DSAA 5012
Advanced Data Management for Data Science

LECTURE 8
STRUCTURED QUERY LANGUAGE (SQL)

STRUCTURED QUERY LANGUAGE (SQL): OUTLINE

- ✓ SQL Basic Structure and Operations
- ✓ Additional Basic Operations
- ✓ Aggregate Queries
- ✓ Nested Subqueries and Set Operations
- ➡ **Database Definition**
  - **Basic Types, User-defined Types/Domains**
  - **Creating, Altering, Destroying Relations**
  - **Integrity Constraints: Domain, Key, Foreign Key, General**
- Database Modification
- Using SQL in Applications

DATA DEFINITION LANGUAGE (DDL)

The SQL DDL allows the specification of:

- The schema for each relation (attributes).
- The types of values associated with each attribute (i.e., the domain of values the attribute, such as string, number, date, etc.).
- Integrity constraints (ICs).
  - domain, key, foreign key, general
- The set of indices to be maintained for each relation.
- The physical storage structure of each relation on disk.
- Security and authorization information for each relation.

BASIC TYPES

char(*n*)	Fixed length character string with length *n*.
varchar2(*n*)	Variable-length character string with maximum length *n*.
int	An integer (a finite subset of the integers that is machine-dependent).
smallint	A small integer (a machine-dependent subset of the integer domain type).
number(*p*,*d*)	A fixed point number with a total of *p* digits (the precision) and *d* digits to the right of the decimal point.
float(*n*)	Floating point number, with user-specified precision of at least *n* digits.
date	A date containing a (4 digit) year, month and day of month.
time	The time of day, in hours, minutes and seconds.
timestamp	A combination of date and time.

☞ **Some relational systems also allow user-defined types.**

CREATING RELATIONS

- The **create table** command is used to define and create a relation.
- The domain type of each attribute needs to be specified.
  - A default value can be specified for an attribute (only used when no value is provided when inserting with attributes *explicitly* specified).
  - Null values are allowed in all the basic domain types.

☞ **The domain type of an attribute is enforced by the DBMS whenever tuples are added or modified.**

```
create table Student (
   studentId    char(8) not null,
   name         varchar2(45) not null,
   email        varchar2(15),
   birthdate    date not null,
   cga          number(3,2));
```

```
create table EnrollsIn (
   studentId    char(8) not null,
   courseId     char(8) not null,
   grade        number(4,1) default 0 not null);
```

ALTERING AND DESTROYING RELATIONS

- The **alter table** command is used to add attributes to, modify attributes in or drop attributes from an existing relation.

Example:

```
alter table Student
    add firstYear int;
```

The schema is altered by adding a new attribute and extending every tuple in the current instance with a **null** value for the new attribute.

```
alter table Student
    drop column firstYear;
```

The schema is altered by dropping the attribute from the relation and deleting its value in every tuple.

- The **drop table** command deletes *all* information about a relation (both data *and* schema).

Example:

```
drop table Student;
```

INTEGRITY CONSTRAINTS (IC)

An integrity constraint (IC) **ensures that authorized changes to the database do not result in a loss of data consistency.**

☞ **An IC guards against accidental damage to the database.**

- ICs are obtained from the requirements of the real-world application that is being described in the database relations.
  - An IC is a statement about *all possible* instances!
  - For the **Student** relation, we know, from common knowledge, that name is not a key, but the constraint that an attribute, such as studentId, is a key must be given to us by the client.
- We can check a database instance to see if an IC is violated, but we can **never** infer that an IC is true by looking at a database instance. **Why?**

DOMAIN CONSTRAINTS

- Domain constraints define valid values for attributes and are used to test values inserted into the database and test queries to ensure that the comparisons make sense.

- Besides a basic domain type, additional constraints can be specified on attributes in the **create table** command.

not null	specifies that null values are not allowed.
primary key	specifies a key for a relation (the value of a key attribute *cannot be null* ⟹ no need to specify not null).
unique	specifies that an attribute or a set of attributes is a candidate key (the attribute value(s) *can be null*).
foreign key	specifies that one or more attributes refer to a primary key attribute in another relation.
check	specifies a predicate that the values in every tuple of the relation must satisfy.

FOREIGN KEY CONSTRAINT

A foreign key is a set of attributes in one relation whose values must match the primary key values in another relation or be null.

☞ **A foreign key must reference the primary key of the referenced relation.**

Example: Only students listed in the Student relation should be allowed to enroll for courses.

```
create table Student (
    studentId   char(8) primary key,
    name        varchar2(45) not null,
    email       varchar2(30),
    birthdate   date not null,
    cga         number(3,2),
    unique (email));
```

```
create table EnrollsIn (
    studentId   char(8),
    courseId    char(8),
    grade       number(4,1) default 0 not null,
    primary key (studentId, courseId),
    foreign key (studentId) references Student(studentId));
```

☞ **Every studentId value in the EnrollsIn relation must reference a tuple in the Student relation with a matching studentId value.**

FOREIGN KEY:
ENFORCING REFERENTIAL INTEGRITY

- What should be done if an **EnrollsIn** tuple with a non-existent student id is inserted?

  ☞ **Reject it!**

- What should be done if a **Student** tuple is deleted?

  1. Disallow deletion of a **Student** tuple that is referred to by an **EnrollsIn** tuple (*default action*).
  2. Alternatively, delete all **EnrollsIn** tuples that refer to it (**on delete cascade**).
  3. Set studentId in **EnrollsIn** tuples that refer to it to a *default value* (**on delete set default**).
  4. Set studentId in **EnrollsIn** tuples that refer to it to a *null value* (**on delete set null**).

  ☞ 3 and 4 are not applicable in the example since studentId is part of the primary key.

FOREIGN KEY:
ENFORCING REFERENTIAL INTEGRITY (cont'd)

- What should be done if the primary key student id of a tuple in **Student** is updated?

☞ **Reject it!**

- Alternatively, propagate the update to the tuples in the **EnrollsIn** relation with matching student ids (**on update cascade**).

```
create table EnrollsIn (
    studentId    char(8),
    courseId     char(10),
    grade        number(4,1) default 0 not null,
    primary key (studentId, courseId),
    foreign key (studentId) references Student(studentId)
        on delete cascade
        on update cascade);
```

The referential integrity actions in the referencing relation (**EnrollsIn**) are triggered when a tuple in the referenced relation (**Student**) is deleted or updated.

Oracle Note
Oracle does not support on update cascade.

CHECK CLAUSE: ATTRIBUTES

- The **check** clause is used to add an integrity constraint for an attribute and can contain an arbitrary predicate.
  - ☞ **The predicates are similar to those allowed in a where clause.**
- The predicate is specified in the definition of a relation and checked whenever there is an update to the relation.

Example: Ensure that semester can have only specified values and that year is between 2020 and 2024.

```
create table Section (
    courseId     char(8),
    sectionId    char(2),
    semester     char(6),
    year         char(4) check (year between '2020' and '2024'),
    check (semester in ('Fall', 'Winter', 'Spring', 'Summer')));
```

STRUCTURED QUERY LANGUAGE (SQL)

EXERCISE 1

BOOK STORE RELATIONAL SCHEMA

Book(bookId, title, subject, quantityInStock, price, *authorId*)

Author(authorId, firstName, lastName)

Customer(customerId, firstName, lastName)

BookOrder(orderId, *customerId*, orderYear)

OrderDetails(*orderId, bookId*, quantity)

Attribute names in italics are foreign key attributes.

Assumptions

– Each author has authored at least one book in the store.

– Each book has exactly one Author.

– Each order is made by exactly one customer and has one or more associated tuples in OrderDetails (e.g., one order may contain several different books).

EXERCISE 1

Given the foreign keys of the Book Store relations and assuming the referential integrity constraints are included in the SQL create statements, what should be the create order?

Book(<u>bookId</u>, title, subject, quantityInStock, price, *authorId*)

Author(<u>authorId</u>, firstName, lastName)

Customer(<u>customerId</u>, firstName, lastName)

BookOrder(<u>orderId</u>, *customerId*, orderYear)

OrderDetails(<u>*orderId, bookId*</u>, quantity)

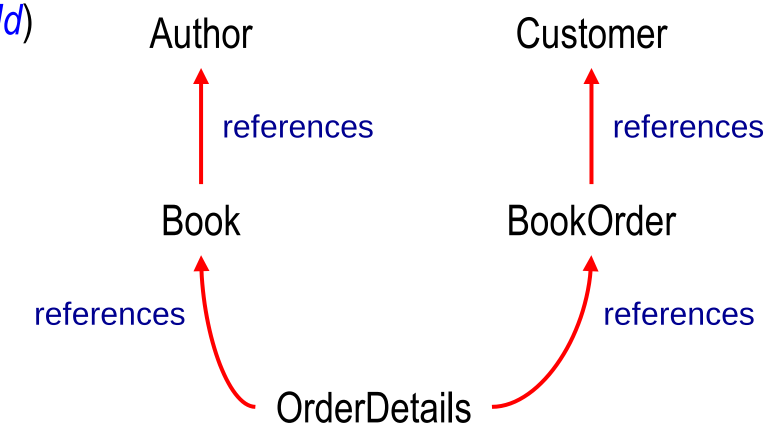

Table	Possible create order					
Author	1	1	2	2	1	3
Customer	2	2	1	1	3	1
Book	3	4	3	4	2	4
BookOrder	4	3	4	3	4	2
OrderDetails	5	5	5	5	5	5

<u>Create Order</u>

Author	*before*	Book
Customer	*before*	BookOrder
Book, BookOrder	*before*	OrderDetails

STRUCTURED QUERY LANGUAGE (SQL): OUTLINE

- ✓ SQL Basic Structure and Operations
- ✓ Additional Basic Operations
- ✓ Nested Subqueries and Set Operations
- ✓ Aggregate Queries
- ✓ Database Definition
- ➡ **Database Modification**
  - **Deleting Tuples**
  - **Inserting Tuples**
  - **Updating Tuples**
- Using SQL in Applications

TUPLE DELETION

- The **delete** command deletes *zero or more tuples* from a relation.

Example: Delete all accounts at the Pacific Place branch.

```
delete from Account
where branchName='Pacific Place';
```

Conceptually, deletion is done in two steps.
1. Find the tuples to delete.
   ```
   select * from Account
   where branchName='Pacific Place';
   ```
2. Delete the tuples found.

- A **delete** statement **where** clause predicate can be as complex as in a **select** statement.

Example: Delete all depositors at the Langham Place branch.

☞ **Must also delete the accounts of these depositors!**

```
delete from Depositor
where accountNo in (select accountNo
                    from Depositor natural join Account
                    where branchName= 'Langham Place');
```

☞ **Can only delete if no integrity constraints are violated!**

TUPLE INSERTION

- The **insert** command adds one or more tuples to a relation.

Example: Add a new **Account**.

```
insert into Account values ('A-732', 1200 , 'Pacific Place' );
```

Example: Add a new **Account** with balance set to null.

```
insert into Account values ('A-733', null, 'Pacific Place');
```

☞ **The order of the values must match the order of the attributes in the relation.**

- Attribute names need to be *specified explicitly* for order-independent insertion and to make use of default values.

```
insert into Account (accountNo, branchName, balance)
    values ('A-734', 'Pacific Place', 1200);
```

COMPLEX INSERTION

- Insertion values can be obtained from the result of a query.

Example: Create a $200 savings account for all loan clients of the Pacific Place branch. Let the loan number serve as the account number for the new savings account.

```
insert into Account
select loanNo, 200, branchName
from Loan
where branchName='Pacific Place';
```

```
insert into Depositor
select clientId, loanNo
from Loan natural join Borrower
where branchName='Pacific Place';
```

The order of the attributes in the **select** clause must match the order of the attributes in the table being inserted into.

Note: The keyword **values** is omitted when the values are obtained from a **select** statement.

Account(accountNo, balance, *branchName*)
Loan(loanNo, amount, *branchName*)

Depositor(*clientId, accountNo*)
Borrower(*clientId, loanNo*)

TUPLE UPDATE

- The **update** command is used to change a value in a tuple.

Example: Increase all accounts with balance over $10,000 by 6%; all other accounts receive 5%.

```
update Account
set balance=balance*1.06
where balance>10000;
```

```
update Account
set balance=balance*1.05
where balance<=10000;
```

☞ **Need two update statements! The order is important! Why?**

- This update can be specified using the **case** statement.

```
update Account
set balance= case
            when balance<=10000 then balance*1.05
            else balance*1.06
        end;
```

 Account(accountNo, balance, *branchName*)

STRUCTURED QUERY LANGUAGE (SQL)

EXERCISES 2, 3

BOOK STORE RELATIONAL SCHEMA

Book(<u>bookId</u>, title, subject, quantityInStock, price, *authorId*)

Author(<u>authorId</u>, firstName, lastName)

Customer(<u>customerId</u>, firstName, lastName)

BookOrder(<u>orderId</u>, *customerId*, orderYear)

OrderDetails(<u>*orderId, bookId*</u>, quantity)

Attribute names in italics are foreign key attributes.

Assumptions

- Each author has authored at least one book in the store.
- Each book has exactly one Author.
- Each order is made by exactly one customer and has one or more associated tuples in OrderDetails (e.g., one order may contain several different books).

EXERCISE 2

For all authors who wrote books on at least two subjects, increase the price of all their books by 5%.

```
update Book
set price=1.05*price
where authorId in (select B1.authorId
                   from Book B1, Book B2
                   where B1.authorId=B2.authorId
                         and B1.subject<>B2.subject);
```

Update the price by 5%.

Select only those tuples where the subject is different (i.e., the result contains only those authors who wrote books on more than one subject).

Join Book with itself on authorId.

Note: Natural join cannot be used if self join is required. Why?

EXERCISE 2 (cont'd)

For all authors who wrote books on at least two subjects, increase the price of all their books by 5%.

Do not use join

```
update Book
set price=1.05*price
where authorId in (select authorId
                   from Book
                   group by authorId
                   having count(distinct subject)>=2);
```

Update the price by 5%.

Authors who wrote books on more than one subject.

Book(bookId, title, subject, quantityInStock, price, *authorId*)

EXERCISE 3

Find the last name and first name of all authors who wrote books on both the subjects of Art and Business.

Can we say ⟹ **where** subject='Art' **and** subject='Business'? No. Why?

☞ Selects nothing.

Can we say ⟹ **where** subject='Art' **or** subject='Business'? No. Why?

☞ Selects authors who wrote either Art or Business books, but not necessarily on both subjects.

```
select lastName, firstName
from (select authorId, lastName, firstName
      from Author natural join Book
      where subject='Art'
      intersect
      select authorId, lastName, firstName
      from Author natural join Book
      where subject='Business');
```

Authors who wrote books on Art.

Select only those authors in the Art set who are also in the Business set.

Authors who wrote books on Business.

Book(bookId, title, subject, quantityInStock, price, *authorId*) Author(authorId, firstName, lastName)

EXERCISE 3 (cont'd)

Find the last name and first name of all authors who wrote books on both the subjects of Art and Business.

Use *only* set membership

```
select lastName, firstName
from Author natural join Book
where subject='Art'
        and authorId in (select authorId
                         from Author natural join Book
                         where subject='Business');
```

Authors who wrote books on Art (Art set).

Select only those authors in the Art set who are also in the Business set.

Authors who wrote books on Business (Business set).

Book(bookId, title, subject, quantityInStock, price, *authorId*) Author(authorId, firstName, lastName)

STRUCTURED QUERY LANGUAGE (SQL): OUTLINE

- ✓ SQL Basic Structure and Operations
- ✓ Additional Basic Operations
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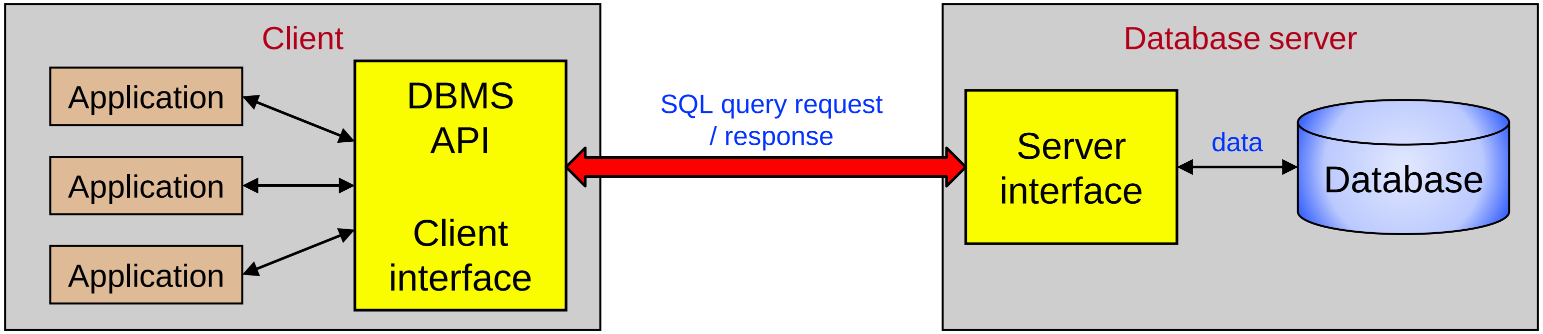
- ✓ Database Definition
- ✓ Database Modification
- ➡ **Using SQL in Applications**
  - **Database APIs**
  - **Oracle PL/SQL**

API BASICS

- To utilize DBMS services, client applications use a specific application programming interface (API) provided by the DBMS.
  - Facebook, Google, Instagram, etc. have such APIs.
  - Proprietary versus generic APIs (e.g., ODBC, JDBC, ADO.NET).

- The DBMS API exposes an interface through which the services provided by the DBMS can be accessed.
  - The client and server interfaces often are implemented in the form of network sockets that use a specific port number on the server (e.g., port 1521 for the course Oracle Database server).



EMBEDDED VS CALL-LEVEL API

Embedded API

– SQL statements are part of the host programming language source code.

– An SQL pre-compiler parses and checks the SQL instructions *before* the program is compiled and replaces these with source code instructions native to the host programming language used.

Call-level API

– Passes SQL instructions to the DBMS by direct calls to a series of procedures, functions or methods provided by the API.

– The calls perform actions such as setting up a database connection, sending queries and iterating over the query result.

EARLY VS LATE BINDING

- SQL binding is the translation of SQL statements in a programming language into a form that can be executed by the DBMS.
  - Involves performing tasks such as validating table and attribute names, checking whether the user or client has sufficient access rights and generating an efficient query plan to access the data.
- Early binding performs these tasks *only once* *before program execution* (i.e., using a pre-compiler with an embedded API).
- Late binding performs these tasks *every time* *at runtime* (i.e., when using a call-level API).

☞ **It is still possible to do early binding using call-level APIs by using stored procedures in the DBMS.**

ORACLE PL/SQL

- PL/SQL (Procedural Language/SQL) allows SQL statements to be embedded into a procedural programming language.

- A PL/SQL program is stored as a database object (stored procedure/function) and can be
  - a procedure, which does not return a value and is invoked using the **exec** keyword.
  - a function, which returns a value using the **return** keyword and is invoked by assigning its result to a variable or using it in a **select** statement.

- Both types of PL/SQL programs can accept parameters.

ORACLE PL/SQL: BASIC STRUCTURE

- The basic processing unit is a block, which is delimited by **begin**…**end** and which can be nested.

create or replace procedure *procedure_name* [**as** | **is**]	
	Declaration section: contains declaration of variables, types, and local subprograms.
begin	**Executable section:** contains procedural and SQL statements. This is the only section of a block that is required.
exception	**Exception handling section:** contains error handling statements.
end;	

Allowed SQL statements: **select**, **insert**, **update**, **delete** (i.e., DML)

Not allowed SQL statements: **create**, **drop**, **alter**, **rename** (i.e., DDL)

PL/SQL PROCEDURE EXAMPLE

Increment the rating of a sailor if the rating is less than 5.

```
create or replace procedure L9Example1 (sid in int) as
   sailorName  Sailor.sName%type;
   sailorRating  Sailor.rating%type;
begin
   -- Fetch the sailor's name and rating into the variables sailorName and sailorRating
   select sName, rating into sailorName, sailorRating from Sailor where sailorId=sid;
   if sailorRating<5 then
      update Sailor set rating=sailorRating+1 where sailorId=sid;
      -- Write record updated message to the Script Output tab
      dbms_output.put_line('Sailor ' || sailorName || '(' || sid || ') rating updated from ' ||
         sailorRating || ' to ' || (sailorRating+1) || '.');
   else
      -- Write record NOT updated message to the Script Output tab
      dbms_output.put_line('Sailor ' || sailorName || '(' || sid || ') rating ' || sailorRating || ' NOT updated.');
   end if;
end L9Example1;
```

Local variables sailorName and sailorRating are of the same type as sName and rating in the Sailor relation.

Must fetch at most one record

Sailor(sailorId, sName, rating, age)

CURSORS

- Procedural programming languages normally process only one record at a time.

- Thus, if a **select** statement returns more than one record, a cursor is needed to process the records one-at-a-time.
  - A cursor is like a pointer that points to a single record in a query result and allows access to the attribute values of that record.

- In PL/SQL a cursor is defined in the **declare** section

  cursor *cursor_name* **is** *select_statement*;

  and can be used and managed
  - *explicitly* using the **open**, **fetch** and **close** commands and by checking cursor status.
  - *implicitly* using the **for**...**loop** statement where the *cursor_name* replaces the range limit so the loop ranges from the first record of the cursor to the last record of the cursor.

Determine which sailors have/have not reserved boats.

PL/SQL CURSOR EXAMPLE

```
create or replace procedure L9Example2 as
   currentSailorId   Sailor.sailorId%type;
   -- Declare the cursors for the sailor and reserves tables
   cursor sailorCursor is select * from Sailor order by sName;
   cursor reservesCursor is select count(boatid) reservations from reserves where sailorId=currentSailorId;
begin
   -- Fetch the sailorCursor records one-by-one
   for sailorRecord in sailorCursor loop
      -- Assign the sailor id for the current sailor record
      currentSailorId:=sailorRecord.sailorId;
      -- Fetch the reservesCursor records one-by-one
      for reservesRecord in reservesCursor loop
         -- Insert into appropriate table
         if reservesRecord.reservations=0 then
            insert into ReservationSummary values (sailorRecord.sailorId, sailorRecord.sName, 'No');
         else
            insert into ReservationSummary values (sailorRecord.sailorId, sailorRecord.sName, 'Yes');
         end if;
      end loop;
   end loop;
end L9Example2;
```

sailorCursor and reservesCursor define what data should be retrieved when their **select** statement is executed.

Executes sailorCursor **select** statement (i.e., retrieves all Sailor records).

Assigns the sailorId value in the current Sailor record to the variable currentSailorId.

Executes reservesCursor **select** statement using the value in currentSailorId (i.e., retrieves only the Reserves records where sailorId=currentSailorId).

Sailor(sailorId, sName, rating, age)

Reserves(sailorId, boatId, rDate)

PL/SQL EXCEPTIONS

- Predefined exceptions are raised implicitly by PL/SQL if the exception occurs.

- User-defined exceptions are declared in the declaration section,

  exception_name **exception**;

  raised explicitly within a **begin**...**end** block

```
if condition then
   raise exception_name;
end if;
```

  and handled in the **exception** section within the **begin**...**end** block.

```
exception
   when exception_name then
      ⋮
```

Predefined Exceptions

ACCESS_INTO_NULL	ORA-06530
CASE_NOT_FOUND	ORA-06592
COLLECTION_IS_NULL	ORA-06531
CURSOR_ALREADY_OPEN	ORA-06511
DUP_VAL_ON_INDEX	ORA-00001
INVALID_CURSOR	ORA-01001
INVALID_NUMBER	ORA-01722
LOGIN_DENIED	ORA-01017
NO_DATA_FOUND	ORA-01403
NOT_LOGGED_ON	ORA-01012
PROGRAM_ERROR	ORA-06501
ROWTYPE_MISMATCH	ORA-06504
SELF_IS_NULL	ORA-30625
STORAGE_ERROR	ORA-06500
SUBSCRIPT_BEYOND_COUNT	ORA-06533
SUBSCRIPT_OUTSIDE_LIMIT	ORA-06532
SYS_INVALID_ROWID	ORA-01410
TIMEOUT_ON_RESOURCE	ORA-00051
TOO_MANY_ROWS	ORA-01422
VALUE_ERROR	ORA-06502
ZERO_DIVIDE	ORA-01476

PL/SQL EXCEPTIONS EXAMPLE

Increment the rating of a sailor if the rating is less than 5.

```
create or replace procedure L9Example3 (sid in int) as
   sailorName   Sailor.sName%type;
   sailorRating  Sailor.rating%type;
begin
   -- Fetch the sailor's name and rating into the variables sailorName and sailorRating
   select sName, rating into sailorName, sailorRating from Sailor where sailorId=sid;
   if sailorRating<5 then
      update Sailor set rating=sailorRating+1 where sailorId=sid;
      -- Write record updated message to the Script Output tab
      dbms_output.put_line('Sailor ' || sailorName || '(' || sid || ') rating updated from ' ||
         sailorRating || ' to ' || (sailorRating+1) || '.');
   else
      -- Write record NOT updated message to the Script Output tab
      dbms_output.put_line('Sailor ' || sailorName || '(' || sid || ') rating ' || sailorRating || ' NOT updated.');
   end if;
exception
   when no_data_found then
      -- Write exception message to the Script Output tab
      dbms_output.put_line('There is no sailor with id ' || sid || '.');
end L9Example3;
```

If the sailor id does not exist, then the no_data_found exception is raised causing execution to pass to the **exception** section and to the no_data_found exception code.

STRUCTURED QUERY LANGUAGE (SQL): SUMMARY

- Structured Query Language (SQL) is a relational query language that provides facilities to

Query Relations

- Select-From-Where Statement
- Set Operations (Union, Intersect, Except)
- Nested Subqueries (to test for set membership, comparison, cardinality)
- Aggregate Functions (avg, min, max, sum, count)
- Group By with Having clause

Create and Modify Relations

- Create, Alter, Drop Tables
- Specify integrity constraints: domain, key, foreign key, general
- Insert, Delete, Update Tuples

Access a Database from a Programming Language

COMP 3311: SYLLABUS

- ✓ Introduction
- ✓ Entity-Relationship (E-R) Model and Database Design
- ✓ Relational Algebra
- ✓ Structured Query Language (SQL)
- ✓ Relational Database Design
- ➡ **Storage and File Structure**
- Indexing
- Query Processing
- Query Optimization
- Transactions
- Concurrency Control
- Recovery System
- NoSQL Databases

STRUCTURED QUERY LANGUAGE (SQL)

EXERCISES 4, 5, 6, 7

Upload your completed exercise worksheet to Canvas by **11 p.m. Feb 26th**