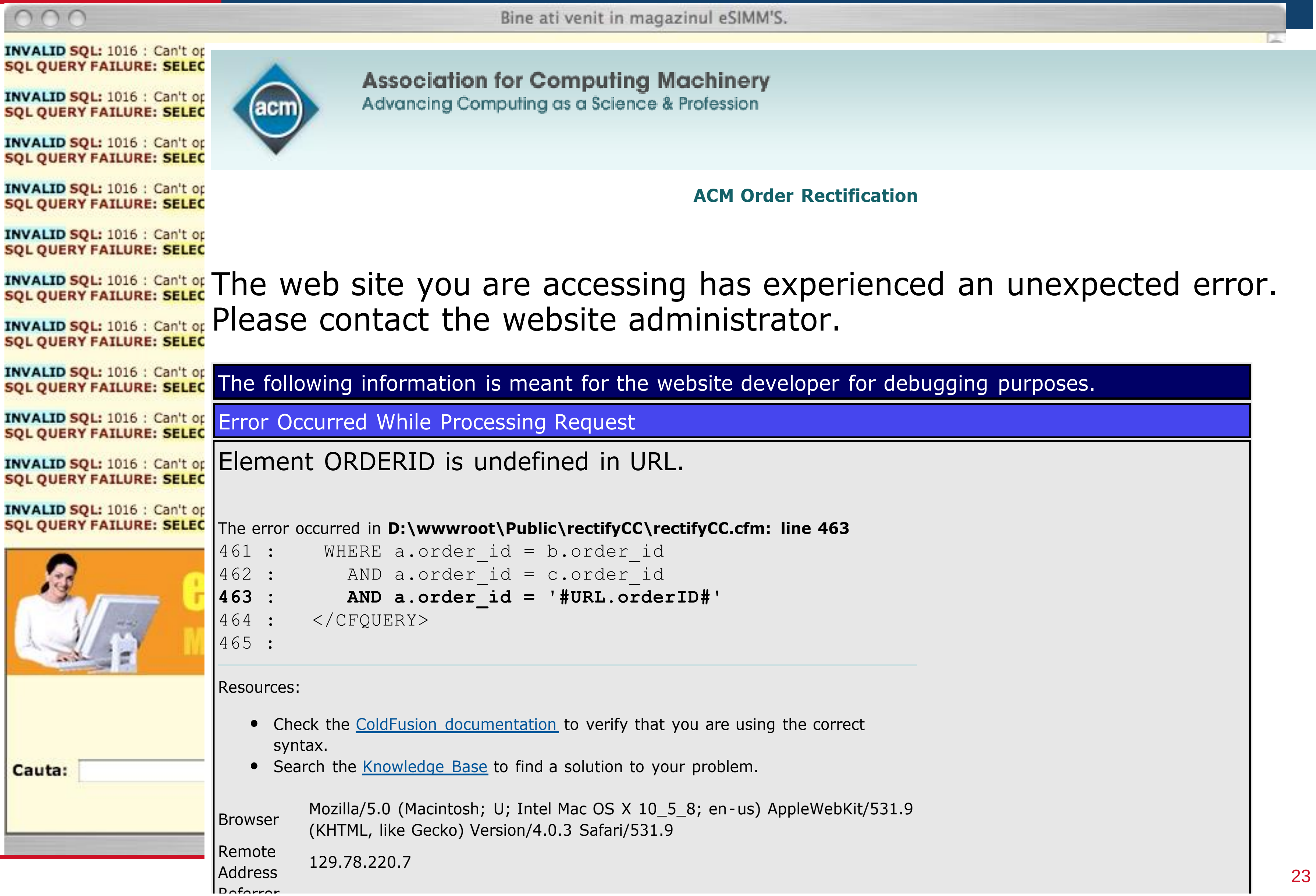
```

Avoid Exposing Errors to End-users



JDBC SQLException: Handling Errors

- Most of java.sql can throw an **SQLException** if an error occurs.
  - Catch and process with **catch**(**SQLException** e) { **...** }
  - Use **getMessage**()or **getSQLState**() or **getErrorCode**() to identify problem

Table 12. Class Code 23: Constraint Violation

SQLSTATE Value	Meaning
23001	The update or delete of a parent key is prevented by a RESTRICT update or delete rule.
23502	An insert or update value is null, but the column cannot contain null values.
23503	The insert or update value of a foreign key is invalid.
23504	The update or delete of a parent key is prevented by a NO ACTION update or delete rule.
23505	A violation of the constraint imposed by a unique index or a unique constraint occurred.
23510	A violation of a constraint on the use of the command imposed by the RLST table occurred.
23511	A parent row cannot be deleted, because the check constraint restricts the deletion.
23512	The check constraint cannot be added, because the table contains rows that do not satisfy the constraint definition.
23513	The resulting row of the INSERT or UPDATE does not conform to the check constraint definition.
23514	Check data processing has found constraint violations.
23515	The unique index could not be created or unique constraint added, because the table contains duplicate values of the specified key.
23520	The foreign key cannot be defined, because all of its values are not equal to a parent key of the parent table.
23521	The update of a catalog table violates an internal constraint.

JDBC SQLException: Handling Errors

- Most of java.sql can throw an **SQLException** if an error occurs.
  - Catch and process with **catch**(**SQLException** e) { **…** }
  - Use **getMessage**()or **getSQLState**() or **getErrorCode**() to identify problem
- Sub-classes available to catch specific types e.g.:
  - **SQLTimeoutException**
  - **SQLIntegrityConstraintViolationException**
- **SQLWarning** is a subclass of **SQLException**; not as severe
  - conn.**getWarnings**();
  - conn.**getNextWarning**();
  - conn.**clearWarnings**();

Example: Error Handling

The following function may fail to work for a number of reasons.

```
void exampleEnrolment() {
  PGSimpleDataSource source = new PGSimpleDataSource();
  source.setServerName(myHost);
  source.setDatabaseName(myDB);
  source.setUser(userid);
  source.setPassword(passwd);
  Connection conn = source.getConnection();

  Statement stmt = conn.createStatement();
  stmt.executeUpdate("INSERT INTO Transcript VALUES
    (123,'COMP9120', 'S1', 2022,'HD')");

  conn.close();
}
```

May fail due to server/connection problems

- Query could time out
- Primary key violation
- Foreign key violation

```
void exampleEnrolment() {
  Connection conn = null;
  try {
    conn = openConnection();
    Statement stmt = conn.createStatement();
    stmt.executeUpdate("INSERT INTO Transcript VALUES (123,'COMP9120', 'S1', 2022,'HD')");
  }
  catch (SQLIntegrityConstraintViolationException e) {
              System.err.println("Violated a constraint!");
  }
  catch (SQLTimeoutException e) {
              System.err.println("Operation timed out");
  }
  catch (SQLException e) {
              System.err.println("Other problem");
  }
finally {
    if (conn != null)
      try{conn.close();} catch(SQLException e) {//handle exception}
  }
}
```

Python DB API: Handling Errors

- Error handling via normal exception mechanism of Python
  - Errors and warnings are made available as Python exceptions
    - **Warning** raised for warnings such as data truncation on insert, etc
    - **Error** exception raised for various db-related errors
- psycopg API extension:
  - Exception attributes for detailed SQL error codes and messages
  - **pgerror** string of the error message returned by backend
  - **pgcode** string with the **SQLSTATE** error code returned by backend
- Example:

```
try:
  psycopg2.connect(…)
except psycopg2.Error as e:
  print("Problem connecting to database:")
  print(e.pgerror)
  print(e.pgcode)
```

Demo purpose only. As said before:
please do not directly print SQL exceptions :)

Python DB API: Handling Errors

```
StandardError
|__ Warning
|__ Error
    |__ InterfaceError
    |__ DatabaseError
        |__ DataError
        |__ OperationalError
        |    |__ psycopg2.extensions.QueryCanceledError
        |    |__ psycopg2.extensions.TransactionRollbackError
        |__ IntegrityError
        |__ InternalError
        |__ ProgrammingError
        |__ NotSupportedError
```

http://initd.org/psycopg/docs/module.html#exceptions

Also see: https://www.python.org/dev/peps/pep-0249

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- Stored Procedure

Security & SQL Injection

User Name:	' or '1'='1
Password:	' or '1'='1

Details:

http://www.open.edu/openlearn/ocw/mod/oucontent/view.php?id=48319&section=1.3

```
Statement stmt = conn.createStatement();
ResultSet rs = stmt.executeQuery(
  "SELECT * FROM Student WHERE
  name = '" + uName + "' AND Pass ='" + uPass + "'");
```

SELECT * **FROM** Student **WHERE**
Name ='John' **AND** Pass ='myPassword'

SELECT * **FROM** Student **WHERE**
Name ='' **or** '1'='1' **AND** Pass ='' **or** '1'='1'

Will return all students' details!!

Security & SQL Injection

User Name:	' or '1'='1
Password:	' or '1'='1

Details:

- How do we limit risks?
  - Hide error messages that expose the internals
  - Use salted hash passwords
  - Prevent SQL injection with:
    - *Prepared Statements* in Java
    - *Anonymous or Named Parameters* in Python

Dynamic SQL with Prepared Statements in JDBC

- **java.sql.PreparedStatement** allows a statement to be executed with host variables after the query plan has been evaluated
- Example:

```
credit(int amount, int accountno) {
  stmt = conn.prepareStatement("UPDATE account
                                SET balance = balance + ?
                                WHERE account_number = ?");

  stmt.setFloat(1, amount);

  stmt.setInt(2, accountno);

  result = stmt.executeQuery();
}
```

- More flexible and secure
- As a rule, always use in preference to Statements

Another example : Security

› What security issues can you identify in this function? How could they be fixed?

```
void getStudentAddress(int studID, String password) {
  Connection conn = openConnection();

  Statement stmt = conn.createStatement();
  ResultSet rs = stmt.executeQuery(
              "SELECT address FROM Student WHERE studId='"
              + studID + "' AND password = '" + password + "'");

  // Process results
  while (rs.next()){
    System.out.println(rs.getString("address"));
  }
  conn.close();
}
```

Try:
getStudentAddress(307088592, "' OR 1=1 -- ");

```
SELECT address FROM Student WHERE studId='307088592' AND password = '' OR 1=1 –-
```

Another example : Security

- What security issues can you identify in this function? How could they be fixed?

```
void getStudentAddress(int studID, String password) {
  Connection conn = openConnection();

  PreparedStatement stmt = conn.prepareStatement(
   "SELECT address FROM Student WHERE studId=? AND password=?");

  stmt.setInt(1, studID);
  stmt.setString(2, password);

  ResultSet rs = stmt.executeQuery();

  // Process results
  while (rs.next()){
    System.out.println(rs.getString("address"));
  }
  conn.close();
}
```

Python DB-API: Avoiding SQL Injection

NEVER ever use Python string concatenation (+) or string parameter interpolation (%) to pass variables to a SQL query string!

=> otherwise your program is vulnerable to SQL Injection attacks

```
query="""SELECT E.studId FROM Enrolled E
        WHERE E.uosCode = """ + uosCode +
        " AND E.semester = " + semester

cursor.execute( query )
```

Python DB-API: Avoiding SQL Injection: Parametrized Queries

Two (safe) approaches for passing query parameters:
(because **execute()** will do any necessary escaping / conversions for parameter markers)

1. Anonymous Parameters

```
studid = 12345
cursor.execute(
    "SELECT name FROM Student WHERE sid=%s",
    (studid,) )
```

2. Named Parameters

```
studid = 12345
cursor.execute(
   "SELECT name FROM Student WHERE sid=%(sid)s",
   {'sid': studid} )
```

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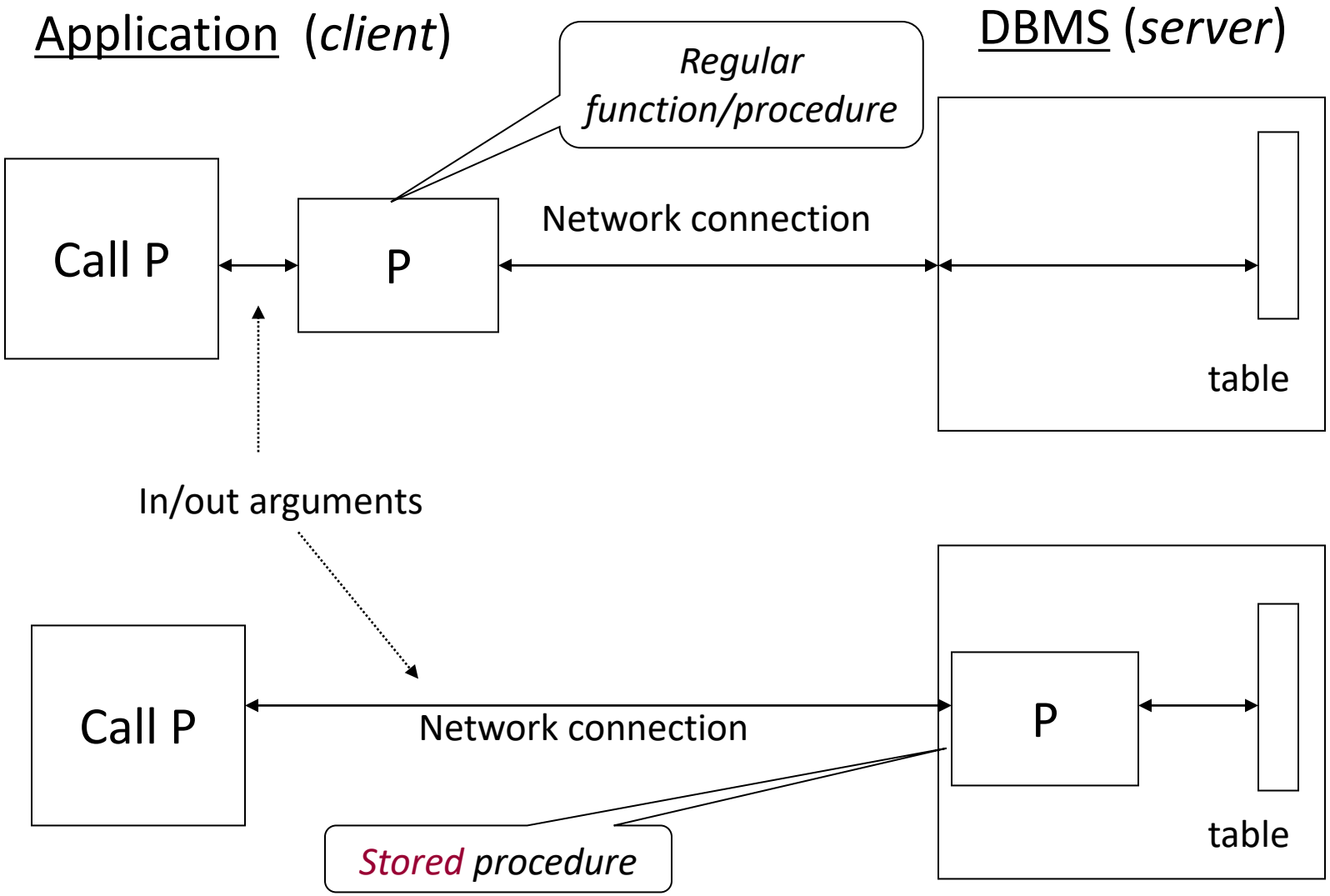
Stored Procedures

- Run logic within the database server
  - Included as schema element (stored in DBMS)
  - Invoked by the application

- Pros:
  - Additional abstraction layer (programmers do not need to know the schema)
  - Reduced data transfer

- Cons:
  - What if you wanted to switch DBMS?
    - rewrite all logic?

Stored Procedures network activity



Stored Procedure features

- All major database systems provide extensions of SQL to a simple, general purpose language
  - PostgreSQL: PL/pgSQL, Oracle: PL/SQL (syntax differs!!!)
- Procedure Declarations (with SQL/PSM)

  CREATE PROCEDURE name (parameter1,…, parameterN)
  local variable declarations
  procedure code;

- Stored Procedures can have parameters
  - of a valid SQL type (parameter types must match)
  - three different modes
    - **IN** arguments to procedure
    - **OUT** return values
    - **INOUT** combination of **IN** and **OUT**
- Stored Procedures have full access to SQL, plus extensions:
  - Local variables, loops, if-then-else conditions

PostgreSQL PL/pgSQL Example

```
CREATE FUNCTION RateStudent(studId INTEGER, uos VARCHAR) RETURNS CHAR AS $$
DECLARE
        grade     CHAR;
        marks     INTEGER;
BEGIN
        SELECT SUM(mark) INTO marks
        FROM Assessment
        WHERE sid=studId AND uosCode=uos;

        IF        marks>=85THEN grade := 'H';
        ELSIF     marks>=75THEN grade := 'D';
        ELSIF     marks>=65THEN grade := 'C';
        ELSIF     marks>=50THEN grade := 'P';
        ELSE                    grade := 'F';
        END IF;

        RETURN grade;
END; $$ LANGUAGE plpgsql;
```

PostgreSQL PL/pgSQL Example

```
CREATE FUNCTION RateStudent_INOUT(IN studId INTEGER, IN uos VARCHAR, OUT result CHAR) AS $$
DECLARE
        grade       CHAR;
        marks       INTEGER;
BEGIN
        SELECT SUM(mark) INTO marks
        FROM Assessment
        WHERE sid=studId AND uosCode=uos;

        IF          marks>=85THEN grade := 'H';
        ELSIF       marks>=75THEN grade := 'D';
        ELSIF       marks>=65THEN grade := 'C';
        ELSIF       marks>=50THEN grade := 'P';
        ELSE                      grade := 'F';
        END IF;

        result := grade;
END; $$ LANGUAGE plpgsql;
```

Calling Stored Procedures from JDBC

- Use **java.sql.CallableStatement** subclass of Statement
- Calling a stored procedure with return value:

```
CallableStatement call = conn.prepareCall("{? = call RateStudent(?, ?)}");
call.registerOutParameter(1, Types.CHAR);
call.setInt(2, 101);
call.setString(3, "COMP9120");
call.execute();

String result = call.getString(1);
```

- Calling a stored procedure with IN/OUT parameter :

```
CallableStatement call = conn.prepareCall("{call RateStudent_INOUT(?, ?, ?)}");
call.setInt(1, 101);
call.setString(2, "COMP9120");
call.registerOutParameter(3, Types.CHAR);
call.execute();

String result = call.getString(3);
```

Calling Stored Procedures from Python DB-API

- **Cursor** objects have an explicit **callproc**()method
  - **cursor.callproc()** makes the OUT parameters available as resultset
- Calling a stored procedure with return value:

```
curs.callproc(“RateStudent”, [101, "comp9120"])
output = curs.fetchone()

result = output[0];
```

- Calling a stored procedure with IN/OUT parameter :

```
curs.callproc(“RateStudent_INOUT”, [101, "comp9120"])
output = curs.fetchone()

result = output[0];
```

Example : Stored Procedures

- The following function performs several queries and updates, incurring several network round trips. Rewrite as a stored procedure and change the function to call this.

```
void enrolStudent(Connection conn, int studID, String uos, String sem, int year)
{
 PreparedStatement stmt = conn.prepareStatement("INSERT INTO Transcript
                                                 VALUES (?, ?, ?, ?, null)");
 stmt.setInt(1, studID);
 stmt.setString(2, uos);
 stmt.setString(3, sem);
 stmt.setInt(4, year);
 stmt.executeUpdate();
 stmt.close();

 stmt = conn.prepareStatement("UPDATE UoSOffering SET enrollment=enrollment+1
                               WHERE UoSCode=? AND Semester=? AND Year=?");
 stmt.setString(1, uos);
 stmt.setString(2, sem);
 stmt.setInt(3, year);
 stmt.executeUpdate();
 stmt.close();
}
```

Example : Stored Procedures

```
CREATE OR REPLACE FUNCTION ENROLSTUDENT ( sid INTEGER, uos VARCHAR,
                                          sem VARCHAR,  yr  INTEGER) AS $$
BEGIN
  INSERT INTO Transcript VALUES (sid, uos, sem, yr, null);
  UPDATE UoSOffering SET enrollment=enrollment+1
                     WHERE uoSCode=uos AND semester=sem AND year=yr;
END; $$ LANGUAGE plpgsql;
```

```
void enrolStudent(Connection conn, int studID, String uos,
                                   String sem, int year) {
  CallableStatement stmt = conn.prepareCall("{call ENROLSTUDENT (?, ?, ?, ?)}");
  stmt.setInt(1, studID);
  stmt.setString(2, uos);
  stmt.setString(3, sem);
  stmt.setInt(4, year);
  stmt.executeUpdate();
  stmt.close();
}
```

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Summary

- Some Keywords
  - Cursors
  - Prepared Statement
  - Stored Procedure
  - SQL Injection
- Understanding (within a DB application API)
  - Error handling
- Skills
  - Write application code (e.g. Java functions with JDBC) to interact with a database
  - Identify and avoid major security flaws in client code
  - Write stored procedures and call from client code

References

- Ramakrishnan/Gehrke (3rd edition - the 'Cow' book)
  - Chapter 6; 7.5
- Kifer/Bernstein/Lewis (2nd edition)
  - Chapter 8
- Ullman/Widom (3rd edition of 'First Course in Database Systems')
  - Chapter 9 (*covers Stored Procedures, ESQL, CLI, JDBC and PHP)*

Further Documentation:

- Java JDBC reference: http://docs.oracle.com/javase/7/docs/api/java/sql/package-summary.html
- **PostgreSQL JDBC Documentation:** https://jdbc.postgresql.org/documentation/head/index.html
- Python DB-API: https://www.python.org/dev/peps/pep-0249/
- A Postgres Python DB-API Adapter: http://initd.org/psycopg/docs/
  - Connection pooling: http://initd.org/psycopg/docs/pool.html
- Database PL/pgSQL Language Reference: https://www.postgresql.org/docs/9.5/static/plpgsql.html

References

- Java & Python Language References:
  - Java
    - https://www.ibm.com/developerworks/learn/java/intro-to-java-course/index.html
    - https://www.udemy.com/java-tutorial/
  - Python
    - https://www.learnpython.org/
    - https://docs.python.org/2/tutorial/

Next Week

- **Transaction Management**
  - Transaction Concept
  - Serializability

- Readings:
  - **Ramakrishnan/Gehrke (Cow book), Chapter 16**
  - Kifer/Bernstein/Lewis book, Chapter 18
  - Ullman/Widom, Chapter 6.6 onwards

Thank you!