How to write SQL injection proof PL/SQL

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ABSTRACT

An internet search for "SQL injection" gets about 4 million hits. The topic excites interest and superstitious fear. This whitepaper dymystifies the topic and explains a straightforward approach to writing database PL/SQL programs that provably guarantees their immunity to SQL injection.

Only when a PL/SQL subprogram executes SQL that it creates at run time is there a risk of SQL injection; and you'll see that it's easier than you might think to freeze the SQL at PL/SQL compile time. Then you'll understand that you need the rules which prevent the risk only for the rare scenarios that do require run-time-created SQL. It turns out that these rules are simple to state and easy to follow.

INTRODUCTION

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At the time of writing, An internet search for "SQL injection" gets about 4 million hits. The topic excites interest and superstitious fear. This whitepaper dymystifies the topic and explains a straightforward approach to writing database PL/SQL programs that provably guarantees their immunity to SQL injection.

The scope of the discussion is strictly limited to PL/SQL units that are stored in the database. Similar principles apply in the discussion of languages, such as C or Java, used to implement client-side programs, but it is very much harder to control access to such programs. It is even harder to ensure that access to the database is made *only* using such client-side programs.

In order best to understand the discussion, the reader must have sound understanding of the various ways that SQL may be executed from a database PL/SQL unit. The whitepaper *Doing SQL from PL/SQL: Best and Worst Practices*[1], addresses this topic in detail. Its study is, therefore, recommended as a prerequisite for the study of this whitepaper. In particular, the *Doing SQL from PL/SQL* whitepaper argues for the strategy that bans direct SQL access to the database and exposes it to the client *only* via a strictly minimal PL/SQL API[2]. If this strategy is adopted, then the proofing against SQL injection is the sole responsibility of database PL/SQL; and a sufficient solution is possible in this regime.

Of course, one cannot avoid what one cannot define — and so we start with the section *"Definition of SQL injection"* on page 4. We use this definition, in the section *"How can SQL injection happen?"* on page 13, to examine some famous examples of code that is vulnerable. We also examine some counter-examples in order to prove our definition of SQL injection.

The discussion in these two sections leads to the understanding that SQL injection is possible only when a PL/SQL subprogram executes a SQL statement whose text it has created at run time using what, here, we can loosely call unchecked user input[3]. Clearly, then, the best way to avoid SQL injection is to execute only SQL statements whose text derives entirely from the source code of the PL/SQL program that executes it.

However, when the watertight approach will not meet the requirements, it is, after all, necessary to handle user input — and to do so safely. A careful study of this topic is presented in the section *"Ensuring the safety of a SQL literal or a simple SQL name"* on page 20.

The material in these first three sections supports the rationale for, and the understanding of, what follows in the section *"Rules for cost-effective, guaranteed prevention of SQL injection"* on page 29. Indeed, if this paper makes an original contribution, it is in the development of the conceptual framework, and the associated terms of art, that then allow the rules to be stated compactly and

[1] *Doing SQL from PL/SQL: Best and Worst Practices* is published on the Oracle Technology Network website. You can find it easily with Internet search.

[2] This is discussed in the section *"Expose the database to clients only via a PL/SQL API"* on page 29.

[3] This notion will be formally defined in the section *"Dynamic text"* on page 36.

precisely. The new terms of art introduced and defined at appropriate points in the discussion. But it proved very hard to find an order of exposition that didn't rely on forward reference to terms not yet defined. Therefore, *Appendix A: Definitions of new terms of art introduced by this paper* on page 52 lists these terms, defines each briefly, and cross-references to the section of the paper where it is introduced.

Next, the section *"Scenarios"* on page 40 discusses some requirements scenarios against which the concepts and the rules developed in the preceding sections can be tested. They seem (to the beginner) to require the use of SQL statements built from user input. However, such scenarios are very much fewer than many programmers think; many can be implemented satisfactorily using SQL statements whose text derives entirely from the source code. Several such scenarios are illustrated.

This paper focuses unashamedly on writing injection-proof *de novo* PL/SQL code. Finally, in the section *"Analysis and hardening of extant code"* on page 49, it turns briefly to the topic of extant, and possibly vulnerable, code.

The rules that this paper explains, and insists on, are reproduced[4] for quick reference, in *Appendix B: Summary of SQL injection prevention rules* on page 56.

They guarantee proof against injection and yet are surprisingly easy to follow. Moreover, as a bonus, they ensure semantic correctness in edge cases that programmers often overlook.

[4] This paper was prepared using Adobe Framemaker 8.0. Its cross-reference feature allows the text of a source paragraph to be included by reference at the destination. The reader can be certain, therefore, that the wording of each rule in the quick-reference summary is identical to the wording where is stated. (Sadly, the mechanism does not preserve font nuances.)

DEFINITION OF SQL INJECTION

The definition of SQL injection requires an informal understanding of the syntax of the SQL language and of how it is parsed.

Consider the two putative SQL statements shown in *Code_1*

```
-- Code_1
select c1 from t where c2 = 'Smith'
```

and *Code_2*.

```
-- Code_2
select c1 from t wear c2 = 'Smith'
```

It is clear, without connecting to an Oracle Database, that *Code_1* is syntactically correct but *Code_2* has a syntax error[5]. Consider next the syntactically correct SQL statements shown in *Code_3*

```
-- Code_3
select a1 from r where a2 = 'Jones'
```

and *Code_4*.

```
-- Code_4
select b1 from s where b2 = :1
```

The token *:1* is a placeholder. If the table *s*, with columns *b1* and *b2*, is accessible, then *Code_4* will parse without error[6].

Introducing a new notion: SQL syntax template

The SQL statements in *Code_1*, *Code_3*, and *Code_4* are different instances of the same *SQL syntax template*; *Template_1* shows it[7].

```
-- Template_1
```

select &&1 from &&2 where &&3 = &4

The SQL syntax template notion and the notation used in *Template_1* are invented for the purposes of this whitepaper.

The notion belongs in the domain of discourse of the Design Specification document. This document would list, with the notation used in *Template_1*, the SQL syntax template or templates that are prescribed for a particular purpose. Then the implementer would ensure, using the programming techniques that this paper explains, that only those SQL statements that were instances of the

[5] The attempt to execute *Code_2* will always cause *ORA-00933: SQL command not properly ended* while the attempt to execute *Code_1* might cause *ORA-00942: table or view does not exist. ORA-00933* is a syntax error and *ORA-00942* is a semantic error. Of course, if table *t(c1 varchar2(30), c2 varchar2(30))* is accessible to the current user, then *Code_1* will be parsed without error.

[6] This is confirmed by executing this PL/SQL statement:

```
DBMS_Sql.Parse(Cur, 'select b1 from s where b2 = :1', DBMS_Sql.Native);
```

in an appropriately written PL/SQL anonymous block.

[7] To emphasize the difference between an ordinary SQL statement and a SQL syntax template, the latter will be rendered using a proportionally spaced italic font.

prescribed SQL syntax templates could be issued at the call site that implements that part of the design.

The & syntax device denotes what we will call a *value placeholder*; and the && syntax device[8] denotes what we will call a *simple SQL name placeholder*. Notice that the value placeholder in a SQL syntax template is not the same notion as a regular placeholder in an ordinary SQL statement. A value placeholder in a SQL syntax template stands for *either* a well-formed SQL literal *or* a regular placeholder in a SQL statement.

A particular SQL syntax template is a specific sequence of intermixed specific keywords, specific operators, simple SQL name placeholders, and value placeholders. The simple SQL name placeholders, and value placeholders imply the possibility of various specializations of the template and so we extend the SQL syntax template notion to include examples where concrete identifiers, literals, and regular placeholders are in use. This is illustrated by the SQL syntax templates shown in *Template_2*; each is a specialization of the most generic form shown in *Template_1*.

```
-- Template_2
select c1 from &&1 where c2 = &1

select &&1 from t where &&2 = 99

select c1 from &&1 where c2 = :1

select c1 from t where c2 = :1
```

Notice that the only freedoms available when composing a particular SQL statement as an instance of a particular SQL syntax template are the textual substitutions[9] of value placeholders and simple SQL name placeholders.

[8] Don't confuse the use of & here with its use in the SQL*Plus scripting language. The choice of & was, however, made in *homage* to SQL*Plus's use. In both cases, the syntax implies early textual substitution before the "real" processing happens.

[9] Notice that by saying "textual substitution" we don't mean that the SQL syntax template is represented as such by a value in PL/SQL source code — so that substitution is done programatically with, for example, *Replace()*. Rather, we mean that a human who reads an example of an actual SQL statement that the PL/SQL program uses at run time will be able to see that it is an instantiation of the SQL syntax template that the Design Specification document prescribes, achieved by the textual substitution we discuss.

With respect to the auditing of this substitution, we consider whitespace to be insignificant. The Design Specification document can lay out a SQL syntax template as it pleases. And the program is free to use a different layout. Ordinary comments of both styles are just a special case of whitespace. However, when the Design Specification document prescribes the special comment that starts with */+ and ends with /*, and that expresses a SQL hint, this must be reproduced faithfully in the actual SQL statements that the program instantiates for this SQL syntax template. Just as is the case for, for example, a keyword, a SQL hint is definitely not a candidate for replacement at instantiation time.

- A value placeholder may be replaced with a regular placeholder[10] or a well-formed SQL literal whose datatype is either *text*, *datetime*, or *numeric*, according to the specified syntax rules[11].
- A simple SQL name placeholder may be replaced only with a simple SQL name[12].
- It is not allowed to substitute any other elements.

In particular, and *by definition* of the notion that this paper introduces, the . and @ characters that are used to form qualified SQL names must be an explicit part of the SQL syntax template; a qualified SQL name may not be used to replace a simple SQL name placeholder[13].

Distinguishing between compile-time-fixed SQL statement text and run-time-created SQL statement text

We define the term *compile-time-fixed SQL statement text* to mean the text of a SQL statement that cannot change at run time and that can be confidently determined by reading the source code. More precisely, it is the text of a SQL statement that is a PL/SQL static *varchar2* expression[14]. The value of a PL/SQL static *varchar2* expression cannot change at run time and could be pre-computed at compile time.

The SQL statement text for embedded SQL is composed by the PL/SQL compiler and cannot change at run time. Therefore, embedded SQL definitely executes only compile-time-fixed SQL statement text[15].

However, it can easily be arranged that any of PL/SQL's methods for executing dynamic SQL will, at a particular call site, execute only compile-time-fixed SQL

[10] The freedom to replace a value placeholder with either a regular placeholder or a SQL literal is only of formal interest; it helps to clarify thought. It is very unlikely indeed that a real program would be specified to implement the replacement of value placeholder with a regular placeholder at run time. Such a design would give cause for concern.

[11] These rules are specified in the SQL Language Reference book.

[12] It is simplest to define a simple SQL name as that which the *DBMS_Assert.Simple_Sql_Name()* function will return without raising an exception. Examples are *SCOTT* (which will be treated the same as, for example, *Scott*) and "*My Table*". *SCOTT* is an example of what this paper calls a common SQL name; and *My Table* is an example of what it calls an exotic SQL name. These notions are discussed in the section *"Example 2: user-supplied table name"* on page 15.

DBMS_Assert.Simple_Sql_Name() is discussed in the section *"Ensuring the safety of a simple SQL name"* on page 26.

[13] We shall defend this strict approach in the section *"Ensuring the safety of a simple SQL name"* on page 26.

[14] The term *PL/SQL static varchar2* expression is defined in the PL/SQL Language Reference book. This also defines a *PL/SQL static varchar2* constant as a variable that is declared using the *constant* keyword and that is initialized using a PL/SQL static *varchar2* expression. The definition is recursive: a *PL/SQL static varchar2* constant can be used in the composition of a PL/SQL static *varchar2* expression. We shall return to this notion in the section *"Static text"* on page 35.

statement text; it is necessary only to establish the statement text as a PL/SQL static *varchar2* expression.

We define the term *run-time-created SQL statement text* to mean the text of a SQL statement that is not compile-time-fixed SQL statement text.

As we shall see, it is the distinction between compile-time-fixed SQL statement text and run-time-created SQL statement text that is significant in the discussion of SQL injection. It is more important to focus on the property of the SQL text than on the method used for its execution. To (we hope!) avoid confusion, the execution methods will be referred to as *embedded SQL*[16], *native dynamic SQL* and *the DBMS_Sql API*[17].

Embedded SQL always executes compile-time-fixed SQL statement text. Dynamic SQL may execute compile-time-fixed SQL statement text or may execute run-time-created SQL statement text.

Distinguishing between a static SQL syntax template and a dynamic SQL syntax template

Sometimes a PL/SQL subprogram executes a SQL statement whose SQL syntax template is frozen at compile time. But sometimes the SQL statement must be composed at run time in such a way that the set of SQL syntax templates to which these must conform is too large be written down explicitly in the Design Specification document. This section addresses this important distinction.

Definition of static SQL syntax template

Consider the definer's rights[18] function *f()* as shown in *Code_5*.

```
-- Code_5
function f(PK in t.PK%type, Wait_Time in pls_integer)
  return t.c1%type
  authid Definer
is
  c1 t.c1%type;
  Stmt constant varchar2(32767) :=
       'select c1 from t where PK = :b for update wait '
    || Wait_Time;
begin
  execute immediate Stmt into c1 using PK;
  return c1;
end f;
```

[15] The fact that this text is characterized in a different domain of discourse (the text of the compiled PL/SQL unit) than text which is a *PL/SQL static varchar2* expression (here, the domain is the source text of the unit) is unimportant with respect to establishing the notion of compile-time-fixed SQL statement text.

[16] We prefer the term *embedded SQL* to the more familiar *static SQL*. As we shall see, *dynamic SQL* may be used to execute *static text*. The term *static* is heavily overloaded.

[17] Procedural APIs other than the *DBMS_Sql* API support the execution of complete SQL statements of restricted kinds or accept fragments of SQL text and concatenate these unchecked to compose and then execute run-time-created SQL statement text. These are listed in *Appendix C: Additional Oracle-supplied subprograms that implement dynamic SQL* on page 59. The rules for using these safely are identical to those for using native dynamic SQL and the *DBMS_Sql* API safely. Therefore, no further mention will be made of these other APIs in the body of this paper.

Its purpose is to return the value of column *c1* from the table *t* for a particular value of the primary key, *PK*, and to lock the row for future update. The function should not fail if another session presently has locked the row — and nor should it wait indefinitely in such a case. Rather, it should allow the caller to specify the maximum wait time. As it happens, SQL syntax does not allow a placeholder for the value that determines the timeout period[19].

Manual inspection is sufficient to show us that, while *f()* does not execute a compile-time-fixed SQL statement text, it *does* execute a SQL statement whose SQL syntax template is frozen at compile time as that shown in *Template_3*[20].

```
-- Template_3
select c1 from t where PK = :b for update wait &1
```

We shall call such a SQL syntax template a *static SQL syntax template*.

Notice that, as a consequence of the definitions, compile-time-fixed SQL statement text always conforms to a static SQL syntax template. But run-time-created SQL statement text may, or may not, conform to a static SQL syntax template.

Definition of dynamic SQL syntax template

Now consider the procedure *x.p()* as shown in *Code_6*.

```
-- Code_6
package x is
  type cw is varray(20) of boolean;
  procedure p(PK in "My Table".PK%type, Wanted in cw);
end x;
```

Its purpose is to report the values of an arbitrary subset of all the columns in the table with the exotic SQL name *My Table*[21] for a particular value of the primary key, *PK*. The author of code that will call *x.p()* knows the purpose of *My Table*, and the names and significance of all its columns. In particular, he knows the order in which these are listed in its external documentation. The *n*th element of the *in* formal parameter *Wanted* determines if the *n*th column of *My Table* is to be included in the report.

Let's say that Functional Specification document requires that the order of the columns in the report be the same as that in the external documentation of the

[18] A belief seems to have arisen that an invoker's rights unit is safe and that a definer's rights unit is risky. This viewpoint is naïve. The proper choice depends on the purpose of the subprogram. Here, the purpose of *f()* is to select from a specific table using the privileges of the table's owner. It's quite likely that *Execute* on *f()* will be granted to a user other than its owner, who has no direct privileges on the table, specifically to give the grantee tightly controlled access to the table. Invoker's rights, on the other hand, is appropriate when the purpose of the subprogram is to perform a parameterized, but powerful, operation using the privileges of the user that invokes it. A risk would, of course, arise when such a subprogram is definer's rights and is owner by, for example, *Sys*!

[19] This code is used to make a teaching point. It would be an unacceptable design in a real world application. Each executed *select* statement would probably be textually different from any that had been seen before; and this would cause a hard parse explosion. A compromise would be to let the caller chose between, say, four values for the wait time: zero, short, long, and infinite. The corresponding formal parameter would express the choice. And the *select* statement would be build using one of four PL/SQL static *varchar2* expressions for the wait time.

table. If the table has *N* columns, then the number of distinct *select* lists is therefore the sum of the number of ways of choosing 1 item from *N*, then 2 items from *N*, through to *N-1* items from *N*, and finally choosing all the items. This[22] is famously 2^N*-1*. For 3 columns, there are 7 distinct *select* lists, for 10 columns there are 1023 distinct *select* lists, and for 20 columns, there are just over *one million* distinct *select* lists. The number grows exponentially[23] with the number of columns.

Procedure *x.p()* models the implementation of a very common requirement: the customizable report[24]. And an underlying table with many more than 20 columns is in no way unusual. It is therefore not feasible to provide each possible statement as compile-time-fixed SQL statement text. Rather, the required SQL statement must be composed programmatically.

The implementation of *p()* in the body of package *x* is shown in *Code_7*. The *Col_List()* inner function composes the *select* list. In this design, *column list* is perhaps not the best mnemonic; as *Code_8* shows, the *select* list is in fact a single item built by concatenating the right-blank-padded values of the chosen columns. This approach allows the simple use of *execute immediate* rather than the

[20] This relies on the fact that the intended timeout value is represented by a *pls_integer* and that when a value of this type is concatenated to a *varchar2*, then it is implicitly converted to that datatype using the single argument overload of *To_Char()*. The result of this conversion is guaranteed to be well-formed SQL *numeric* literal. Because it's an integral quantity, there's never decimal separator. The second actual (that determines the format model) cannot be influenced through the environment; its default requests a decimal separator but no group separator. And the third actual, that determines the characters used for the decimal separator and the group separator, and that can be set using this statement:

```
alter session set NLS_Numeric_Characters
```

therefore has no effect. This is a subtle but crucial point. Had the datatype of the *in* formal parameter *Wait_Time* been *number*, then the SQL syntax template of *Stmt* would have been unpredictable. We shall return to it in the section *"Ensuring the safety of a SQL numeric literal"* on page 24.

[21] We use the exotic SQL name *My Table* just as a subliminal reminder that such names can occur. We need do no more in the code discussed in this section than surround its use, as is shown, with double quote characters. The uses occur only in ordinary PL/SQL source code (in the declaration of the formal parameter *PK*) and in a PL/SQL static *varchar2* expression. We shall return to this point in the section *"Query by example form"* on page 42.

[22] The internet searching required to confirm this is left as an exercise for the reader.

[23] The expression *to grow exponentially* is often used metaphorically; here, it is used literally and correctly!

more complicated use of the *DBMS_Sql* API for a *select* list whose composition is unknown until run time.

```
-- Code_7
procedure p(PK in "My Table".PK%type, Wanted in cw) is

  function Col_List return varchar2;

  Stmt constant varchar2(32767) :=
       'select '
    || Col_List()
    || ' Report from "My Table" where PK = :b';

  Report varchar2(32767);

  function Col_List return varchar2 is ... end Col_List;

begin
  execute immediate Stmt into Report using PK;
  DBMS_Output.Put_Line(Report);
end p;
```

Notice that *Stmt* is declared using the *constant* keyword and that this means that it must be initialized as part of the declaration. This is not essential, but it is a highly recommended approach.

When composing a SQL statement programmatically, help the code reviewer by declaring variables used for intermediate results as *constant*.

Rule_1

When it is necessary to compose a SQL statement programmatically, the code usually needs, or at least benefits from the use of, variables for intermediate results. Aim to declare these as *constant*, assigning the values in the declarations. This sometimes requires the use of nested block-statements or forward-declared functions. This technique makes code review easier because the reader can be sure that the value of a variable cannot change between its initial assignment and its use.

For completeness, the implementation of the *Col_List()* function is shown in *Code_8*.

```
-- Code_8
function Col_List return varchar2 is
  type cn is varray(20) of varchar2(30);
  Col_Names constant cn :=
    cn('c1', 'c2', 'c3', 'c4', ..., 'c20');
  Seen_One boolean := false;
  List varchar2(32767);
begin
  for j in 1..Wanted.Count() loop
    if Wanted(j) then
      List :=
           List
        || case Seen_One when true then '||'
                         else           ''
           end
        || 'Rpad('||Col_Names(j)||', 10)';
      Seen_One := true;
    end if;
  end loop;
  return List;
end Col_List;
```

24. Another common requirement is to let the user specify comparison criteria for any subset of the columns (the so-called query-by-example paradigm). We shall return to this in the section *"Don't confuse the need to use a dynamic SQL syntax template with the need for dynamic text"* on page 34 and then in the section *"Query by example form"* on page 42.

Notice that the elements from which *List* is composed are all PL/SQL static *varchar2* expressions[25].

Suppose that, as the use of the type constructor *varray(20)* suggests, the table *My Table* has 20 columns. The set of the more than one million distinct SQL statements that *x.p()* might execute is too numerous to allow each one to be inspected. Rather, the programmer (and auditor) must reason, from the self-evident predictability of the possible return values of the *Col_List* function, what the possible members are — and from that deduce what the possible SQL syntax templates are[26]. In this example, there are 20 distinct SQL syntax templates. *Template_4* shows some.

```
-- Template_4
select Rpad(&&1, 10) Report
from "My Table" where PK = :b

select Rpad(&&1, 10)||Rpad(&&2, 10)||Rpad(&&3, 10) Report
from "My Table" where PK = :b

select Rpad(&&1, 10)||Rpad(&&2, 10)|| ... ||Rpad(&&20, 10) Report
from "My Table" where PK = :b
```

We shall call each such a SQL syntax template a *dynamic SQL syntax template*.

A static SQL syntax template can, by trivial inspection of the PL/SQL source code that composes it, be written down by the auditor with certainty. A dynamic SQL syntax template is one of a large set of such templates that are composed for execution at a particular call site where the set is too large to allow each to be written down but where, nevertheless, the set can be described with certainty.

Understand what is meant by the term SQL syntax template and the difference between a static SQL syntax template and a dynamic SQL syntax template.

Rule_2

Understand what is meant by the term SQL syntax template. Apply this understanding to the design of any code that constructs run-time-created SQL statement text. Understand the difference between a static SQL syntax template and a dynamic SQL syntax template.

SQL injection (finally) defined

We define SQL injection, as it might occur from a PL/SQL subprogram, to mean the execution, by that subprogram, of a SQL statement with a SQL syntax template which differs, at a particular call site, from that which the subprogram's author intended for that call site.

This dangerous result occurs when the attacker supplies text for what the author intends will replace a value placeholder or a simple SQL name placeholder in the SQL syntax template. The attacker's text subverts the quoting syntax and so is parsed as a fragment of SQL syntax. This is the origin of the use of the term "injection": the attacker's fragment has been injected into the programmer's intended statement. The attacker's purpose is served when the resulting non-conforming SQL is legal and so executes without detection to produce an

[25] The term PL/SQL static *varchar2* expression is defined in the PL/SQL Language Reference book and its significance is discussed in the section *"Static text"* on page 35.

[26] It would be possible to describe the universe of possible SQL statements and possible SQL syntax templates using the regular expression syntax.

unintended result. The next section, *How can SQL injection happen?*, gives several examples of the attacks to which badly written code is vulnerable.

Self-evidently, SQL injection cannot occur from a call site that uses embedded SQL. Nor can it occur from a call site that uses dynamic SQL to execute compile-time-fixed SQL statement text.

The injected text may come directly via one of the subprogram's formal parameters (a so-called first order attack); or it may come indirectly, for example via a table which the subprogram reads, and trusts, to obtain a component of the SQL statement that it is building, but into which the attacker has contrived to insert a rogue value (a so-called second order attack).

Understand that SQL injection is the execution of a SQL statement with an unintended SQL syntax template and that the risk can occur only when run-time-created SQL statement text is executed using dynamic SQL.

Rule_3

Understand how to define the term SQL injection as the execution of a SQL statement with an unintended SQL syntax template. Know that only run-time-created SQL statement text that, therefore, must be executed using dynamic SQL is potentially vulnerable to SQL injection.

HOW CAN SQL INJECTION HAPPEN?

This is best demonstrated by examples. These will also enable us to tighten the definition of SQL injection. In this section, we will not ask why the programmer does not use compile-time-fixed SQL statement text[27]; we shall see later that there are indeed use cases that do require run-time-created SQL statement text. The fragments shown here, though not plausible, illustrate the SQL injection techniques.

Example 1: user-supplied column-comparison value

Consider the PL/SQL fragment shown in *Code_9*.

```
-- Code_9
  ...
  q constant varchar2(1) := '''';
  SQL_VC2_Literal constant varchar2(32767) :=
    q||Raw_User_Input||q;
begin
  Stmt :=
    'select c2 from t where c1 = '||SQL_VC2_Literal;
  execute immediate Stmt bulk collect into v;
  ...
```

Presumably *Raw_User_Input* holds a PL/SQL *text* value that the programmer expects to a possible value for the column *t.c2*. Is this vulnerable to SQL injection? It is tempting to reply “no” because the SQL syntax template seems to be fixed at compile time to this:

```
-- Template_5
select c1 from t where c2 = &1
```

If *Raw_User_Input* has this value:

```
-- Value_1
Smith
```

then *Stmt* will now be this:

```
-- Value_2
select c1 from t where c2 = 'Smith'
```

All seems to be well. But suppose that *Raw_User_Input* has this value:

```
-- Value_3
O'Brien
```

The value of the PL/SQL variable *Stmt* will now be this:

```
-- Value_4
select c1 from t where c2 = 'O'Brien'
```

[27] Of course, the intent of *Template_5* can be achieved using embedded SQL (which, under the covers, generates at compile time and uses at run time a compile-time-fixed SQL statement text that includes a placeholder). *Code_9* therefore violates the principles advocated in the section *“Use compile-time-fixed SQL statement text unless you cannot”* on page 29. However, we have seen code where native dynamic SQL has been used where embedded SQL was sufficient. Sometimes the explanation is nothing more than what ordinarily explains poorly conceived and written programs; sometimes, it might be the work of a disgruntled and malicious employee.

While this is unremarkable as a PL/SQL *text* value, it is syntactically incorrect as a SQL statement (the single quote characters don't balance) and will cause *ORA-00933: SQL command not properly ended* when it is parsed. The programmer intended to construct a SQL *text* literal from a PL/SQL *text* value by surrounding it with an opening and a closing single quote character[28]. But he forgot that *O'Brien* is a perfectly plausible value for a *text* column and that, therefore, the PL/SQL *text* value might legally contain interior single quote characters. The rules for constructing a SQL *text* literal from a PL/SQL *text* value require that each interior single quote character be escaped by doubling it *before* surrounding it with an opening and a closing single quote character[29]. Because the programmer forgot this, the singleton interior single quote character closes the SQL *text* literal, and *Brien'* is parsed as two SQL tokens, *Brien* and *'*.

This might seem to be an ordinary bug — and, of course, it should be avoided for ordinary reasons. However, if present, it could go undetected indefinitely; and it has a shocking manifestation when an ingeniously, and maliciously, contrived value for *Raw_User_Input* is provided.

Suppose that *Raw_User_Input* has this value:

```
-- Value_5
'
union
select Username c1 from All_Users --
```

Stmt will now be this:

```
-- Value_6
select c1 from t where c2 = ''
union
select Username c1 from All_Users --'
```

Notice that the would-be closing single quote character that the programmer adds, and that would cause a syntax error if it were unbalanced, is disarmed because *Value_5* finishes with the -- token that starts a single line comment.

The result is a legal SQL statement. Because, in Oracle Database, the empty string is the same as *null*, and because an equality comparison with *null* always results in *null*, no rows are selected from *t*; so the SQL statement reduces to this:

```
-- Value_7
select Username c1 from All_Users
```

This SQL statement an instance of a very different SQL syntax template than *Template_5* shows — and is surely not what the programmer intended. We have

[28] The point here, of course, is that the programmer is writing the source code of a PL/SQL program whose purpose is to create, at run-time, the source text of another program (a SQL statement) and then to execute that.

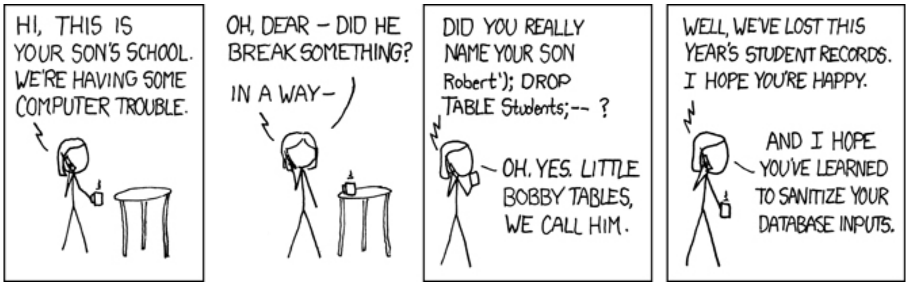
[29] Oracle Database 10*g* introduced an alternative quoting syntax for both SQL and PL/SQL — the so-called alternative quoting mechanism (sometimes know as the user-defined quoting mechanism, or the q-quote syntax). It aims to increase usability when the value itself contains single quote characters. Here is an example in PL/SQL:

```
v varchar2(80) := q'{You can't do that}';
```

The opening *q'* and the closing *'* are non-negotiable; The user chooses the inner parentheses, in this example { and }.We will see in the section *"Ensuring the safety of a SQL text literal"* on page 20 that this mechanism should be avoided.

seen, therefore, that the subprogram that executes *Stmt* is indeed vulnerable to SQL injection.

This is the canonical example of SQL injection. The superstitious fear is that *any* program that issues run-time-created SQL statement text is vulnerable to such an attack. However, as the cartoon[30] suggests, such attacks can always be prevented by following simple immunization practices.


HI, THIS IS YOUR SON'S SCHOOL. WE'RE HAVING SOME COMPUTER TROUBLE.
OH, DEAR – DID HE BREAK SOMETHING?
IN A WAY–
DID YOU REALLY NAME YOUR SON Robert'); DROP TABLE Students;-- ?
OH, YES. LITTLE BOBBY TABLES, WE CALL HIM.
WELL, WE'VE LOST THIS YEAR'S STUDENT RECORDS. I HOPE YOU'RE HAPPY.
AND I HOPE YOU'VE LEARNED TO SANITIZE YOUR DATABASE INPUTS.

The proper practice in this example is clear: when a PL/SQL *text* value is to be converted to a SQL *text* literal, then the result must be a string that starts and ends with a single quote character; and between these, there must be no singleton single quote characters and no runs of an odd number of single quote characters. This is discussed formally in the section *"Ensuring the safety of a SQL literal"* on page 20.

Example 2: user-supplied table name

Consider the PL/SQL fragment shown in *Code_10*.

```
-- Code_10
...
Stmt :=
  'select c1 from '||Raw_User_Input||' where c2 = ''Smith''';

execute immediate Stmt bulk collect into v;
...
```

Presumably *Raw_User_Input* holds a value that the programmer expects to be the name of a table or view. Is this vulnerable to SQL injection? As with *Example 1*, it is tempting to reply "no" because the SQL syntax template seems to be fixed at compile time to this:

```
-- Template_6
select c1 from &&1 where c2 = 'Smith'
```

If *Raw_User_Input* has this value:

```
-- Value_8
t
```

then *Stmt* will now be this:

```
-- Value_9
select c1 from t where c2 = 'Smith'
```

[30] The original of this cartoon is to be found at xkcd.com/327/. A footnote states "...you're free to copy and share these comics (but not to sell them)".

Again, all seems to be well. But recall that, though few programmers take advantage of it[31], the following SQL*Plus script runs without error.

```
-- Code_11
drop table "a /"
/
create table "a /"("?" number, "a'b" number, " " number)
/
insert into "a /"("?", "a'b", " ") values (1, 2, 3)
/
select * from "a /" where "?" = 1
/
select    '['||Table_Name||']' x from User_Tables
union
select    '['||Column_Name||']' x from User_Tab_Cols
where     Table_Name = 'a /'
order by  x
/
```

A SQL identifier can consist of any sequence of one or more characters in the database character set provided that the representation needs no more than 30 bytes[32]. The final *select* in *Code_10* produces an output that includes these rows:

```
[ ]
[?]
[a /]
[a'b]
```

Notice how the values end up in metadata in the catalog views; and notice how, when these views are queried, the rules are no different from those for any other tables and views. Especially, because an identifier may legally contain singleton single quote characters, the same care must be used when constructing a SQL *text* literal to represent one in a metadata query.

It helps to think that SQL ordinarily requires that every identifier is surrounded with double quote characters. Only if the identifier happens to start with an alphabetic character, and happens thereafter to contain only alphanumeric characters or *underscore*, # or *$*, then (as a usability bonus) the double quote characters may be omitted. And if they are omitted, then the SQL parser upper-cases the identifier.

There seem to be no established terms of art to capture this distinction. We will use the term *common SQL name* to denote one that starts with an upper case alphabetic character in the range *A..Z* and then has only upper case alphanumeric characters in the range *A..Z*, or underscore, # or $. A common SQL name doesn't need to be surrounded by double quote characters in a SQL statement; and if it is not so surrounded, the case with which it is written doesn't matter. It may, however, be so surrounded. If it is, then because the SQL

[31] GUI tools for the DBA and the developer are becoming increasingly popular. These support object creation without typing the SQL directly. It is therefore more likely these days to encounter exotic SQL names (like *Line Items*) than it used to be.

[32] There is one exception: this DDL statement:

```
create table "a""b"(n number)
```

fails with *ORA-03001: unimplemented feature*. An identifier may not contain the double quote character. Oracle Database no longer allows this. The text of the message might seem to suggest a possibility that a later version of Oracle Database might, again, allow this. This is misleading. There is no intention to do this.

parser preserves its case, it must be written in all upper case. We will use the term *exotic SQL name* to denote one that violates the rules for a common SQL name and that *must*, therefore, be surrounded by double quote characters in a SQL statement.

Suppose, then, that the value for the simple SQL name placeholder in *Template_6* is *a /* rather than *t*; *Raw_User_Input* will have this value:

```
-- Value_10
a /
```

Stmt will now be this:

```
-- Value_11
select c1 from a / where c2 = 'Smith'
```

This is syntactically incorrect and will cause *ORA-00933: SQL command not properly ended* when it is parsed.

The programmer intended to construct a SQL identifier from a PL/SQL *text* value. But he forgot about the possibility of getting a exotic SQL name. The rules for constructing a SQL identifier from a PL/SQL *text* value need to take account of this. This is discussed formally in the section *"Ensuring the safety of a simple SQL name"* on page 26.

Again, this might seem to be an ordinary bug; and again it could go undetected indefinitely. (The use of exotic SQL names is relatively rare.) But again the bug has a shocking manifestation when an ingeniously, and maliciously, contrived value for *Raw_User_Input* is provided.

Suppose that *Raw_User_Input* has this value:

```
-- Value_12
t where 1=2
union
select Username c1 from All_Users --
```

Stmt will now be this:

```
-- Value_13
select c1 from t where 1=2
union
select Username c1 from All_Users -- where c2 = 'Smith'
```

The code expects only a common SQL name. But the caller has supplied an exotic SQL name. It has been cunningly designed so that the result is a legal SQL statement. As in *Example 1*, again the SQL statement reduces to this:

```
-- Value_14
select Username c1 from All_Users
```

Again, this is an instance of a very different SQL syntax template than *Template_6* shows and again it is surely not what the programmer intended. Of course, then, the subprogram that executes *Stmt* is vulnerable to SQL injection.

The proper practice in this example, too, is clear: when a PL/SQL *text* value is to be used to compose a SQL identifier, then the conversion must acknowledge the difference between a common SQL name and an exotic SQL name, must handle case accordingly, and must surround the final result with double quote characters.

Counter-example 3: user-supplied where clause

Consider next the PL/SQL fragment shown in *Code_12*.

```
-- Code_12
...
Stmt := 'select c1 from t where '||Raw_User_Input;
execute immediate Stmt bulk collect into v;
...
```

Assuming that the PL/SQL identifier is appropriately named, then the intended SQL syntax template is simply unspecified. Formally, therefore, it falls outside the scope of the discussion of SQL injection — just as does SQL*Plus, which is specified to be able to execute any arbitrary SQL statement.

The programmer probably did have an informal notion of the set of possible SQL syntax templates that *Stmt* may instantiate, for example an equality comparison with a literal for each of any arbitrary combination of columns from table *t*. However, unlike checking that a string is a well-formed SQL literal or SQL identifier, it is very difficult to check that a putative complete *where* clause is an instantiation of one of a set of intended SQL syntax templates.

A Functional Specification document for a PL/SQL program that offers the powerful flexibility implied by *Code_12* must be rejected unless it can be guaranteed that it can be executed only by a user who anyway could connect directly to the database and execute arbitrary *select* statements against the same table.

We shall return to this point in the section *"Use a static SQL syntax template for run-time-created SQL statement text unless you cannot"* on page 31.

Counter-example 4: SQL syntax template with a questionable intent

Consider next the procedure shown in *Code_13*.

```
-- Code_13
procedure Make_DBA(Raw_User_Input in varchar2)
  authid Definer -- Current_User
is
  Double_Quote_Test constant char(3) := '%"%';
begin
  if Raw_User_Input like Double_Quote_Test then
    Raise_Application_Error(-20000, 'Interior " is illegal');
  end if;

  declare
    Username constant varchar2(32767) :=
      '"'||Raw_User_Input||'"';
    Stmt constant varchar2(32767) :=
        'grant DBA to '
      || Username
      || ' identified by x with Admin Option';
  begin
    DBMS_Output.Put_Line(Stmt);
    execute immediate Stmt;
  end;
end Make_DBA;
```

Because a value of *Raw_User_Input* that has an interior double quote character[33] causes an error, and because a value that does not is then surrounded by double quotes[34], there is no risk that the SQL syntax template will be anything other than this:

```
-- Template_7
grant DBA to &&1 identified by x
```

There is, therefore, no risk of SQL injection[35], and further discussion of it is beyond the scope of this whitepaper.

Not to leave it unsaid, though, the intent of this SQL syntax template does signal the need for some serious analysis[36]. Because *Make_DBA()* is an invoker's rights procedure, then it can be executed without error only by a user that already has the *DBA* role *with Admin Option*. Nominally, then, it should be safe to grant *Execute* on this to *public*. There is, however, a subtle secondary point to consider. If there exists a subprogram in the database, whose owner has the *DBA* role *with Admin Option*, and that is vulnerable to injection, then it might be possible to inject an invocation of this procedure[37] where it would not be possible to inject the SQL that it executes. Clearly, then, the existence of a procedure like *Make_DBA()* makes a security audit harder.

[33] A simple SQL name must not contain a double quote character. An attempt to use such a name in a SQL statement causes *ORA-03001: unimplemented feature*.

[34] This crude programming device is used in this example in order not to pre-empt the discussion, in the section *"Ensuring the safety of a simple SQL name"* on page 26, of the proper approach. We shall see there that the proper approach is to use *DBMS_Assert.Simple_Sql_Name()*.

[35] You might question the usability of the interpretation of *Raw_User_Input*. If you wanted to specify a user whose name was the common SQL name *SCOTT*, then you would have to be careful to spell it in all upper case. This is not the convention in SQL. However, the usability is not interesting in this example. The example is designed to illuminate the discussion of SQL injection.

[36] To keep the code simple, the password is specified as an explicit identifier. But the point of this example would be unchanged even if the password were specified by user input that not only was surrounded with double quotes but also was required to pass a stringent password strength test.

[37] This would require wrapping it in an invoker's rights function that was defined with the *Autonomous_Transaction* pragma.

ENSURING THE SAFETY OF A SQL LITERAL OR A SIMPLE SQL NAME

Only two kinds of element in a SQL syntax template may be replaced with dynamic text[38]: a value placeholder may be replaced with a SQL literal and a simple SQL name placeholder may be replaced with a simple SQL name. However, as we have seen in the section *"Example 1: user-supplied column-comparison value"* on page 13 and the section *"Example 2: user-supplied table name"* on page 15, it is precisely in this replacement that the risk of SQL injection occurs. This section, therefore, prescribes the approaches that guarantee immunity to that risk.

Ensuring the safety of a SQL literal

There are three kinds of SQL literal: *text*, *datetime*, and *numeric*[39]. Each deserves separate attention.

Ensuring the safety of a SQL *text* literal

If the value *O'Brien* is to be presented as a SQL *text* literal, then it can be written either using the default mechanism shown in *Code_14* or using the so-called alternative quoting mechanism[40] shown in *Code_15*.

```
-- Code_14
...where Last_Name = 'O''Brien'

-- Code_15
...where Last_Name = q'{O'Brien}'
```

While the alternative quoting mechanism can improve readability for values that have interior singleton occurrences of the single quote character, its use must be banned for the purpose of composing a safe SQL *text* literal[41].

The *DBMS_Assert* package[42] exposes the function *Enquote_Literal()*. It has a single formal parameter, *Str*, of datatype *varchar2* and mode *in*.; and its return datatype is *varchar2*. When the input is a well-formed SQL *text* literal, then the output is identical to the input; but when the input is not a well-formed SQL *text* literal, then the predefined exception *Standard.Value_Error* is raised[43].

[38] The term *dynamic text* is formally defined in the section *"Dynamic text"* on page 36. For now, it is sufficient to assume the intuitive meaning: text whose composition cannot be traced back to only PL/SQL static *varchar2* expressions.

[39] This syntax definition for these items is given in the SQL Language Reference book.

[40] Support for the alternative quoting mechanism was introduced in Oracle Database 10*g*.

[41] The reason is simple: the *DBMS_Assert* package does not provide a function to assert the safety of this syntax.

[42] The *DBMS_Assert* package was first documented in Oracle Database 11*g*.

[43] There is one exception: when the input has only properly doubled interior single quote characters, but neither starts nor ends with a single quote character, then *Enquote_Literal()* will quietly add these. There are those (for example, Bryn Llewellyn!) who feel that this was an unfortunate design and that the function would have been better conceived of as a pure asserter. However, it is what it is; and backwards compatibility considerations prohibit changing it. This paper encourages the approach, which is always possible, that uses it as a pure asserter.

These, then, are the rules for composing a safe SQL *text* literal from a PL/SQL *text* value:

- Replace each singleton occurrence, within the PL/SQL *text* value, of the single quote character with two consecutive single quote characters.
- Concatenate one single quote character before the start of the value and one single quote character after the end of the value.
- Assert that the result is safe with *DBMS_Assert.Enquote_Literal()*[44].

Notice that the mandate in the third bullet is the crucial one. It is this one that guarantees immunity to injection; the first mandate prevents annoying run-time errors.

Ensuring the safety of a SQL *datetime* literal

A SQL *datetime* literal is a SQL *text* literal which must conform to the additional condition that it must be capable of conversion to a value of a *datetime* datatype. Obviously, then, the safety of a SQL *datetime* literal must be asserted with *DBMS_Assert.Enquote_Literal()* in exactly the same way as a SQL *text* literal.

It is interesting to see what can happen if this simple rule is forgotten, and if the documented behaviors of the single argument *To_Char(d)*, where *d* has a *datetime* datatype, and the single argument *To_Date(t)*, where *t* has a *text* datatype, are forgotten too. Consider the contrived procedure whose first few lines are shown in *Code_16*.

```
-- Code_16
procedure p is
  q constant varchar2(1) := '''';
  d constant date :=
    To_Date('2008-09-22 17:30:00', 'yyyy-mm-dd hh24:mi:ss');
  Stmt constant varchar2(32767) :=
     'select t.PK from t where t.d > ' || q||d||q;
  ...
begin
  execute immediate Stmt bulk collect into Results;
  ...
```

The author might understand that, with the code as presented, the single argument *To_Char()* is implicitly invoked by PL/SQL when *d* is concatenated into *Stmt*; and that, next, the single argument *To_Date()* is implicitly invoked by SQL when *Stmt* is executed. He might even remember that both the output of the single argument *To_Char()* and that of the single argument *To_Date()* are affected by the environment setting of the *NLS_Date_Format* parameter — and might reason that the second conversion is the antidote to the first, and that there is, therefore, no cause for concern.

However, this understanding is naïve. At the very least, he has programmed an ordinary bug that can lead to unreliable query results because of a loss of date

[44] In all the code examples in this paper, the name of this package is always qualified with its owner, as *Sys.DBMS_Assert*, rather than using the bare public synonym. This measure is essential for safety. It ensures that the simple name cannot be captured by a private synonym or package in the same schema as the PL/SQL unit which refers to what is intended to be the Oracle-supplied *DBMS_Assert* package.

precision. Suppose that table *t* had been populated by the SQL*Plus script shown in *Code_17*.

```
-- Code_17
alter session set NLS_Date_Format = 'yyyy-mm-dd hh24:mi:ss'
/
begin
  insert into t(PK, d) values(1, '2008-09-23 17:30:00');
  insert into t(PK, d) values(2, '2008-09-21 17:30:00');
  commit;
end;
/
```

And suppose, now, that *p()* is executed using the SQL*Plus script shown in *Code_18*.

```
-- Code_18
alter session set NLS_Date_Format = 'dd-Mon-yy hh24:mi:ss'
/
begin p(); end;
/
alter session set NLS_Date_Format = 'yyyy'
/
begin p(); end;
/
```

The first execution of *p()*, though it runs with a different setting of *NLS_Date_Format* than was current when table *t* was populated, still produces the expected result: only the row with *PK=1* is selected. (This is because it honors the precision with which the dates were stored.) However, the second execution produces what is almost certainly an unexpected result: both the row with *PK=1* and the row with *PK=2* are selected. The reason, of course, is that the conversion of the value in the PL/SQL variable *d*, after lossy conversion to *text* and then conversion back to a *datetime* datatype, has ended up as (what would display as) *2008-01-01 00:00:00*. This no longer honors the intended precision.

One who has followed the discussion of the case presented in the section *"Example 1: user-supplied column-comparison value"* on page 13), will not be surprised to learn that procedure *p()* is not only ordinarily buggy; it is also vulnerable to SQL injection. Suppose that *p()* is executed using the SQL*Plus script shown in *Code_19*.

```
-- Code_19
alter session set
  NLS_Date_Format = '"'' and Scott.Evil()=1--"'
/
begin p(); end;
/
```

The value shown in *Value_15* is assigned to *Stmt*.

```
-- Value_15
select t.PK from t where t.d > '' and Scott.Evil()=1--'
```

This is surely not an instance of the intended SQL syntax template. Therefore, SQL injection has occurred. The explanation is a twist on the usual one: a singleton occurrence of the single quote character has been injected into the run-time composed SQL statement, but this time *from the side*[45] — via an NLS environment parameter — rather than directly. Of course, all bets are off now. The invocation of the malicious function is injected, and the would-be closing single quote character that *p()* adds is disarmed by the -- token that starts a single line comment. *Scott.Evil()* is invoked!

While the argument just presented might seem tortuous, the conclusion is simple to understand and simple to implement. These, then, are the rules for composing a safe SQL *datetime* literal from a PL/SQL *datetime* value:

- Use the two-parameter overload, for an input of datatype *date*, *To_Char(d, Fmt)*, to compose a SQL *datetime* literal[46], *t*. (This, of course, will be a PL/SQL *varchar2*.) Use a value for *Fmt* that is consistent with what the Functional Specification document requires for the precision.
- Concatenate one single quote character before the start of this value and one single quote character after its end.
- Assert that the result is safe with *DBMS_Assert.Enquote_Literal()*.
- Compose the date predicate in the SQL statement using the two-parameter overload for *To_Date(t, Fmt)* and using the identical value for *Fmt* as was used to compose *t*.

Notice that the mandate in the third bullet is the crucial one. It is this one that guarantees immunity to injection; the first two and the fourth mandates prevent annoying run-time errors.

The procedure *p_Safe()*, whose first few lines are shown in *Code_20*, implements this approach.

```
-- Code_20
procedure p_Safe(d in date) is
  q constant varchar2(1) := '''';

  -- Choose precision according to purpose.
  Fmt constant varchar2(32767) := 'J hh24:mi:ss';

  Safe_Date_Literal constant varchar2(32767) :=
    Sys.DBMS_Assert.Enquote_Literal(q||To_Char(d, Fmt)||q);

  Fmt_Literal constant varchar2(32767) := q||Fmt||q;

  Safe_Stmt constant varchar2(32767) :=
       ' insert into t(d) values(To_Date('
    || Safe_Date_Literal
    || ', '
    || Fmt_Literal
    || '))';
begin
  execute immediate Safe_Stmt;
  ...
```

[45] This form of attack has been referred to as *lateral* SQL injection by David Litchfield. The article is available on the internet here:
www.databasesecurity.com/dbsec/lateral-sql-injection.pdf

[46] Of course, *date* is not the only *datetime* datatype. The same reasoning applies for, for example, a *timestamp* literal.

When *p_Safe()* is invoked using *Sysdate()*, a value like that shown in *Value_16*[47] is assigned to *Safe_Stmt*.

```
-- Value_16
insert into t(d) values(To_Date('2454723 18:01:05', 'J hh24:mi:ss'))
```

The composition of *Safe_Stmt* is immune to the effect of changes to the *NLS_Date_Format* parameter.

Ensuring the safety of a SQL *numeric* literal

Unlike a SQL *datetime* literal, which is a specialized kind of SQL *text* literal, a SQL *numeric* literal has specific syntax. It always uses a dot as the decimal character and never contains a group separator. Here are some examples (notice that there are no surrounding single quote characters)[48]:

```
42
-1
+6.34
0.5
-123.4567
25e-03
25f
+6.34F
0.5d
-1D
```

The SQL syntax does not recognize national differences. However, the output of the overload of the *To_Char()* function for a *numeric* datatype does. This function has three sub-overloads with one, two, and three formal parameters.

For the overload with three formal parameters, the second formal parameter, called *Fmt*, specifies the format model and the third formal parameter, called *NLSparam*, specifies the actual characters that will be used for notions like the decimal character, the group separator, the currency symbol, and so on.

For the overload with two formal parameters, the second formal parameter specifies the format model. Notably, if this overload is used, the value for (the components of) *NLSparam* is determined by the *NLS_Numeric_Characters*, *NLS_Currency*, and *NLS_ISO_Currency* environment parameters. Even more notably, if the overload with one formal parameter is used, then the value for *Fmt* has a fixed default: it cannot be controlled from the environment. But the value for *NLSparam* is *still* determined by the environment and *still* has an effect.

Suppose that table t has been populated using the *insert* statement shown in *Code_21*.

```
-- Code_21
insert into t(n) values (123456.789)
```

[47] The Julian date *2454723* is *13-Sep-2008*.

[48] These are taken from the SQL Language Reference book.

Then the SQL*Plus script shown in *Code_22*

```
-- Code_22
select n from t
/
alter session set NLS_Numeric_Characters = ',.'
/
alter session set NLS_Currency = 'NOK '
/
select To_Char(n, 'L999G999G999D999') n from t
/
select n from t
/
select To_Char(n, 'TM', 'NLS_Numeric_Characters = ''!.''') n
from t
/
alter session set NLS_Numeric_Characters = '''.'
/
select 'c1 = '||n x from t
/
```

will produce this output:

```
123456.789

           NOK 123.456,789

123456,789

123456!789

c1 = 123456'789
```

If a SQL *numeric* literal is not composed carefully, there is a risk of generating a SQL statement with a syntax error — in other words, a different SQL syntax template than was intended. The ability to inject a singleton single quote character is particularly alarming. This is another example of lateral SQL injection, and the moral is clear.

These, then, are the rules for composing a safe SQL *numeric* literal from a PL/SQL *numeric* value:

- Use explicit conversion with the *To_Char()* overload with three formal parameters. This overload requires that a value be supplied for *Fmt*. Explicitly provide the value that supplies the default when the overload with one formal parameter is used. This is *'TM'*.[49]
- Explicitly provide the value that supplies the default for the *NLS_Numeric_Characters* parameter when the one of the overloads with one or two formal parameters is used. This is *'.,'*.

We shall return to this point in the section *"Safe dynamic text"* on page 36, where we introduce the shorthand *To_Char(x f, n)* for this overload.

[49] *'TM'* is the so-called text minimum number format model. It returns the smallest number of characters possible in fixed notation unless the output exceeds 64 characters. In that case, the number is returned as if the model had been *'TMe'*. *'TMe'* returns the smallest number of characters possible in scientific notation. If the Functional Specification document suggests this, it is safe also to specify the *'TMe'* model explicitly. In fact, *any* format model is safe provided that it is chosen deliberately, together with the value for the *NLSparam* argument, in the light of the requirements for precision given in the Functional Specification document.

Ensuring the safety of a simple SQL name

Suppose that a user exists with the exotic SQL name[50] *O'Brien* in whose schema there exists a procedure with the common SQL name *PROC* and a package with the common SQL name *PKG*. Suppose that this package has a procedure with the exotic SQL name *Do it*. Finally, suppose there exists, in a different database, a link to this one with the common SQL name *LNK*. Here are some examples of the various qualified SQL names that, in different contexts, might be used in a SQL statement:

```
Proc
"O'Brien".Pkg
Pkg."Do it"
Proc@"Lnk"
"O'Brien".Pkg."Do it"
"O'Brien".Pkg@lnk
"O'Brien".Pkg."Do it"@LNK
```

This is the general form of a qualified SQL name:

```
a [ .b [ .c ]][ @dblink ]
```

Each of the items *a*, *b*, *c*, and *DBlink* is a simple SQL name. A simple SQL name is either a common SQL name or an exotic SQL name and an exotic SQL name must be surrounded with double quote characters. Notice that this is just a prescription for the syntax; *a.b* might denote the element *b* in the package *a* (as in *Proc."Do it"*) or it might denote the object *b* owner by the user *a* (as in *"O'Brien".Pkg*).

The ability to compose a qualified SQL name by assembling simple SQL names with the punctuation characters . and @ delivers a powerful generality in the context of a SQL statement. However, we have argued in this paper that the power of expression of SQL should be fully available only to the author of a subprogram[51] that executes it. This logic applies no less to the assembly of a qualified SQL name. This is the reason that we insist that the . and @ punctuation characters are part of the SQL syntax template and that the simple SQL name placeholder be exactly that: this placeholder must not be replaced by a qualified SQL name. This rule will be restated formally in the section *"Safe SQL statement text"* on page 36.

It might be argued that the usability of a subprogram which allows the caller to choose the object it operates on is improved if the familiar syntax of the qualified SQL name can be expressed in a single actual argument. There is a simple way to accommodate such a requirement. The Oracle-supplied procedure *DBMS_Utility.Name_Tokenize()* decomposes a qualified SQL name into its simple SQL names. It takes no account of semantics: the denoted object need not exist;

[50] The rules for composing a common SQL name and an exotic SQL name are given in the SQL Language Reference book; however, as was mentioned in the section *"Example 2: user-supplied table name"* on page 15, these terms of art were invented for this paper.

[51] To be precise, we should use the term *top level PL/SQL block*, as is defined in the section *"Static text"* on page 35, rather than *subprogram*.

and it therefore gives no information about whether *a.b* is the element *b* in the package *a* or the object *b* owner by the user *a*. *Code_23* shows how to invoke it.

```
-- Code_23
procedure p(Qualified_SQL_Name in varchar2) is
  a varchar2(32767);
  b varchar2(32767);
  c varchar2(32767);
  DBlink varchar2(32767);
  Dummy pls_integer;
begin
  DBMS_Utility.Name_Tokenize(
    Qualified_SQL_Name,
    a,
    b,
    c,
    DBlink,
    Dummy);
```

The utility's first formal parameter (for which the actual *Qualified_SQL_Name* is used) has the mode *in*; and the remaining formal parameters (for which the actuals *a*, *b*, *c*, *DBlink*, and *Dummy* are used) have the mode *out*. The returned value of *a* will never be *null*. The values of *b*, *c*, and *DBlink* might be *null*; but *c* will never be *not null* unless *b* is also *not null*. *Dummy* carries no useful information: it is always equal to *Length(Qualified_SQL_Name)*.

An arguably better API design for a subprogram which allows the caller to choose the object it operates on is to provide an explicit formal parameter for each simple SQL name that will be used to compose the qualified SQL name. However, the choice of approach is unimportant with respect to this paper's focus.

Notice that by allowing the replacement of a simple SQL name placeholder in a SQL syntax template only with a simple SQL name, we force the programmer to take a deliberate decision in the design about, for example, whether an object in a remote database may be referenced. This self-evidently improves the safety of the design[52].

These, then, are the rules for composing a safe simple SQL name from a PL/SQL *numeric* value:

- Design the API so that the caller provides the putative name, in the PL/SQL *numeric* value, using exactly the syntax that would be used in a SQL statement: a common SQL name may be presented without enclosing double quote characters (when it will then be treated case-insensitively); an exotic SQL name must be presented with enclosing double quote characters.

- Ensure the safety of the name with *DBMS_Assert.Simple_Sql_Name()*.

The *DBMS_Assert.Simple_Sql_Name()* is a pure asserter: either the output is identical to the input; or the exception *DBMS_Assert.Invalid_Sql_Name* is raised.

[52] The have been some discussions in public internet forums about how a program that uses the *DBMS_Assert* functions inappropriately can be vulnerable to injection. See, for example, the paper *Bypassing Oracle DBMS_Assert* by Alexander Kornbrust and discussions about it. This paper insists that the safety of object identification be asserted always and only with *DBMS_Assert.Simple_Sql_Name()*. Of course, other functions from the package may be used, *before the final check*, for their ordinary utility value.

If the input *is not* surrounded by double quote characters, it is taken to be a common SQL name; here, the exception is raised if it violates the rules for such a name. If the input *is* surrounded by double quote characters, it is taken to be an exotic SQL name; here, the exception is raised only if the name contains a singleton double quote character or a consecutive run of an odd number of such characters. However, a name that contains only properly doubled double quote characters will fail when it is used[53].

Finally, in this section, we should note that the *DBMS_Assert* package has functions to establish whether a putative first class object or a putative schema actually exists. While these might be convenient utilities for use in some very well-controlled scenarios, they have no value with respect to immunizing against the risk of SQL injection. Oracle Database is famously a multiuser, multiaccess environment. Therefore, a check for object existence might report a fact which no longer holds true at the moment an action is taken that should supposedly depend of the outcome of that check.

[53] The attempt will cause *ORA-03001: unimplemented feature.*

RULES FOR COST-EFFECTIVE, GUARANTEED PREVENTION OF SQL INJECTION

Like any rules of best practice, the following do not prescribe the only way to achieve the goal. These rules are recommended because they are simple to state, easy to follow, easy to audit in a manual code review[54], and — most importantly — because they guarantee the objective: they make PL/SQL database code that adheres to them proof against SQL injection. The rules necessarily limit freedom. But we argue that the limited freedom that remains is sufficient to allow all reasonable application requirements to be supported.

Expose the database to clients only via a PL/SQL API

Briefly, the paradigm is to establish a database user as the *only* one to which a client may connect[55]. This user may own *only* private synonyms; and these may denote *only* PL/SQL units. Necessarily, by application of this rule, the denoted PL/SQL units are owned by users as whom the client may not connect. The *Execute* privilege on exactly and only these denoted PL/SQL units is granted to the user as whom the client may connect.

This approach formally defines the API — subject to the caveat that objects that are accessible via privileges granted to *public* are therefore part of the API. (If appropriate, the scheme can be extended to several such users, for access by different kinds of client end-user, where each user has appropriate privileges.)

The API-defining PL/SQL units may be definer's rights or invoker's rights according to their purpose.

This paradigm locates the responsibility to prevent SQL injection where it belongs: in the subsystem of the overall application stack that executes the SQL. And it offers the only approach whose safety can be proved. The paradigm is a natural extension of the thinking that places all code that is responsible for the enforcement of data integrity in the database[56].

Expose the database to clients only via a PL/SQL API.

> *Rule_4*
> Expose the database to clients only via a PL/SQL API. Carefully control privileges so that the client has no direct access to the application's objects of other kinds — especially tables and views.

Use compile-time-fixed SQL statement text unless you cannot

If the complete text of a SQL statement, and not just the SQL syntax template, is fixed at compile time, then it takes no effort to prove that the call site that issues that statement is proof against SQL injection: because the statement text is fixed, then so, in turn, is the SQL syntax template. We don't even need to discuss

[54] They also allow the possibility, in a future release of Oracle Database, of at least partial mechanical auditing.

[55] The passwords of all the other users are closely guarded and are not revealed to engineers who implement client-side code.

[56] Notice that, as a side-benefit, the paradigm liberates the designer from requiring to use triggers to implement data integrity logic. When all data changes are made through PL/SQL subprograms, these can *directly* implement the data integrity logic.

whether dynamic text[57] has been made safe, and the auditing task is therefore trivial (and correspondingly cheap).

Notice that while using embedded SQL guarantees a compile-time-fixed SQL statement text, it is not the only way to guarantee this. *Code_24* shows an obvious alternative.

```
-- Code_24
declare
  Stmt constant varchar2(80) :=
    'alter session
       set NLS_Date_Format = ''AD yyyy-mm-dd hh24:mi:ss''';
begin
  execute immediate Stmt;
  ...
end;
```

Here, we imagine that the Functional Specification document for the application insists that a report which lists some *datetime* values do so in a particular way[58].

The use of *constant* with an assignment statement that uses only PL/SQL static *varchar2* expressions[59] provably fixes the SQL statement text at compile time. The auditor need not study whatever expanse of code lies between the declaration of *Stmt* and its use as the argument of *execute immediate*; the PL/SQL compiler will refuse to compile the unit if it includes code that would change *Stmt*.

It is important, therefore, to separate the discussion of the method for executing the SQL at a particular call site from the discussion of the SQL syntax template that will be executed at that call site. Embedded SQL supports only these kinds of statement: *select*, *insert*, *update*, *delete*, *merge*, *lock table*, *commit*, *rollback*, *savepoint*, and *set transaction*.

For all other kinds of statement, one of PL/SQL's methods for dynamic SQL must be used. Moreover, for these, the *execute immediate* statement is sufficient in almost every case[60].

There are plausible use cases that require SQL statements of the kinds that embedded SQL does not support in ordinary application code. But these occur very much more rarely for ordinary application code than for system code.

Insist that the Design Specification document for ordinary application code defends any propsal to execute SQL using any method other than Embedded SQL.

> *Rule_5*
>
> When the Design Specification document for ordinary application code proposes to use anything other than embedded SQL, insist on examining the

[57] The notion of dynamic text is defined formally in the section *"Dynamic text"* on page 36.

[58] For example, the report could be generated in a marked-up format for the specific purpose of import into a spreadsheet where the convention for representing dates has already been established.

[59] The term PL/SQL static *varchar2* expression is defined in the PL/SQL Language Reference book and its significance is discussed in the section *"Static text"* on page 35.

[60] The cases where *execute immediate* is not sufficient are very rare indeed, and all need special consideration with respect to security. One example is when DDL statement must be executed in a remote database. In such cases, the *DBMS_Sql* API is needed.

rationale very carefully when the document is reviewed. The design may well be defensible. But this defense must be made explicitly.

Notice that the converse is true: when a statement of one of the kinds that Embedded SQL does support is to be executed, and when the statement text can be fixed at compile time, then dynamic SQL is never needed. Therefore, embedded SQL should always be used for these cases. We understand now why the example in *Code_9* is a violation of the rule stated in this section.

There is, however, a practical consideration which forces us to moderate the statement of this rule. Sometimes, while the universe of possible SQL syntax templates that may be issued from a particular call site is fixed at compile time, the number of these is so great (because they are generated programatically, albeit by assembling components all of which are fixed at compile time) that they cannot be set up at compile time as embedded SQL statements. This use case was discussed in the section *"Distinguishing between a static SQL syntax template and a dynamic SQL syntax template"* on page 7. And it is illustrated in the section *"Query by example form"* on page 42.

Use compile-time-fixed SQL statement text unless you cannot. Use Embedded SQL or *execute immediate* with a PL/SQL static *varchar2* expression.

Rule_6
Use compile-time-fixed SQL statement text unless you cannot. Use embedded SQL when the SQL statement is of a kind that this supports. Otherwise, use *execute immediate* with single PL/SQL *constant* argument composed using only PL/SQL static *varchar2* expressions. When you conclude that you cannot, review the Functional Specification document and the Design Specification document carefully with colleagues and then explain in the latter exactly why compile-time-fixed SQL statement text cannot be used.

Use a static SQL syntax template for run-time-created SQL statement text unless you cannot

There are only very few requirements scenarios that might be used to justify a deliberate violation of *Rule_6*. Each must be examined very carefully when the Design Specification document is reviewed.

Replacement of a value placeholder in a SQL syntax template

This requirement arises for two different reasons.

- There is no SQL syntax for binding to a regular placeholder for the required parameterization.
- Pre Oracle Database 11*g*, a literal value is required to encourage an optimal execution plan[61].

There are three reasons why binding to a placeholder might not be supported.

- While the SQL statement is of the kind that embedded SQL supports, there is a requirement to parameterize a value like that which determines the timeout period in a *select... for update* statement[62]. SQL does not support the use of a regular placeholder for this purpose.
- There is a requirement to execute a SQL statement of the kind that requires Dynamic SQL and to parameterize it in some way[63]. An example is provided

by an extension to the requirement that led to the implementation shown in *Code_24*. Suppose, now, that *NLS_Date_Format* must be set at run-time in response to conditions that are first discovered then.

- The SQL statement (or fragment, like a *where clause*) is to be executed by one of the subprograms listed in *Appendix C: Additional Oracle-supplied subprograms that implement dynamic SQL* on page 59 and this subprogram does not support binding to placeholders.

The safety of the dynamic text that is used to replace a value placeholder must be ensured according to the principles established in the section *"Ensuring the safety of a SQL literal"* on page 20. This is stated compactly in *Rule_10* on page 36.

Consider the implied Functional Specification document that led to the injectable implementation shown in *Code_12* on page 18. Because the *from* list specifies exactly one item, it is likely that the requirement is to let the user mention some subset of the item's columns and, for each, to express a comparison with a value. And it is likely that the combination of the predicates can be constrained to either uniformly mutual *or* (any of the predicates is satisfied) or mutual *and* (all of the predicates is satisfied). With about a dozen columns, the number of distinct SQL syntax templates is several thousand, so it is easy to see why it is tempting to let the user supply the *where clause* as string. However, there is no general way to define an algorithm that checks if such a string is indeed one of the several thousand allowed templates. There is, then, only one acceptable approach; this discussion is taken up in the section *"Don't confuse the need to use a dynamic SQL syntax template with the need for dynamic text"* on page 34.

Insist on a justification for a design that proposes to replace a value placeholder in a SQL syntax template.

Rule_7

A Design Specification document that proposes to replace a value placeholder in a SQL syntax template (whether this is a static SQL syntax template or a

[61] This use case used to occur in the implementation of an application to expose the information in a datawarehouse. In such cases, the tables are enormous and the queries are complex. Moreover, the number of concurrent users is relatively low. The classical wisdom (bind to placeholders rather than using literals to reduce the frequency of the so-called SQL hard parse) used not to hold. Parse time can be tiny in comparison to execution time, and contention is unimportant. Here, the use of a literal in a predicate, allowing more specific advantage to be taken of statistics, used sometimes to be critical for getting acceptably short execution times.

However, Oracle Database 11*g* brings enhanced bind peeking. Later releases brought more adaptive methods for calculating the execution plan. There is now *never* any need to encode literal values into a SQL statement in order to get the optimal execution plan. Nor is there any other reason to prefer literals.

[62] Code to implement this use case was shown in *Code_5* on page 7.

[63] It so happens that none of the kinds of SQL statement that embedded SQL does not support allows the use of a regular placeholder.

However it is relatively rare for ordinary application code to need to execute the kind of SQL that isn't supported by embedded SQL. This need occurs only within special kinds of program. The higher level Functional Specification document should be very carefully reviewed to ensure that the proposed approach is essential.

dynamic SQL syntax template) should be regarded with extreme suspicion. It must present a convincing argument for this approach before it is signed off.

Replacement of a simple SQL name placeholder in a SQL syntax template

The general characterization of the use case is that the application needs to operate on an object (which is typically a table) whose shape and purpose is given in the Design Specification document but whose identity is not known until run time.

While the safe approach for this scenario has been prescribed in the section *"Ensuring the safety of a simple SQL name"* on page 26, it is still useful, as each new Design Specification document is written, to determine if an alternative approach is possible which uses only compile-time-fixed SQL statement text, and (for accessing a table) can therefore be implemented with embedded SQL.

Consider the sort of utility that is aimed manipulating data in one of a set of schemas where each such schema is populated by objects with the same names and purposes. A naïve approach would encode the value returned by the *Sys_Context()* function for *Current_Schema* in the *Userenv* namespace into a qualified SQL name for each object to be accessed and would execute these statements with Dynamic SQL. The ideal solution, though, is to encapsulate the SQL statements that access the objects in an Invoker's Rights unit. The access can then be implemented ideally with embedded SQL which uses unqualified names. The code can be pointed at the intended objects by changing the *Current_Schema* — either programatically or by simply letting it follow the *Current_User*.

Sometimes an application needs to handle a very large quantity of data (more than can safely be held in a PL/SQL collection) but does not need to retain it beyond the lifetime of a session. Historically, applications used a pool of nominally temporary tables together with a management system to allocate, and later reclaim, such a table for use by a particular session. This, of course, meant that the table name was not known until run time. Oracle8*i* Database introduced the global temporary table. It is perfect for this purpose because it can be accessed using embedded SQL but no session sees another session's data.

However, there are some compelling use cases that non-negotiably require the replacement of a simple SQL name placeholder in a SQL syntax template with a simple SQL name. They tend to arise in the design of what is loosely referred to as system software. A convincing example is given by an implementation of a domain index that uses the ODCI framework. Each different index will use a set of tables whose names are typically derived from that of that index. The ODCI client code will need to derive such names at run time when it is called, by the Oracle system, with the name of the current index of interest.[64]

Insist on a justification for a design that proposes to replace a simple SQL name placeholder in a SQL syntax template.

Rule_8

A Design Specification document that proposes to replace a simple SQL name placeholder in a SQL syntax template (whether this is a static SQL syntax template or a dynamic SQL syntax template) should be regarded

[64] Oracle Text works this way.

with some suspicion. It must present a convincing argument for this approach before it is signed off.

Don’t confuse the need to use a dynamic SQL syntax template with the need for dynamic text

The kind of Functional Specification document that cannot be implemented using a static SQL syntax template has already been briefly discussed[65] and the concept for the safe implementation has been illustrated with code[66]. There, the requirement was to handle a *select* list whose composition is not known until run time. The requirement often goes hand-in-hand with one optionally to specify a restriction criterion for each column by supplying both the value and the comparison operator (*exact equals*, *like*, *less than*, and so on). There is also often a requirement to specify which columns to use, in which order, and with *ascending* or *descending* for each, to sort the results.

The requirement to handle a *where* clause whose composition is not known until run time can lead junior programmers to decide that binding to placeholders when the requirement is not known at compile time is not feasible[67]. More mature programmers realize that the *DBMS_Sql* API provides exactly the primitives that are needed to implement this. The approach is illustrated in the section *“Query by example form”* on page 42.

The coding effort is certainly nontrivial. But the size of that effort is never enough to justify abandoning binding in favor of encoding literals directly into the SQL statement.

In other words, the requirement to encode literals directly into the SQL statement (in this use case only for the reason of improving the execution plan) is orthogonal to the requirement to implement binding to a set of placeholders whose composition emerges first at run time.

Don’t confuse the need to use a dynamic SQL syntax template with the need to replace value placeholders in the template

Rule_9

Don’t confuse the requirement to bind to a set of placeholders whose composition emerges first at run time, which is fully supported by the *DBMS_Sql* API, with a requirement to use directly encoded literals in pursuit of optimal query execution performance.

Formal sufficient prescription for guaranteed safety

The foregoing exposition has aimed to show how a PL/SQL application that is vulnerable to SQL injection is also ordinarily buggy. It focussed, therefore, on how to write bug-free code that has the pleasant bonus of being proof against SQL injection. This section takes the auditor’s viewpoint whose aim is to certify proof against SQL injection by inspecting extant code.

First, we need to establish some definitions.

[65] See the section *“Definition of dynamic SQL syntax template”* on page 8.

[66] See *Code_6* on page 8, *Code_7* on page 10, and *Code_8* on page 10.

[67] You need only to try to write the code to do this using *execute immediate* to realize that, because its *using* clause is fixed at compile time, the task is impossible.

Static text

Static text is either

- a PL/SQL static *varchar2* expression as defined in the PL/SQL Language Reference book[68], or
- an expression formed by an arbitrary concatenation of static text items, or
- the value of a local variable[69] that has been visibly assigned with static text.

This definition is intentionally recursive. A variable can be assigned some static text and then that variable (strictly speaking, its value[70]) can be used to build another yet larger static text. The tower can be built as high as one likes; but its foundation must consist only of PL/SQL static *varchar2* expressions.

Notice that the concatenation may be controlled by tests whose outcome is not known until run time. But it must be self-evident, following trivial human inspection, that every possible concatenation will result only in static text according to the rules stated in the preceding three bullets; this is what we mean by *visibly assigned*. (One might say that you must be able to see the foundation when you are standing on the top of a static text tower.)

Code_25 shows an extract from the declarations in function *f()* shown in *Code_26* on page 38.

```
-- Code_25
Tab_1 constant varchar2(32767) := 'Tab_1';
Tab_2 constant varchar2(32767) := 'Tab_2';
...
Tab constant varchar2(32767) :=
  case b
    when true then Tab_1
    else           Tab_2
  end;
```

[68] This is the list:

— a simple literal, for example, *'abcdef'*
— a concatenation of simple literals, for example, *'abc'||'def'*
— the literal *null*
— *To_Char(x)*, where *x* is a *pls_integer* static expression
— *To_Char(x f, n)* where *x* is a *pls_integer* static expression
and *f* and *n* are PL/SQL static *varchar2* expressions
— *x||y* where each of *x* and *y* is either a PL/SQL static *varchar2* expression
or a *pls_integer* static expression.

The list is extended to include a *constant* declared in the specification of a package that has been assigned with PL/SQL static *varchar2* expressions.

Of course, *pls_integer* static expression is also defined in the same book.

The value of a PL/SQL static *varchar2* expressions is known, and therefore fixed, at compile time.

[69] A local variable is one that is declared within the present top level PL/SQL block A top level PL/SQL block is one of the following: a schema-level function; a schema-level procedure; a function or procedure defined at top level within a package body or a type body; a package's initialization block; or the implementation of a trigger. Thus a variable that is declared at top level in a package or package body is, by definition, not a local variable.

Notice that *b* is a formal parameter and so the value of *Tab* will not be known until run time and will be, in general, different for each invocation of *f()*. Nevertheless, *Tab* is a static text according to the definition given above.

Dynamic text

Dynamic text is any text that is not static text. Obvious examples are formal parameters, variables declared at top level in a package without the *constant* keyword, and ordinary variables that are assigned by executing a SQL statement or as the actual argument for the *Buffer* formal parameter to *Utl_File.Get_Line()*.

Safe dynamic text

Safe dynamic text is the output of either

- *DBMS_Assert.Enquote_Literal()*, or
- *To_Char(x f, 'NLS_Numeric_Characters = ''.,''')* where *x* is a variable of a numeric datatype and *f* is an the explicit format model *'TM'*, or
- *DBMS_Assert.Simple_Sql_Name()*.

Hereinafter, the shorthand *To_Char(x f, n)* will be used to denote *To_Char(x f, 'NLS_Numeric_Characters = ''.,''')*. The background for this rule was established in the section *"Ensuring the safety of a SQL numeric literal"* on page 24.

Notice that it follows from the definition of dynamic text that the safety of safe dynamic text must be established within the present top level PL/SQL block.

Safe SQL statement text

Safe SQL statement text is an arbitrary concatenation of static text and safe dynamic text. (A careful definition would require similar wording to that used in the definition of static text. Local variables may be used for intermediate results or for the final result; and it must be self-evident that every possible concatenation will result only in safe SQL statement text.)

We can now define a necessary prescription for guaranteed safety:

Dynamic SQL may execute only a concatentation of static text and safe dynamic text. Safe dynamic text is the output of one of exactly three Oracle-supplied functions: *Simple_Sql_Name()*, *Enquote_Literal()*, and *To_Char(x f, n)*.

> *Rule_10*
>
> When a SQL statement represented by a PL/SQL *text* expression is executed using one of PL/SQL's APIs for dynamic SQL, then the expression must be safe SQL statement text. Safe SQL statement text is a concatenation of static text and safe dynamic text. Static text is composed only of PL/SQL static *varchar2* expressions. Dynamic text is anything that isn't static text. Safe dynamic text is the output of one of exactly three Oracle-supplied functions: *DBMS_Assert.Simple_Sql_Name()*, *DBMS_Assert.Enquote_Literal()*, and *To_Char(x f, n)*.

[70] The distinction between a variable and its (current) value becomes uninteresting when the declaration of the variable uses the *constant* keyword. It is always possible, with appropriate use of nested block statements, to declare all the variables that are used for the composition of static text this way. This practice is strongly encouraged because it makes the task of the human auditor very much easier.

Notice that the definition of safe SQL statement text pays no attention to the semantics of the resulting SQL statement and is, therefore, not sufficient.

Nevertheless, this rule is useful because, as it is easy to imagine, the PL/SQL compiler, in a future version of Oracle Database, could be enhanced to detect a violation of *Rule_10*. Application code that violates the rule is definitely suspect and must be studied.

We must also guarantee that the composed SQL syntax template is only one of those that the programmer intended. We need to add *Rule_11* to *Rule_10* to give the sufficient prescription for guaranteed safety.

Use *Simple_Sql_Name()*, to ensure the safety of a SQL name. Use *Enquote_Literal()* to ensure the safety of a string or datetime literal. Use *To_Char(x f, n)* to ensure the safety of a numeric literal.

> *Rule_11*
> The safe dynamic text produced by *DBMS_Assert.Enquote_Literal()* or by *To_Char(x f, n)* should be used only at a spot within the SQL statement where a SQL literal is intended; and the safe dynamic text produced by *DBMS_Assert.Simple_Sql_Name()* should be used only at a spot within the SQL statement where a simple SQL name is intended.

It is very much harder to imagine how adherence to the stricter *Rule_11* could be mechanically policed. It would require a run-time check, for every single dynamic execution of SQL, by a subsystem that implemented complete knowledge of SQL syntax. Anyway, both *Rule_10* and *Rule_11* must be policed by ordinary human code review.

Code_26 shows an example[71] that honors *Rule_10* and *Rule_11*. Function *f()* is guaranteed always to compose a SQL statement that conforms to the SQL syntax template shown in *Template_8*.

```
-- Template_8
select PK from &&1 where VC2 = &2
```

```
-- Code_26
function f(b in boolean, VC2 in varchar2) return number is
  Quote         constant varchar2(1) := '''';
  Doubled_Quote constant varchar2(2) := Quote||Quote;

  Start_   constant varchar2(32767) := 'select PK from ';
  Tab_1    constant varchar2(32767) := 'Tab_1';
  Tab_2    constant varchar2(32767) := 'Tab_2';
  Where_   constant varchar2(32767) := ' where VC2 = ';

  Tab constant varchar2(32767) :=
    case b
      when true then Tab_1
      else           Tab_2
    end;

  SQL_Text_Literal constant varchar2(32767) :=
    Quote||Replace(VC2, Quote, Doubled_Quote)||Quote;

  Stmt constant varchar2(32767) :=
    Start_||
    Tab||
    Where_||
    Sys.DBMS_Assert.Enquote_Literal(SQL_Text_Literal);

  PK number;
begin
  execute immediate Stmt into PK;
  return PK;
end f;
```

When *f()* is invoked with actual arguments with values *true* for *b* and *O'Brien* for *VC2*, then the safe SQL statement text shown in *Value_17* is composed.

```
-- Value_17
select PK from Tab_1 where VC2 = 'O''Brien'
```

Establish the safety of run-time-created SQL statement text in the code that immediately precedes its execution

The definition established for safe dynamic text[72] insists that it be composed in the same top level PL/SQL block that executes the SQL statement, into which it is concatenated, using dynamic SQL. This is a sufficient condition to allow the future possibility of a mechanical check. However, the task of the human auditor is made very much easier if all calls to *DBMS_Assert.Simple_Sql_Name()*, *DBMS_Assert.Enquote_Literal()*, or to *To_Char(x f, n)* are made in code that composes the SQL statement immediately before the PL/SQL statement that executes it.

[71] Because this example replaces a value placeholder in a SQL syntax template, we must assume that this approach was deliberately chosen in preference to binding to a regular placeholder in order to increase the probability of a good execution plan as was discussed in the section *"Replacement of a value placeholder in a SQL syntax template"* on page 31.

[72] See the section *"Safe dynamic text"* on page 36.

Code_26 honors this principle.

Rule_12
Make the job of the auditor easy by establishing the safety of run-time-created SQL statement text in the code that immediately precedes the PL/SQL statement that executes it.

Keep the code that invokes *Simple_Sql_Name()*, *Enquote_Literal()*, or *To_Char(x f, n)* very close to the code that executes the SQL statement that these calls make safe.

SCENARIOS

Each of the following requirements scenarios can be implemented very well using embedded SQL. Yet (incredibly, in the case of the first scenario) we have seen real production code where dynamic SQL has been used unsafely because the author didn't know how to program the embedded SQL solution.

Make a *like* predicate by adding leading and trailing % characters

Code_27 shows an embedded SQL statement that implements a *like* predicate.

```
-- Code_27
select t.PK, t.c1 bulk
collect into Results
from t where c1 like '%'||x||'%';
```

It's impossible to speculate on the origin of the strange myth that says that this needs run-time-created SQL statement text.

It might help to see the SQL statement that the PL/SQL compiler constructs from this source code. The simplest way to observe this is, on one's own private development database, to encapsulate the code shown in Code_27 in a procedure, to execute it, and to query the *v$Sql* view using a restriction that is selective enough to filter out irrelevant results[73]. Code_28 shows such a query.

```
-- Code_28
select  Sql_Text
from    v$Sql
where   Lower(Sql_Text) not like '%v$sql%'
and     Lower(Sql_Text) like 'select%t.pk%t.c1%'
```

This is the output of Code_28:

```
SELECT T.PK, T.C1 FROM T WHERE C1 LIKE '%'||:B1 ||'%'
```

Notice that the regular placeholder *:B1* has been established in the position where the variable *x* was used in the embedded SQL statement. The PL/SQL compiler generates appropriate code to do the binding.

As the companion paper, *Doing SQL from PL/SQL: Best and Worst Practices*, explains at some length, PL/SQL's embedded SQL and PL/SQL's dynamic SQL are both processed the same way at run time: the text of the SQL statement is submitted by the PL/SQL run-time system to the SQL subsystem for execution. The difference is that the PL/SQL compiler generates the text of the SQL statement from an embedded SQL statement at compile time and stores it with the unit's compiled code; but the SQL statement executed by dynamic SQL is composed at run time when the unit executes. Of course, as this paper has advocated, that composition might be no more demanding than the initialization of a PL/SQL *constant* with a PL/SQL static *varchar2* expression[74].

A programmer who thought that embedded SQL could not support a *like* predicate must have thought, if pushed to explain his thoughts, that the expression *'%'||:B1||'%'* was not legal in SQL; it most certainly is.

[73] This is easy to arrange by inventing an unusual name for the test table. An alternative is simply to flush the shared pool before executing the test procedure.

[74] It turns out that the optimizing PL/SQL compiler can do this at compile time.

In list with number of elements not known until run-time

This use case is described in the companion paper, *Doing SQL from PL/SQL: Best and Worst Practices*. For convenience, the account is reproduced here — slightly reworded to suit the needs of this paper's pedagogy.

If, for some relatively improbable reasons, you need a query whose *where clause* uses an *in list* with, say, exactly five items, then you can write the embedded SQL statement without noticing the challenge that will present itself later when the requirements change to reflect the more probable use case. *Code_29* shows this unlikely statement.

```
-- Code_29
select             a.PK, a.v1
bulk collect into  b.Results
from               t a
where              a.v1 in (b.p1, b.p2, b.p3, b.p4, b.p5);
```

Code_30 expresses the intention of the far more likely statement.

```
-- Code_30
select             a.PK, a.v1
bulk collect into  b.Results
from               t a
where              a.v1 in (b.ps(1), b.ps(2), b.ps(3),
                            b.ps(4), b.ps(5), b.ps(6),
                            b.ps(7), b.ps(8), b.ps(9),
                            ...                       );
```

The problem is immediately apparent: we cannot bear to write an explicit reference to each element in a collection using a literal for the index value — and even if we could, the text would become unmanageably voluminous. Rather, we need a syntax that expresses the notion “all the elements in this collection, however many that might be”. Such a syntax exists and is supported in embedded SQL; *Code_31* shows it.

```
-- Code_31
  ps Strings_t;
begin
  select             a.PK, a.v1
  bulk collect into  b.Results
  from               t a
  where              a.v1 in (select  Column_Value
                               from    table(b.ps));
```

However, this seems to be relatively little known, possibly because it uses the *table* operator[75]. The datatype of *ps* must be declared at schema level. *Code_32* shows the SQL*Plus script that creates it.

```
-- Code_32
create type Strings_t is table of varchar2(30)
/
```

It is not uncommon for programmers who don't know about the *table* operator to satisfy the functionality requirement by building the text of the SQL statement at run time. At best, this implementation is cumbersome and inefficient; and at worst, it will be vulnerable to SQL injection.

[75] The use of the *table* operator is explained in the section *Manipulating Individual Collection Elements with SQL* in the Object-Relational Developer's Guide. The PL/SQL Language Reference mentions it, with no explanation, only in the *PL/SQL Language Elements* section.

Query by example form

This scenario complements the one discussed in the section *"Definition of dynamic SQL syntax template"* on page 8 [76]. There, the Functional Specification document required a customizable report format for a fixed restriction condition (primary key identity). In this section, the Functional Specification document requires a fixed report format but a customizable restriction condition. This leads to the need for a design which, if it is to avoid replacing value placeholders in the dynamic SQL syntax template with SQL literals, needs to bind to placeholders, the number of which, and the datatypes of what they stand for, are unknown until run time.

Neither the requirement to handle a *select* list whose composition is not known until run time nor the requirement to handle an *order by* clause whose composition is not known until run time leads to design choices that impact the discussion of exposure to the risk of SQL injection. Therefore, to keep the code illustrations as short as possible, this section shows only how to code when the *where clause* is not known at compile time.

This paper needs to do only two things: to show how to build a SQL statement as an instance of a dynamic SQL syntax template but using only static text; and to show how to implement the binding that this implies[77].

consider the procedure *x.p()* as shown in *Code_33*.

```
-- Code_33
package x is
  type t1 is Record(
    Val varchar2(4000),
    Exact boolean := false);
  type t2 is varray(20) of t1;
  procedure p(Cols in t2);
end x;
```

Its purpose is to list the values of the primary key, PK, for rows that satisfy the customizable *where clause*. Just as with *Code_6* on page 8, the author of code that will call *x.p()* knows the purpose of *My Table*[78], and the names and significance of all its columns. All this, and especially the names, is fixed in the Design Specification document. In particular, the programmer knows the order in which the columns are listed in its external documentation. The *n*th element of the *in* formal parameter *Columns* determines if, and how, the *n*th column of *My Table* is to be used in the *where clause*. When *Val* is not null, the *n*th column is to be

[76] The code that implements this scenario is shown in *Code_6* on page 8, *Code_7* on page 10, and *Code_8* on page 10.

[77] The need to compose the *order by* clause at run time impacts only the composition of the SQL statement; it has no impact on binding nor on how the results are fetched. The need to compose the *select* list at run time, while it has no impact on binding, does potentially affect how the results are fetched. The approach shown in *Code_7* on page 10 sidesteps this by concatenating all the required columns into a single *text* item. Sometimes, though, each *select* list item must be fetched into its own variable, and the datatypes of the columns have to be taken into account. The *DBMS_Sql* API is well able to support this; but the techniques have no consequence for the subject of this paper.

[78] The exotic name *My Table* was chosen deliberately to make a teaching point in this example.

included; and, in this case, *Exact* specifies whether an equality comparison or a *like* comparison is to be used.

The implementation of *p()* in the body of package *x* is shown in *Code_34*. The *Where_Clause()* inner function composes the *where clause*.

```
-- Code_34
procedure p(Cols in t2) is
  type t3 is varray(200) of "My Table".PK%type;
  Results t3;

  type cn is varray(20) of varchar2(30);
  Col_Names constant cn := cn('c1', 'c2', 'c3', 'c4');

  function Where_Clause return varchar2;

  Stmt constant varchar2(32767) :=
       'select PK from "My Table"'
    || Where_Clause()
    || ' order by PK';

  function Where_Clause return varchar2 is ... end Where_Clause;

begin
  DBMS_Output.Put_Line(Stmt);

  declare
    nc integer := DBMS_Sql.Open_Cursor(Security_Level=>2);
    rc Sys_Refcursor;
    Dummy number;
  begin
    DBMS_Sql.Parse(nc, Stmt, DBMS_Sql.Native);

    for j in 1..Cols.Count() loop
      if Cols(j).Val is not null then
        DBMS_Sql.Bind_Variable(nc, ':b'||j, Cols(j).Val);
      end if;
    end loop;

    Dummy := DBMS_Sql.Execute(nc);

    rc := DBMS_Sql.To_Refcursor(nc);
    fetch rc bulk collect into Results;
    for j in 1..Results.Count() loop
      DBMS_Output.Put_Line(Results(j));
    end loop;
    close rc;
  end;
end p;
```

Notice that, following this paper's recommendation in *Rule_1* on page 10, *Stmt* is declared using the *constant* keyword and that this means that it must be initialized as part of the declaration. Notice too that the assignment to *Stmt* starts like this:

```
Stmt constant varchar2(32767) :=
  'select PK from "My Table"' || ...
```

The exotic SQL name *My Table* is enclosed with double quote characters but its safety is *not* ensured with *DBMS_Assert.Simple_Sql_Name()*. This is entirely safe. The reason is that it occurs within a PL/SQL static *varchar2* expression and therefore its spelling is established with certainty by the PL/SQL source text[79]. The same logic applies to the list *('c1', 'c2', 'c3', 'c4')* that initializes the *Col_Names*

[79] It would not be harmful to use *DBMS_Assert.Simple_Sql_Name()* in the initialization of *Stmt*. However, because this is manifestly unnecessary, to do so might confuse subsequent maintainers of the code.

static *constant*. The names of the columns are given in the Design Specification document; and *x.p()* is specified to work against *My Table* with the columns it has. Because the columns all have common SQL names, there is no need to surround each with double quote characters[80].

The key feature in this example, with respect to the binding challenge, is that *DBMS_Sql.Bind_Variable()*, as a procedure, can be invoked in a loop as many times as emerges at run time to be necessary and with actual arguments whose values are known only then. The *execute immediate* statement and the *open rc for* statement, because the elements to be bound are written in the source code of the PL/SQL unit, support only a binding requirement that is fixed at compile time.

The design capitalizes on the fact that the *select* list is known at compile time. It uses *DBMS_Sql.To_Refcursor()*[81] to move from the regime of the *DBMS_Sql* API to that of native dynamic SQL to fetch the results in a single *fetch... bulk collect* statement. Notice that the call to *DBMS_Sql.Open_Cursor()* uses an actual value *2* for the formal *Security_Level*[82]. Using this ensures that every operation attempted using a cursor opened this way must be done by the same user that opened it with the same, or greater, set of enabled roles[83].

[80] Writing the list as *('“C1”', '“C2”', '“C3”' '“C4”')* would have no consequence for correctness of for immunity to SQL injection. (Curly double quote characters are used to write this because the straight double quote character that source code demands is, in the font used, visually indistinguishable from two straight single quote characters.)

[81] This function, and its counterpart *DBMS_Sql.To_Cursor_Number()*, were introduced in Oracle Database 11*g*.

[82] The new overload for *DBMS_Sql.Open_Cursor()*, that has the *Security_Level* formal, was introduced in Oracle Database 11*g*.

[83] This eliminates the a rather different kind of vulnerability named by David Litchfield as *Cursor Injection* and described his article available on the internet here: www.databasesecurity.com/dbsec/cursor-injection.pdf.

For completeness, the implementation of the *Where_Clause()* function is shown in *Code_35*.

```
-- Code_35
function Where_Clause return varchar2 is
  Clause varchar2(32767);
  Seen_One boolean := false;
begin
  for j in 1..Cols.Count() loop
    if Cols(j).Val is not null then
      Clause :=
           Clause
        || case Seen_One
             when true then ' and '
             else           ' where '
           end
        || Col_Names(j)
        || case Cols(j).Exact
             when true then ' = :b'||j
             else           ' like ''%''||:b'||j||'||''%'''
           end;
      Seen_One := true;
    end if;
  end loop;
  return Clause;
end Where_Clause;
```

Notice that the design is very similar to that for the *Column_List()* function shown in *Code_8* on page 10 and that elements from which *Clause* is composed, here too, are all PL/SQL static *varchar2* expressions.

Again as with the *Column_List()* function, the set of the more than one million distinct SQL statements that *x.p()* might execute is too numerous to allow each one to be inspected. Rather, the programmer (and auditor) must reason what the possible members are — and from that deduce what the possible SQL syntax templates are. In this example, there are very many distinct SQL syntax templates. *Template_9* shows some.

```
-- Template_9
select PK from "My Table"
where c1 like '%'||:b1||'%' order by PK

select PK from "My Table"
where c1 = :b1 order by PK

select PK from "My Table"
where c1 like '%'||:b1||'%' and c3 = :b3 and c4 = :b4 order by PK
```

Because these templates use no value placeholders or simple SQL name placeholders, there is no need for dynamic text and, tautologically, no need to ensure its safety. This approach is self-evidently not vulnerable to SQL injection. Should, in a bungled maintenance cycle, the name of the table or any of its columns be changed without correspondingly updating the implementation of *x.p()*, then it would simply fail at run time with an ordinary semantic error.

Callback

The requirement is that a compiled PL/SQL unit must, without recompiling it, be somehow instructed to call a subprogram whose identity isn't known until run time. Though the identity is unknown, the signature of formal parameters and their meanings is known[84]. This scenario is relatively common in ISV applications that allow the customer to supply code to perform a generically characterized operation in a customer-specific fashion.

The challenge can be illustrated by specifying this simple shape for the to-be-called subprogram:

```
function Callback(Input in integer) return integer
```

The "obvious" design, shown in *Code_36, uses* dynamic SQL.

```
-- Code_36
procedure p(Name in varchar2) is
  ...
  Safe_Name constant varchar2(32767) :=
    Sys.DBMS_Assert.Simple_Sql_Name(Name);
  Stmt constant varchar2(32767) :=
    'begin :x := '||Safe_Name||'(:n); end;';
begin
  execute immediate Stmt using out x, in n;
```

Here, *p* is the unit that must not be recompiled. The actual for *P.Name* would be obtained at run-time by, for example, selecting from a schema-level table[85].

The approach does follow the rules that this paper sets out and is proof against SQL injection. However, as we shall see, a better approach is available; it takes advantage of dynamic polymorphism — sometimes known as virtual dispatch[86]. This is one of the cornerstones of object-oriented programming and it goes hand-in-hand with subtyping. The to-be-called subprogram is described first as the *not final* member method of an abstract datatype. *Code_37* shows this.

```
-- Code_37
type Hook authid Current_User is object(
  Dummy number,
  not instantiable member function Callback(
    self in Hook,
    Input in integer ) return integer
)
not final
not instantiable
```

Other syntactic elements are needed in the definition of the *type*.

- A *type* has at least one data attribute. It is declared as *"Dummy number"* to emphasize that it has no significance for the implementation.
- The element *not final* allows a *type* to be created *under Hook*.
- The *Callback()* method is declared as *not instantiable* because no implementation will be provided at this level in the *type* hierarchy. *Hook* will be the supertype of a subtype which will describe the actual implementation. Because it has a *not instantiable* method, *Hook* itself must also be declared as *not instantiable*.

[84] This is analogous to the scenario where a table's identity is unknown until run time but the name and purpose of each column is.

[85] The ISV's instructions would explain that the customer should create a callback function with the required shape and with any name. To simplify this example, we assume that this must be done in a specified schema. Then the customer should insert a row into a specified table to state what name he used for the callback.

[86] The complete listing, from which the code in this section is extracted, is shown in *Appendix D: Self-contained code to illustrate implementing callback using dynamic polymorphism.* on page 62.

- Every member method of a *type* has the implicit first formal *self* which by default is of *in out* mode. It may alternatively be declared as *in*, but not as *out*. *In out* is the default because member methods are typically used to set data attributes. *In out* formals are passed by value unless the *nocopy* hint is used. For this particular use case, where the attribute *Dummy* is never referenced, the best practice is to establish *self* explicitly as *in*; formals with mode *in* are passed by reference.

- The qualifier *authid current_user* — to establish the supertype with invoker's rights — is used in accordance with probable best practice. The choice between invoker's rights and definer's rights would be taken in a real project in the light of the overall requirements.

As mentioned, the implementation of the to-be-called subprogram is described in a subtype of *Hook* :

```
-- Code_38
type My_Implementation under Hook(
  overriding member function Callback(
    ...
    input in integer) return integer
)

type body My_Implementation is
  overriding member function Callback(
    ...
    input in integer) return integer
  is
  begin
    ...
    return ...;
  end Callback;
end;
```

The element *overriding member* establishes the method as the actual implementation for the virtual declaration in the supertype.

The magic of the above construct is that a variable of the supertype *Hook* — say, *Obj* — can be given a value at run-time which is an instance of the subtype *My_Implementation*; and an invocation of what is apparently the supertype's virtual method — *Obj.Callback()* — will in that case denote the overriding match declared in the subtype. This gives you what we could loosely call a dynamic case statement whose legs can be determined after having compiled the statement, and without recompiling it, simply by creating new compilation units. It's as if you could make *p()*, in *Code_39*, acquire an new leg to invoke *Callback3()* in its *case* expression by merely by establishing *Callback3()* in a new compilation unit — without needing to recompile *p()*.

```
-- Code_39
function Callback1(input in integer) return integer is
  begin return input*2; end Callback1;

function Callback2(input in integer) return integer is
  begin return input*2; end Callback2;

procedure P(Which pls_integer) is
  ...
begin
  x := case Which
         when 1 then Callback1(n)
         when 2 then Callback2(n)
         ...
       end;
  ...
```

Code_40 shows how to implement intent of *Code_36* using dynamic polymorhism.

```
-- Code_40
procedure p(Obj in Hook) is
  ...
begin
  ...
  x := Obj.Callback(n);
  ...
```

The actual for *p.Obj* would be obtained at run-time by, for example, selecting from a schema-level table. This time, instead of using a *varchar2* column to hold the name of the implementation, the column would have datatype *Hook* and would be populated with an instance of the subtype *My_Implementation*.

The dynamic SQL approach, shown in *Code_36*, uses a static SQL syntax template and safely replaces a simple SQL name placeholder with a simple SQL name. It would take the auditor some effort to prove that this code was safe. The approach that uses dynamic polymorhism, shown in *Code_40*, doesn't use SQL at all and so is self-evidently safe.

As a bonus, the approach that uses dynamic polymorhism has two additional advantages.

- Tests show that the dynamic polymorhism approach is on the order of 10 times faster than the dynamic SQL approach when, as is typical, the body of the callback executes relatively quickly compared to the cost of the PL/SQL to SQL to PL/SQL context switch.
- When the dynamic polymorhism approach is used, *Callback()*'s formal parameters may have any PL/SQL datatype but when the dynamic SQL approach is used, these datatypes are limited to only those that SQL understands.

ANALYSIS AND HARDENING OF EXTANT CODE

This must be a mainly manual task. Notice that Oracle Database 12*c* Release 2 brought enhancements to PL/Scope to list every source code location where dynamic SQL is is used. *Ad hoc* methods must be used to find those top level PL/SQL blocks that do dynamic SQL.

It is easy to find all of the call sites where a procedural API is used[87]. PL/Scope[88] can be used to identify each call site with no risk of omission or of false positives. However, there is no corresponding method to find the call sites that issue native dynamic SQL[89]. There is no alternative except to search the source code manually. Any PL/SQL unit with such a call sites will contain either both words *execute* and *immediate* or both words *open* and *for*. Therefore, a mechanical search in *User_Source*, seen from the viewpoint of the relevant users, might be able to prune away some units.

Once the interesting units have been identified then it remains, for each relevant top level PL/SQL block, to inspect the source code manually to determine if the rules that this paper has advocated have been followed.

When violations are found, they will be where a SQL statement is executed using a run-time-created SQL statement text composed with dynamic text that has not been made safe according to the principles that this paper has described[90].

In a fortunate case, the auditor will be able to establish quickly that a static SQL syntax template was intended but that dynamic text is being used unsafely. Here, the addition of calls to *DBMS_Assert.Simple_Sql_Name()*, *DBMS_Assert.Enquote_Literal()*, or *To_Char(x f, n)* just before the PL/SQL statement that executes the run-time-created SQL statement text will eliminate the vulnerability.

In a less fortunate case, where the design relies on the assumption that SQL keywords and operators will be supplied as dynamic text, the solution can only be radical re-design. But, at least, the vulnerability will have been identified.

[87] The relevant subprograms are listed in *Appendix C: Additional Oracle-supplied subprograms that implement dynamic SQL* on page 59.

[88] PL/Scope was introduced by Oracle Database 11*g*. It is described in the chapter *Using PL/Scope* in the Oracle Database Development Guide.

[89] Enhancement request 6913337 asks to provide a way to do this.

[90] See especially the section *"Ensuring the safety of a SQL literal or a simple SQL name"* on page 20 and the section *"Formal sufficient prescription for guaranteed safety"* on page 34.

CONCLUSION

This paper has carefully defined, and named, some notions[91] that are essential to support a proper discussion of SQL injection and its avoidance[92]:

- *common SQL name* and *exotic SQL name*
- *compile-time-fixed SQL statement text* and *run-time-created SQL statement text*
- *value placeholder*, *simple SQL name placeholder*
- *SQL syntax template*, *static SQL syntax template*, and *dynamic SQL syntax template*
- *static text*, *dynamic text*, *safe dynamic text*, and *safe SQL statement text*
- *top level PL/SQL block*

And it has relied on careful use of some established notions and terminology:

- *regular placeholder*, *simple SQL name*, *qualified SQL name*
- *embedded SQL*, *native dynamic SQL*, and the *DBMS_Sql API*
- *PL/SQL numeric value*, *PL/SQL datetime value*, and *PL/SQL text value*
- *SQL numeric literal*, *SQL datetime literal*, and *SQL text literal*
- *PL/SQL static varchar2 expression* and *PL/SQL static varchar2 constant*

This allowed us to establish a simple, brief definition of the paper's topic, from its asserted perspective: SQL injection occurs at a particular call site in a PL/SQL subprogram when a SQL statement us executed whose SQL syntax template differs from what the subprogram's author intended. It also allowed us to see that SQL injection is possible only when run-time-created SQL statement text is executed.

This gave the basis for understanding how most cost-effectively to ensure that PL/SQL code is not vulnerable to SQL injection.

- Aim to use execute only compile-time-fixed SQL statement text using, as appropriate, either embedded SQL, *execute immediate*, or *open for* with a PL/SQL static *varchar2* expression.
- Only after explaining carefully in the Design Specification document why compile-time-fixed SQL statement text is insufficient to meet the requirements in the Functional Specification document, aim to execute run-time-created SQL statement text that is entirely static text.
- Only after explaining carefully why neither compile-time-fixed SQL statement text nor run-time-created SQL statement text that is entirely static text is sufficient, use run-time-created SQL statement text that is safe SQL statement text.
- When composing this safe SQL statement text

[91] See *Appendix A: Definitions of new terms of art introduced by this paper* on page 52.

[92] This seems never to have been done before.

- ensure the safety of dynamic text that replaces a value placeholder in the SQL syntax template with *DBMS_Assert.Enquote_Literal()* or with *To_Char(x f, n)*. For this design, explain explicitly why binding to a regular placeholder is insufficient. Use the former for a SQL *text* literal or a SQL *datetime* literal. Additionally, when composing a SQL *datetime* literal, use *To_Char()* with a format model appropriate for the required precision and encode *To_Date()* with the same model into the safe SQL statement text. Use *To_Char(x f, n)* for a SQL *numeric* literal
- ensure the safety of dynamic text that replaces a simple SQL name placeholder in the SQL syntax template with *DBMS_Assert.Simple_Sql_Name()*.

Clearly, then, the expense of implementing a design that is proof against SQL injection increases with each successively more sophisticated approach. However, this expense must never be used to justify taking shortcuts in the implementation. Only by honoring the principles that this paper has set out can you be sure that you are safe from the threat of SQL injection.

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APPENDIX A:
DEFINITIONS OF NEW TERMS OF ART INTRODUCED BY THIS PAPER

This appendix collects the definitions of the new terms of art that this paper has introduced.

common SQL name

A *common SQL name* starts with an upper case alphabetic character in the range *A..Z* and then has only upper case alphanumeric characters in the range *A..Z*, or underscore, # or $. A common SQL name doesn't need to be surrounded by double quote characters in a SQL statement; and if it is not so surrounded, the case with which it is written doesn't matter. It may, however, be so surrounded. If it is, then because the SQL parser preserves its case, it must be written in all upper case.

See *Example 2: user-supplied table name* on page 15.

exotic SQL name

An *exotic SQL name* is one that violates the rules for a common SQL name and that *must*, therefore, be surrounded by double quote characters in a SQL statement.

See *Example 2: user-supplied table name* on page 15.

compile-time-fixed SQL statement text

Compile-time-fixed SQL statement text is the text of a SQL statement that cannot change at run time and that can be confidently determined by reading the source code of the PL/SQL unit that executes the SQL statement in question. For dynamic SQL, it is the text of a SQL statement that is a PL/SQL static *varchar2* expression. The value of a PL/SQL static *varchar2* expression cannot change at run time and could be pre-computed at compile time. Because the PL/SQL compiler composes the text of the SQL statement that implements a PL/SQL embedded SQL statement, we regard this, too, as compile-time-fixed SQL statement text.

See *Distinguishing between compile-time-fixed SQL statement text and run-time-created SQL statement text* on page 6.

run-time-created SQL statement text

Run-time-created SQL statement text is the text of a SQL statement that is *not* compile-time-fixed SQL statement text.

See *Distinguishing between compile-time-fixed SQL statement text and run-time-created SQL statement text* on page 6.

SQL syntax template

A *SQL syntax template* looks something like a regular SQL statement but the notion belongs in the domain of discourse of the Design Specification document. Here is an example:

select &&1 from &&2 where &&3 = &4

It is a documentation device to prescribe the set of regular SQL statements that are instances of the template. Instantiation, by a PL/SQL program, is achieved by using regular SQL elements in place of the elements that start with *&&* or *&* in the template. All the other non- whitespace elements in the template must be reproduced faithfully in the instantiation as a regular SQL statement. This includes a SQL hint — but excludes ordinary comments, which can be treated as whitespace.

See *Introducing a new notion: SQL syntax template* on page 4.

value placeholder

A *value placeholder* is the element in a SQL syntax template that starts with *&*. It stands for *either* a well-formed SQL literal *or* a regular placeholder in a regular SQL statement.

See *Introducing a new notion: SQL syntax template* on page 4.

simple SQL name placeholder

A *simple SQL name placeholder* is the element in a SQL syntax template that starts with *&&*. It stands for a simple SQL name in a regular SQL statement.

See *Introducing a new notion: SQL syntax template* on page 4.

static SQL syntax template

A *static SQL syntax template* is a SQL syntax template that can be written down explicitly in the Design Specification document. The implementation that instantiates and executes a static SQL syntax template can always be written like this, and *should* be:

```
<<Some_Inner_Block>>declare
  Stmt constant varchar2(32767) :=
       'select c1 from '
    || Sys.DBMS_Assert.Simple_Sql_Name(Dynamic_Name)
    || ' where PK = :b for update wait '
    || Sys.DBMS_Assert.Enquote_Literal(Dynamic_Value);
begin
  execute immediate Stmt...
  ...
end Some_Inner_Block;
```

The assignment is a single concatenation of one or several PL/SQL static *varchar2* expressions with one or several invocations of any of

- *DBMS_Assert.Enquote_Literal()*, or
- *To_Char(x f, 'NLS_Numeric_Characters = ''.,''')*, or
- *DBMS_Assert.Simple_Sql_Name()*.

A static SQL syntax template can be used, for example, when it would have been possible to use embedded SQL were it not for the fact that the name(s) of the *from* list items are not known until run time.

By definition, compile-time-fixed SQL statement text conforms to a static SQL syntax template.

See *Definition of static SQL syntax template* on page 7.

dynamic SQL syntax template

A *dynamic SQL syntax template* is one of a large set of such templates that are designed to prescribe the regular SQL statements for execution at a particular call site, where the set is too large to allow each to be written down but where, nevertheless, the set can be described with certainty. The description could be written in the Design Specification document using, for example, regular expression syntax.

A set of dynamic SQL syntax templates is needed, for example, to implement a query by example interface of the kind illustrated in the section *"Query by example form"* on page 42. A dynamic SQL syntax template needs to use neither simple SQL name placeholders nor value placeholders in order to be useful — and its safety is easier to determine in a code review when it does not. In such a use, every regular SQL statement that conforms to the set of dynamic SQL syntax templates for a particular call site will be composed using only PL/SQL static *varchar2* expressions.

Run-time-created SQL statement text might conform to a static SQL syntax template or might conform to a dynamic SQL syntax template.

See *Definition of dynamic SQL syntax template* on page 8.

static text

Static text is either

- a PL/SQL static *varchar2* expression as defined in the PL/SQL Language Reference book, or
- an expression formed by an arbitrary concatenation of static text items, or
- the value of a local variable that has been visibly assigned with static text. (A local variable is one that is declared within the present top level PL/SQL block.)

This definition is intentionally recursive. The concatenation may be controlled by tests whose outcome is not known until run time. But it must be self-evident, following trivial human inspection, that every possible concatenation will result only in static text whose ultimate source is only PL/SQL static *varchar2* expressions.

See *Static text* on page 35.

dynamic text

Dynamic text is any text that is not static text. Obvious examples are formal parameters, variables declared at top level in a package without the *constant* keyword, and ordinary variables that are assigned by executing a SQL statement or as the actual argument for the *Buffer* formal parameter to *Utl_File.Get_Line()*.

See *Dynamic text* on page 36.

safe dynamic text

Safe dynamic text is the output of either

- *DBMS_Assert.Enquote_Literal()*, or

- *To_Char(x f, 'NLS_Numeric_Characters = ''.,''')* where *x* is a variable of a numeric datatype and *f* is an the explicit format model *'TM'*, or
- *DBMS_Assert.Simple_Sql_Name()*.

See *Safe dynamic text* on page 36.

safe SQL statement text

Safe SQL statement text is an arbitrary concatenation of static text and safe dynamic text. Local variables may be used for intermediate results or for the final result.

See *Safe SQL statement text* on page 36.

top level PL/SQL block

A top level PL/SQL block is one of the following: a schema-level function; a schema-level procedure; a function or procedure defined at top level within a package body or a type body; a package's initialization block; or the implementation of a trigger. Thus a variable that is declared at top level in a package or package body is, by definition, not a local variable.

See *Static text* on page 35.

APPENDIX B: SUMMARY OF SQL INJECTION PREVENTION RULES

This appendix collects the rules for immunization against SQL injection that have been advocated in this paper.

When composing a SQL statement programmatically, help the code reviewer by declaring variables used for intermediate results as constant.

- ✔ *Rule_1:* When it is necessary to compose a SQL statement programmatically, the code usually needs, or at least benefits from the use of, variables for intermediate results. Aim to declare these as constant, assigning the values in the declarations. This sometimes requires the use of nested block-statements or forward-declared functions. This technique makes code review easier because the reader can be sure that the value of a variable cannot change between its initial assignment and its use. (page 10)

Understand what is meant by the term SQL syntax template and the difference between a static SQL syntax template and a dynamic SQL syntax template.

- ✔ *Rule_2:* Understand what is meant by the term SQL syntax template. Apply this understanding to the design of any code that constructs run-time-created SQL statement text. Understand the difference between a static SQL syntax template and a dynamic SQL syntax template. (page 11)

Understand that SQL injection is the execution of a SQL statement with an unintended SQL syntax template and that the risk can occur only when run-time-created SQL statement text is executed using dynamic SQL.

- ✔ *Rule_3:* Understand how to define the term SQL injection as the execution of a SQL statement with an unintended SQL syntax template. Know that only run-time-created SQL statement text that, therefore, must be executed using dynamic SQL is potentially vulnerable to SQL injection. (page 12)

Expose the database to clients only via a PL/SQL API.

- ✔ *Rule_4:* Expose the database to clients only via a PL/SQL API. Carefully control privileges so that the client has no direct access to the application's objects of other kinds — especially tables and views. (page 29)

Insist that the Design Specification document for ordinary application code defends any propsal to execute SQL using any method other than Embedded SQL.

- ✔ *Rule_5:* When the Design Specification document for ordinary application code proposes to use anything other than embedded SQL, insist on examining the rationale very carefully when the document is reviewed. The design may well be defensible. But this defense must be made explicitly. (page 30)

Use compile-time-fixed SQL statement text unless you cannot. Use Embedded SQL or execute immediate with a PL/SQL static varchar2 expression.

✔ *Rule_6:* Use compile-time-fixed SQL statement text unless you cannot. Use embedded SQL when the SQL statement is of a kind that this supports. Otherwise, use execute immediate with single PL/SQL constant argument composed using only PL/SQL static varchar2 expressions. When you conclude that you cannot, review the Functional Specification document and the Design Specification document carefully with colleagues and then explain in the latter exactly why compile-time-fixed SQL statement text cannot be used. (page 31)

Insist on a justification for a design that proposes to replace a value placeholder in a SQL syntax template.

✔ *Rule_7:* A Design Specification document that proposes to replace a value placeholder in a SQL syntax template (whether this is a static SQL syntax template or a dynamic SQL syntax template) should be regarded with extreme suspicion. It must present a convincing argument for this approach before it is signed off. (page 32)

Insist on a justification for a design that proposes to replace a simple SQL name placeholder in a SQL syntax template.

✔ *Rule_8:* A Design Specification document that proposes to replace a simple SQL name placeholder in a SQL syntax template (whether this is a static SQL syntax template or a dynamic SQL syntax template) should be regarded with some suspicion. It must present a convincing argument for this approach before it is signed off. (page 33)

Don't confuse the need to use a dynamic SQL syntax template with the need to replace value placeholders in the template with SQL literals.

✔ *Rule_9:* Don't confuse the requirement to bind to a set of placeholders whose composition emerges first at run time, which is fully supported by the DBMS_Sql API, with a requirement to use directly encoded literals in pursuit of optimal query execution performance. (page 34)

Dynamic SQL may execute only a concatentation of static text and safe dynamic text. Safe dynamic text is the output of one of exactly three Oracle-supplied functions: Simple_Sql_Name(), Enquote_Literal(), and To_Char(x f, n).

✔ *Rule_10:* When a SQL statement represented by a PL/SQL text expression is executed using one of PL/SQL's APIs for dynamic SQL, then the expression must be safe SQL statement text. Safe SQL statement text is a concatenation of static text and safe dynamic text. Static text is composed only of PL/SQL static varchar2 expressions. Dynamic text is anything that isn't static text. Safe dynamic text is the output of one of exactly three Oracle-supplied functions: DBMS_Assert.Simple_Sql_Name(), DBMS_Assert.Enquote_Literal(), and To_Char(x f, n). (page 36)

Use Simple_Sql_Name(), to ensure the safety of a SQL name. Use Enquote_Literal() to ensure the safety of a string or datetime literal. Use To_Char(x f, n) to ensure the safety of a numeric literal.

- ✔ *Rule_11:* The safe dynamic text produced by DBMS_Assert.Enquote_Literal() or by To_Char(x f, n) should be used only at a spot within the SQL statement where a SQL literal is intended; and the safe dynamic text produced by DBMS_Assert.Simple_Sql_Name() should be used only at a spot within the SQL statement where a simple SQL name is intended. (page 37)

Keep the code that invokes Simple_Sql_Name(), Enquote_Literal(), or To_Char(x f, n) very close to the code that executes the SQL statement that these calls make safe.

- ✔ *Rule_12:* Make the job of the auditor easy by establishing the safety of run-time-created SQL statement text in the code that immediately precedes the PL/SQL statement that executes it. (page 39)

Ensure the safety of the run-time-created SQL statement text in the same way no matter to which of the several Oracle-supplied APIs for executing dynamic SQL you submit it.

- ✔ *Rule_13:* Learn the full list of Oracle-supplied APIs that are designed to execute run-time-created SQL statement text. Ensure the safety such text by using exactly the same rules as you use to ensure the safety of text that is used with native dynamic SQL and the DBMS_Sql API. The approach is identical whether the text represents a complete SQL statement or a component of one. (page 59)

Don't use DBMS_Utility.Exec_DDL_Statement() in new code.

- ✔ *Rule_14:* There is never a good reason to use DBMS_Utility.Exec_DDL_Statement() in new code. Avoid it. (page 60)

APPENDIX C: ADDITIONAL ORACLE-SUPPLIED SUBPROGRAMS THAT IMPLEMENT DYNAMIC SQL

PL/SQL programmers are used to thinking that there are just two ways to execute a SQL statement that is presented as a PL/SQL *text* value: native dynamic SQL and the *DBMS_Sql* API. This is not the case. Others exist, and they are described in this appendix.

Some are designed to accept and execute a complete SQL statement but insist that it must be of a certain kind (for example, a DDL statement of any kind or a DDL statement to create a PL/SQL unit). Others are designed to accept a component of a SQL statement (for example. a *where clause*) and concatenate this with other components that they compose programatically to compose a SQL statement and then execute it.

All these APIs share the property that they were designed specifically on the assumption that it is the caller's responsibility to ensure immunity to SQL injection.

Ensure the safety of the run-time-created SQL statement text in the same way no matter to which of the several Oracle-supplied APIs for executing dynamic SQL you submit it.

> *Rule_13*
>
> Learn the full list of Oracle-supplied APIs that are designed to execute run-time-created SQL statement text. Ensure the safety such text by using exactly the same rules as you use to ensure the safety of text that is used with native dynamic SQL and the *DBMS_Sql* API. The approach is identical whether the text represents a complete SQL statement or a component of one.

DBMS_Utility.Exec_DDL_Statement()

Code_41 shows the important part of the implementation of *DBMS_Utility.Exec_DDL_Statement()*.

```
-- Code_41
Cur := DBMS_Sql.Open_Cursor();
DBMS_Sql.Parse(Cur, Stmt, DBMS_Sql.Native);
DBMS_Sql.Close_Cursor(Cur);
```

It turns out that when *Stmt* is a DDL statement[93], then this code is sufficient to execute it[94]. But for other kinds of statement that are not supported by embedded SQL, like for, for example, *alter session*, it is necessary to call *DBMS_Sql.Execute()*. This fact has the consequence that *DBMS_Utility.Exec_DDL_Statement()* will quietly ignore anything but a DDL statement.

It's hard to imagine a Design Specification document that would prescribe this as the intended behavior. Therefore, in new code, you should use *execute immediate* to execute a DDL statement. And you should use native dynamic SQL or the *DBMS_Sql* API to execute other kinds of statement when embedded SQL cannot be used. The purpose of the calling code is known; and the SQL statement text will have been composed specifically for that purpose.

[93] The list of the kinds of statement that are classified as DDL statements is given in the SQL Language Reference book.

[94] This fact is documented in the PL/SQL Packages and Types Reference book.

Don't use *DBMS_Utility.Exec_DDL_Statement()* in new code.

Rule_14

There is never a good reason to use *DBMS_Utility.Exec_DDL_Statement()* in new code. Avoid it.

DBMS_DDL.Create_Wrapped()

The purpose of this procedure is to create a PL/SQL unit and to store the code in the catalog using the obfuscated representation. The input is the plain text of the appropriate *create or replace* statement. If it was not required to obfuscate the source, you would simply use *execute immediate*.

Use cases do arise where it is appropriate generate a PL/SQL unit programmatically. One example is given by code that implements post-installation steps when ISV code is installed at a customer site. The logic of particular subprograms needs to reflect specific properties of the installation environment. Notice that *Rule_10* on page 36 *and Rule_11* on page 37 limit the freedom with which PL/SQL can be programmatically composed. The huge bulk of such source must be composed as static text; only identifiers and *text* literals within the source may derive from dynamic text. Huge caution must be used with respect to *text* literals[95], even when, as this paper requires, safe dynamic text is used. For example, it would clearly be unsafe to allow safe dynamic text as the argument for *execute immediate*. Probably the only sensible use of anything other than static text is for externally visible names, like the name of the unit itself or of the subprograms it exposes.

DBMS_HS_Passthrough

The pass-through facility provides a mechanism for developers to execute a SQL statement on a non-Oracle system without being interpreted by Oracle Database.

DBMS_HS_Passthrough.Execute_Immediate().

This function runs a SQL statement immediately. Any valid SQL statement except a *select* statement will be run immediately. Internally, the SQL statement is run using the *passthrough SQL* protocol sequence of *Open_Cursor()*, *Parse()*, *Execute_Non_Query()*, *Close_Cursor()*. The SQL statement cannot contain placeholders.

DBMS_HS_Passthrough.Parse()

This function parses the provided SQL statement at the non-Oracle system. The execution of the statement occurs at the subsequent *DBMS_HS_Passthrough.Execute_Non_Query()* or in the case of a *select* statement *DBMS_HS_Passthrough.Fetch()*. The SQL statement cannot contain placeholders.

[95] While composing the source code of a PL/SQL unit using safe *numeric* and *datetime* literals isn't intrinsically risky, it's very hard to see how a sensible Design Specification document could call for this.

OWA_Util

The *OWA_Util* package provides, among other things, the ability to generate HTML pages or page fragments using the results of a *select* statement presented as a PL/SQL *text* value.

OWA_Util.Bind_Variables()

This function is intended to prepare a *select* statement for subsequent use by other *OWA_Util* subprograms. However, it is nothing other than a wrapper for calls to *DBMS_Sql.Open_Cursor()*, *DBMS_Sql.Parse()*, and a series of calls to *DBMS_Sql.Bind_Variable()*. It returns an ordinary *DBMS_Sql* numeric cursor.

OWA_Util.Bind_Variables() has 25 pairs of formal parameters with names like *bv17Name*, *bv17Value*, all with datatype *varchar2*, and with default value *null* so the they can be omitted according to purpose. Each *not null* pair causes a corresponding call to *DBMS_Sql.Bind_Variable()*.

OWA_Util.ListPrint()

This procedure generates an HTML form user-interface element (a selection list) from the output of a *select* statement. It has two versions: the first takes a complete *select* statement as a PL/SQL *text* value; and the second takes a *DBMS_Sql* numeric cursor prepared, for example, by a preceding call to *OWA_Util.Bind_Variables()*.

OWA_Util.TablePrint()

This function generates an HTML fragment to represent the contents of a database table. It does not take full *select* statement; rather, the caller supplies the table's name, a comma separated list of the required columns, and specifies the *where clause* and *order by* clause. The the *where clause* cannot contain placeholders.

APPENDIX D:
SELF-CONTAINED CODE TO ILLUSTRATE IMPLEMENTING CALLBACK USING DYNAMIC POLYMORPHISM.

This code can be run as any ordinary user. To save space, it is written as if none of the objects it creates already exist.

To prove that the implementation that uses dynamic polymorphism gives the same results as the naïve implementation with *execute immediate*, the test harness — procedure *p()* at the end — uses each method in turn to compute a checksum over many invocations with different arguments. You can easily add some timing code — use *DBMS_Utility.Get_CPU_Time()* — and greatly increase the range of input values over which the checksum is computed.

```
create function Callback(Input in integer) return integer is
begin
  return Input*Input;
end Callback;
/


create type Hook authid Current_User is object(
  Dummy number,
  not instantiable member function Callback(
    self in Hook,
    Input in integer ) return integer
)
not final
not instantiable
/


create type My_Implementation under Hook(
  overriding member function Callback(
    self in My_Implementation,
    Input in integer) return integer
)
/


create type body My_Implementation is
  overriding member function Callback(
    self in My_Implementation,
    Input in integer) return integer
  is
  begin
    return Input*Input;
  end Callback;
end;
/


create package Which_Callback is
  function The_Callback return Hook;
end Which_Callback;
/
```

```
create package body Which_Callback is
  -- Implements some logic to chose an instance of
  -- the appropriate subtype of Hook
  function The_Callback return Hook is
    Which constant Hook := My_Implementation(0);
  begin
    return Which;
  end;
end Which_Callback;
/


create procedure p(Name in varchar2, Obj in Hook) is
  No_Of_Repeats    constant pls_integer := 100;
  Checksum         integer;
  n                integer;
  x integer;

  Safe_Name constant varchar2(32767) :=
    Sys.DBMS_Assert.Simple_Sql_Name(Name);
  Stmt constant varchar2(32767) :=
    'begin :x := '||Safe_Name||'(:n); end;';

  procedure Check_It is
  begin
    if(Checksum is null or Checksum <> 338350) then
      Raise_Application_Error(-20000,
        'Callback: unexpected Checksum: ' || Checksum);
    end if;
  end Check_It;
begin
  Checksum := 0;
  n := 0;
  for r in 1..No_Of_Repeats loop
    n := n + 1;
    execute immediate Stmt using out x, in n;
    Checksum := Checksum + x;
  end loop;
  Check_It();

  Checksum := 0;
  n := 0;
  for r in 1..No_Of_Repeats loop
    n := n + 1;
    Checksum := Checksum + Obj.Callback(n);
  end loop;
  Check_It();
end p;
/


begin p('Callback', Which_Callback.The_Callback()); end;
/
```

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How to write SQL injection proof PL/SQL
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