# Embedded SQL

- After completing this chapter, you should be able to
  - ▷ work with **programming language (PL) interfaces** to an RDBMS, the basis for database **application development,**
  - ▷ develop (simple) programs that use **Embedded SQL,**

    Syntax of Embedded SQL, how to preprocess/compile **C programs containing embedded SQL statements**, usage of **host variables**, **error handling, indicator variables,** *etc.*
  - ▷ explain the use of **cursors** (and why they are needed to interface with a PL).

# Embedded SQL

## Overview

# Introduction (1)

- SQL is a database language, but **not a programming language.**
  - ▷ Complex queries (and updates) may be expressed using rather short SQL commands.

    Writing equivalent code in C would take significantly more time.
  - ▷ SQL, however, is **not functionally complete.**

    Not every computable function on the database states is expressible in SQL. Otherwise, **termination of query evaluation** could not be guaranteed.

# Introduction (2)

- SQL is used directly for **ad-hoc queries** or **one-time updates** of the data.
- **Repeating tasks** have to be supported by **application programs** written in some PL.

  Internally, these programs generate SQL commands which are then shipped to the DBMS.

- Most database users do *not* know SQL or are even unaware that they interact with a DBMS.
- Even if a user knows SQL, an application program might be more effective than the plain SQL console.

  Think of **visual representation** of query results or **sanity checks** during data entry.

# Introduction (3)

- Languages/tools widely used for **database application programming:**
  - ▷ **SQL scripts,**

    Like UNIX shell scripting language but interpreted by non-interactive SQL console.
  - ▷ **C with Embedded SQL,**
  - ▷ **C with library procedure calls (ODBC),**
  - ▷ **Java with library procedure calls (JDBC),**
  - ▷ **Scripting languages** (Perl/DBI, PHP (LAMP), Python/DB-API, . . . ),
  - ▷ **Web interfaces** (CGI, Java Servlets, . . . ).

# Introduction (4)

- Almost always, developers work with more than one language (*e.g.*, C and SQL) to develop an application.
  This leads to several problems:
  - ▷ The interface is not smooth: **type systems differ** and the infamous impedance mismatch problem occurs.

    **Impedance mismatch:** SQL is declarative and set-oriented. Most PLs are imperative and record- (tuple-) oriented.
  - ▷ SQL commands are spread throughout the application code and can never be optimized as a whole database workload.
  - ▷ Query evaluation plans should be persistently kept inside the DBMS between program executions, but programs are external to the DBMS.

# Introduction (5)

- Note that these problems could be avoided with **real database programming languages,** *i.e.*, a tight integration of DBMS and PL compiler and runtime environment.
  Proposed solutons:
  - ▷ **Persistent programming languages** (*e.g.*, Napier88, Tycoon, Pascal/R [Pascal with type `relation`]),
  - ▷ **stored procedures,**

    Application code stored inside DBMS, DBMS kernel has built-in language interpreter or calls upon external interpreter.
  - ▷ **object-oriented DBMS,**

    OODBMS stores methods (behaviour) along with data.
  - ▷ **deductive DBMS.**

    DBMS acts as huge fact storage for a Prolog-style PL.

# Making Good Use of SQL

- Way too often, application programs use a relational DBMS only to make records persistent, but perform all computation under the control of the PL.

  Such programs typically retrieve single rows (records) one-by-one and perform joins and aggregations by themselves.

- Using more powerful SQL commands might
  - ▷ simplify the program, and
  - ▷ **significantly** improve the performance.

    There is a considerable overhead for executing an SQL statement: send to DBMS server, compile command, send result back. The fewer SQL statements sent, the better.

# Example Database

STUDENTS

| SID | FIRST | LAST | EMAIL |
|---|---|---|---|
| 101 | Ann | Smith | ... |
| 102 | Michael | Jones | (null) |
| 103 | Richard | Turner | ... |
| 104 | Maria | Brown | ... |

EXERCISES

| CAT | ENO | TOPIC | MAXPT |
|---|---|---|---|
| H | 1 | Rel.Alg. | 10 |
| H | 2 | SQL | 10 |
| M | 1 | SQL | 14 |

RESULTS

| SID | CAT | ENO | POINTS |
|---|---|---|---|
| 101 | H | 1 | 10 |
| 101 | H | 2 | 8 |
| 101 | M | 1 | 12 |
| 102 | H | 1 | 9 |
| 102 | H | 2 | 9 |
| 102 | M | 1 | 10 |
| 103 | H | 1 | 5 |
| 103 | M | 1 | 7 |

# Embedded SQL

## Overview

1. Introduction and Overview
2. Embedded SQL

# Embedded SQL (1)

- **Embdedded SQL** inserts specially marked SQL statements into program source texts written in C, C++, Cobol, and other PLs.
- Inside SQL statements, **variables of the PL** may be used where SQL allows a constant term only (parameterized queries).

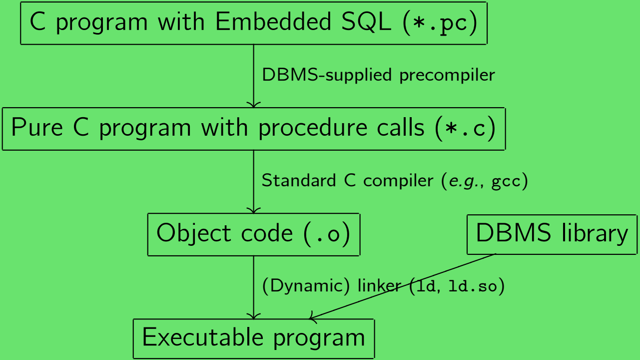
**Insert a row into table `RESULTS`:**

```
EXEC SQL INSERT INTO RESULTS(SID, CAT, ENO, POINTS)
         VALUES (:sid, :cat, :eno, :points);
```

▷ Here, `sid` *etc.* are C variables and the above may be emdbedded into any C source text.

# Embedded SQL (2)

## Compilation/linkage of Embedded SQL programs



# A Mini C Recap (1)

- The **C** programming language was designed by Dennis Ritchie around 1972 at Bell Labs.

**Traditional first C program.**

```
#include <stdio.h>
int main (void)
{
    printf ("Hello, world!\n");  /* \n = newline */
    return 0;
}
```

Execution starts at mandatory procedure `main`. Return value `0` is a signal to the OS that the execution went OK (also see `exit()`). Header file `"stdio.h"` contains declaration of library function `printf` used for output. Braces (`{`, `}`) enclose nested statement blocks.

# A Mini C Recap (2)

- In C, a **variable declaration** is written as

$$\langle \mathit{Type} \rangle \; \langle \mathit{Variable} \rangle \; ;$$

**Declare integer variable `sid`:**

```
int sid; /* student ID */
```

- There are integer types of different size, *e.g.*, `long` and `short`.

  The type `short` (or `short int`) typically is 16 bits wide: $-32768 \ldots 32767$. Type `int` corresponds to the word size of the machine (today: 32 bits). Type `long` is at least 32 bits wide. Integer types may be modified with the `unsigned` prefix, *e.g.*, `unsigned short` has the range $0 \ldots 65535$.

# A Mini C Recap (3)

- The type `char` is used to represent characters (today, effectively an 8 bit value).

  The type `unsigned char` is guaranteed to provide the value range 0 . . . 255.

**Declaration of an array of characters `a[0]..a[19]`:**

```
char a[20];
```

- In C, **strings** are represented as such character arrays. A null character (`'\0'`) is used to mark the string end.

  String `"xyz"` is represented as `a[0] = 'x'`, `a[1] = 'y'`, `a[2] = 'z'`, `a[3] = '\0'`.

# A Mini C Recap (4)

- **Variable assignment:**

```
sid = 101;
```

- **Conditional statement:**

```
if (retcode == 0)   /* == is equality */
    printf ("Ok!\n");
else
    printf ("Error!"\n);
```

- C has no **Boolean** type but uses the type `int` instead to represent truth values: 0 represents *false*, anything else indicates *true*.

# A Mini C Recap (5)

- **Print an integer** (`printf`: print formatted):

  ```
  printf ("The current student ID is: %d\n", sid);
  ```

  First argument is a format string that determines number and type of further arguments. Format specifiers like `%d` (print `int` in decimal notation) consume further elements in order.

- **Read an integer** (`%d`: in decimal notation):

  ```
  ok = scanf ("%d", &sid);
  ```

  `&sid` denotes a pointer to variable `sid`. Since C knows *call by value* only, references are implemented in terms of pointers. Library function `scanf` returns the number of converted format elements (here `1` if no problems occur). Trailing newlines are not read.

# A Mini C Recap (6)

- Suppose that variable name is declared as

```
char name[21];
```

- In C, variable assignment via = does *not* work for strings (arrays), instead use the library function strncpy (declared in header file "string.h"):

```
strncpy (name, "Smith", 21);
```

  The C philosophy is that = should correspond to a single machine instruction. In C, the programmer is responsible to avoid string/buffer overruns during copying. This is *the* source of nasty bugs and security holes. strncpy never copies more characters than specified in the last argument.

# A Mini C Recap (7)

- To read an entire line of characters (user input) from the terminal, use

```
fgets (name, 21, stdin);
name[(strlen (name) - 1] = '\0';  /* overwrite '\n' */
```

  The second argument of `fgets` specifies the maximum number of characters read (minus 1). A trailing newline is stored and a `'\0'` is placed to mark the string end. `stdin` denotes the terminal (if not redirected). Library function `strlen` does the obvious.

# Host Variables (1)

- If SQL is embedded in C, then C is the **host language.** C variables which are to be used in SQL statements are referred to as **host variables.**
- Note that SQL uses a **type system** which is quite different from the C type system.

  For example, C has no type `DATE` and no C type corresponds to `NUMERIC(30)`.

- In addition, C has no notion of null values.
- Even if there is a natural correspondence between an SQL type and a C type, the value **storage format** might be considerable different.

  Think of endianness, for example.

# Host Variables (2)

- Oracle, for example, stores variable length strings (SQL type `VARCHAR(`*n*`)`) as a pair ⟨length information, array of characters⟩. C uses `'\0'`-terminated `char` arrays.

- Oracle stores numbers with mantissa and exponent (scientific notation) with the mantissa represented in BCD (4 bits/digit). C uses a binary representation.

- **Type/storage format conversion** has to take place whenever data values are passed to/from the DBMS.

  ▷ The **precompiler** can help quite a lot here, but some work remains for the programmer.

# Host Variables (3)

- The DBMS maintains a translation table between *internal types* and *external types* (host language types) and possible conversions between these.
- In Embedded SQL, many conversion happen **automatically**, *e.g.*, `NUMERIC(`$p$`)`, $p < 10$, into the C type `int` (32 bits).

  Also, `NUMERIC(`$p$`,`$s$`)` may be mapped to `double`, although precision may be lost.

- For `VARCHAR(`$n$`)`, however, the program either prepares C a `struct` that corresponds to the DBMS storage format or explicitly states that a conversion to `'\0'`-terminated C strings is to be done.

# Host Variables (4)

- The precompiler must be able to extract and understand the **declaration of the host variables.**
- Usually, the Embedded SQL precompiler does not fully "understand" the C syntax (with all its oddities).

**Correct C declaration syntax?**

```
unsigned short int        short int unsigned
unsigned int short        int unsigned short
short unsigned int        int short unsigned
```

- Thus, variable declarations relevant to the precompiler must be enclosed in `EXEC SQL BEGIN DECLARE SECTION` and `EXEC SQL END DECLARE SECTION`.

# Host Variables (5)

- The declaration section might look as follows:

```
EXEC SQL BEGIN DECLARE SECTION;
   int     sid;                /* student ID */
   VARCHAR first[20];          /* student first name */
   char    last[21];           /* student last name */
   EXEC SQL VAR last IS STRING(20);
EXEC SQL END DECLARE SECTION;
```

  ▷ `sid` is a standard C integer variable, the DBMS will automatically convert to and from `NUMERIC(`*p*`)`.

  ▷ `last` is a standard C character array (string).

    The conversion to/from this format is explicitly requested (note: due to `'\0'`-termination, max. string length is 20).

# Host Variables (6)

- `VARCHAR first[20]` is *not* a standard C data type.
  - ▷ The precompiler translates this declaration into

```
struct { unsigned short len;
         unsigned char  arr[20];
} first;
```

  which is a C type whose **memory layout** exactly matches the DBMS-internal `VARCHAR(20)` representation.

  - ▷ The conversion from a standard C char array `s` could be done as follows:

```
first.len = MIN (strlen (s), 20);
strncpy (first.arr, s, 20);
```

# Host Variables (7)

- The variables in the `DECLARE SECTION` may be global as well as local.
- The types of these variables must be such that the precompiler can interpret them.

  Especially, non-standard user-defined types (`typedef`) are not allowed here.

- In SQL statements, host variables are prefixed with a colon (`:`) and may thus have the same name as table columns.

# Error Checking (1)

- Similar coding guidelines apply whenever the program interacts with the operating system or with the DBMS: **after every interaction check for possible error conditions.**
- One possibility to do this is to declare a special variable

```
char SQLSTATE[6];
```

- As required by the SQL-92 standard, if this variable is declared, the DBMS stores a **return code** whenever an SQL statement has been executed.

  `SQLSTATE` contains error class and subclass codes. First two characters `"00"` indicate "*okay*" and, for example, `"02"` indicates "*no more tuples to be returned*".

# Error Checking (2)

- An alternative is the SQL **communication area** `sqlca` (a C `struct`) which can be declared via

```
EXEC SQL INCLUDE SQLCA;
```

  ▷ Component `sqlca.sqlcode` then contains the return code, for example, 0 for "*okay*", 1403: "*no more tuples*".

  ▷ Component `sqlca.sqlerrm.sqlerrmc` contains the error message text, `sqlca.sqlerrm.sqlerrml` contains its length:

```
printf ("%.*s\n", sqlca.sqlerrm.sqlerrml,
                  sqlca.sqlerrm.sqlerrmc);
```

# Error Checking (3)

- The precompiler supports the programmer in enforcing a consistent error checking discipline:

  EXEC SQL WHENEVER SQLERROR GOTO ⟨*Label*⟩;

  or

  EXEC SQL WHENEVER SQLERROR DO ⟨*Stmt*⟩;

  ▷ The C statement ⟨*Stmt*⟩ typically is a C procedure call to an error handling routine (any C statement is allowed).

- Such WHENEVER SQLERROR declarations may be cancelled via

  EXEC SQL WHENEVER SQLERROR CONTINUE;

# Example Database (recap)

**STUDENTS**

| SID | FIRST | LAST | EMAIL |
|---|---|---|---|
| 101 | Ann | Smith | ... |
| 102 | Michael | Jones | (null) |
| 103 | Richard | Turner | ... |
| 104 | Maria | Brown | ... |

**EXERCISES**

| CAT | ENO | TOPIC | MAXPT |
|---|---|---|---|
| H | 1 | Rel.Alg. | 10 |
| H | 2 | SQL | 10 |
| M | 1 | SQL | 14 |

**RESULTS**

| SID | CAT | ENO | POINTS |
|---|---|---|---|
| 101 | H | 1 | 10 |
| 101 | H | 2 | 8 |
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| 102 | H | 2 | 9 |
| 102 | M | 1 | 10 |
| 103 | H | 1 | 5 |
| 103 | M | 1 | 7 |

# Example (1)

```
/* program to enter a new exercise */

#include <stdio.h>
EXEC SQL INCLUDE SQLCA;   /* SQL communication area */
EXEC SQL BEGIN DECLARE SECTION;
  VARCHAR user[128];      /* DB user name */
  VARCHAR pw[32];         /* password */
  VARCHAR cat[1];
  int     eno;
  int     points;
  VARCHAR topic[42];
EXEC SQL END DECLARE SECTION;
...
```

# Example (2)

```
...
/* called in case of (non-SQL) errors */
void fail (const char msg[])
{
    /* print error message */
    fprintf (stderr, "Error: %s\n", msg);

    /* close DB connection */
    EXEC SQL ROLLBACK WORK RELEASE;

    /* terminate */
    exit (1);
}
...
```

# Example (3)

```
...
int main (void)
{
    char line[80];

    /* catch SQL errors */
    EXEC SQL WHENEVER SQLERROR GOTO error;

    /* log into DBMS */
    strncpy (user.arr, "grust", 128);
    user.len = strlen (user.arr);
    strncpy (pw.arr, "******", 32);
    pw.len = strlen (pw.arr);
    EXEC SQL CONNECT :user IDENTIFIED BY :pw;
...
```

# Example (4)

```
...
/* read CAT, ENO of new exercise */
printf ("Enter data of new exercise:\n");
printf ("Category (H,M,F) and number (e.g., M6): ");
fgets (line, 80, stdin);
if (line[0] != 'H' && line[0] != 'M' &&
    line[0] != 'F')
    fail ("Invalid category");
cat.arr[0] = line[0];
cat.len    = 1;
if (sscanf (line + 1, "%d", &eno) != 1)
    fail ("Invalid number");
...
```

# Example (5)

```
...
/* read TOPIC of new exercise */
printf ("Topic of the exercise: ");
fgets ((char *) topic.arr, 42, stdin);
topic.len = strlen (topic.arr) - 1;  /* remove '\n' */

/* read MAXPT for new exercise */
printf ("Maximum number of points: ");
fgets (line, 80, stdin);
if (sscanf (line, "%d", &points) != -1)
    fail ("Invalid number");
...
```

# Example (6)

```
...
/* show read exercise data */
printf ("%c %d [%s]: %d points\n",
        cat.arr[0], eno, title.arr, maxpt);

/* execute SQL INSERT statement */
EXEC SQL INSERT INTO
         EXERCISES (CAT, ENO, TOPIC, MAXPT)
         VALUES (:cat, :eno, :topic, :points);

/* end transaction, log off */
EXEC SQL COMMIT WORK RELEASE;
...
```

# Example (7)

```
...
/* terminate program (success) */
return 0;

/* jumped to in case of SQL errors */
error:
    EXEC SQL WHENEVER SQLERROR CONTINUE;
    fprintf (stderr, "DBMS Error: %.*s\n",
             sqlca.sqlerrm.sqlerrml,
             sqlca.sqlerrm.sqlerrmc);
    EXEC SQL ROLLBACK WORK RELEASE;
    exit (EXIT_FAILURE);
...
```

# Simple Queries (1)

- The above example shows how to pass values **from the program into the DBMS** (*e.g.*, for `INSERT`).
- Now the task is to extract values **from the database into host variables.**
- If is it guaranteed that a query can **return at most one tuple,** the following may be used:

**`SELECT INTO`: read student tuple specified by `sid`.**

```
EXEC SQL SELECT  FIRST, LAST
         INTO    :first, :last
         FROM    STUDENTS
         WHERE   SID = :sid
```

# Simple Queries (2)

- It is an error if the `SELECT INTO` yields more than one row.

**`SELECT INTO` using a "soft key".**

```
EXEC SQL SELECT  SID
         INTO    :sid
         FROM    STUDENTS
         WHERE   FIRST = :first
         AND     LAST = :last
```

▷ The DBMS will execute the statement without warning as long as there is at most one `SID` returned. A result of two or more tuples will raise an SQL error.

# Simple Queries (3)

- After issuing a SELECT statement, the program is expected to check whether a row was found at all. (An empty result is no error, but then the INTO host variables are **undefined.**)

①
```
if (sqlca.sqlcode == 0)
    ... process returned tuple data ...
```

②
```
EXEC SQL WHENEVER NOT FOUND GOTO empty;
EXEC SQL SELECT ... INTO ...;
    ... process returned tuple data ...
empty:
    ... no tuple returned ...
```

# General Queries (1)

- In general, a SQL query will yield a table, *i.e.*, more than a single tuple. Since C lacks a type equivalent to the relational table concept, **the query result must be read tuple-by-tuple** in a loop.
  - ▷ A DBMS-maintained **cursor** points into the table, marking the next tuple to be read.

**Declaring a SQL cursor:**

```
EXEC SQL DECLARE c1 CURSOR FOR
         SELECT  CAT, ENO, POINTS
         FROM    RESULTS
         WHERE   SID = :sid
```

  - ▷ Note: at this point, the query is not yet executed and the value of `:sid` is immaterial.

# General Queries (2)

- The next step is to **open the cursor:**

```
EXEC SQL OPEN c1;
```

  - ▷ This initiates **query evaluation** and the then current value of the query parameter `:sid` is used.
  - ▷ The program may **close** the cursor and **reopen** it again with a different value of `:sid`.

# General Queries (3)

- The query result may then be read **one tuple at a time** into host variables

FETCH

```
EXEC SQL WHENEVER NOT FOUND GOTO done;
while (1) {   /* while (forever) */
    EXEC SQL FETCH c1 INTO :cat, :eno, :points;
    ... process result tuple data ...
}
done:
    ... all tuples processed ...
```

# General Queries (4)

- Other variants:

```
EXEC SQL WHENEVER NOT FOUND DO break;
while (1) {   /* while (forever) */
    EXEC SQL FETCH c1 INTO :cat, :eno, :points;
    ... process result tuple data ...
}
... all tuples processed ...
```

①

```
EXEC SQL FETCH c1 INTO :cat, :eno, :points;
while (sqlca.sqlcode == 0) {
    ... process result tuple data ...
    EXEC SQL FETCH c1 INTO :cat, :eno, :points;
}
... all tuples processed ...
```

②

# General Queries (5)

- The last step is to **close** the cursor:

```
EXEC SQL CLOSE c1;
```

  ▷ Open cursors allocate memory and, more importantly, **retain locks on the data** which can get in the way of other concurrent users.

# Positioned Updates/Deletes

- A program can refer to the last tuple `FETCH`ed in `UPDATE` and `DELETE` commands:

```
EXEC SQL UPDATE RESULTS SET POINTS = :points
         WHERE CURRENT OF c1;
```

  ▷ This is helpful if the new attribute value (here: `points`) is computed by the C program (*e.g.*, read from the terminal) and not by an SQL query.

# Null Values (1)

- If a column value in a query result can possibly yield NULL, the program is required to declare two host variables: one variable will receive the **data value** (if any), the other will **indicate whether the value is NULL.**
  - ▷ Such variables are called **indicator variables** (normally of C type `short`).
  - ▷ The indicator variable will be set ot -1 if NULL was returned by the query (otherwise set to 0).

# Null Values (2)

**Cursor declared to fetch student data:**

```
EXEC SQL DECLARE stud CURSOR FOR
         SELECT  FIRST, LAST, EMAIL
         FROM    STUDENTS;
```

- An indicator variable may be attached to any variable in an SQL statment, *e.g.*:

```
EXEC SQL FETCH stud INTO :first, :last,
                         :email INDICATOR :null;
```

- It is an error to `FETCH` a `NULL` value without indicator variables set up (this includes the result of aggregation fuctions!).
- Indicator variables may also be used during `INSERT` to insert `NULL` column values into the DB.

# Dynamic SQL (1)

- Up to here, table and column names were already known at program **compile time.** At runtime, the current value of host variables is inserted into these **static SQL statements.**
  - ▷ In the case of static SQL, the precompiler checks the existence of tables and columns (via lookups in the DBMS **data dictionary**).
  - ▷ In some systems (*e.g.*, IBM DB2), static queries are already **optimized** at compile time and the resulting query evaluation plans are stored in the database.

# Dynamic SQL (2)

- In contrast, it is possible to compose strings containing SQL statements at **runtime** and then ship the string to the DBMS for execution.

  This is exactly how the the **SQL console** application is built.

- If the SQL command is *not* a query (whose result needs to be consumed), dynamic execution works as follows:

```
EXEC SQL EXECUTE IMMEDIATE :sql_cmd;
```

# Dynamic SQL (3)

- A problem of the dynamic SQL approach is that the command has to compiled (into a query evaluation plan) every time it is submitted to the DBMS. Query optimization may be costly.

  The DBMS may cache recent query evaluation plans. These may be reused if a query is re-issued (possibly with different host variable values).

- If an SQL statement is executed several times with different host variables values, the DBMS can be explicitly asked to **precompile** ("prepare") the query using `EXEC SQL PREPARE` and then calling

  `EXECUTE ... USING` ⟨*Variables*⟩`;`

# Dynamic SQL (4)

- Note that, for dynamic queries, the **result schema** (tuple format) is not known until runtime.

  This rules out the use a construct like `SELECT INTO`.

- In this case, an SQL **descriptor area** (`SQLDA`) is used to obtain information about the result columns (column names, types)..

  ▷ The SQL `DESCRIBE` statement stores the number, names, and datatypes of the result columns of a dynamic query in the `SQLDA`.

  The `SQLDA` also contains slots for pointers to variables which will contain the retrieved data values (the `FETCH` host variables).

# Dynamic SQL (5)

- The sequence of steps:

  ① Allocate an `SQLDA` (SQL-92: `ALLOCATE DESCRIPTOR`).

  ② Compose the query string.

  ③ Compile the query using `PREPARE`.

  ④ Use `OPEN` to execute the query and open a result cursor.

  ⑤ Fill the `SQLDA` using `DESCRIBE`.

  ⑥ Allocate variables for the query result (place pointers in `SQLDA`).

  ⑦ Call `FETCH` repeatedly to read the result tuples.