Oracle8*i*

Data Cartridge Developer's Guide

Release 8.1.5

February, 1999

Part No. A68002-01

Oracle8*i* Data Cartridge Developer’s Guide, Release 8.1.5

Part No. A68002-01

Primary Author: Denis Raphaely, Chuck Murray

Contributing Authors: Nippun Agarwal, Sandeepan Banerjee, Dinesh Das, Ravi Murthy, Cahtleen Trezza-Miller.

Contributors: Samuel DeFazio, Robert Hankel, Ravikanth Ksamsetty, Viswanathan Krishnamurthy, Srinath Krishnaswamy, Daniel Mullen, Mark Scardina, Sriram Samu, Tomas Saulys, Jagannathan Srinivasan.

Graphic Designer: Valarie Moore

Contents

Part IV Scenarios and Examples

11 Power Demand Cartridge Example

Send Us Your Comments

Oracle8*i* Data Cartridge Developer's Guide, Release 8.1.5

Part No. A68002-01

Oracle Corporation welcomes your comments and suggestions on the quality and usefulness of this publication. Your input is an important part of the information used for revision.

- Did you find any errors?
- Is the information clearly presented?
- Do you need more information? If so, where?
- Are the examples correct? Do you need more examples?
- What features did you like most about this manual?

If you find any errors or have any other suggestions for improvement, please indicate the chapter, section, and page number (if available). You can send comments to the Information Development department in the following ways:

- Electronic mail - infodev@us.oracle.com
- FAX - (650) 506-7228 Attn: Oracle Server Documentation
- Postal service:
  Oracle Corporation
  Server Documentation Manager
  500 Oracle Parkway
  Redwood Shores, CA 94065
  USA

If you would like a reply, please give your name, address, and telephone number below.

If you have problems with the software, please contact your local Oracle World Wide Support Center.

Preface

This Preface includes the following information:

- How This Book is Organized
- What You Will Need In Addition To This Guide
- Notation

How This Book is Organized

This Guide is organized into 5 parts.

1. **Introduction** — Chapters 1 and 2 provide basic information, including introduction of a comprehensive example.
2. **Data Cartridge Components** — Chapters 3 through 9 lay out the components that go into building a data cartridge.
3. **Advanced Topics** — Chapters 10 and 11 discuss design considerations and using Oracle cartridges.
4. **A Comprehensive Example** — Chapter 12 elaborates the *Power Utility* example introduced in chapter 3.
5. **Reference** — Chapters 13 through 15 provide data cartridge specific reference.

What You Will Need In Addition To This Guide

This book on its own does not provide you with all the information you might need to build every kind of data cartridge. This is because generic Oracle technology — that is, technology that is not specific to data cartridges — is defined in the manuals, guides and reference books that make up rest of the Oracle documentation set.

In reading through the chapters, you will come across many references to these manuals. We suggest that you keep the Oracle documentation set by your side.

Notation

The following notation is used in this Guide:

[ ]	Square brackets enclose optional items in syntax descriptions.
< >	Angle brackets enclose the name of a syntactic element in syntax descriptions.
{ }	Braces enclose items, only one of which is required.
|	A vertical bar separates options within brackets or braces
..	Two dots separate the lowest and highest values in a range.
...	An ellipsis shows that the preceding parameter can be repeated or that statements or clauses irrelevant to the discussion were left out

Part I

Introduction

1 What Is a Data Cartridge?

With the release of Oracle8*i*, the traditional server has evolved into an *Object-Relational Database Management System* (ORDBMS). This means that in addition to the efficient and secure management of data ordered under the relational model, Oracle now also provides support for data organized under the object model. Object types and other Oracle8*i* features, such as large objects (`LOBs`), external procedures, extensible indexing and query optimization, can be used to build powerful, reusable server-based components called *data cartridges*.

This chapter introduces the following introductory information about data cartridges:

- What Are Data Cartridges?
- Why Build Data Cartridges?
- Extending the Server — Services and Interfaces
- Extensibility Services
- Extensibility Interfaces
- Cartridges as Software Components

What Are Data Cartridges?

Within the framework of the Oracle Extensibility Architecture, *data cartridges* are the mechanism for extending the capabilities of the Oracle server. What does this mean?

First, Oracle8*i* lets you capture the business logic and processes associated with domain-specific data in user-defined datatypes. In some cases, where the data cartridge provides new behavior without needing new attributes, the vehicle of implementation may be packages rather than formal types. Once you have defined these types using either of these approaches, Oracle8*i* allows you to determine the manner in which the server interprets, stores, retrieves, and indexes the data. Ultimately, *data cartridges* are the means to package this functionality as software components that can then be plugged into a server to extend its capabilities into a new domain.

This is all possible because the database has itself been made *extensible*. That is, you can now customize the database management system so that it treats user-defined business objects and rich types on a par with native types with regard to server mechanisms such as indexing and query optimization. Where some aspects of a native service is not adequate for the specialized processing you require, you can provide your own implementations of these services. These implementations are then registered with the server using the *extensibility interfaces*.

The key characteristics of data cartridges areas follows:

- *Data cartridges are server- based*. Their constituents reside at the server or are accessed from the server. The bulk of processing for data cartridges occurs at the server, or is dispatched from the server in the form of an external procedure.
- *Data cartridges extend the server.* They define new types and behavior to provide componentized, solution-oriented capabilities previously unavailable in the server. Users of data cartridges can freely use the new types in their application to get the new behavior. Having loaded an Image data cartridge, the user can define a table `Person` with a column `Photo` of type `Image`.
- *Data cartridges are integrated with the server.* The extensions made to the server by defining new types are integrated with the server engine so that the optimizer, query parser, indexer and other server mechanisms recognize and respond to the extensions. The Oracle8*i* Extensibility Framework defines a set of interfaces that enable data cartridges to integrate with the components of the server engine. For example, the interface to the indexing engine allows for domain-specific indexing. Optimizer interfaces similarly allow data cartridges to specify the cost of accessing data by means of its functionality.

- *Data cartridges are packaged.* A data cartridges is installed as an unit. Once installed, the data cartridge handles all access issues arising out of the possibility that its target users might be in different schema, have different privileges and so on.

Why Build Data Cartridges?

The Need to Handle Complex Data Objects

Over the years, virtually every industry has evolved sophisticated models to handle complex data objects that make up the essence of their business. By *data objects*, we mean both the structures that relate different units of information to one another and the operations that are performed on them.

The simple names given these data objects often conceal the complexity of the expertise they embody. For example, the banking industry has many different types of *bank accounts*. Each bank account has customer demographic information, balance information, transaction information, and rules that embody its behavior (deposit, withdrawal, interest accrual, and so forth).

As will be described below, data cartridges allow you to leverage this expertise by encapsulating this business logic in software components that integrate with the Oracle server. The notion of adding logic to data in a database has been available for some time by way of stored procedures. With the addition of object-relational extensions, the Oracle8*i* server can now be enhanced by application programmers and independent software vendors to support a new generation of data types, processes, and logic in order to model business objects.

The Need to Operate on Complex and Multimedia Datatypes

At the same time as business models have led to the development of increasingly complex data objects, the revolution in information technology has made it necessary to work with new kinds of data: satellites images, X-rays, animal sounds, seismic vibrations, chemical models — all these complex and multimedia datatypes are now forms of information that have to be stored and retrieved, queried and analyzed.

Today’s web-based applications routinely include many different kinds of complex data. The ability to extend the database to include application-specific data types as well as the business logic associated with these types requires a new class of networked, content-rich, multi-tiered, distributed applications. As will be described below, data cartridges allow you to meet this need by combining scalar and unstructured datatypes in domain-specific components. You can further combine these components to provide both horizontal (across industries) and vertical (niche specific) functionality.

Data Cartridge Domains

The complexity of data objects, which may entail the need to handle specialized data, gives rise to application *domains*. Put another way: a data cartridge is typically domain-specific. Domains are characterized by content and scope.

In terms of *content*, a data cartridge can accommodate either scalar data or complex and multimedia forms of data. Scalar data is data that can be modeled using native SQL types such as `INTEGER`, `NUMBER`, or `CHAR`. Complex forms of data include time series, matrixes, temperature and magnetic grids, and compound documents. Multimedia types include video, voice, and image data.

In terms of *scope*, a data cartridge can have broad horizontal (cross-industry) coverage or it can be specialized for a specific type of business. For example, a data cartridge for general storage and retrieval of textual data is cross-industry in scope, whereas a data cartridge for the storage and retrieval of legal documents for litigation support is industry-specific.

Table 1–1 shows a way of classifying data cartridge domains according to their content (type of data) and scope (cross-industry or industry-specific), with some examples.

Table 1–1 Data Cartridge Domains by Content and Scope

Content		**Scope**
	Cross-Industry Uses	**Industry-Specific Extensions**
Scalar Data	Statistical conversion	Financial and Petroleum
Multimedia and Complex Data	Text	Legal
	Image	Medical
	Audio/Video	Broadcasting
	Time Series	Securities
	Spatial	Utilities

Oracle8*i* furnished the ability to utilize built-in scalar datatypes to construct more complex user-defined types. The Object-Relational Database Management System has now evolved to the point that Oracle 8*i* now provides foundational cartridges that package multimedia and complex data which can be used as bases for applications across many different industries:

Table 1–2 Oracle Cartridges as Bases for Development

Cartridge	Database Model	Behavior
Time	Ordered list of tuples	Compute Rolling Averages, Compare Time Periods, Construct Calendars...
Text	Tokenized serial byte stream	Display, Compress, Reformat, Index...
Image	Structured large object	Compress, Crop, Scale, Rotate, Reformat...
Spatial	Geometric objects such as points, lines, polygons	Project, Rotate, Transform, Map...
Video	Structured large object of serial (dynamic) image data	Compress, Play, Rewind, Pause...

Following from this, you can see that another way of viewing the relationship of cartridges to domains is to view basic multimedia datatypes as forming a foundation that can be extended in specific ways by specific industries. For example, Table 1–3 shows cartridges that could be built for medical applications:

Table 1–3 Medicine-Specific Extensions to Basic Cartridges

Text	Image	Audio	Video	Time Series	Spatial
Records	MRI	Heartbeat	Teaching	Patient Status	Demographic Analysis

A cartridge providing basic services may be deployed across many industries, as a text cartridge may be utilized within both law and medicine. A cartridge can also leverage domain expertise across an industry, as an image cartridge may provide basic functionality for both X-rays and Sonar within medicine. These cartridges can in turn be further extended for more specialized vertical applications. For instance, any of the cartridges mentioned above could be specialized by being extended by other cartridges:

Table 1–4 Examples of Extensions to a Basic Cartridge

Image
Image -> MRI -> Brain MRI -> Neonatal Brain MRI

In other words, you can develop a cartridge for both horizontal and vertical market penetration.

In summary: data cartridges allow you to define new datatypes and behavior which can then provide, in component form, solution-oriented capabilities previously unavailable in the server. In some cases, where the data cartridge provides new behavior without needing new attributes, the data cartridge may provide PL/SQL packages but not new datatype definitions. Users of data cartridges can freely use the new datatypes in their application to take advantage of the new behavior. For example, after an image data cartridge is installed, you can define a table called *Person* with a *Photo* column of type *Image*

Extending the Server — Services and Interfaces

The Oracle8*i* server provides services for basic data storage, query processing, optimization, and indexing. Various applications use these services to access database capabilities. However, data cartridges have specialized needs because they incorporate domain-specific data. To accommodate these specialized applications, the basic services have been made *extensible* in the Oracle8*i* series of releases.

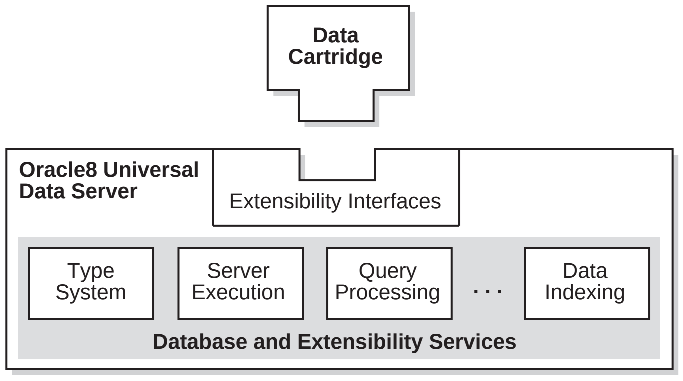
That is, where some aspects of a standard Oracle8*i* service are not adequate for the processing a data cartridge requires, you as the data cartridge developer can provide services that are specially tuned to your cartridge. Every data cartridge can provide its own implementations of these services. These specialized implementations are registered with the server using the Oracle8*i* extensibility interfaces.

For example, suppose you want to build a spatial data cartridge for geographical information systems (GIS) applications. In this case, you may need to implement routines that create a spatial index, insert an entry into the index, update the index, delete from the index, and perform any other required operations. To do this you would register your implementations with the Oracle8*i* server using extensible indexing interface, and then the server will invoke your implementation every time indexing operations were needed for spatial data. In effect, you extend the indexing service of the server.

Extensibility Services

Figure 1–1 shows the standard services implemented by the Oracle8*i* server. This section describes some of these services, not to provide exhaustive descriptions but to highlight major Oracle8*i* capabilities as they relate to data cartridge development.

Figure 1–1 Oracle8i Services



Extensible Type System

The Oracle8*i* universal data server provides both native and extensible type system services. Historically, mainstream applications have focused on accessing and modifying corporate data that is stored in tables composed of native SQL datatypes, such as `INTEGER`, `NUMBER`, `DATE`, and `CHAR`. Oracle8*i* adds support for new types, including:

- user-defined objects
- collections:
  - `VARRAY` (varying length array)
  - multi-set (nested table)
- `REF` (relationship)
- internal large object types:
  - `BLOB` (binary large object)
  - `CLOB` (character large object)
- `BFILE` (external file)

This section discusses these new types.

Object Types

An *object type* differs from native SQL datatypes in that it is user-defined and it specifies both the underlying persistent data (attributes) and the related behaviors (methods). Object types are used to extend the modeling capabilities provided by the native datatypes. You can use object types to make better models of complex entities in the real world by binding data attributes to semantic behaviors.

An object type can have one or more *attributes*. Each attribute has a name and a type. The type of an attribute can be a native SQL type, a LOB, a collection, another object type, or a REF type. The syntax for defining object types is discussed in Chapter 3.

A *method* is a procedure or a function that is part of an object type definition. Methods can access and manipulate attributes of the related object type. Methods can run within the execution environment of the Oracle8*i* server. Methods can also be dispatched outside the server as part of the extensible server execution environment.

Collection Types

Collections are SQL datatypes that contain multiple elements. Each element, or value, for a collection is the same datatype. In Oracle8*i*, collections of complex types can be VARRAYs or nested tables.

A *VARRAY* contains a variable number of ordered elements. The VARRAY datatype can be used for a column of a table or an attribute of an object type. The element type of a VARRAY can be either a native datatype, such as NUMBER, or an object type.

A *nested table* can be created using Oracle8*i* SQL to provide the semantics of an unordered collection. As with a VARRAY, a nested table can be used to define a column of a table or an attribute of an object type.

Relationship Types (REF)

If you create an object table in Oracle8*i*, you can obtain a *reference* that acts as a database pointer to an associated row object. References are important for navigating among object instances, particularly in client-side applications.

The REF operator obtains a reference to a row object. Because REFs rely on the underlying object identity, you can use REF only with an object stored as a row in an object table or objects composed from an object view.

For further information about the REF operator and examples of its use, see the chapter on object types in the *PL/SQL User’s Guide and Reference*.

Large Objects

Oracle8*i* provides *large object* (`LOB`) types to handle the storage demands of images, video clips, documents, and other forms of non-structured data. For an extensive coverage of Large Objects, please see *Oracle8i Application Developer's Guide - Large Objects (LOBs).* Large objects are stored in a way that optimizes space utilization and provides efficient access. Large objects are composed of locators and the related binary or character data. The `LOB` locators are stored in-line with other table columns and, for internal `LOBs` (`BLOB`, `CLOB`, and `NCLOB`), the data can be in a separate database storage area. For external `LOBs` (`BFILE`), the data is stored outside the database tablespaces in operating system files. A table can contain multiple `LOB` columns (in contrast to the limit of one `LONG RAW` column per table). Each `LOB` column can be stored in a separate tablespace, and even on different secondary storage devices.

Oracle8*i* SQL data definition language (DDL) extensions let you create, modify, and delete tables and object types that contain large objects (`LOBs`). The Oracle8*i* SQL data manipulation language (DML) includes statements to insert and delete complete `LOBs`. There is also an extensive set of statements for piece-wise reading, writing, and manipulating of `LOBs` with PL/SQL and the Oracle Call Interface (OCI) software.

For internal `LOB` types, both the locators and related data participate fully in the transactional model of the Oracle server. The data for `BFILEs` does not participate in transactions; however, `BFILE` locators are fully supported by Oracle server transactions. For more information about `LOBs` and transactions, see the *Oracle8i Application Developer's Guide - Large Objects (LOBs).*

With SQL alone, the data residing within Oracle8*i* `LOBs` is opaque and cannot be queried. However, you can use the various `LOB` APIs to build modules, including methods of object types, to access and manipulate `LOB` content. Further, unlike scalar quantities, a `LOB` value cannot be indexed. The extensible indexing framework lets you define the semantics of data residing in `LOBs`, and to manipulate the data using these semantics.

Oracle8*i* provides you a variety of interfaces and environments to access and manipulate `LOBs`, which are described in great detail in *Oracle8i Application Developer's Guide - Large Objects (LOBs).*The use of `LOBs` to store and manipulate binary and character data to represent your domain is discussed Chapter 6, "Working with Multimedia Datatypes".

Extensible Server Execution Environment

The Oracle8*i* type system decouples the implementation of a member method for an object type from the specification of the method. Components of an Oracle8*i* data cartridge can be implemented using any of the popular programming languages. In Oracle8*i*, methods, functions, and procedures can be developed using PL/SQL, external C language routines, or Java. Thus, the database server runtime environment can be extended by user-defined methods, functions, and procedures.

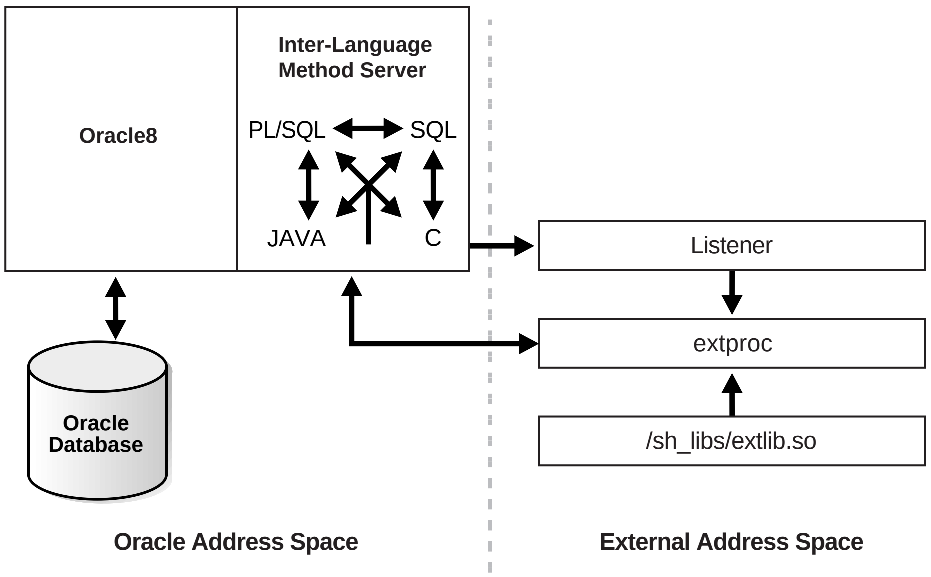
In Oracle8*i*, Java offers data cartridge developers a powerful implementation choice for data cartridge behavior. In addition, PL/SQL offers a data cartridge developer a powerful procedural language that supports all the object extensions for SQL. With PL/SQL, program logic can execute on the server and perform traditional procedural language operations such as loops, if-then-else clauses, and array access.

While PL/SQL and Java are powerful, certain computation-intensive operations such as a Fast Fourier Transform or an image format conversion are handled more efficiently by C programs. With the Oracle8*i* Server, you can call C language programs from the server. Such programs are executed as in a separate address space than the server. This ensures that the database server is insulated from any program failures that might occur in external procedures and, under no circumstances, can an Oracle8*i* database be corrupted by such failures.

With certain reasonable restrictions, external routines can *call back* to the Oracle Server using OCI. Callbacks are particularly useful for processing `LOBs`. For example, by using callbacks an external routine can perform piece-wise reads or writes of `LOBs` stored in the database. External routines can also use callbacks to manipulate domain indexes stored as Index-Organized Tables in the database.

Figure 1–2 External Program Executing in Separate Address Space

Extensible Indexing



Typical database management systems support a few types of access methods (B+Trees, Hash Indexes) on a limited set of data types (numbers, strings, and so on). For simple data types such as integers and small strings, all aspects of indexing can be easily handled by the database system. However, in recent years, databases are being used to store different types of data such as text, spatial, image, video and audio that require content-based retrieval. This raises the need for indexing complex data types and also specialized indexing techniques.

Complex data types have application-specific formats, indexing requirements, and selection predicates. For example, there are many different means of document encoding (ODA, XML, plain text) and information retrieval techniques (keyword, full-text boolean, similarity, probabilistic, and so on). Similarly, R-trees are an efficient method of indexing spatial data. No database server can be built with support for all possible kinds of complex data and indexing. Oracle's solution is to build an extensible server which lets you define new index types as required.

The framework to develop new index types is based on the concept of cooperative indexing where a data cartridge and the Oracle server cooperate to build and maintain indexes for data types such as text, spatial and On-line-Analytical

Processing (OLAP). The cartridge is responsible for defining the index structure, maintaining the index content during load and update operations, and searching the index during query processing. The index structure itself can either be stored in Oracle database as an index-organized table or externally as an operating system file.

To this end, Oracle8*i* introduces the concept of an *indextype*. The purpose of an indextype is to enable efficient search and retrieval functions for complex domains such as text, spatial, image, and OLAP by means of a data cartridge. An indextype is analogous to the sorted or bit-mapped index types that are built-in within the Oracle Server. The essential difference is that the implementation for an indextype is provided by the data cartridge developer, whereas the Oracle kernel implements built-in indexes. Once a new indextype has been implemented by a data cartridge developer, end users of the data cartridge can use it just as they would built-in indextypes.

With extensible indexing, the application

- defines the structure of the domain index,
- stores the index data either inside or outside the Oracle database, and
- manages, retrieves and uses the index data to evaluate user queries.

When the database system handles the physical storage of domain indexes, data cartridges

- define the format and content of an index. This enables cartridges to define an index structure that can accommodate a complex data object.
- build, delete, and update a domain index. The cartridge handles building and maintaining the index structures. Note that this is a significant departure from the medicine indexing features provided for simple SQL data types. Also, since an index is modeled as a collection of tuples, in-place updating is directly supported.
- access and interpret the content of an index. This capability enables the data cartridge to become an integral component of query processing. That is, the content-related clauses for database queries are handled by the data cartridge.

Typical database systems (RDBMS and ORDBMS) do not support extensible indexing. Consequently, many applications maintain file-based indexes for complex data residing in relational database tables. A considerable amount of code and effort is required to maintain consistency between external indexes and the related relational data, support compound queries (involving tabular values and external indexes), and to manage a system (backup, recovery, allocate storage, and so on) with multiple forms of persistent storage (files and databases). By supporting extensible indexes, the Oracle8*i* Server significantly reduces the level of effort needed to develop solutions involving high-performance access to complex datatypes.

Extensible Optimizer

The extensible optimizer functionality allows authors of user-defined functions and indexes to create statistics collection, selectivity, and cost functions. This information is used by the optimizer in choosing a query plan. The cost-based optimizer is thus extended to use the user-supplied information; the rule-based optimizer is unchanged.

The optimizer generates an execution plan for a SQL statement. An execution plan includes an access method for each table in the `FROM` clause, and an ordering (called the join order) of the tables in the `FROM` clause. System-defined access methods include indexes, hash clusters, and table scans. The optimizer chooses a plan by generating a set of join orders or permutations, computing the cost of each, and selecting the one with the lowest cost. For each table in the join order, the optimizer computes the cost of each possible access method and join method and chooses the one with the lowest cost. The cost of the join order is the sum of the access method and join method costs. The costs are calculated using algorithms which together compose the cost model. A cost model can include varying level of detail about the physical environment in which the query is executed. Our present cost model includes only the number of disk accesses with minor adjustments to compensate for the lack of detail. The optimizer uses statistics about the objects referenced in the query to compute the costs. The statistics are gathered using the `ANALYZE` command. The optimizer uses these statistics to calculate cost and selectivity. The selectivity of a predicate is the fraction of rows in a table that will be chosen by the predicate. It is a number between 0 and 100 (expressed as percentage).

Extensible indexing functionality allows users to define new operators, index types, and domain indexes. For such user-defined operators and domain indexes, the extensible optimizer functionality will allow users to control the three main components used by the optimizer to select an execution plan: *statistics*, *selectivity*, and *cost*.

Extensibility Interfaces

Extensibility interfaces fall into the following classes:

- DBMS interfaces

- Cartridge basic service interfaces
- Data cartridge interfaces

DBMS Interfaces

The DBMS interfaces are the simplest kind of extensibility services. DBMS interfaces are made available through extensions to SQL or to the Oracle Call Interface (OCI). For example, the extensible type manager utilizes the CREATE TYPE syntax in SQL. Similarly, extensible indexing uses DDL and DML support for specifying and manipulating indexes.

Cartridge Basic Service Interfaces

Generic interfaces provide basic services like memory management, context management, internationalization, and cartridge-specific management. These cartridge basic interface services are used by data cartridges to implement behavior for new datatypes in the context of the server's execution environment. These services provide helper routines that make it easy for data cartridge developers to write robust, portable server-side methods.

Data Cartridge Interfaces

Sometimes the DBMS needs to call the data cartridge functions for implementations provided by the data cartridge developer. So, for user-defined indexing, the DBMS must use the implementation of the index interface whenever an index search or fetch operation is performed. For user-defined query optimization, the query optimizer must call functions implemented by the data cartridge to compute cost of user-defined operators or functions.

These standard data cartridge functions are similar to callback functions that the DBMS can invoke. In the future, data cartridge interfaces will be made available to enable the data cartridge to include the specifications for such functions.

Cartridges as Software Components

The accumulated expertise that underlies a set of data objects comprises a knowledge base that can be marketed as a stand-alone cartridge, or as a cartridge that could be extended in different ways by different users. But how does one achieve this? The data and rules that apply to the software components are often spread across many different applications. With data cartridges, you gather the definition and rules together for use throughout the data processing environment.

Packaging domain-specific component expertise in a data cartridge allows the cartridge to access the corporate information repository and add both organizational and operational value to the data. Such *software components* are applications that can be "plugged" into other software components, and which are themselves "pluggable".

Their constituents reside at the server or are accessed from the server. Most processing for data cartridges occurs at the server or is dispatched from the server in the form of an external procedure.

The Structure of a Data Cartridge

A data cartridge generally defines one or more object types. Object types from this and potentially other data cartridges can provide users with new or extended capabilities conveniently packaged. A data cartridge includes both the definition of object types and the code that implements their capabilities. A data cartridge can be used as the foundation for the definition of other data cartridges.

Each object type includes two components. The order in which these components are made available to the server (that is, the order in which they are defined) is important. The major components include:

- Object type specification
- Object type body code

In addition, a data cartridge may use the extended server execution environment. The use of external procedures involves two additional components:

- External library linkage specification
- External library code

Simple data cartridges consist of these components, which are described in this section. More complex data cartridges will use the extensibility services and interfaces (see Chapter 9, "Using Cartridge Services"). Complex Data Cartridges contain domain operators and domain indextypes (see Chapter 7, "Building Domain Indexes"), and optimization functions (see Chapter 8, "Query Optimization").

Object Type Specification

A data cartridge consists of one or more of these domain-specific objects packaged and integrated with the server. Each domain-specific type is an *object type* (or ODT, for object data type) and includes both of the following:

- *Attribute* data that holds object state information

  Attributes can be defined using built-in datatypes or other object types.

- *Methods* that incorporate the object’s behavior

  Methods can be simple (such as adding two numbers) or complex (such as computing prices of financial derivatives), and can be coded either in PL/SQL or in a third-generation language (3GL) such as C.

The *object type specification* gives the object a name, and it defines the types of persistent data, called attributes, that an instance of this object will include. It also specifies names, return values, and argument types of the related behaviors, or methods. Much like a C++ class definition in a header (.h) prefix file, the type specification lays out the object framework (attributes and method signatures), but does not include the actual method code that performs the functions. The object type specifications for the various object types defined by your data cartridge will be written in SQL and stored in a SQL script that will be input to the server at cartridge installation time.

Object Type Body Code

The *type body* provides the code that implements the object type's methods. Method code can be implemented in PL/SQL, Java, C, C++, or any other 3GL. Most simple methods can be written in PL/SQL and Java. (See the *PL/SQL User’s Guide and Reference* for a complete discussion of PL/SQL syntax.)

Code written in C, C++, and other 3GLs must be packaged in a runtime or dynamic link library. This is described in "External Library Linkage Specification" on page 1-16 and "External Library Code" on page 1-17.

External Library Linkage Specification

If the implementation of your methods is in C, C++, or some other 3GL, the methods must be packaged within a runtime or dynamic link library. The external library linkage specification is necessary to tell the server about this library, including its location, the binding of the type's methods to the library's entry points, and the methods’ parameters.

Any 3GL code dispatched through the external library linkage specification will run in a separate process from the Oracle server. As such, the dispatch involves communication overhead. In deciding which methods should be implemented in external libraries, you should be aware of this overhead. In general, the cost of dispatch is less significant for methods that are complex or computation intensive.

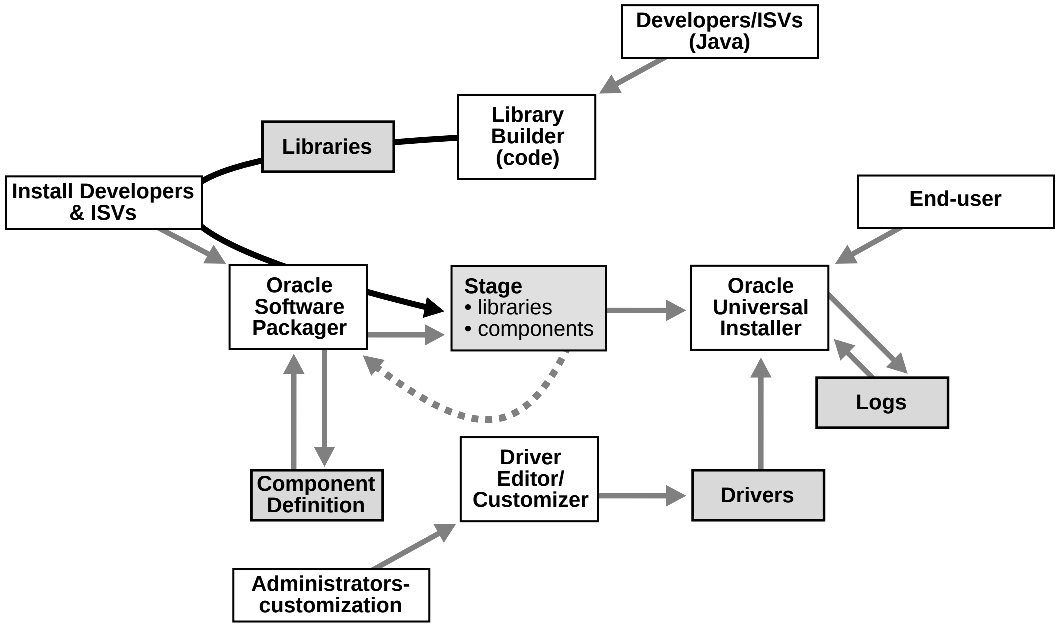
External Library Code

The external library is the runtime or dynamic link library that contains any 3GL method code. You implement the 3GL methods in a language such as C, and then use operating-system-specific commands to build a shared-object library on UNIX platforms or a DLL on Windows NT systems.

Installing a Data Cartridge

Data cartridges are packaged so that their constituents (type definitions, PL/SQL packages, external procedures, users, roles, synonyms, and so forth) can be installed into or de-installed from the Oracle universal data server as a unit.

Figure 1–3 Installation of a Data Cartridge Using the Oracle Software Packager



The preceding diagram describes the relationship between the *Oracle Universal Installer* and the *Oracle Software Packager*, as well as other components that you may need to deploy. For more information, see the *Oracle Software Packager User's Guide.*

2 Roadmap to Building a Data Cartridge

This chapter describes a recommended development process, including relationships and dependencies among parts of the process. Topics include:

Development Process

The simplest questions are the most profound: *Who? What? When? Where? How?* You could say that this chapter is concerned with the *when* and *where* of *how*. But before we examine the road-map to building data cartridges, it would be wise to give a moment to viewing the project as a whole.

What

The very first step in developing a data cartridge is to establish the domain-specific value you intend to provide. Clearly define the new capabilities the cartridge will make available. More specifically: What are the objects that cartridge will expose to users as a means to accessing to these capabilities?

Who

Who are the intended users of this cartridge? Are they other developers — in which case the extensibility of the cartridge is of crucial importance. Are they end- users — in which case the cartridge must be highly attuned to the domain in question. Building a cartridge is a non-trivial project that should be founded in a business model that clearly distinguishes who these users are.

Being realistic about the complexity of building a data cartridge, raises the question of who it is that will perform the task. Are all the necessary skills present in the development team? Most essentially, the developers (be they one or many) must be able to bridge the object-relational database management system with the domain.

When and Where

What are the deliverables? How much time is there for development? Is there a software development process? The project is much more likely to succeed if there are clearly defined expectations and milestones. This chapter should aid you in mapping out a realistic development path.

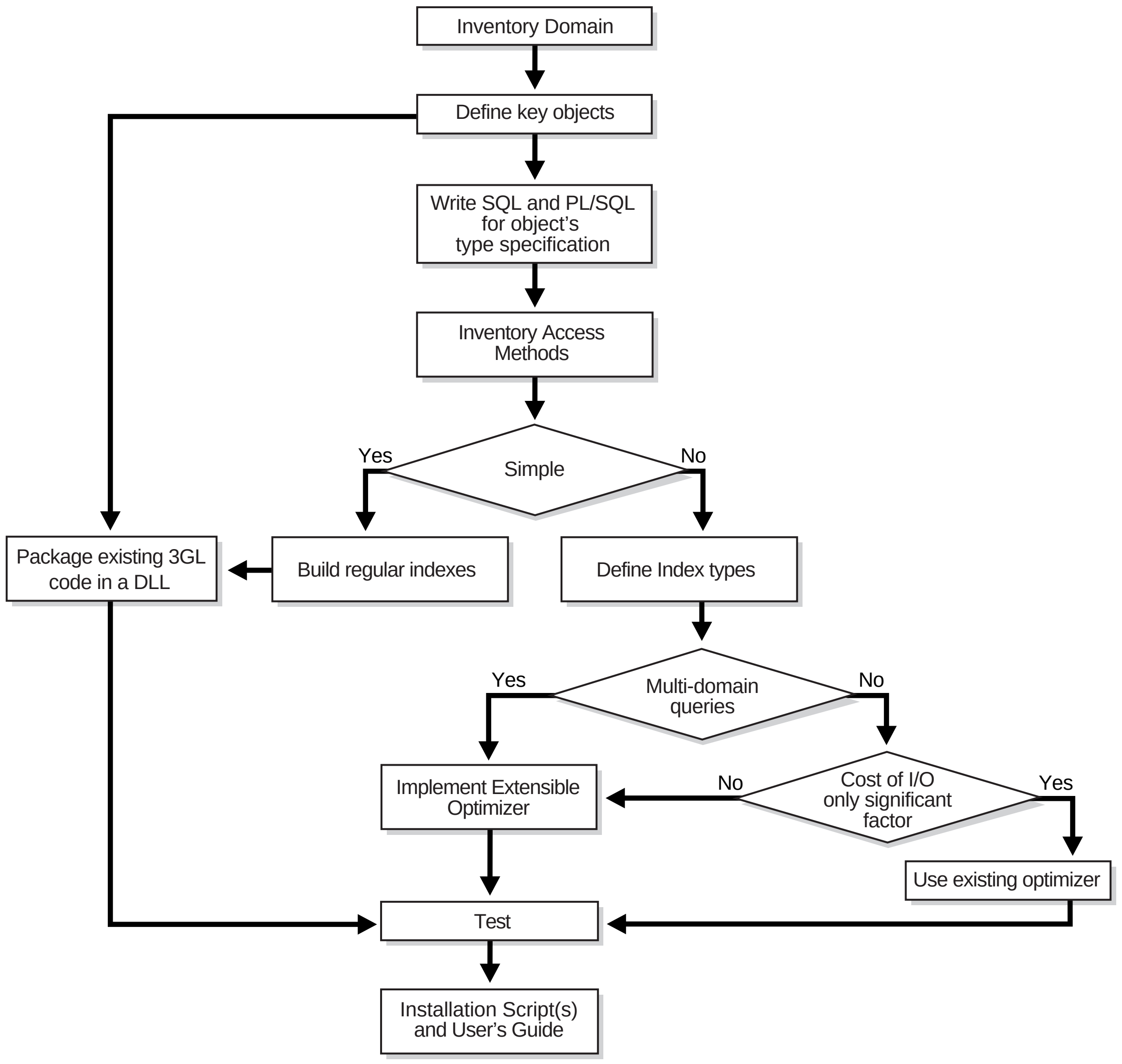
How

Choose and design objects so that their names and semantics are familiar in the developer's and users' domain. Given the complexity of the project, you should consider using one of the standard object-oriented design methodologies.

In defining a collection of objects, give care to the interface between the SQL side of object methods and the 3GL code that incorporates your value-added technology. Keep this interface as simple as possible by limiting the number of methods that call out to library routines and by allowing the 3GL code to do a block of work independently. Avoid defining hundreds of calls into low-level library entry points.

With this interface defined, you can proceed along parallel paths, as illustrated in Figure 2–1. You can complete the paths sequentially or alternately work among the paths until you complete all three.

Figure 2–1 Cartridge Development Process


Inventory Domain
Define key objects
Write SQL and PL/SQL for object's type specification
Inventory Access Methods
Simple
Yes
No
Package existing 3GL code in a DLL
Build regular indexes
Define Index types
Multi-domain queries
Yes
No
Implement Extensible Optimizer
Cost of I/O only significant factor
No
Yes
Use existing optimizer
Test
Installation Script(s) and User's Guide

The ’leftmost’ of these parallel paths packages any existing 3GL code that performs operations relevant to your domain in a DLL, possibly with new entry points on top of old code. The DLL will be called by the SQL component of the object's method code. Where possible, this code should all be tested in a stand-alone fashion using a 3GL test program.

The ’middle’ path defines and writes the object's type specification and the PL/SQL components of the object's method code. Some methods may be written entirely in PL/SQL, while others may call into the external library. If your application requires an external library, provide the library definition and the detailed bindings to library entry routines.

The direction you take at the choice point results from the simplicity or complexity of the access methods you need to deploy, which in turn derives from the nature of the data as represented by columns in the table. If you the methods you need to query your data are relatively simple, you can build regular indexes. By contrast, dealing with complex data means you will need to define complex index types as the basis for making use of Oracle’s extensible indexing technology. If you are in addition faced with implementing multi-domain queries, you should choose to make use of Oracle’s extensible optimizer technology.

It may be that you do not have execute queries on multiple domains. If I/O is the only significant factor affecting performance, you can make use of standard optimizing techniques. If, however, there are other factors in play, you may still need to utilize the extensible optimizer.

Finally, you will want to test the application and create the necessary installation scripts.

Installation and Use

Before you can use a data cartridge, you must install it. Installation is the process of assembling the sub-components so that the server can locate them and understand the object type definitions.

Putting the sub-components in place involves defining object types and tables in the server (usually accomplished by running SQL scripts), putting dynamic link libraries in the location expected by the linkage specification, and copying on-line documentation, help files, and error message files to a managed location.

Telling the server about the object types involves running SQL scripts that load the individual object types defined by the cartridge. This step must be done from a privileged account.

Finally, users of the cartridge must be granted the necessary privileges to use it.

Requirements and Guidelines for Data Cartridge Constituents.

The following requirements and guidelines apply to certain database objects associated with the data cartridge.

Schema

The database components that make up each cartridge must be installed in a schema of the same name as the cartridge name. If a cartridge needs multiple schemas, the first 10 characters of the schema must be the same as the cartridge name. Note that the maximum permissible length of schema names in Oracle8*i* is 30 bytes (30 characters in single-byte languages.)

The following database components of a data cartridge must be placed in the cartridge schema:

- Type names
- Table names
- View names
- Directory names
- Library names
- Package names

The choice of a schema name determines the Oracle username, because the schema name and username are always the same in Oracle8*i*.

Globals

Some database-level constituents of cartridges may be global in scope, and so not within the scope of a particular user (schema) but visible to all users. Examples of such globals are:

- Roles
- Synonyms
- Sequences

All globals should start with the cartridge name. For example, a global role for the Acme video cartridge should have a unique global name like *C$ACMEVID1ROL1*, and not merely *ROL1*.

Error Message Names or Error Codes

Currently, error codes 2000-2099 are reserved for user errors or application errors. When a cartridge encounters an error, it should generate an error of the form *ORA 2000: %s*, where *%s* is a place holder for a cartridge-specific error message. Cartridge developers must ensure that their error messages are unique. You can ensure uniqueness by having all cartridge-specific error messages consist of a cartridge message name in the format C$pppptttm-nnnn, as well as a cartridge message text. For example, an error raised by the Acme video cartridge might reported as:

```
ORA 2000: C$ACMEVID1-0001: No such file
```

In this example:

- `ORA 2000` is the server error code.
- `C$ACMEVID1` is the cartridge name.
- `0001` is the number assigned by Acme for this specific error.
- `No such file` is the description of the error, as written by Acme.

Cartridge Installation Directory

In many cases, a cartridge installation directory is desirable. All the operating system-level components of the cartridge, such as shared libraries, configuration files, and so on, can be put under a directory that is specific to a vendor or organization.

This directory name should be the same as the prefix chosen by the organization, and the directory should be created under the root directory for the platform. For example, if the Acme Cartridge Company needs to store any files, libraries, or directories, it must create a directory /ACME, and then store any files in cartridge-specific subdirectories.

Files

Message files that associate cartridge error or message numbers with message text can be put in one or more cartridge-specific subdirectories.

Configuration files can be placed in a cartridge-specific subdirectory. For example:

```
/ACME/VID1/Config
```

Shared Library Names for External Procedures

Use one of the following guidelines for each shared library (.so or .dll file):

- Place it in the cartridge installation directory. In this case, ensure that all library names are unique.
- Place it in a directory other than the cartridge installation directory. In this case, the file name should start with the cartridge name without the *C$* part. If there are multiple such libraries, the name should start with the first seven letters of the cartridge name without the *C$* part.

Deployment Checklist

At the *deployment* level, you will face a number of common issues. The most optimal approach to these problems will depend on the particular needs of your application. We list the tasks that we think should form the basis of your checklist, and in some cases propose solutions.

- You will need a way to install and de-install your cartridge components. This includes libraries, database objects, flat files, programs, configuration tools, administration tools, and other objects. Explore whether your cartridge might be able to utilize the *Oracle Universal Installer* and the *Oracle Software Package*r (see the *Oracle Software Packager User's Guide.).*
- You should allow for installation of multiple versions of a cartridge to provide backward compatibility and availability. Make use of Oracle's migration facilities as part of your larger strategy.
- You will need to track which cartridges are installed in order to install data cartridges that depend on other data cartridge, or to handle different versions of installed components.
- You will need to provide an upgrade path for migrating to newer versions of cartridges. Make use of Oracle's migration facilities as part of your larger strategy.
- To be able to limit access to cartridge components to specific users and roles, deploy Oracle's security mechanisms together with a blend of procedures that operate under invoker's and definer's rights depending on the need.

- You will need to be able to keep track of which users have access to a cartridge (for ease of administration). Consider making use o fa table with appropriate triggers.
- How do you know where cartridges are installed? This is more of a security/administration concern than a requirement. There is currently no easy way of knowing which cartridges are installed in a particular database or what users have access to the cartridge or any of its components.

Naming Conventions

This section discusses how the components of a data cartridge should be named. It is intended for independent software vendors (ISVs) and others who are creating cartridges to be used by others.

Note: Most examples in this manual do not follow the naming conventions, because they are intended to be as simple and generic as possible. However, as your familiarity with the technology increases and you consider building data cartridges to be used by others, you should understand and follow these naming conventions.

The naming conventions in this chapter assume a single-byte character set. "National Language Support (NLS)" described elsewhere in this document discusses other character sets.

Need for Naming Conventions

In a production environment, an Oracle8*i* database may have multiple data cartridges installed. These data cartridges may be from different development groups or vendors, and may have been developed in isolation. Each data cartridge consists of various schema objects inside the database, as well as other components visible at the operating system level, such as external procedures in shared libraries. If multiple data cartridges tried to use the same names for schema objects or operating system-level entities, the result would be incorrect and inconsistent behavior.

Furthermore, because exception conditions during the runtime operation of data cartridges can cause the Oracle8*i* server to return errors, it is important to prevent conflicts between error or message codes of different data cartridges. These conflicts can arise if, for example, two cartridges use the same error code for different error conditions. Having unique error and message codes ensures that the origin of the exception condition can be readily identified.

Unique Name Format

To prevent multiple data cartridge components from having the same name, Oracle recommends the following convention to ensure unique naming of data cartridges. Naming is to be done on a per-vendor or per-supplier basis. That is, each organization developing data cartridges must choose an unique name, and Oracle will provide a name reservation service.

Each organization should choose an reserve a prefix. Oracle will add C$ to the start of the string chosen by the organization, to ensure a unique prefix. This prefix can then be used to name the database schema in which the database components of the data cartridge reside, or to name the directory in which the operating-system components of the data cartridge are placed.

Data cartridges and their components should have names of the following format:

C$pppptttm.ccccccccc

The following table describes the parts of this naming convention format.

Table 2–1 Data Cartridge Naming Conventions

Part	Explanation	Example
C$	Recommended by Oracle for all data cartridges.	
pppp	Prefix selected by the data cartridge creator. (Must be exactly four characters.)	`ACME`
ttt	Type of cartridge, using an abbreviation meaningful to the creator. Three characters.	`AUD (for` *audio*`)`
m	Miscellaneous information indicator, to allow a designation meaningful to the creator. One character.	`1 (perhaps a version number)`
. (period)	Period required if specifying an object in full *schema.object* form.	
`ccccccccc`	Component name. Variable length.	`mf_set_volume (method function adjusting volume)`

Oracle recommends that except for the dollar sign ($) as the second character, all characters in the name should be alphanumeric (letters and numbers, with underscores and hyphens permitted).

For example, Acme Cartridge Company chooses and registers a prefix of *ACME*. It provides an audio data cartridge and a video data cartridge, and chooses *AUD* and *VID* as the type codes, respectively. It has no other information to include in the cartridge name, and so it chooses an arbitrary number *1* for the miscellaneous information indicator. As a result, the two cartridge names are:

- C$ACMEAUD1
- C$ACMEVID1

For each cartridge, a separate schema must be created, and Acme uses the cartridge name is the schema name. Thus, all database components of the audio cartridge must be created under the schema C$ACMEAUD1, and all database components of the video cartridge must be created under the schema C$ACMEVID1. Examples of some components might include:

- `C$ACMEVID1.mf_rewind`
- `C$ACMEVID1.vid_ops_package`
- `C$ACMEVID1.vid_stream_lib`

Each organization is responsible for specific naming requirements after the *C$pppp* portion of the object name. For example, Acme Cartridge Company must ensure that all of its cartridges have unique names and that all components within a cartridge have unique names.

Name Registration

To register the prefix for your organization, send e-mail to the Oracle Data Cartridge Program with your proposed four-character prefix. Send the message to the following address:

```
dcprog@us.oracle.com
```

Oracle will send you a confirmation that the prefix (with *C$* added at the start) has been reserved for you.

Cartridge Registration

How do you register cartridges and components?

In order to make a naming scheme work, you need to have a registration process that will handle the administration of names of components that make up a data cartridge.

Directory Structure and Standards

You need some directory standard to know where to put your binaries, support files, messages files, administration files, and libraries.

You also need to define a database user who will install your cartridges. One possible solution is to use EXDSYS, for External Data Cartridge System user.

Note:

The EXDSYS user is a user with special privileges required for running cartridges. This user could be installed as part of cartridge installation, but would better be part of the database installation. To do this, you will need to move this process into a standard database creation script.

Your long range planning should consider ways to integrate directory structure with the Network Computer Architecture (NCA).

Cartridge Upgrades

Administrators need a safe way to upgrade a cartridge and its related meta-data to a newer version of the cartridge. You also require a process for upgrading data and removing obsolete data. This may entail installation support (Enterprise Manager) and database support for moving to newer database cartridge types

Administrators also require a means to update tables using cartridge types when a cartridge changes.

Import and Export

In order to handle the import and export handle objects, you need to understand how Oracle's import and export facilities handle Oracle8*i* objects. In particular, you need to know how types are handled and whether the type methods are imported and exported, and also whether user defined methods are supported.

Cartridge Versioning

There are two types of cartridge versioning problems that need to be addressed. They are:

- Internal Versioning
- External Versioning

Internal Versioning

Internal versioning is the harder problem. Ideally, you would like a mechanism to support multiple versions of a cartridge in the database. This would provide backward compatibility and also make for high availability.

Types are amenable to changing methods, but not to changing the type attributes themselves. This implies that upgrades are complicated for types that change over time. You may need a way to use multiple versions of type, and some method to insure that administrators can gradually update your technology.

External Versioning

External versioning is the easier of the two versioning problems. You need to be able to track a cartridge version number and be able to take action accordingly upon installation or configuration based on versioning information.

Internationalization

You may want to internationalize your cartridges. This means they will need to be able to support multiple languages and have access to an NLS facility for messages as well as an NLS facility for parsing.

It is recommended that the names for data cartridge components be chosen using the ASCII character set.

If you must name the data cartridge components in a character set other than ASCII, Oracle8*i* will still assign you a four-character unique prefix. This will, however, increase the number of bytes required to hold the prefix. The names of all Oracle schema objects must fit into 30 bytes. In ASCII, this equals 30 characters. If you have, for example, a six-byte character set and request a four-character prefix string, Oracle may truncate your request to a smaller number of characters.

External Access

- How do administrators know who has access to a cartridge?

Administrators need to administer access rights to internal and external components such as programs and data files to specific users and roles.

Internal Access

- How do administrators restrict access to certain tables, types, views, and other cartridge components to individual users and roles?

  Administrators for security reasons must be allowed to restrict access to types on an individual basis.

  For instance, some data cartridges, such as Oracle's Image Cartridge, have few security issues. These cartridges may grant privileges to every user in the database. Other cartridges that are more complex, such as Oracle' Time Series Cartridge, may need differing security models. In building complex data cartridges, you will need a way to identify the various components that make up a cartridge and also an instance of a cartridge and be able to grant and revoke security roles on identifiable components.

  It may be that Oracle will provide a visual tool will identify components of a cartridge and allow roles be assigned to each component.

Invoker's Rights

Invoker's rights is a special privilege that allows the system to access database objects that it wouldn't normally have access to. This has been the case for the special SYS user. It also will need to be done for cartridges under whatever user you use (e.g. EXDSYS).

If you don't have invoker's rights, then any types you construct in a central user space (e.g. EXDSYS) will have to grant privileges to public, which is not necessarily desirable.

Test and Debug Services

You will need a way to test and debug your cartridges.Please refer to the guides which pertains to your operating environment (PL/SQL, Java, C/C++)

Administration

Configuration

Data Cartridges need a front end to handle deployment issues, such as installation, as well as configuration tools. While each data cartridge may have differing security needs, a basic front end that allows a user to install, configure, and administer data cartridge components is necessary.

This front end may just be some form of knowledge base or on-line documentation. In any case, it should be on-line, easily navigable, and contain templates exhibiting standards and starting points.

Suggested Development Approach

In developing a data cartridge, it is best to take a systematic approach, starting with small, easy tasks and building incrementally toward a comprehensive solution.This section presents a suggested approach.

To create a prototype data cartridge:

1. Read this book and try the examples on disk and in example chapter.
2. Create the prototype of your own data cartridge, creating a single object type and a few data elements and methods. You can add object types, data elements, and methods, specific indextypes, and user-defined operators as you expand the cartridge's capabilities.)
3. Begin by implementing your methods entirely in SQL, and add callouts to 3GL code (if any) later.
4. Test and debug your cartridge.

After you have the prototype working, you may want to follow a development process that includes these steps:

1. Identify your areas of domain expertise.
2. Identify those areas of expertise that are relevant to persistent data.
3. Consider the feasibility of packaging one or more of these areas as a new data cartridge or as an extension to an existing cartridge.
4. Use an object-oriented methodology to help decide what object types to include in data cartridges.
5. Build and test the cartridges, one at a time.

Part II

Building Data Cartridges

3

Defining Object Types

This chapter summarizes provides an example of starting with a schema for a data cartridge. Object types are crucial to building data cartridges in that they enable domain-level abstractions to be captured in the database.

Topics include:

- Objects and Object Types
- Assigning an OID to an Object Type
- Constructor Methods
- Object Comparison

For information about creating and using object types, following manuals also contain relevant information:

- *Oracle8i Concepts*
- *Oracle8i Application Developer's Guide - Fundamentals*
- *PL/SQL User's Guide and Reference*.

For example, the *Oracle8i Application Developer's Guide - Fundamentals* describes the creation of types as columns in relational tables, the use of types as rows in object tables, forward type declarations, object type dependencies, and object type references.

Objects and Object Types

Note: The production release of this documentation will discuss the following topics in terms of the example application. Here we only refer to this technology in general terms.

In the Oracle8*i* ORDBMS, you use object types to model real-world entities. An object type has attributes, which reflect the entity's structure, and methods, which implement the operations on the entity. Attributes are defined using built-in types or other object types. Methods are functions or procedures written in PL/SQL or an external language like C and stored in the database.

A typical use for an object type is to impose structure on some part of the data kept in the database. For example, an object type named *DataStream* could used by a cartridge to store large amounts of data in a character `LOB`. (`LOBs`, or *large objects*, are discussed elsewhere in this document and in the *Oracle8i Application Developer's Guide - Large Objects (LOBs)*.) This object type has attributes such as an identifier, a name, a date, and so on. The following statement defines the *DataStream* datatype:

```
CREATE OR REPLACE TYPE DataStream AS OBJECT (
   id INTEGER,
   name VARCHAR2(20),
   createdOn DATE,
   data CLOB,
   MEMBER FUNCTION DataStreamMin  RETURN pls_integer,
   MEMBER FUNCTION DataStreamMax  RETURN pls_integer,
   MAP MEMBER FUNCTION DataStreamToInt  return integer,
   PRAGMA restrict_references(DataStreamMin, WNDS, WNPS),
   PRAGMA restrict_references(DataStreamMax, WNDS, WNPS));
```

A method is a procedure or function that is part of the object type definition and that can operate on the object type data attributes. Such methods are called **member methods**, and they take the keyword `MEMBER` when you specify them as a component of the object type. The *DataStream* type definition declares three methods. The first two, *DataStreamMin* and *DataStreamMax*, calculate the minimum and maximum values, respectively, in the data stream stored inside the character `LOB`.

The third method (*DataStreamToInt*), a **map method**, governs comparisons between instances of data stream type. Map methods are described in elsewhere in this document.

The pragma (compiler directive) RESTRICT_REFERENCES is necessary for security, and is discussed below.

After declaring the type, define the type body. The body contains the code for type methods. The following example shows the type body definition for the *DataStream* type. It defines the member function methods (*DataStreamMin* and *DataStreamMax*) and the map method (*DataStreamToInt*).

```
CREATE OR REPLACE TYPE BODY DataStream IS

    MEMBER FUNCTION DataStreamMin RETURN pls_integer IS
      a pls_integer := DS_Package.ds_findmin(data);
      BEGIN RETURN a; END;
    MEMBER FUNCTION DataStreamMax RETURN pls_integer IS
      b pls_integer := DS_Package.ds_findmax(data);
      BEGIN RETURN b; END;
    MAP MEMBER FUNCTION DataStreamToInt RETURN integer IS
      c integer := id;
      BEGIN RETURN c; END;
END;
```

DataStreamMin and *DataStreamMax* involve calling routines in a PL/SQL package called *DS_Package*. Since these methods are likely to be compute-intensive (they process numbers stored in the CLOB to determine minimum and maximum values), they are defined as external procedures and implemented in C. The external dispatch is routed through a PL/SQL package named *DS_Package*. Such packages are discussed in *Oracle8i Supplied Packages Reference*.

The third method (*DataStreamToInt*), the map method, is implemented in PL/SQL. Because we have a identifier (*id*) attribute in *DataStream*, this method can return the value of the identifier attribute. (Most map methods, however, are more complex than *DataStreamToInt*.).

Assigning an OID to an Object Type

The CREATE TYPE statement has an optional keyword OID, which associates a user-specified object identifier (OID) with the type definition. This feature was available effective with release 8.0.3; however, it was not documented because it is intended for use primarily by Oracle product developers and by developers of data cartridges. However, it should be used by anyone who creates an object type that will be used in more than one database.

Each type has an OID. If you create an object type and do not specify an OID, Oracle generates an OID and assigns it to the type. Oracle8*i* uses the OID internally for operations pertaining to that type. Using the same OID for a type is important if you plan to share instances of the type across databases for such operations as export/import and distributed queries.

Note: Most other Oracle8*i* documentation refers to the use of OIDs with rows in object tables. In CREATE TYPE with OID, an OID is assigned to the type itself. Of course, each row created in a table with a column of the specified type will also still have a row-specific OID.

For example, assume that you want to create a type named *SpecialPerson* and then instantiate that type in two different databases with tables named *SpecialPersonTable1* and *SpecialPersonTable2*. The RDBMS needs to know that the *SpecialPerson* type is the same type in both instances, and therefore the type must be defined using the same OID in both databases. If you do not specify an OID with CREATE TYPE, a unique identifier is created automatically by the RDBMS.

The syntax for specifying an OID for an object type is as follows:

```
CREATE OR REPLACE TYPE type_name OID 'oid' AS OBJECT (attribute datatype
[,...]);
```

In the following example, the SELECT statement generates an OID, and the CREATE TYPE statement uses the OID in creating an object type named *mytype*. Be sure to use the SELECT statement to generate a different OID for each object type to be created, because this is the only way to guarantee that each OID is valid and globally unique.

```
SVRMGR> SELECT SYS_OP_GUID() FROM DUAL;
SYS_OP_GUID()
--------------------------------
19A57209ECB73F91E03400400B40BBE3
1 row selected.

SVRMGR> CREATE TYPE mytype OID '19A57209ECB73F91E03400400B40BBE3'
     2> AS OBJECT (attrib1 NUMBER);
Statement processed.
```

Constructor Methods

The system implicitly defines a **constructor method** for each object type that you define. The name of the constructor method is the same as the name of the object type. The parameters of the constructor method are exactly the data attributes of the object type, and they occur in the same order as the attribute definition for the object type. At present, only one constructor method can be defined, and thus you cannot define other constructor methods.

For example, when the system executes the following statement to create a type named *rational_type*, it also implicitly creates a constructor method for this object type.

```
CREATE TYPE rational_type (
     numerator integer,
     denominator integer);
```

When you instantiate an object of *rational_type*, you invoke the constructor method. For example:

```
CREATE TABLE some_table (
     c1 integer, c2 rational_type);
INSERT INTO some_table
     VALUES (42, rational_type(223, 71));
```

Object Comparison

SQL performs comparison operations on objects. Comparisons can be explicit, using the comparison operators (=, <, >, <>, <=, >=, !=) and the `BETWEEN` and `IN` predicates. Comparisons can be implicit, as in the `GROUP BY`, `ORDER BY`, `DISTINCT`, and `UNIQUE` clauses.

Comparison of objects makes use of special member functions of the object type: map methods and order methods. To perform object comparison, you must implement either a map method or order method in the `CREATE TYPE` and `CREATE TYPE BODY` statements.

For example, the type body for the *DataStream* type, implements the map member function for *DataStream* comparison as:

```
MAP MEMBER FUNCTION DataStreamToInt RETURN integer IS
      c integer := id;
      BEGIN RETURN c; END;
```

This definition of the map member function relies on the presence of the *id* attribute of the *DataStream* type to map instances to integers. Whenever a comparison operation is required between objects of type *DataStream*, the map function *DataStreamToInt ()* is called implicitly by the system.

The object type *rational_type* does not have a simple *id* attribute like that for *DataStream*. For *rational_type*, the map member function is slightly more complicated. Because a map function can return any of the built-in types; *rational_type* can return a value or type REAL:

```
MAP MEMBER FUNCTION RationalToReal RETURN REAL IS
     BEGIN
         RETURN numerator/denominator;
     END;
...
```

If you have not defined a map or order function for an object type, only equality comparisons are allowed on objects of that type. Oracle SQL performs the comparison by doing a field-by-field comparison of the attributes of that type.

4

Methods: Using C/C++ and Java

This chapter describes how to use C to implement the methods of a data cartridge. Methods are procedures and functions that define the operations permitted on data defined using the data cartridge.

This chapter focuses on issues related to developing and debugging external procedures, including:

External Procedures

PL/SQL is powerful language for database programming. However, because some methods can be complex, it may not be possible to code such a method optimally using PL/SQL. For example, a routine to perform numerical integration will probably run faster if it is implemented in C than if it is implemented in PL/SQL.

To support such special-purpose processing, PL/SQL provides an interface for calling routines written in other languages. This makes the strengths and capabilities of 3GLs like C available through calls from a database server. Such a 3GL routine, called an **external procedure**, is stored in a shared library, registered with PL/SQL, and called from PL/SQL at runtime to perform special-purpose processing. Details on external procedures and their use can be found in the *PL/SQL User's Guide and Reference*.

External procedures are an important tool for data cartridge developers. They can be used not only to write fast, efficient, computation-intensive routines for cartridge types, but also to integrate existing code with the database as data cartridges. Shared libraries already written and available in other languages, such as a Windows NT DLL with C routines to perform format conversions for audio files, can be called directly from a method in a type implemented by an audio cartridge. Similarly, you can use external procedures to process signals, drive devices, analyze data streams, render graphics, or process numerical data.

Using Shared Libraries

A **shared library** is an operating system file, such as a Windows DLL or a Solaris shared object, that stores the coded implementation of external procedures. Access to the shared library from Oracle occurs by using an **alias library**, which is a schema object that represents the library within PL/SQL. For security, creation of an alias library requires DBA privileges. To create the alias library (such as *DS_Lib* in the following example), you must decide on the operating system location for the library, log in as a DBA or as a user with the `CREATE LIBRARY PRIVILEGE`, and then enter a statement such as the following:

```
CREATE OR REPLACE LIBRARY DS_Lib AS
     '/data_cartridge_dir/libdatastream.so;
```

Note: In Oracle8*i*, the absolute path to the shared library must be specified, because Oracle does not search operating system environment variables (such as LD_LIBRARY_PATH) to resolve the location of shared libraries from the alias library name.

This example creates the alias library schema object in the database, and hereafter you can refer to the shared library by the name *DS_Lib* from within PL/SQL.

Registering an External Procedure

To call an external procedure, you must not only tell PL/SQL the alias library in which to find the external procedure, but also how to call the procedure and what arguments to pass to it.

Earlier, the type *DataStream* was defined, and certain methods of type *DataStream* were defined by calling functions from a package *DS_Package*. Also, this package was specified. The following statement defines the body of this package (*DS_Package*).

```
CREATE OR REPLACE PACKAGE BODY DS_Package AS
     FUNCTION DS_Findmin(data  CLOB) RETURN PLS_INTEGER IS EXTERNAL
     NAME "c_findmin" LIBRARY DS_Lib LANGUAGE C WITH CONTEXT;
     FUNCTION DS_Findmax(data CLOB) RETURN PLS_INTEGER IS EXTERNAL
     NAME "c_findmax" LIBRARY DS_Lib LANGUAGE C WITH CONTEXT;
   END;
```

In the PACKAGE BODY declaration clause of this example, the package functions are tied to external procedures in a shared library. The EXTERNAL clause in the function declaration registers information about the external procedure, such as its name (found after the NAME keyword), its location (which must be an alias library, following the LIBRARY keyword), the language in which the external procedure is written (following the LANGUAGE keyword), and so on. For a description of the parameters that can accompany an EXTERNAL clause, see the *PL/SQL User's Guide and Reference.*

Note: In Oracle8*i*, only C is supported as a language for external procedures. However, it is easy to call routines in other languages, such as C++, by dispatching from the server as C but coding the external procedures as *extern "C"*. Thus, by creating C wrappers, you can easily call external procedures written in other languages.

The final part of the `EXTERNAL` clause in the example is the `WITH CONTEXT` specification. This means that a context pointer is passed to the external procedure. The context pointer is opaque to the external procedure, but is available so that the external procedure can call back to the Oracle8*i* server, to potentially access more data in the same transaction context. The `WITH CONTEXT` clause is discussed in "Using the WITH CONTEXT Clause" on page 4-9.

Although the example describes external procedure calls from object type methods, a data cartridge can use external procedures from a variety of other places in PL/SQL. External procedure calls can appear in:

- Anonymous blocks
- Standalone and packaged subprograms
- Methods of an object type
- Database triggers
- SQL statements (calls to packaged functions only)

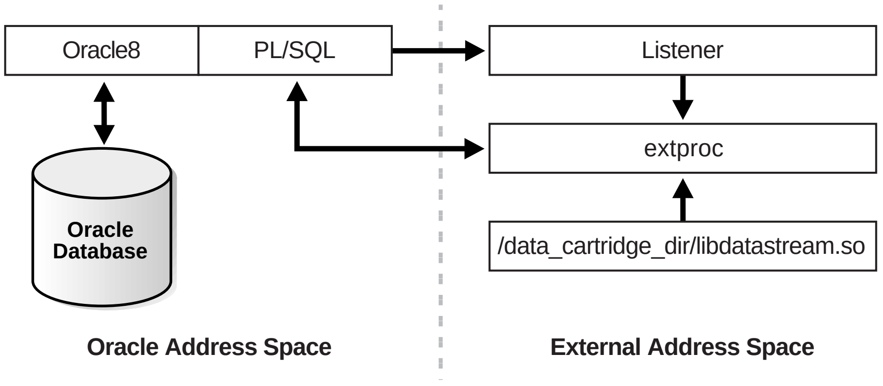
How PL/SQL Calls an External Procedure

To call an external procedure, PL/SQL must know the DLL or shared library in which the procedure resides. PL/SQL looks up the alias library in the `EXTERNAL` clause of the subprogram that registered the external procedure. The data dictionary is used to determine the actual path to the operating system shared library or DLL.

PL/SQL alerts a Listener process, which in turn spawns (launches) a session-specific agent named *extproc*. The Listener hands over the connection to *extproc*. PL/SQL passes to *extproc* the name of the DLL, the name of the external procedure, and any parameters passed in by the caller.

Then, *extproc* loads the DLL and runs the external procedure. Also, *extproc* handles service calls (such as raising an exception) and callbacks to the Oracle server. Finally, *extproc* passes to PL/SQL any values returned by the external procedure. Figure 4–1 shows the flow of control.

Figure 4–1 How an External Procedure is Called



Note: The Listener must start *extproc* on the system that runs the Oracle server. Starting *extproc* on a different system is not supported.

After the external procedure completes, *extproc* remains active throughout your Oracle session. (When you log off, *extproc* is killed.) Thus, you incur the cost of spawning *extproc* only once, no matter how many calls you make. Still, you should call an external procedure only when the computational benefits outweigh the cost.

See Also: For information about administering extproc and external procedure calls, see the *Oracle8i Administrator's Guide.*

Configuration Files for External Procedures

The configuration files listener.ora and tnsnames.ora must have appropriate entries so that the Listener can dispatch the external procedures.

The Listener configuration file listener.ora must have a `SID_DESC` entry for the external procedure. For example:

```
# Listener configuration file
# This file is generated by stkconf.tsc

CONNECT_TIMEOUT_LISTENER = 0

LISTENER = (ADDRESS_LIST=
 (ADDRESS=(PROTOCOL=ipc)(KEY=o8))
 (ADDRESS=(PROTOCOL=tcp)(HOST=unix123)(PORT=1521))
)

SID_LIST_LISTENER = (SID_LIST=
(SID_DESC=(SID_NAME=o8)(ORACLE_HOME=/rdbms/u01/app/oracle/product/8.0
.3))

(SID_DESC=(SID_NAME=extproc)(ORACLE_HOME=/rdbms/u01/app/oracle/product/
8.0.3)(PROGRAM=extproc))
)
```

This listener.ora example assumes the following:

- The Oracle instance is called *o8*.
- The system or node on which the Oracle server runs is named *unix123*.
- The installation directory for the Oracle server is /rdbms/u01.
- The port number for Oracle TCP/IP communication is the default Listener port 1521.

The tnsnames.ora file (network substrate configuration file) must also be updated to refer to the external procedure. For example:

```
o8      =
(DESCRIPTION=(ADDRESS=(PROTOCOL=tcp)(HOST=unix123)(PORT=1521))(CONNECT_
DATA=(SID=o8)))
extproc_connection_data =
(DESCRIPTION=(ADDRESS=(PROTOCOL=ipc)(KEY=o8))(CONNECT_DATA=(SID=extproc)))
```

This tnsnames.ora example assumes that IPC mechanisms are used to communicate with the external procedure. You can also use, for example, TCP/IP for communication, in which case the `PROTOCOL` parameter must be set to *tcp*.

For more information about configuring the listener.ora and tnsnames.ora files, see the *Oracle8i Administrator's Guide*.

Passing Parameters to an External Procedure

Passing parameters to an external procedure is complicated by several circumstances:

- The set of PL/SQL datatypes does not correspond one-to-one with the set of C datatypes.

- PL/SQL parameters can be null, whereas C parameters cannot. (Unlike C, PL/SQL includes the RDBMS concept of nullity.)
- The external procedure might need the current length or maximum length of `CHAR`, `LONG RAW`, `RAW`, and `VARCHAR2` parameters.
- The external procedure might need character set information about `CHAR`, `VARCHAR2`, and `CLOB` parameters.
- PL/SQL might need the current length, maximum length, or null status of values returned by the external procedure.

In the following sections, you learn how to specify a parameter list that deals with these circumstances.

An example of parameter passing is shown in "Doing Callbacks" on page 4-10, where the package function *DS_Findmin(data CLOB)* calls the C routine *c_findmin* and the CLOB argument is passed to the C routine as an *OCILobLocator* *.

Specifying Datatypes

You do not pass parameters to an external procedure directly. Instead, you pass them to the PL/SQL subprogram that registered the external procedure. So, you must specify PL/SQL datatypes for the parameters. For guidance, see Table 4–1. Each PL/SQL datatype maps to a default external datatype. (In turn, each external datatype maps to a C datatype.)

Table 4–1 Parameter Datatype Mappings

PL/SQL Type	Supported External Types	Default External Type
BINARY_INTEGER, BOOLEAN, PLS_INTEGER	CHAR, UNSIGNED CHAR, SHORT, UNSIGNED SHORT, INT, UNSIGNED INT, LONG, UNSIGNED LONG, SB1, UB1, SB2, UB2, SB4, UB4, SIZE_T	INT
NATURAL, NATURALN, POSITIVE, POSITIVEN, SIGNTYPE	CHAR, UNSIGNED CHAR, SHORT, UNSIGNED SHORT, INT, UNSIGNED INT, LONG, UNSIGNED LONG, SB1, UB1, SB2, UB2, SB4, UB4, SIZE_T	UNSIGNED INT
FLOAT, REAL	FLOAT	FLOAT
DOUBLE PRECISION	DOUBLE	DOUBLE

Table 4–1 Parameter Datatype Mappings (Cont.)

PL/SQL Type	Supported External Types	Default External Type
CHAR, CHARACTER, LONG, ROWID, VARCHAR, VARCHAR2	STRING	STRING
LONG RAW, RAW	RAW	RAW
BFILE, BLOB, CLOB	OCILOBLOCATOR	OCILOBLOCATOR

In some cases, you can use the PARAMETERS clause to override the default datatype mappings. For example, you can re-map the PL/SQL datatype BOOLEAN from external datatype INT to external datatype CHAR.

To avoid errors when declaring C prototype parameters, refer to Table 4–2, which shows the C datatype to specify for a given external datatype and PL/SQL parameter mode. For example, if the external datatype of an OUT parameter is CHAR, specify the datatype **char *** in your C prototype.

Table 4–2 External Datatype Mappings

	IN,	IN by Ref,	
External Datatype	**RETURN**	**RETURN by Ref**	**IN OUT, OUT**
CHAR	char	char *	char *
UNSIGNED CHAR	unsigned char	unsigned char *	unsigned char *
SHORT	short	short *	short *
UNSIGNED SHORT	unsigned short	unsigned short *	unsigned short *
INT	int	int *	int *
UNSIGNED INT	unsigned int	unsigned int *	unsigned int *
LONG	long	long *	long *
UNSIGNED LONG	unsigned long	unsigned long *	unsigned long *
SIZE_T	size_t	size_t *	size_t *

Table 4–2 External Datatype Mappings (Cont.)

	IN,	**IN by Ref,**	
External Datatype	**RETURN**	**RETURN by Ref**	**IN OUT, OUT**
SB1	sb1	sb1 *	sb1 *
UB1	ub1	ub1 *	ub1 *
SB2	sb2	sb2 *	sb2 *
UB2	ub2	ub2 *	ub2 *
SB4	sb4	sb4 *	sb4 *
UB4	ub4	ub4 *	ub4 *
FLOAT	float	float *	float *
DOUBLE	double	double *	double *
STRING	char *	char *	char *
RAW	unsigned char *	unsigned char *	unsigned char *
OCILOBLOCATOR	OCILobLocator *	OCILobLocator *	OCILobLocator **

Using the Parameters Clause

You can optionally use the PARAMETERS clause to pass additional information about PL/SQL formal parameters and function return values to an external procedure. You can also use this clause to reposition parameters.

See Also: For more information about the PARAMETERS clause, see the *PL/SQL User's Guide and Reference.*

Using the WITH CONTEXT Clause

Once launched, an external procedure may need to access the database. For example, *DS_Findmin* does not copy the entire CLOB data over to *c_findmin*, because doing so would vastly increase the amount of stack that the C routine needs. Instead, the PL/SQL function just passes a LOB locator to the C routine, with the intent that the database will be re-accessed from C to read the actual LOB data.

When the C routine reads the data, it can use the OCI buffering and streaming interfaces associated with LOBs (see the *Oracle Call Interface Programmer's Guide* for details), so that only incremental amounts of stack are needed. Such re-access of the database from an external procedure is known as a **callback**.

To be able to call back to a database, you need to use the WITH CONTEXT clause to give the external procedure access to the database environment, service, and error handles. When an external procedure is called using WITH CONTEXT, the corresponding C routine automatically gets as its first parameter an argument of type OCIExtProcContext *. (The order of the parameters can be changed using the PARAMETERS clause.) You can use this context pointer to fetch the handles using the OCIExtProcGetEnv call, and then call back to the database. This procedure is shown in "Doing Callbacks" on page 4-10.

OCIExtProcGetEnv

This service routine enables OCI callbacks to the database during an external procedure call. Use the OCI handles obtained by this function only for callbacks. If you use them for standard OCI calls, the handles establish a new connection to the database and cannot be used for callbacks in the same transaction. In other words, during an external procedure call, you can use OCI handles for callbacks or a new connection but not for both.

The C prototype for this function follows:

```
sword OCIExtProcGetEnv(
   OCIExtProcContext *with_context,
   OCIEnv    **envh,
   OCISvcCtx **svch,
   OCIError  **errh);
```

The parameter *with_context* is the context pointer, and the parameters *envh*, *svch*, and *errh* are the OCI environment, service, and error handles, respectively. The return values OCIEXTPROC_SUCCESS and OCIEXTPROC_ERROR indicate success or failure.

"Doing Callbacks" on page 4-10 shows how OCIExtProcGetEnv might be used in callbacks. For a working example, see the script extproc.sql in the PL/SQL demo directory. (For the location of this directory, see your Oracle installation or user's guide.) This script demonstrates the calling of an external procedure. The companion file extproc.c contains the C source code for the external procedure. To run the demo, follow the instructions in extproc.sql. You must use the *SCOTT/TIGER* account, which must have CREATE LIBRARY privileges.

Doing Callbacks

An external procedure executing on the Oracle8*i* server can call the access function OCIExtProcGetEnv to obtain OCI environment and service handles. With the

OCI, you can use callbacks to execute SQL statements and PL/SQL subprograms, fetch data, and manipulate LOBs. Moreover, callbacks and external procedures operate in the same user session and transaction context, so they have the same user privileges.

The following example is a version of `c_findmin` that is simplified to illustrate callbacks. The complete listing is available on the disk that is included with this kit.

```
Static  OCIEnv   *envhp;
Static  OCISvcCtx  *svchp;
Static OCIError   *errhp;
Int   c_findmin (OCIExtProcContext *ctx, OCILobLocator  *lobl) {
sword  retval;
retval = OCIExtProcGetEnv (ctx, &envhp, &svchp, &errhp);
if ((retval != OCI_SUCCESS) && (retval !=  OCI_SUCCESS_WITH_INFO))
   exit(-1);
   /* Use lobl to read the CLOB, compute the minimum, and store the value
       in retval. */
return retval;
}
```

Restrictions on Callbacks

With callbacks, the following SQL statements and OCI routines are not supported:

- Transaction control statements such as `COMMIT`
- Data definition statements such as `CREATE`
- Object-oriented OCI routines such as `OCIRefClear`
- Polling-mode OCI routines such as `OCIGetPieceInfo`
- All these OCI routines:

```
OCIEnvInit
OCIInitialize
OCIPasswordChange
OCIServerAttach
OCIServerDetach
OCISessionBegin
OCISessionEnd
OCISvcCtxToLda
OCITransCommit
OCITransDetach
OCITransRollback
OCITransStart
```

- Also, with OCI routine `OCIHandleAlloc`, the following handle types are not supported:

  ```
  OCI_HTYPE_SERVER
  OCI_HTYPE_SESSION
  OCI_HTYPE_SVCCTX
  OCI_HTYPE_TRANS
  ```

OCI Access Functions for External Procedures

When called from an external procedure, a service routine can raise exceptions, allocate memory, and get OCI handles for callbacks to the server. To use the functions, you must specify the `WITH CONTEXT` clause, which lets you pass a context structure to the external procedure. The context structure is declared in header file ociextp.h as follows:

```
typedef struct OCIExtProcContext OCIExtProcContext;
```

This section describes how service routines use the context information. For more information and examples of usage, see the chapter on external procedures in the*Oracle8i Application Developer's Guide - Fundamentals*.

OCIExtProcAllocCallMemory

This service routine allocates *n* bytes of memory for the duration of the external procedure call. Any memory allocated by the function is freed as soon as control returns to PL/SQL.

Note: Do not use any other function to allocate or free memory.

The C prototype for this function follows:

```
dvoid *OCIExtProcAllocCallMemory(
   OCIExtProcContext *with_context,
   size_t amount);
```

The parameters *with_context* and *amount* are the context pointer and number of bytes to allocate, respectively. The function returns an untyped pointer to the allocated memory. A return value of zero indicates failure.

OCIExtProcRaiseExcp

This service routine raises a predefined exception, which must have a valid Oracle error number in the range 1..32767. After doing any necessary cleanup, the external procedure must return immediately. (No values are assigned to `OUT` or `IN OUT` parameters.) The C prototype for this function follows:

```
int OCIExtProcRaiseExcp(
   OCIExtProcContext *with_context,
   size_t error_number);
```

The parameters *with_context* and *error_number* are the context pointer and Oracle error number. The return values `OCIEXTPROC_SUCCESS` and `OCIEXTPROC_ERROR` indicate success or failure.

OCIExtProcRaiseExcpWithMsg

This service routine raises a user-defined exception and returns a user-defined error message. The C prototype for this function follows:

```
int OCIExtProcRaiseExcpWithMsg(
   OCIExtProcContext *with_context,
   size_t error_number,
   text   *error_message,
   size_t  len);
```

The parameters `with_context`, `error_number`, and `error_message` are the context pointer, Oracle error number, and error message text. The parameter *len* stores the length of the error message. If the message is a null-terminated string, *len* is zero. The return values `OCIEXTPROC_SUCCESS` and `OCIEXTPROC_ERROR` indicate success or failure.

Common Potential Errors

This section presents several kinds of errors you might make in running external procedures.

Calls to External Functions

```
Can't Find DLL
ORA-06520: PL/SQL: Error loading external library
ORA-06522: Unable to load DLL
ORA-06512: at "<name>", line <number>
```

```
ORA-06512: at "<name>", line <number>
ORA-06512: at line <number>
```

You may have specified the wrong path or wrong name for the DLL file, or you may have tried to use a DLL on a network mounted drive (a remote drive).

RPC Time Out

```
ORA-28576: lost RPC connection to external procedure agent
ORA-06512: at "<name>", line <number>
ORA-06512: at "<name>", line <number>
ORA-06512: at line <number>
```

This error might occur after you exit a debugger while debugging a shared library or DLL. Simply disconnect your client and reconnect to the database.

Debugging External Procedures

Usually, when an external procedure fails, its C prototype is faulty. That is, the prototype does not match the one generated internally by PL/SQL. This can happen if you specify an incompatible C datatype. For example, to pass an `OUT` parameter of type `REAL`, you must specify float *. Specifying float, double *, or any other C datatype will result in a mismatch.

In such cases, you might get a lost RPC connection to external procedure agent error, which means that agent *extproc* terminated abnormally because the external procedure caused a core dump. To avoid errors when declaring C prototype parameters, refer to Table 4–2

Using Package DEBUG_EXTPROC

To help you debug external procedures, PL/SQL provides the utility package `DEBUG_EXTPROC`. To install the package, run the script `dbgextp.sql`, which you can find in the PL/SQL demo directory.

To use the package, follow the instructions in dbgextp.sql. Your Oracle account must have `EXECUTE` privileges on the package and `CREATE LIBRARY` privileges.

Note: `DEBUG_EXTPROC` works only on platforms with debuggers that can attach to a running process.

Debugging C Code in DLLs on Windows NT Systems

If you are developing on a Windows NT system, you may perform the following additional actions to debug external procedures:

1. Invoke the Windows NT Task Manager (press Ctrl+Alt+Del.and select Task Manager).
2. In the Processes display, select ExtProc.exe.
3. Right click, and select Debug.
4. Select OK in the message box.

   At this point, if you have built your DLL in a debug fashion with Microsoft Visual C++, Visual C++ is activated.
5. In the Visual C++ window, select Edit > Breakpoints.
6. Use the breakpoint identified in *dbgextp.sql* in the PL/SQL demo directory.

Guidelines for Using External Procedures with Data Cartridges

In future releases, *extproc* might be a multithreaded process. So, be sure to write thread-safe external procedures. That way, they will continue to run properly if *extproc* becomes multithreaded. In particular, avoid using static variables, which can be shared by routines running in separate threads. Otherwise, you might get unexpected results.

For help in creating a dynamic link library, look in the RDBMS subdirectory /public, where a template makefile can be found.

When calling external procedures, never write to IN parameters or overflow the capacity of `OUT` parameters. (PL/SQL does no runtime checks for these error conditions.) Likewise, never read an `OUT` parameter or a function result. Also, always assign a value to `IN OUT` and `OUT` parameters and to function results. Otherwise, your external procedure will not return successfully.

If you include the `WITH CONTEXT` and `PARAMETERS` clauses, you must specify the parameter `CONTEXT`, which shows the position of the context pointer in the parameter list. If you omit the `PARAMETERS` clause, the context pointer is the first parameter passed to the external procedure.

If you include the `PARAMETERS` clause and the external routine is a function, you must specify the parameter `RETURN` (not `RETURN` *property*) in the last position.

For every formal parameter, there must be a corresponding parameter in the `PARAMETERS` clause. Also, make sure that the datatypes of parameters in the `PARAMETERS` clause are compatible with those in the C prototype because no implicit conversions are done.

A parameter for which you specify `INDICATOR` or `LENGTH` has the same parameter mode as the corresponding formal parameter. However, a parameter for which you specify `MAXLEN`, `CHARSETID`, or `CHARSETFORM` is always treated like an `IN` parameter, even if you also specify `BY REF`.

With a parameter of type `CHAR`, `LONG RAW`, `RAW`, or `VARCHAR2`, you must use the property `LENGTH`. Also, if that parameter is `IN OUT` or `OUT` and null, you must set the length of the corresponding C parameter to zero.

5 Methods: Using PL/SQL

This chapter describes how to use PL/SQL to implement the methods of a data cartridge. Methods are procedures and functions that define the operations permitted on data defined using the data cartridge. Topics include:

Methods

A **method** is procedure or function that is part of the object type definition, and that can operate on the attributes of the type. Such methods are also called **member methods**, and they take the keyword MEMBER when you specify them as a component of the object type.

See the *Oracle8i Concepts* manual for information about:

- Method specification
- Method names
- Method name overloading

Map methods, which govern comparisons between object types, are discussed above.

The following sections show simple examples of implementing a method, invoking a method, and referencing an attribute in a method. For further explanation and more detailed examples, see the chapter on object types in the *PL/SQL User's Guide and Reference*.

Implementing Methods

To implement a method, create the PL/SQL code and specify it within a CREATE TYPE BODY statement.

For example, consider the following definition of an object type named *rational_type*:

```
CREATE TYPE rational_type AS OBJECT
( numerator INTEGER,
  denominator INTEGER,
  MAP MEMBER FUNCTION rat_to_real RETURN REAL,
  MEMBER PROCEDURE normalize,
  MEMBER FUNCTION plus (x rational_type)
       RETURN rational_type);
```

The following definition is shown merely because it defines the function gcd, which is used in the definition of the normalize method in the CREATE TYPE BODY statement later in this section.

```
CREATE FUNCTION gcd (x INTEGER, y INTEGER) RETURN INTEGER AS
-- Find greatest common divisor of x and y. For example, if
-- (8,12) is input, the greatest common divisor is 4.
-- This will be used in normalizing (simplifying) fractions.
-- (You need not try to understand how this code works, unless
--  you are a math wizard. It does.)
--
   ans INTEGER;
BEGIN
   IF (y <= x) AND (x MOD y = 0) THEN
      ans := y;
   ELSIF x < y THEN
      ans := gcd(y, x);  -- Recursive call
   ELSE
      ans := gcd(y, x MOD y);  -- Recursive call
   END IF;
   RETURN ans;
END;
```

The following statement implements the methods (`rat_to_real`, `normalize`, and `plus`) for the object type `rational_type`:

```
CREATE TYPE BODY rational_type
( MAP MEMBER FUNCTION rat_to_real RETURN REAL IS
   -- The rat-to-real function converts a rational number to
   -- a real number. For example, 6/8 = 0.75
   BEGIN
      RETURN numerator/denominator;
   END;

   -- The normalize procedure simplifies a fraction.
   -- For example, 6/8 = 3/4
   MEMBER PROCEDURE normalize IS
      divisor INTEGER := gcd(numerator, denominator);
   BEGIN
      numerator := numerator/divisor;
      denominator := denominator/divisor;
   END;

   -- The plus function adds a specified value to the
   -- current value and returns a normalized result.
   -- For example, 1/2 + 3/4 = 5/4
   --
   MEMBER FUNCTION plus(x rational_type)
         RETURN rational_type IS
         -- Return sum of SELF + x
   BEGIN
      r = rational_type(numerator*x.demonimator +
             x.numerator*denominator,
             denominator*x.denominator);
```

```
            -- Example adding 1/2 to 3/4:
            -- (3*2 + 1*4) / (4*2)
      -- Now normalize (simplify). Here, 10/8 = 5/4
      r.normalize;
      RETURN r;
   END;
END;
```

Note: If an object type has no methods, no `CREATE TYPE BODY` statement for that object type is required.

Invoking Methods

To invoke a method, use the following syntax:

<object_name>.<method_name>([parameter_list])

In SQL statements only, you can use the following syntax:

<correlation_variable>.<method_name>([parameter_list])

The following PL/SQL example invokes a method named *get_emp_sal*:

```
DECLARE
   employee employee_type;
   salary number;
   ...
BEGIN
   salary := employee.get_emp_sal();
   ...
END;
```

An alternative way to invoke a method is by using the `SELF` built-in parameter. Because the implicit first parameter of each method is the name of the object on whose behalf the method is invoked, the following example performs the same action as the line after `BEGIN` in the preceding example:

```
salary := get_emp_sal(SELF => employee);
```

In this example, *employee* is the name of the object on whose behalf the `get_emp_sal` method is invoked.

Referencing Attributes in a Method

As shown in the example in "Implementing Methods" on page 3-1, member methods can reference the attributes and member methods of the same object type without using a qualifier. A built-in reference is always provided to the object on whose behalf the method is invoked. This reference is called SELF.

Consider the following trivial example, in which two statements set the value of variable *var1* to 42:

```
CREATE TYPE a_type AS OBJECT (
   var1 INTEGER,
   MEMBER PROCEDURE set_var1);
CREATE TYPE BODY a_type (
   MEMBER PROCEDURE set_var1 IS
   BEGIN
      var1 := 42;
      SELF.var1 := 42;
   END set_var1;
);
```

In this example, *var1 := 42* and *SELF.var1 := 42* are in effect the same statement. Because *var1* is the name of an attribute of the object type *a_type* and because *set_var1* is a member method of this object type, no qualification is required to access *var1* in the method code. However, for code readability and maintainability, you can use the keyword SELF in this context to make the reference to *var1* more clear.

PL/SQL Packages

A **package** is a group of PL/SQL types, objects, and stored procedures and functions. The **specification** part of a package declares the public types, variables, constants, and subprograms that are visible outside the immediate scope of the package. The **body** of a package defines the objects declared in the specification, as well as private objects that are not visible to applications outside the package.

The following example shows the package specification for the package named *DS_package*. This package contains the two stored functions *ds_findmin* and *ds_findmax*, which implement the *DataStreamMin* and *DataStreamMax* functions defined for the *DataStream* object type.

```
CREATE OR REPLACE PACKAGE DS_package AS
    FUNCTION  ds_findmin(data clob) RETURN pls_integer;
    FUNCTION  ds_findmax(data clob) RETURN pls_integer;
     PRAGMA restrict_references(ds_findmin, WNDS, WNPS);
    PRAGMA restrict_references(ds_findmax, WNDS, WNPS);
END;
```

For the *DataStream* type and type body definitions, see Chapter 2, "Roadmap to Building a Data Cartridge".

For more information about PL/SQL packages, see the chapter about using procedures and packages in the *Oracle8i Supplied Packages Reference*.

Pragma RESTRICT_REFERENCES

To execute a SQL statement that calls a member function, Oracle must know the **purity level** of the function, that is, the extent to which the function is free of side effects. The term **side effect**, in this context, refers to accessing database tables, package variables, and so forth for reading or writing. It is important to control side effects because they can prevent the proper parallelization of a query, produce order-dependent (and therefore indeterminate) results, or require impermissible actions such as the maintenance of package state across user sessions.

A member function called from a SQL statement can be restricted so that it cannot:

- Insert into, update, or delete database tables
- Be executed remotely or in parallel if it reads or writes the values of packaged variables
- Write the values of packaged variables unless it is called from a SELECT, VALUES, or SET clause
- Call another method or subprogram that violates any of these rules
- Reference a view that violates any of these rules

For more information about the rules governing purity levels and side effects, see the *PL/SQL User's Guide and Reference*.

You use the pragma (compiler directive) RESTRICT_REFERENCES to enforce these rules. For example, the purity level of the *DataStreamMax* method of type *DataStream* is asserted to be *write no database state* (WNDS) and *write no package state* (WNPS) in the following way:

```
CREATE TYPE DataStream AS OBJECT (
         ....
PRAGMA RESTRICT_REFERENCES (DataStreamMax, WNDS, WNPS)
         ... );
```

Member methods that call external procedures cannot do so directly, but must be routed through a package. The reason for this requirement is that currently the arguments to external procedures cannot be object types; a member function automatically gets a SELF reference (a reference to that specific instance) as its first argument. Therefore, member methods in objects types cannot call out directly to external procedures.

Collecting all external calls into a package makes for a better design. The purity level of the package must also be asserted. Therefore, when the package named DS_Package is declared and all external procedure calls from type DataStream are routed through this package, the purity level of the package is also declared, as follows:

```
CREATE OR REPLACE PACKAGE DS_Package AS
   ...
PRAGMA RESTRICT_REFERENCES (ds_findmin, WNDS, WNPS)
   ...
END;
```

In addition to WNDS and WNPS, it is possible to specify two other constraints: *read no database state* (RNDS) and *read no package state* (RNPS). These two constraints are normally useful if you have parallel queries.

Each constraint is independent of the others and does not imply another. Choose the set of constraints based on application-specific requirements. For more information about controlling side effects using the RESTRICT_REFERENCES pragma, see the *Oracle8i Application Developer's Guide - Fundamentals*.

You can also specify the keyword DEFAULT instead of a method or procedure name, in which case the pragma applies to all member functions of the type (or procedures of the package). For example:

```
PRAGMA RESTRICT_REFERENCES (DEFAULT, WNDS, WNPS)
```

Privileges Required to Create Procedures and Functions

To create a standalone procedure or function, or package specification or body, you must have the CREATE PROCEDURE system privilege to create a procedure or package in your schema, or the CREATE ANY PROCEDURE system privilege to create a procedure or package in another user's schema.

For the compilation of the procedure or package, the *owner* of the procedure or package must have been explicitly granted the necessary object privileges for all objects referenced within the body of the code. *The owner cannot have obtained required privileges through roles.*

For more information about privilege requirements for creating procedures and functions, see the chapter about using procedures and packages in the *Oracle8i Application Developer's Guide - Fundamentals*.

Debugging PL/SQL Code

One of the simplest ways to debug PL/SQL code is to try each method, block, or statement interactively using SQL*Plus, and fix any problems before proceeding to the next statement. If you need more information on an error message, enter the statement `SHOW ERRORS`. Also consider displaying statements for runtime debugging, such as those of the general form:

```
Location in module: <location>
Parameter name: <name>
Parameter value: <value>
```

You can debug stored procedures and packages using the `DBMS_OUTPUT` package. You insert `PUT` and `PUTLINE` statements in your code to output the value of variables and expressions to your terminal. The `DBMS_OUTPUT` package is described in the *Oracle8i Supplied Packages Reference* and the *PL/SQL User's Guide and Reference*.

To debug stored procedures and packages, *though not object type methods at present*, you can use Procedure Builder, which is a part of the Oracle Developer/2000 tool set. Procedure Builder lets you execute PL/SQL stored procedures and triggers in a controlled debugging environment, and you can set breakpoints, list the values of variables, and perform other debugging tasks. See the *Oracle8i Java Stored Procedures Developer's Guide*

A PL/SQL tracing tool provides more information about exception conditions in application code. You can use this tool to trace the execution of server-side PL/SQL statements. Object type methods cannot be traced directly, but you can trace any PL/SQL functions or procedures that a method calls. The tracing tool also provides information about exception conditions in the application code. The trace output is written to the Oracle server trace file.

Note: Only the database administrator has access to this trace file. The tracing tool is described in the *Oracle8i Application Developer's Guide - Fundamentals*.

Notes for C and C++ Programmers

If you are a C or C++ programmer, several PL/SQL conventions and requirements may differ from your expectations. Note the following about PL/SQL:

- = means equal (not assign).
- := means assign (as in Algol).
- `VARRAYs` begin at index 1 (not 0).
- Comments begin with two hyphens (--), not with // or /*.
- The `IF` statement requires the `THEN` keyword.
- The IF statement must be concluded with the `END IF` keyword (which comes after the `ELSE` clause, if there is one).
- There is no `PRINTF` statement. The comparable feature is the `DBMS_OUTPUT.PUT_LINE` statement. In this statement, literal and variable text is separated using the double vertical bar (||).
- A function must have a return value, and a procedure cannot have a return value.
- If you call a function, it must be on the right side of an assignment operator.
- Many PL/SQL keywords cannot be used as variable names.

For complete information on PL/SQL, see the *PL/SQL User's Guide and Reference*.

Common Potential Errors

This section presents several kinds of errors you may make in creating a data cartridge.

Signature Mismatches

```
13/19    PLS-00538: subprogram or cursor '<name>' is declared in an object
         type specification and must be defined in the object type body
15/19    PLS-00539: subprogram '<name>' is declared in an object type body
         and must be defined in the object type specification
```

If you see either or both of these messages, you have made an error with the signature for a procedure or function. In other words, you have a mismatch between the function or procedure prototype that you entered in the object specification, and the definition in the object body.

Ensure that parameter orders, parameter spelling (including case), and function returns are identical. Use copy-and-paste to avoid errors in typing.

RPC Time Out

```
ORA-28576: lost RPC connection to external procedure agent
ORA-06512: at "<name>", line <number>
ORA-06512: at "<name>", line <number>
ORA-06512: at line 34
```

This error might occur after you exit the debugger for the DLL. Restart the program outside the debugger.

Package Corruption

```
ERROR at line 1:
ORA-04068: existing state of packages has been discarded
ORA-04063: package body "<name>" has errors
ORA-06508: PL/SQL: could not find program unit being called
ORA-06512: at "<name>", line <number>
ORA-06512: at line <number>
```

This error might occur if you are extending an existing data cartridge; it indicates that the package has been corrupted and must be recompiled.

Before you can perform the recompilation, you must delete all tables and object types that depend upon the package that you will be recompiling. To find the dependents on a Windows NT system, use the Oracle Administrator toolbar. Click the Schema button, log in as *sys\change_on_install*, and find packages and tables that you created. Drop these packages and tables by entering SQL statements of the following form into the SQL*Plus interface:

```
DROP TYPE <type_name>;
DROP TABLE <table_name> CASCADE CONSTRAINTS;
```

The recompilation can then be done using a SQL statement of the following form:

```
ALTER TYPE <type_name> COMPILE BODY;
or
ALTER TYPE <type_name> COMPILE SPECIFICATION;
```

6

Working with Multimedia Datatypes

This chapter includes the following topics:

Overview

Some data cartridges need to handle large amounts of raw binary data, such as graphic images or sound waveforms, or character data, such as text or streams of numbers. Oracle8*i* supports large objects (LOBs) to handle these kinds of data.

Internal LOBs are stored in the database tablespaces in way that optimizes space and provides efficient access. Internal LOBs participate in the transactional model of the server. **External** LOBs are stored in operating system files outside the database tablespaces. External LOBs do not participate in transactions.

Internal LOBs can store binary data (BLOBs), single-byte character data (CLOBs), or fixed-width single-byte or multibyte character data (NCLOBs). An NCLOB consists of character data that corresponds to the national character set defined for the Oracle database. Varying-width character data is not supported in Oracle8*i*. External LOBs store only binary data (BFILEs). Together, internal and external LOBs provide considerable flexibility in handling large amounts of data.

Data stored in a LOB is called the LOB's **value**. To the Oracle8*i* server, a LOB's value is unstructured and cannot be queried. You must unpack and interpret a LOB's value in cartridge-specific ways.

LOBs can be manipulated using the Oracle Call Interface (OCI) or the PL/SQL DBMS_LOB package. You can write functions (including methods on object types that can contain LOBs) to manipulate parts of LOBs. Details on LOBs can be found in the *Oracle8i Application Developer's Guide - Large Objects (LOBs)*.

DDL for LOBs

LOB definition can involve the CREATE TYPE and the CREATE TABLE statements. For example, the following statement specifies a CLOB within a datatype named *lob_type*:

```
CREATE OR REPLACE TYPE lob_type AS OBJECT (
        id  INTEGER,
        data CLOB );
```

The following statement creates an object table (*lob_table*) in which each row is an instance of *lob_type* data:

```
CREATE TABLE lob_table OF lob_type;
```

The following statement stores LOBs in a regular table, as opposed to an object table as in the preceding statement:

```
CREATE TABLE lob_table1  (
                id  INTEGER,
                b_lob   BLOB,
                c_lob   CLOB,
                nc_lob  NCLOB,
                b_file  BFILE );
```

When creating LOBs in tables, you can set the LOB storage, buffering, and caching properties. See the *Oracle8i SQL Reference* manual and the *Oracle8i Application Developer's Guide - Large Objects (LOBs)* for information about using LOBs in the following DDL statements:

- CREATE TABLE and ALTER TABLE
  - LOB columns
  - LOB storage clause
  - NOCACHE and NOLOGGING options
- CREATE TYPE and ALTER TYPE
  - BLOB, CLOB and BFILE datatypes

LOB Locators

LOBs can be stored with other row data or separate from row data. Regardless of the storage location, each LOB has a **locator**, which can be viewed as a handle or pointer to the actual location. Selecting a LOB returns the LOB locator instead of the LOB value.

The following PL/SQL code selects the LOB locator for *b_lob* and place it a PL/SQL local variable named *image1*:

```
DECLARE
       image1  BLOB;
       image_no  INTEGER := 101;
BEGIN
       SELECT b_lob  INTO image1 FROM lob_table
                  WHERE key_value = image_no;
             ...
END;
```

When you use an API function to manipulate the LOB value, you refer to the LOB using the locator. The PL/SQL DBMS_LOB package contains useful routines to manipulate LOBs, such as PUT_LINE and GETLENGTH:

```
BEGIN
     DBMS_OUTPUT.PUT_LINE('Size of the Image is: ',
                       DBMS_LOB.GETLENGTH(image1));
END;
```

In the OCI, LOB locators are mapped to LOBLocatorPointers (*OCILobLocator* *).

The OCI LOB interface and the PL/SQL DBMS_LOB package are described briefly in this chapter. The OCI is described in more detail in the *Oracle Call Interface Programmer's Guide*. The DBMS_LOB API is described in the *Oracle8i Application Developer's Guide - Large Objects (LOBs)*.

For a BFILE, the LOB column has its own distinct locator, which refers to the LOB's value that is stored in an external file in the server's file system. This implies that two rows in a table with a BFILE column may refer to the same file or two distinct files. A BFILE locator variable in a PL/SQL or OCI program behaves like any other automatic variable. With respect to file operations, it behaves like a file descriptor available as part of the standard I/O library of most conventional programming languages.

EMPTY_BLOB and EMPTY_CLOB Functions

You can use the special functions EMPTY_BLOB and EMPTY_CLOB in INSERT or UPDATE statements of SQL DML to initialize a NULL or non-NULL internal LOB to empty. These are available as special functions in Oracle8*i* SQL DML, and are not part of the DBMS_LOB package.

Before you can start writing data to an internal LOB using OCI or the DBMS_LOB package, the LOB column must be made non-null, that is, it must contain a locator that points to an empty or populated LOB value. You can initialize a BLOB column's value to empty by using the function EMPTY_BLOB in the VALUES clause of an INSERT statement. Similarly, a CLOB or NCLOB column's value can be initialized by using the function EMPTY_CLOB.

Syntax

```
FUNCTION EMPTY_BLOB() RETURN BLOB;
FUNCTION EMPTY_CLOB() RETURN CLOB;
```

Note: The parentheses are required syntax for both functions.

Parameters

None.

Return Values

EMPTY_BLOB returns an empty locator of type BLOB and EMPTY_CLOB returns an empty locator of type CLOB, which can also be used for NCLOBs.

Pragma

None.

Exceptions

An exception is raised if you use these functions anywhere but in the VALUES clause of a SQL INSERT statement or as the source of the SET clause in a SQL UPDATE statement.

Examples

The following example shows EMPTY_BLOB used with SQL DML:

```
INSERT INTO lob_table VALUES (1001, EMPTY_BLOB(), 'abcde', NULL);
UPDATE lob_table SET c_lob = EMPTY_CLOB() WHERE key_value = 1001;
INSERT INTO lob_table VALUES (1002, NULL, NULL, NULL);
```

The following example shows the correct and erroneous usage of EMPTY_BLOB and EMPTY_CLOB in PL/SQL programs:

```
DECLARE
  loba         BLOB;
  lobb         CLOB;
  read_offset  INTEGER;
  read_amount  INTEGER;
  rawbuf       RAW(20);
  charbuf      VARCHAR2(20);
BEGIN
  loba := EMPTY_BLOB();
  read_amount := 10; read_offset := 1;
  -- the following read will fail
  dbms_lob.read(loba, read_amount, read_offset, rawbuf);

  -- the following read will succeed;
  UPDATE lob_table SET c_lob = EMPTY_CLOB() WHERE key_value =
         1002 RETURNING c_lob INTO lobb;
dbms_lob.read(lobb, read_amount, read_offset, charbuf);
  dbms_output.put_line('lobb value: ' || charbuf);
```

Using the OCI to Manipulate LOBs

The OCI includes functions that you can use to access data stored in BLOBs, CLOBs, NCLOBs, and BFILEs. These functions are mentioned briefly in Table 6–1. For detailed documentation, including parameters, parameter types, return values, and example code, see the *Oracle Call Interface Programmer's Guide*.

Table 6–1 OCI Functions for Manipulating LOBs

Function	Description
`OCILobAppend()`	Appends LOB value to another LOB.
`OCILobAssign()`	Assigns one LOB locator to another.
`OCILobCharSetForm()`	Returns the character set form of a LOB.
`OCILobCharSetId()`	Returns the character set ID of a LOB.
`OCILobCopy()`	Copies a portion of a LOB into another LOB.
`OCILobDisableBuffering()`	Disables the buffering subsystem use.
`OCILobEnableBuffering()`	Uses the LOB buffering subsystem for subsequent read and write operations of LOB data.
`OCILobErase()`	Erases part of a LOB, starting at a specified offset.
`OCILobFileClose()`	Closes an open BFILE.
`OCILobFileCloseAll()`	Closes all open BFILEs.
`OCILobFileExists()`	Tests to see if a BFILE exists.
`OCILobFileGetName()`	Returns the name of a BFILE.
`OCILobFileIsOpen()`	Tests to see if a BFILE is open.
`OCILobFileOpen()`	Opens a BFILE.
`OCILobFileSetName()`	Sets the name of a BFILE in a locator.
`OCILobFlushBuffer()`	Flushes changes made to the LOB buffering subsystem to the database (server)
`OCILobGetLength()`	Returns the length of a LOB or a BFILE.
`OCILobIsEqual()`	Tests to see if two LOB locators refer to the same LOB.
`OCILobLoadFromFile()`	Loads BFILE data into an internal LOB.
`OCILobLocatorIsInit()`	Tests to see if a LOB locator is initialized.
`OCILobLocatorSize()`	Returns the size of a LOB locator.

Table 6–1 OCI Functions for Manipulating LOBs (Cont.)

Function	Description
OCILobRead()	Reads a specified portion of a non-null LOB or a BFILE into a buffer.
OCILobTrim()	Truncates a LOB.
OCILobWrite()	Writes data from a buffer into a LOB, writing over existing data.

Table 6–2 compares the OCI and PL/SQL (DBMS_LOB package) interfaces in terms of LOB access.

Table 6–2 OCI and PL/SQL (DBMS_LOB) Interfaces Compared

OCI (ociap.h)	PL/SQL DBMS_LOB (dbmslob.sql)
N/A	DBMS_LOB.COMPARE()
N/A	DBMS_LOB.INSTR()
N/A	DBMS_LOB.SUBSTR()
OCILobAppend	DBMS_LOB.APPEND()
OCILobAssign	N/A [use PL/SQL assign operator]
OCILobCharSetForm	N/A
OCILobCharSetId	N/A
OCILobCopy	DBMS_LOB.COPY()
OCILobDisableBuffering	N/A
OCILobEnableBuffering	N/A
OCILobErase	DBMS_LOB.ERASE()
OCILobFileClose	DBMS_LOB.FILECLOSE()
OCILobFileCloseAll	DBMS_LOB.FILECLOSEALL()
OCILobFileExists	DBMS_LOB.FILEEXISTS()
OCILobFileGetName	DBMS_LOB.FILEGETNAME()
OCILobFileIsOpen	DBMS_LOB.FILEISOPEN()
OCILobFileOpen	DBMS_LOB.FILEOPEN()
OCILobFileSetName	N/A (use BFILENAME operator)

Table 6–2 OCI and PL/SQL (DBMS_LOB) Interfaces Compared (Cont.)

OCI (ociap.h)	**PL/SQL DBMS_LOB (dbmslob.sql)**
`OCILobFlushBuffer`	N/A
`OCILobGetLength`	`DBMS_LOB.GETLENGTH()`
`OCILobIsEqual`	N/A [use PL/SQL equal operator]
`OCILobLoadFromFile`	`DBMS_LOB.LOADFROMFILE()`
`OCILobLocatorIsInit`	N/A [always initialize]
`OCILobRead`	`DBMS_LOB.READ()`
`OCILobTrim`	`DBMS_LOB.TRIM()`
`OCILobWrite`	`DBMS_LOB.WRITE()`

The following example shows a `LOB` being selected from the database into a locator. This example assumes that the type *lob_type* has two attributes (*id* of type `INTEGER` and *data* of type `CLOB`) and that a table (*lob_table*) of this type (*lob_type*) has been created.

```
/*-----------------------------------------------------------------------*/
/* Select lob locators from a CLOB column */
/* We need the 'FOR UPDATE' clause because we need to write to the LOBs. */
/*-----------------------------------------------------------------------*/
static OCIEnv       *envhp;
static OCIServer    *srvhp;
static OCISvcCtx    *svchp;
static OCIError     *errhp;
static OCISession   *authp;
static OCIStmt      *stmthp;
static OCIDefine    *defnp1;
static OCIBind      *bndhp;

sb4 select_locator(int rowind)
{
  sword retval;
  boolean flag;
  int colc = rowind;
  OCILobLocator *clob;
  text  *sqlstmt = (text *)"SELECT DATA FROM LOB_TABLE WHERE ID = :1 FOR
UPDATE";

  if (OCIStmtPrepare(stmthp, errhp, sqlstmt, (ub4) strlen((char *)sqlstmt),
                  (ub4) OCI_NTV_SYNTAX, (ub4) OCI_DEFAULT))
  {
    (void) printf("FAILED: OCIStmtPrepare() sqlstmt\n");
    return OCI_ERROR;
  }

  if (OCIStmtBindByPos(stmthp, bndhp, errhp, (ub4) 1,
                    (dvoid *) &colc, (sb4) sizeof(colc), SQLT_INT,
                    (dvoid *) 0, (ub2 *)0, (ub2 *)0,
                    (ub4) 0, (ub4 *) 0, (ub4) OCI_DEFAULT))
  {
    (void) printf("FAILED: OCIStmtBindByPos()\n");
    return OCI_ERROR;
  }


  if (OCIDefineByPos(stmthp, &defnp1, errhp, (ub4) 1,
             (dvoid *) &clob, (sb4) -1, (ub2) SQLT_CLOB,
                (dvoid *) 0, (ub2 *) 0, (ub2 *) 0, (ub4) OCI_DEFAULT))
  {
    (void) printf("FAILED: OCIDefineByPos()\n");
    return OCI_ERROR;
  }

  /* Execute the select and fetch one row */
  if (OCIStmtExecute(svchp, stmthp, errhp, (ub4) 1, (ub4) 0,
                  (CONST OCISnapshot*) 0, (OCISnapshot*) 0,
                  (ub4) OCI_DEFAULT))
  {
    (void) printf("FAILED: OCIStmtExecute() sqlstmt\n");
    report_error();
    return OCI_ERROR;
  }

  /* Now test to see if the LOB locator is initialized */
  retval = OCILobLocatorIsInit(envhp, errhp, clob, &flag);
  if ((retval != OCI_SUCCESS) && (retval != OCI_SUCCESS_WITH_INFO))
  {
    (void) printf("Select_Locator --ERROR: OCILobLocatorIsInit(), retval =
%d\n", retval);
    report_error();
    checkerr(errhp, retval);
    return OCI_ERROR;
  }
  if (!flag)
  {
   (void) printf("Select_Locator --ERROR: LOB Locator is not initialized.\n");
    return OCI_ERROR;
  }


  return OCI_SUCCESS;
}
```

A sample program (populate.c) that uses the OCI to populate a CLOB with the contents of a file is included on the disk.

Using DBMS_LOB to Manipulate LOBs

The DBMS_LOB package can be used to manipulate LOBs from PL/SQL.

The routines that can modify BLOB, CLOB, and NCLOB values are:

- APPEND() -- append the contents of the source LOB to the destination LOB
- COPY() -- copy all or part of the source LOB to the destination LOB
- ERASE() -- erase all or part of a LOB
- LOADFROMFILE() -- load BFILE data into an internal LOB
- TRIM() -- trim the LOB value to the specified shorter length
- WRITE() -- write data to the LOB from a specified offset

The routines that read or examine LOB values are:

- GETLENGTH() -- get the length of the LOB value
- INSTR() -- return the matching position of the *nth* occurrence of the pattern in the LOB
- READ() -- read data from the LOB starting at the specified offset
- SUBSTR() -- return part of the LOB value starting at the specified offset

The read-only routines specific to BFILEs are:

- FILECLOSE() -- close the file
- FILECLOSEALL() -- close all previously opened files
- FILEEXISTS() -- test to see if the file exists on the server
- FILEGETNAME() -- get the directory alias and file name

- FILEISOPEN() -- test to see if the file was opened using the input BFILE locators
- FILEOPEN() -- open a file

The following example calls the TRIM procedure to trim a CLOB value to a smaller length is shown below. This example assumes that the type *lob_type* has two attributes (*id* of type INTEGER and *data* of type CLOB) and that a table (*lob_table*) of this type (*lob_type*) has been created.

```
PROCEDURE Trim_Clob IS
        clob_loc  CLOB;
BEGIN
 -- get the LOB Locator
       SELECT data into clob_loc  FROM lob_table
       WHERE id  =  179 FOR UPDATE;
   -- call the TRIM Routine
       DBMS_LOB.TRIM(clob_loc, 834004);
       COMMIT;
END;
```

Because this example deals with CLOB data, the second argument (834004) to DBMS_LOB.TRIM specifies the number of characters. If the example dealt with BLOB data, this argument would be interpreted as the number of bytes.

LOBs in External Procedures

LOB locators can be passed as arguments to an external procedure. The corresponding C routine gets an argument of type OCILobLocator *. For example, a PL/SQL external procedure could be defined as:

```
FUNCTION DS_Findmin(data CLOB) RETURN PLS_INTEGER IS EXTERNAL
                   NAME "c_findmin" LIBRARY DS_Lib LANGUAGE C;
```

When this function is called, it invokes a routine (*c_findmin*) with the signature:

```
int   c_findmin (OCILobLocator *)
```

This routine in a shared library associated with *DS_Lib*. In order to use the pointer OCILobLocator * to get data from the LOB (for example, using OCILobRead()), you must reconnect to the database by performing a callback. External procedures and callbacks are discussed in "Doing Callbacks" on page 5-10.

LOBs and Triggers

You cannot write to a LOB (:old or :new value) in any kind of trigger.

In regular triggers, you can read the :old value but you cannot read the :new value. In INSTEAD OF triggers, you can read the :old and the :new values.

You cannot specify LOB type columns in an OF clause, because BFILE types can be updated without updating the underlying table on which the trigger is defined.

Using OCI functions or the DBMS_LOB package to update LOB values or LOB attributes of object columns will not fire triggers defined on the table containing the columns or the attributes.

Using Open/Close as Bracketing Operations for Efficient Performance

The Open/Close functions let you indicate the beginning and end of a series of LOB operations so that large-scale operations, such updating indexes, can be performed once the Close function is called. This means that once the Open call is made, the index would not be updated each time the LOB is modified, and that such updating would not resume until the Close call.

You do not have to wrap all LOB operations inside the Open/Close operations, but this function can be very useful for cartridge developers.

For one thing, if the you do not wrap LOB operations inside an Open/Close call, then each modification to the LOB will implicitly open and close the LOB, thereby firing any triggers. But if do you wrap the LOB operations inside a pair of Open/Close operations, then the triggers will not be fired for each LOB modification. Instead, one trigger will be fired at the time the Close call is made. LIkewise, extensible indexes will not be updated until the user calls Close. This means that any extensible indexes on the LOB are not valid between the Open/Close calls.

You need to apply this technology carefully since state, such as the changes to the LOB, will not be saved between the Open and the Close operations. Once you have called Open, Oracle no longer keeps track of what portions of the LOB value were modified, nor the old and new values of the LOB that result from any modifications. The LOB value is still updated directly on a per OCILob* or DBMS_LOB operation basis and the usual read consistency mechanism is still in place. Moreover, you may want extensible indexes on the LOB to be updated as LOB modifications are made because in that case, the extensible LOB indexes are always valid and may be used at any time.

The API allows you to find out if the LOB is "open" or not. In all cases openness is associated with the LOB, not the locator. The locator does not save any information as to whether the LOB to which it refers is open.

Errors and Restrictions Regarding Open/Close Operations

Note that it is an error to commit the transaction before closing all previously opened LOBs. At transaction rollback time, all LOBs that are still open will be discarded, which means that they will not be closed thereby firing the triggers).

Only 32 LOBs may be open at any one time. An error will be returned when the 33rd LOB is opened. Assigning an already opened locator to another locator does not incur a round trip to the server and does not count as opening a new LOB (both locators refer to the same LOB).

It is an error to Open/Close the same LOB twice either with different locators or with the same locator. It is an error to close a LOB that has not been opened.

Example

Assume loc1 is refers to an opened LOB and is assigned to loc2. If loc2 is subsequently used to modify the LOB value, the modification is grouped together with loc1's modifications (i.e., there's only one entry in the LOB manager's state, not one per each locator). Once the LOB is closed (via loc1 or loc2), the triggers are fired and all updates made to the LOB through any locator are committed. After the close of the LOB, if the user tries to use either locator to modify the LOB, the operation will be performed as Open/operation/Close. Note that consistent read is still maintained on a per-locator basis. This discussion is merely showing that the LOB, not the locator, is opened and closed. No matter how many copies of the locator are made, the triggers for the LOB are fired only once on the first Close call.

For example:

```
open (loc1);
loc2 := loc1;
write (loc1);
write (loc2);
open (loc2);  /* error because the LOB is already open */
close (loc1); /* triggers are fired and all LOB updates made prior to this
                 statement by any locator are incorporated in the extensible
                 index */
write (loc2); /* implicit open, write, implicit close */
```

7 Building Domain Indexes

This chapter describes extensible indexing, including:

- Introduction to Extensible Indexing
- The Extensible Indexing API

Introduction to Extensible Indexing

What is extensible indexing? Why is it important to you as a cartridge developer? How should you go about implementing it?

To answer these questions we first need to understand the modes of indexing provided by the Oracle, which in turn requires that we first consider the role of indexing in information management systems.

What is Indexing?

The impetus to index data arises because of the need to locate specific information and then to retrieve it as efficiently as possible. If you could keep the entire dataset in main memory (equivalent to a person memorizing a book), there would be no need for indexing. Since this is not possible, and since disk access times are much slower than main memory access times, you are forced to wrestle with the art of indexing.

If you think of the form of indexing with which we are most familiar — the index at the back of a technical book — you will note that every index token has three characteristics which refer to the item being indexed:

- Identity — the token must allows us to identify the item in such a way that it is distinguished from the rest of the mass of the data. But this is not simply a representative relationship. By defining an index item you filter the information, implicitly providing a the logical structure for the indexed information.

  There has many implications. For one, it means that the same data can be subject to different indexing schemes. For another, it means that the indexing scheme provides a pathway of access to the information. The index in the back of the book gives you access to the entire range of topics covered in the book. Provided that its structure meets your needs, its presorting of the data means that you do not have to sift through every iota of information.

- Location —the token must allows us to locate the information. In the case of a book, this is a page number, and may also include a chapter designation. This is not very precise since we still have to search the page for the item. In contrast to the normal index, conversation analysis makes use of line numbers because of the need for greater precision in locating the item:

  ```
  10296   HELEN: If you really loved me you wouldn't go to war.
  10297   PARIS: If you really loved me you wouln't stand in the way of my
                 duty.
  ```

- Storage — the index token has to be located somewhere, and the information that it maps also has to be stored. In the case of books, a page is normally the unit of storage in both cases, but the nature of the storage is different. While the body text is stored as sentences, the index tokens have an altogether different structure.

The upshot is that you can retrieve the information much quicker than if you had to page through the entire book (equivalent to sequential scanning of a file)! However, note that while indexing speeds up retrieval, it slows down inserts because you have to update the index.

Index Structures

An index can be any structure which can be used to represent information that can be used to efficiently evaluate a query.

The Relationship between Logical and Physical Structures

There is no single structure that is optimal for all applications.

- If you want to discover if any `Regions` contain a city named Metropolis, you will deploy an equality operator that will return an exact match (or not).
- If you are interested how many time-periods have power demands between two stipulated numbers, you will use an operator that can process a range of data.

In each case, you will want to organize the data in a different index structure since different queries require that information be indexed in different ways. As we will discuss below, a Hash structure is best suited for determining exact match, whereas a B-tree is much better suited for range queries.

Moreover, these are not the only kind of queries. What if you want to discover whether Power Station A or B can best service Quadrant 3, or to determine the overlapping coverage zones derived from different distributions of power stations? In these cases, you will want to create operators (`inRangeOf`, `servesArea`, etc.) that meet your specific requirements. Unfortunately, you cannot do this by means of either the Hash or B-tree indextypes.

The Need for Index Structures that Encompass Unstructured Data

The limitation of Hash and B-tree indextypes is important because one criterion that distinguishes cartridges from other database applications is that data often incorporates many different kinds of information. While database systems are accomplished in processing scalar values, they cannot encompass the domain-specific data of interest to cartridge developers. Information in these contexts may be made up of text, images, audio, video — and combinations of these that comprise domain-specific datatypes.

One way to resolve this problem is to create an index that serves as an intermediate structure. This is a logical extension of the basic idea underlying software-based indexing, namely that pointers refer to data (records, pages, files). In this scheme, keywords used to index video may be stored as an index. Going one step further, an intermediate structure may itself be indexed, as you might index abstracts (capsule text descriptions) of films.The advantage of this approach is that it may be easier to construct an index based on textual description of film than it is to index video footage. Employing this strategy you can scan the index without ever referring to the primary data (the film).

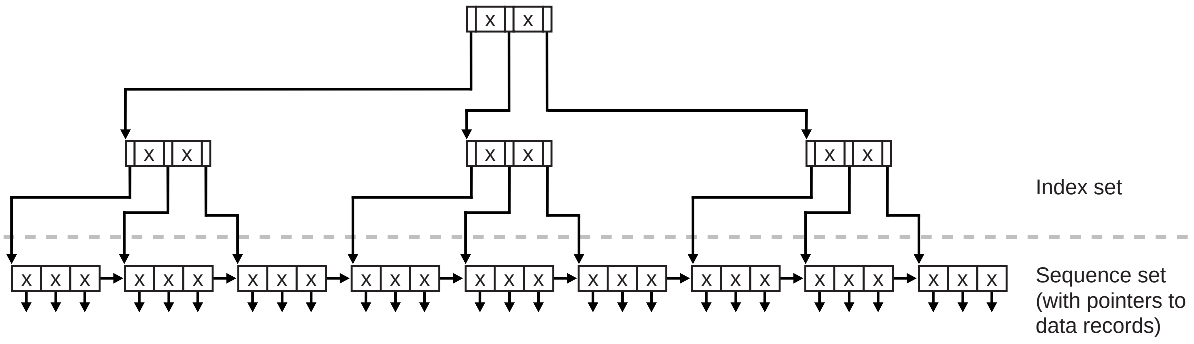
Unfortunately, intermediate structures in which text or scalars are used to represent unstructured data cannot satisfy all requirements. For one thing, they are always slower than direct indexing of the data because they introduce a level of indirection. More importantly, if the task is to analyze the density of bone in x-rays, or to categorize primate gestures, or to record the radio emissions of stars, there is no efficient substitute for direct indexing of unstructured data.

Examples of Indextypes

B-tree

While there is no single indextype that can satisfy all needs, the B-tree indextype comes closest to meeting the requirement. Here we describe the Knuth variation in which the index consists of two parts: a sequence set that provides fast sequential access to the data, and an index set that provides direct access to the sequence set.

Figure 7–1 B-tree Indextype Structure



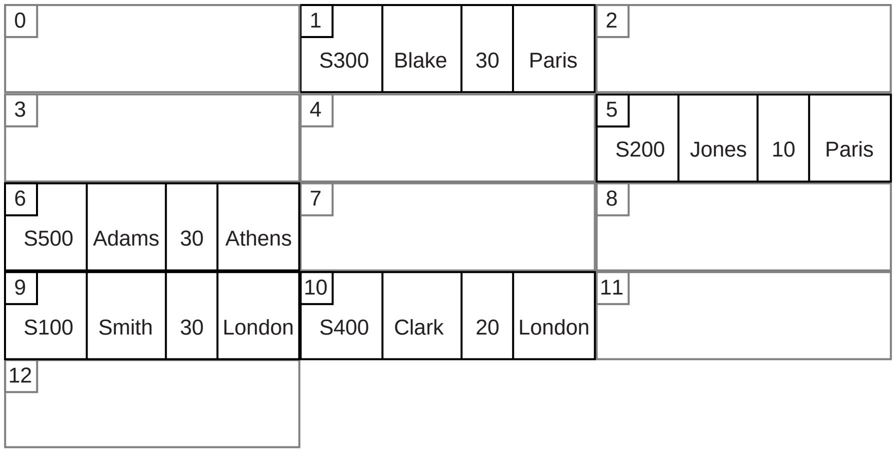
While the nodes of a B-tree will generally not contain the same number of data values, and will usually contain a certain amount of unused space, the B-tree algorithm ensures that it remains balanced (the leaf nodes will all be at the same level).

Hash

Hashing gives fast direct access to a specific stored record based on a given field value. Each record is placed at a location whose address is computed as some function of some field of that record. The same function is used both at the time of insertion and retrieval.

The problem with hashing is that the physical ordering of records has little if any relation to their logical ordering. Also, there may be large unused areas on the disk.

Figure 7–2 Hash Indextype Structure

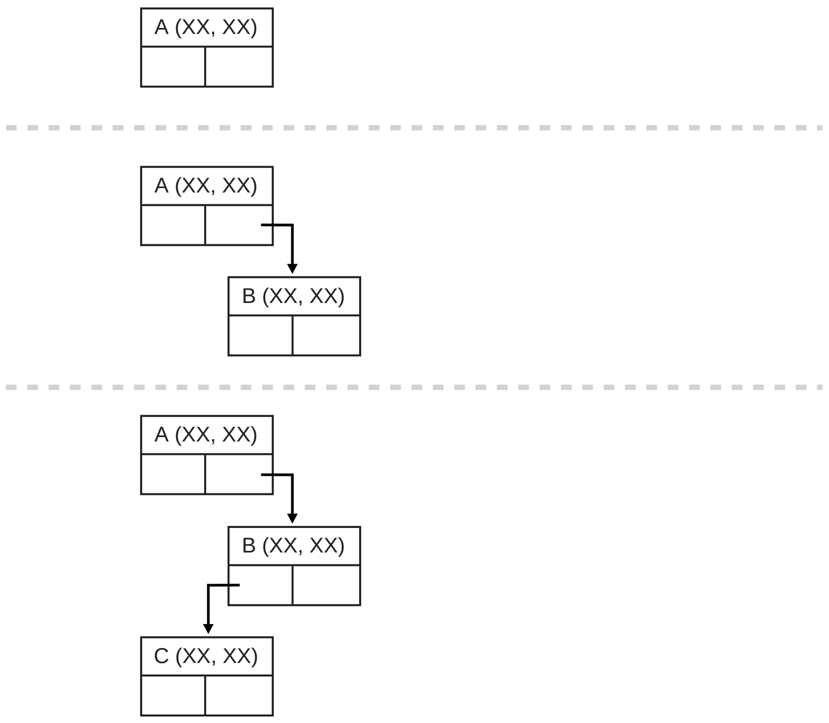


k-d tree

Our sample scenario integrates geographic data with other kinds of data. Insofar as we are interested in points that can be defined with two dimensions (latitude and longitude), such as geographic location of power stations, we can use a variation on the k-d tree known as the 2-d tree.

In this structure, each node is a datatype with fields for information, the two co-ordinates, a left-link and a right-link which can point to two children.

Figure 7–3   2-d Indextype Structure

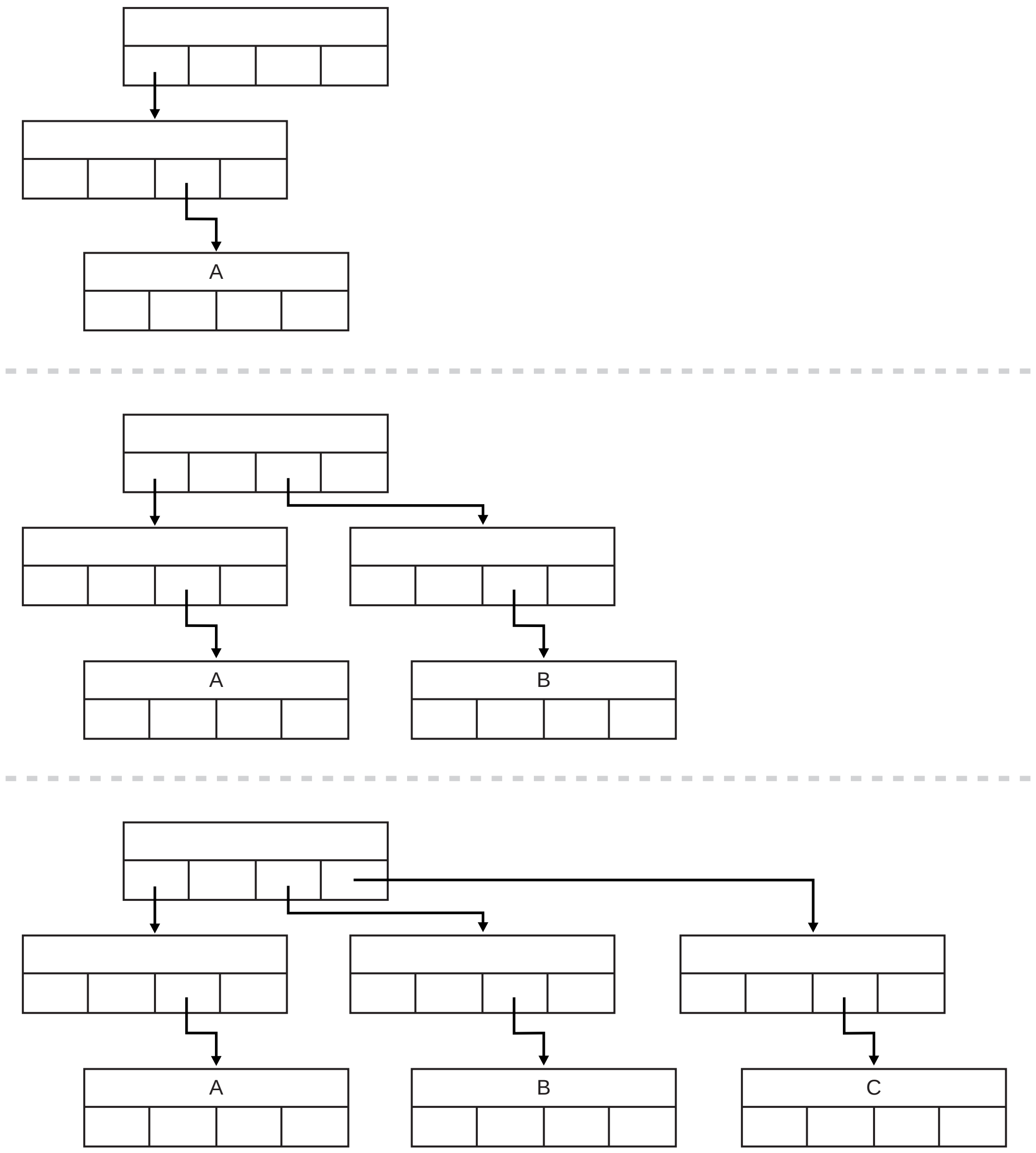


The structure allows for range queries. That is, if the user specifies a point (xx, xx) and a distance, the query will return the set of all points within the specified distance of the point.

2-d trees are very easy to implement. However,the fact that a 2-d tree containing *k* nodes may have a height of *k* means that insertion and querying may be complex.

Point Quadtree

Figure 7–4 Point Quadtree Indextype Structure



The point quadtree is also used to represent point data in a two dimensional spaces. But these structures divide regions into four parts while 2-d trees divide regions into two. The fields of the record type for this node are comprised of an attribute for information, two co-ordinates, and four compass points (NW, SW, NE, SE) that can therefore point to four children.

Like 2-d trees, point quadtrees are very easy to implement. Also like 2-d trees, the fact that a point quadtree containing *k* nodes may have a height of *k* means that insertion and querying may be complex. Each comparison requires comparisons on at least two co-ordinates. However, in practice the lengths from root to leaf tend to be shorter in point quadtrees.

Why is Extensible Indexing Necessary?

The fact is that Oracle provides a limited number of indextypes, so that if (for instance) you wish to utilize either the k-d tree or the point quadtree, you will have to implement this yourself. As you consider your need to access your data, you need to keep in mind the following restrictions that pertain to the standard indextypes:

An Inability to Index Unstructured Data

Oracle's standard modes of indexing do not permit indexing a column that contains `LONG` or `LOB` values.

An Inability to Index Attributes of Column Objects

You may not be able to index a column object using Oracle's standard indexing schemes or the elements of a collection type.

An Inability to Index Values Derived from Domain-specific Operations

Oracle object types may be compared using either a map function or an order function. If the object utilizes a map function, then you can define a functional index that can be used implicitly to evaluate relational predicates. However, if an order function is used, you will not be able to use this to construct an index.

Further, you cannot utilize functions in predicates in which the range of the parameters is infinite. With Oracle8*i* functional indexes allow you to include a function in a predicate, provided you can precompute the function values for all the rows. Typically the index would store the rowid and the functional value. Queries that apply relational operators to values based on derived values utilize the index.

However, you can use functional indexes only if the function is so designed that there are a finite number of input combinations. Put another way: you cannot use functional indexes in cases in which the input parameters do not have a limited cardinality.

The Extensible Indexing API

This SQL-based interface allows you to define domain-specific operators and indexing schemes, and integrate these into the Oracle8*i* server.

Oracle8*i* provides a set of pre-defined operators which include arithmetic operators (+, -, *, /), comparison operators (=, >, <) and logical operators (`NOT`, `AND`, `OR`). These operators take as input one or more arguments (or operands) and return a result. They are represented by special characters (+) or keywords (`AND`).

Like built-in operators, user-defined operators (e.g., `Contains`) take a set of operands as input and return a result. The implementation of the operator is provided by the user. After a user has defined a new operator, it can be used in SQL statements like any other built-in operator.

For instance, suppose you define a new operator `Contains`, which takes as input a text document and a keyword, and returns `1` if the document contains the specified keyword. You can then write an SQL query as:

```
SELECT * FROM Employees WHERE Contains(resume, 'Oracle and UNIX')=1;
```

Oracle8*i* uses indexes to efficiently evaluate some built-in operators. For example, a B-tree index can be used to evaluate the comparison operators =, > and <. Similarly, user-defined domain indexes can be used to efficiently evaluate user-defined operators.

Typical database management systems support a few types of access methods (B+Trees, Hash Index) on some set of data types (numbers, strings, etc.). In recent years, databases are more and more being used to store different types of data, such as text, spatial, image, video and audio. In these complex domains, there is a need for indexing complex data types and also specialized indexing techniques. For instance, R-trees are an efficient method of indexing spatial data. No database server can be built with support for all possible kinds of complex data and indexing. The solution is to provide an extensible server which allows the user to define new index types.

The framework to develop new index types is based on the concept of cooperative indexing where an application and the Oracle server cooperate to build and maintain indexes for data types such as text, spatial and On-line-Analytical

Processing (OLAP). The application software, in the form of a cartridge, is responsible for defining the index structure, maintaining the index content during load and update operations, and searching the index during query processing. The index structure itself can either be stored in an Oracle database as an Index-Organized Table, etc., or externally as a file.

The extensible indexing framework consists of the following components:

- **Indextype**: A schema object Indextype specifies the routines that manage all aspects of an application-specific index, namely, index definition, index maintenance, and index scan operations. This schema object enables the Oracle8*i* Server to establish a user-defined index on a column of a table or attribute of an Object. It encapsulates the set of routines that together manage and access the user-defined index.
- **Domain Index**: Using the Indextype schema object, an application-specific index can be created. Such an index is called a domain index since it is used for indexing data in application-specific domains. A domain index is an instance of an index which is created, managed, and accessed by routines supplied by an indextype. This is in contrast to B-tree indexes maintained by Oracle internally, which are simply referred to as indexes.
- **Operators**: Queries and data manipulation statements can involve application-specific operators, like the `Overlaps` operator in the spatial domain. In general, user-defined operators can be bound to functions. However, operators can also be evaluated using indexes. For instance, the equality operator can be evaluated using a hash index. An indextype provides index-based implementation for the operators listed in the indextype definition.
- **Index-Organized tables**: This feature enables applications to define, build, maintain, and access indexes for complex objects using a table metaphor. To the application, an index is modeled as a table, where each row is an index entry. In addition, this feature extends the current sorted access method to handle indexing content-rich objects by providing improved handling of duplicate index entries. For detailed information on index-organized tables see *Oracle8i Administrator's Guide.*

To illustrate the role of each of these components, let us consider a text domain application. Suppose a new indextype `TextIndexType` be defined as part of the text cartridge. It contains routines for managing and accessing the text index. The text index is an inverted index storing the occurrence list for each token in each of the text documents. The text cartridge also defines the `Contains` operator for performing content-based search on textual data. It provides both a functional implementation (a simple number function) and an index implementation (using the text index) for the Contains operator.

Now, let `Employees` be an employee table with a `resume` column containing textual data.

```
CREATE TABLE Employees
(name VARCHAR(128), id INTEGER, resume VARCHAR2(1024));
```

A domain index can be created on resume column as follows:

```
CREATE INDEX ResumeTextIndex ON Employees(resume)
INDEXTYPE IS TextIndexType;
```

The Oracle server invokes the routine corresponding to the create method in the `TextIndexType`, which results in the creation of an index-organized table to store the occurrence list of all tokens in the resumes (essentially, the inverted index data). The inverted index modeled by `ResumeTextIndex` is automatically maintained by invoking routines defined in `TextIndexType`, whenever an `Employees` row is inserted, updated, or deleted.

Content-based search on the resume column can be performed as follows:

```
SELECT * FROM Employees WHERE Contains(resume, 'Oracle and UNIX')=1;
```

Index-based implementation of the `Contains` operator can take advantage of the previously built inverted index. Specifically, the Oracle server can invoke routines specified in `TextIndexType` to search the domain index for identifying candidate rows, and then do further processing such as filtering, selection, and fetching of rows. Note that the above query can also be evaluated using the non-index implementation of the `Contains` operator, if the Oracle server chooses to not use the index defined on resume column. In such a case, the filtering of rows will be done by applying the non-index implementation on each resume instance of the table.

In summary, the extensible indexing interface will

- Allow encapsulating application-specific index management routines as an indextype schema object,
- Support defining a domain index (an application-specific index) on table columns, and
- Provide efficient processing of application-specific operators.

This interface will enable a domain index to operate essentially the same way as any other Oracle Server index, the primary difference being that the Oracle Server will invoke application code specified as part of the indextype to create, drop, truncate, modify, and search a domain index.

It should be noted that an index designer may choose to store the index data in files, rather than in index-organized tables. The SQL interface for extensible indexing makes no restrictions on the location of the index data, only that the application adhere to the protocol for index definition, maintenance and search operations.

Concepts: Extensible Indexing

This section describes the key concepts of the Extensible Indexing Framework.

Overview

For simple data types such as integers and small strings, all aspects of indexing can be easily handled by the database system. This is not the case for documents, images, video clips and other complex data types that require content-based retrieval (CBR). The essential reason is that complex data types have application specific formats, indexing requirements, and selection predicates. For example, there are many different document encodings (e.g., ODA, SGML, plain text) and information retrieval (IR) techniques (e.g., keyword, full-text boolean, similarity, probabilistic, and so on). To effectively accommodate the large and growing number of complex data objects, the database system must support application specific indexing. The approach that we employ to satisfy this requirement is termed *extensible indexing*.

With Extensible indexing,

- The application defines the structure of the domain index
- The application stores the index data either inside the Oracle database (e.g., in form of index-organized tables) or outside the Oracle database
- The application manages, retrieves and uses the index data to evaluate user queries

In effect, the application controls the structure and semantic content of the domain index. The database system interacts with the application to build, maintain, and employ the domain index. It is highly desirable for the database to handle the physical storage of domain indexes. In the following discussion, we implicitly make the assumption that the index is stored in an index-organized table. Note however, that the extensible indexing paradigm does not impose this requirement. The index could be stored in one or more external files.

To illustrate the notion of extensible indexing, we consider a textual database application with IR functionality. For such applications, document indexing involves parsing the text and inserting the words, or tokens, into an inverted index. Such index entries typically have the following logical form

(token, <docid, data>)

where *token* is the key, *docid* is a unique identifier (e.g., object identification) for the related document, and *data* is a segment containing IR specific quantities. For example, a probabilistic IR scheme could have a data segment with token frequency and occurrence list attributes. The occurrence list identifies all locations within the related document where the token appears. Assuming an IR scheme such as this, each index entry would be of the form:

(token, <docid, frequency, occlist> ..)

The following sample index entry for the token Archimedes illustrates the associated logical content.

```
(Archimedes, <5, 3, [7 62 225]>, <26, 2, [33, 49]>, ...);
```

In this sample index entry, the token "Archimedes" appears in document 5 at 3 locations(7, 62, and 225), and in document 26 at 2 locations(33 and 49). Note that the index would contain one entry for every document with the word "Archimedes".

IR applications can use domain indexes to locate documents that satisfy some given selection criteria. After consulting the index, the documents of interest are retrieved with the related *docid* values. It should be noted that the occurrence lists are required for queries that contain proximity expressions (e.g., the phrase "Oracle Corporation").

When the database system handles the physical storage of domain indexes, applications must be able to:

- Define the format and content of an index. This enables applications to define an index structure that can accommodate a complex data object.
- Build, delete, and update a domain index. With this capability, the application software handles building and maintaining the index structures. Note that this is a significant departure from the "automatic" indexing features provided for simple SQL data types. Also, since an index is modeled as a collection of tuples, in-place updating is directly supported.
- Access and interpret the content of an index. This capability enables the application software to become an integral component of query processing.

That is, the content-related clauses for database queries are handled by application software.

In the following section, we illustrate the extensible indexing framework by building a text domain index.

Example: A Text Indextype

This section presents an example of adding a text indexing scheme to Oracle RDBMS using the extensible indexing framework. It describes:

- Defining a new indexing scheme using text indextype.
- Use of text indextype by the end user to index and operate on textual data.

Text Indextype Designer

’The sequence of steps required to define the Text Indextype are:

- Define and code functions to support functional implementation of operators which would eventually be supported by the text indextype.

The text cartridge intends to support an operator `Contains`, that takes as parameters a text value and a key and returns a number value indicating whether the text contained the key. The functional implementation of this operator is a regular function defined as:

```
CREATE FUNCTION TextContains(Text IN VARCHAR2, Key IN VARCHAR2)
RETURN NUMBER AS
BEGIN
.......
END TextContains;
```

- Create a new operator, and define its specification, namely, the argument and return datatypes, and the functional implementation

```
CREATE OPERATOR Contains
 BINDING (VARCHAR2, VARCHAR2) RETURN NUMBER USING TextContains;
```

- Define a type that implements the index interface `ODCIIndex`. This involves implementing routines for index definition, index maintenance, and index scan operations.

  The index definition routines (`ODCIIndexCreate`, `ODCIIndexAlter`, `ODCIIndexDrop`, `ODCIIndexTruncate`) build the text index when index is created, alter the index information when index is altered, remove the index information when the index is dropped, and truncate the text index when the base table is truncated.

The index maintenance routines (`ODCIIndexInsert`, `ODCIIndexDelete`, `ODCIIndexUpdate`) maintain the text index when the table rows are inserted, deleted, or updated.

The index scan routines (`ODCIIndexStart`, `ODCIIndexFetch`, `ODCIIndexClose`) implement access to the text index to retrieve rows of the base table that satisfy the operator predicate. In this case, the `Contains`(...) =1, whose arguments are passed to the index scan routines. The index scan routines scan the text index and return the qualifying rows to the system.

```
CREATE TYPE TextIndexMethods
(
FUNCTION ODCIIndexCreate(...)
...
);
CREATE TYPE BODY TextIndexMethods
(
...
);
```

- Create the `Text Indextype` schema object. The Indextype definition also specifies all the operators supported by the new indextype and specifies the type that implements the index interface.

```
CREATE INDEXTYPE TextIndexType
FOR Contains(VARCHAR2, VARCHAR2)
USING TextIndexMethods;
```

End User of Text Indextype

Suppose that the text indextype presented in the previous section has been defined in the system. You can define text indexes on text columns and use the associated `Contains` operator to query text data.

Consider the `Employees` table defined as follows:

```
CREATE TABLE Employees
(name VARCHAR2(64), id INTEGER, resume VARCHAR2(2000));
```

A text domain index can be built on the resume column as follows:

```
CREATE INDEX ResumeIndex ON Employees(resume) INDEXTYPE IS TextIndexType;
```

The text data in the resume column can be queried as:

```
SELECT * FROM Employees WHERE Contains(resume, 'Oracle') =1;
```

The query execution will use the text index on resume to efficiently evaluate the Contains predicate.

The following sections describe the concepts of indextypes, domain indexes and operators in greater detail.

Indextypes

The purpose of an indextype is to enable efficient search and retrieval functions for complex domains such as text, spatial, image, and OLAP using external software. An indextype is analogous to the sorted or bit-mapped indextype that are supplied internally within the Oracle Server. The essential difference is that the implementation for an indextype is provided by application software, as opposed to the Oracle Server internal routines.

Interface A set of routine specifications. It does not refer to a separate schema object but rather a logical set of documented method specifications.

ODCIIndex Interface The set of index definition, maintenance and scan routine specifications.

The interface specifies all the routines which have to be implemented by the index designer. The routines are implemented as type methods.

Creating Indextypes

After the type implementing the `ODCIIndex` interface has been defined, a new indextype can be created by specifying the list of operators supported by the indextype and referring to the type that implements the index interface.

Using the information retrieval example, the DDL statement for defining the new indextype `TextIndexType` which supports the `Contains` operator and whose implementation is provided by the type `TextIndexMethods` (implemented in the previous section) is as follows:

```
CREATE INDEXTYPE TextIndexType
        FOR Contains (VARCHAR2, VARCHAR2)
        USING TextIndexMethods;
```

In addition to the `ODCIIndex` interface routines, the implementation type must always implement the `ODCIGetInterfaces` routine. This function returns the list of names of the interfaces implemented by the type. The routine is invoked by Oracle when `CREATE INDEXTYPE` is executed. In Oracle8*i* there is only one set of extensible indexing interface routines called `SYS.ODCIINDEX1`. Thus, the

ODCIGetInterfaces routine must return 'SYS'.'ODCIINDEX1' as one of the implemented interfaces.

Dropping Indextypes

A corresponding DROP statement is supported to remove the definition of an indextype. For our example, this statement would be of the following form:

```
DROP INDEXTYPE TextIndexType;
```

The default DROP behavior is DROP RESTRICT semantics, that is, if one or more domain indexes exist that uses the indextype then the DROP operation is disallowed. User can override the default behavior with the FORCE option, which drops the indextype and marks dependent domain indexes (if any) invalid. For more details on object dependencies and drop semantics see "Object Dependencies, Drop Semantics, and Validation" on page 7-37.

ODCI Index Interface

The ODCIIndex (Oracle Data Cartridge Interface Index) interface consists of the following classes of methods:

- Index Definition methods
- Index Maintenance methods
- Index Scan methods
- Index Metadata method

Index Definition Methods

Index definition methods allow specification of CREATE, ALTER, DROP, and TRUNCATE behaviors.

ODCIIndexCreate

The ODCIIndexCreate procedure is called when a CREATE INDEX statement is issued that references the indextype. Upon invocation, any physical parameters specified as part of the CREATE INDEX... PARAMETERS (...) statement are passed in along with the description of the index.

A typical action of this procedure is to create tables/files to store index data. Further, if the base table is not empty, this routine should build the index for the existing data in the indexed columns.

ODCIIndexAlter

The `ODCIIndexAlter` procedure is invoked when a domain index is altered using an `ALTER INDEX` statement. The description of the domain index to be altered is passed in along with any specified physical parameters.

In addition, this procedure is allowed to handle `ALTER` with `REBUILD` option, which supports rebuilding of domain index. The precise behavior in these two cases is defined by the person who implements indextype.

The `ODCIIndexAlter` routine is also invoked when a domain index is renamed using the `ALTER INDEX ... RENAME` command.

ODCIIndexTruncate

The `ODCIIndexTruncate` procedure is called when a `TRUNCATE` statement is issued against a table that contains a column or `OBJECT` type attribute indexed by the indextype. After this procedure executes, the domain index should be empty.

ODCIIndexDrop

The `ODCIIndexDrop` procedure is invoked when a domain index is destroyed using a `DROP INDEX` statement.

Index Maintenance Methods

Index maintenance methods allow specification of index `INSERT`, `UPDATE`, and `DELETE` behaviors.

ODCIIndexInsert

The `ODCIIndexInsert` procedure in the indextype is called when a record is inserted in a table that contains columns or `OBJECT` attributes indexed by the indextype. The new values in the indexed columns are passed in as arguments along with the corresponding row identifier.

ODCIIndexDelete

The `ODCIIndexDelete` procedure in the indextype is called when a record is deleted from a table that contains columns or `OBJECT` attributes indexed by the indextype. The old values in the indexed columns are passed in as arguments along with the corresponding row identifier.

ODCIIndexUpdate

The `ODCIIndexUpdate` procedure in the indextype is called when a record is updated in a table that contains columns or `OBJECT` attributes indexed by the indextype. The old and new values in the indexed columns are passed in as arguments along with the row identifier.

Index Scan Methods

Index scan methods allow specification of an index-based implementation for evaluating predicates containing operators.

An index scan is specified through three routines, `ODCIIndexStart`, `ODCIIndexFetch`, and `ODCIIndexClose`, which can perform initialization, fetch rows (essentially row identifiers) satisfying the predicate, and clean-up once all rows satisfying the predicate are returned.

ODCIIndexStart

`ODCIIndexStart`() is invoked to initialize any data structures and start an index scan. The index related information and the operator related information are passed in as arguments.

A typical action performed when `ODCIIndexStart`() is invoked is to parse and execute SQL statements that query the tables storing the index data. It could also generate some set of result rows to be returned later when `ODCIIndexFetch`() is invoked (see below).

Since the index and operator related information are passed in as arguments to `ODCIIndexStart`() and not to the other index scan routines (`ODCIIndexFetch`() and `ODCIIndexClose`()), any information needed in the later routines must be saved. This is referred to as the **state** that has to be shared among the index scan routines. There are two ways of doing this:

- **Return State**: If the state to be maintained is small, it can be returned back to Oracle RDBMS through an output SELF argument.
- **Return Handle**: If the state to be maintained is large (for example, a subset of the results), cursor-duration memory can be allocated to save the state. In this case, a handle to the memory (see the Chapter 13, "Reference — Cartridge Services" for details and restrictions) can be returned to Oracle RDBMS through the output `SELF` parameter.

In both cases, Oracle RDBMS will pass the `SELF` value to subsequent `ODCIIndexFetch`() and `ODCIIndexClose`() calls which can then use the to access the relevant context information.

There are two modes of evaluating the operator predicate to return the result set of rows.

- **Precompute All**: Compute the entire result set in `ODCIIndexStart`(). Iterate over the results returning a row at a time in `ODCIIndexFetch`(). This mode is required for operators involving some sort of ranking over the entire collection, etc. Evaluating such operators would require looking at the entire result set to compute the ranking, relevance, etc. for each candidate row.

- **Incremental Computation**: Compute one result row at a time as part of `ODCIIndexFetch`(). This mode is applicable for operators which can determine the candidate rows one at a time without having to look at the entire result set.

The choice of evaluating modes as well as what gets saved is left to the index designer. In either case, the Oracle RDBMS simply executes the `ODCIIndexStart`() routine as part of processing query containing operators which returns the context as an output `SELF` value.The returned value is passed back to subsequent `ODCIIndexFetch`() and `ODCIIndexClose`() calls.

ODCIIndexFetch

`ODCIIndexFetch`() returns the "next" row identifier of the row that satisfies the operator predicate.The operator predicate is specified in terms of the operator expression (name and arguments) and a lower and upper bound on the operator return values. Thus, a `ODCIIndexFetch`() call returns the row identifier of the rows for which the operator return value falls within the specified bounds. A `NULL` is returned to indicate end of index scan. The fetch method supports returning a batch of rows in each call. The state returned by `ODCIIndexStart`() or a previous call to `ODCIIndexFetch`() is passed in as an argument.

ODCIIndexClose

`ODCIIndexClose`() is invoked when the cursor is closed or reused. In this call the Indextype can perform any clean-ups, etc. The current state is passed in as an argument.

Index Metadata Method

The `ODCIIndexGetMetadata` routine, if it is implemented, is called by the export utility to write implementation-specific metadata into the export dump file. This metadata might be policy information, version information, per-user settings, and so on, which are not stored in the system catalogs. The metadata is written to the dump files as anonymous PL/SQL blocks that get executed at import time immediately prior to the creation of the associated index.

This method on the `ODCIIndex` interface is required in version 8.1.3 and must be implemented by all domain index implementation types. If `ODCIIndexGetMetadata` is not found, export will abort the creation of the index. However, for the final release of 8.1, this method will be optional if no implementation-specific metadata is required.

Transaction Semantics during Index Method Execution

The index interface routines (with the exception of index definition methods, namely, `ODCIIndexCreate()`, `ODCIIndexAter()`, `ODCIIndexTruncate()`, `ODCIIndexDrop()`) are invoked under the same transaction that triggered these actions. Thus, the changes made by these routines are atomic and are committed or aborted based on the parent transaction. To achieve this, there are certain restrictions on the nature of the actions that can be performed in the different indextype routines.

- Index definition routines have no restrictions.
- Index maintenance routines can only execute DML statements. However, the DML statements cannot update the base table on which the domain index is created.
- Index scan routines can only execute SQL query statements.

For example, if an `INSERT` statement caused the `ODCIIndexInsert()` routine to be invoked, `ODCIIndexInsert()` runs under the same transaction as `INSERT`. The `ODCIIndexInsert()` routine can execute any number of DML statements (for example, insert into index-organized tables). If the original transaction aborts, all the changes made by the indextype routines are rolled back.

However, if the indextype routines cause changes external to the database (like writing to external files), transaction semantics are not assured.

Transaction Semantics for Index Definition Routines

The index definition routines do not have any restrictions on the nature of actions within them. Consider `ODCIIndexCreate()` to understand this difference. A typical set of actions to be performed in `ODCIIndexCreate()` could be:

1. Create an index-organized table
2. Insert data into the index-organized table
3. Create a secondary index on a column of the index-organized table

To allow `ODCIIndexCreate()` to execute an arbitrary sequence of DDL and DML statements, we consider each statement to be an independent operation. Consequently, the changes made by `ODCIIndexCreate()` are not guaranteed to be atomic. The same is true for other index-definition routines.

Consistency Semantics during Index Method Execution

The index maintenance (and scan routines) execute with the same snapshot as the top level SQL statement performing the DML (or query) operation. This enables the index data processed by the index method to be consistent with the data in the base tables.

Privileges During Index Method Execution

Indextype routines always execute as the owner of the index. To support this, the index access driver will dynamically change user mode to index owner before invoking the indextype routines.

For certain operations, indextype routines may require to store information in tables owned by indextype designer. Indextype implementation must code those actions in a separate routine which will be executed using definer's privileges. For more information on syntax, see CREATE TYPE in the *Oracle8i SQL Reference*.

Domain Index

This section describes the domain index operations and how metadata associated with the domain index can be obtained.

Domain Index Operations

Creating a Domain Index

A domain index can be created on a column of a table just like a B-tree index. However, an indextype must be explicitly specified. For example:

```
CREATE INDEX ResumeTextIndex ON Employees(resume)
INDEXTYPE IS TextIndexType
PARAMETERS (':Language English :Ignore the a an');
```

The INDEXTYPE clause specifies the indextype to be used. The PARAMETERS clause identifies any parameters for the domain index, specified as a string. This string is passed uninterpreted to the ODCIIndexCreate routine for creating the domain index. In the above example, the parameters string identifies the language of the text document (thus identifying the lexical analyzer to use) and the list of stop words which are to be ignored while creating the text index.

Altering a Domain Index

A domain index can be altered using ALTER INDEX statement. For example:

```
ALTER INDEX ResumeTextIndex PARAMETERS (':Ignore on');
```

The parameter string is passed uninterpreted to `ODCIIndexAlter()` routine, which takes appropriate actions to alter the domain index. In the above example, additional stop words to ignore in the text index are specified.

The `ALTER` statement can be used to rename a domain index.

```
ALTER INDEX ResumeTextIndex RENAME TO ResumeTIdx;
```

The `ODCIIndexAlter()` routine is invoked, which takes appropriate actions to rename the domain index.

In addition, the `ALTER` statement can be used to rebuild a domain index.

```
ALTER INDEX ResumeTextIndex REBUILD PARAMETERS (':Ignore of');
```

The same `ODCIIndexAlter()` routine is called but with additional information about the `ALTER` option.

Truncating Domain Index

There is no explicit statement for truncating a domain index. However, when the corresponding table is truncated the truncate procedure specified as part of the indextype is invoked. For example:

```
TRUNCATE TABLE Employees;
```

will result in truncating ResumeTextIndex by calling `ODCIIndexTruncate`() routine.

Dropping a Domain Index

To drop an instance of a domain index, the `DROP INDEX` statement is used. For our example, this statement would be of the form:

```
DROP INDEX ResumeTextIndex;
```

This results in calling the `ODCIIndexDrop`() routine and passing information about the index.

Domain Index Meta Data

For B-tree indexes, users can query the `USER_INDEXES` view to get index information. To provide similar support for domain indexes, indextype designers can add any domain-specific metadata in the following manner:

- The indextype designer can define one or more tables that will contain this meta information. The key column of this table must be a unique identifier for the index. This unique key could be the index name (`schema.index`). The remainder of the column definitions are at the discretion of the index designer.

- Views can be created that join the system defined metadata tables with the index meta tables to provide a comprehensive set of information for each instance of a domain index. It is the responsibility of the indextype designer to provide the view definition.

Export/Import of Domain Indexes

Like B-tree and bitmap indexes, domain indexes are exported and subsequently imported when their base tables are exported. However, domain indexes can have implementation-specific metadata associated with them that are not stored in the system catalogs. For example, a text domain index can have associated policy information, a list of irrelevant words, and so on. Export/Import provides a mechanism to opaquely move this metadata from the source platform to target platform.

To move the domain index metadata, the indextype needs to implement the `ODCIIndexGetMetadata` interface routine (see the reference chapters for details). This interface routine gets invoked when a domain index is being exported. The domain index information is passed in as a parameter. It can return any number of anonymous PL/SQL blocks that are written into the dump file and executed on import. If present, these anonymous PL/SQL blocks are executed immediately before the creation of the associated domain index.

Note that the `ODCIIndexGetMetadata` is an optional interface routine. It is needed only if the domain index has extra metadata to be moved.

Operators

A user-defined operator is a top-level schema object. It is identified by a name which is in the same namespace as tables, views, types and stand-alone functions.

Operator Bindings

An operator binding identifies the operator with a unique signature (via argument data types), and allows associating a function that provides an implementation for the operator. This enables Oracle to execute the function when the operator is invoked. Multiple operator bindings can be defined as long as they differ in their signatures.

- **Signature:** is the sequence of datatypes of the arguments to the function

Thus, any operator has an associated set of one or more bindings. Each of this binding can be evaluated using an user-defined function which could be one of

- Stand-alone functions
- Package functions or
- `OBJECT` member methods.

An operator created in a schema can be evaluated using functions defined in the same or different schemas. The operator bindings can be specified at the time of creating the operator. It is ensured that the signatures of the bindings are unique.

Creating operators

An operator can be created by specifying the operator name and its bindings.

For example, an operator Contains can be created in the `Ordsys` schema with two bindings and the corresponding functions that providing the implementation in Text and Spatial domains.

```
CREATE OPERATOR Ordsys.Contains
BINDING
(VARCHAR2, VARCHAR2) RETURN NUMBER USING text.contains,
(Spatial.Geo, Spatial.Geo) RETURN NUMBER USING Spatial.contains;
```

Note: Although the return data type is specified as part of operator binding declaration, it is not considered to determine the uniqueness of the binding, However, the specified function must have the same argument and return datatypes as the operator binding.

Dropping operators

An existing operator and all its bindings can be dropped using the `DROP OPERATOR` statement as follows:

```
DROP OPERATOR Contains;
```

The default `DROP` behavior is `DROP RESTRICT` semantics. Namely, if there are any dependent indextypes for any of the operator bindings, then the `DROP` operation is disallowed.

However, users can override the default behavior by using the `FORCE` option. For example,

```
DROP OPERATOR Contains FORCE;
```

drops operator Contains and all its binding marks any dependent indextype objects (if any) invalid.

Operator Invocation

Operator Usage

User-defined operators can be invoked anywhere built-in operators can be used. i.e. wherever expressions can occur. For example, user-defined operators can be used in the following:

- the select list of a `SELECT` command
- the condition of a `WHERE` clause
- the `ORDER BY` and `GROUP BY` clauses

Operator Execution

When an operator is invoked, the evaluation of the operator is transformed to the execution of one of the functions bound to it. This transformation is based on the datatypes of the arguments to the operator. If none of the functions bound to the operator satisfy the signature with which the operator is invoked, an error is raised. There might be some implicit type conversions present during the transformation process.

Examples

Consider the operator created with the following statement:

```
CREATE OPERATOR Ordsys.Contains
BINDING
(VARCHAR2, VARCHAR2) RETURN NUMBER
USING text.contains,
(spatial.geo, spatial.geo) RETURN NUMBER
USING spatial.contains;
```

Consider the operator `Contains` being used in the following SQL statements:

```
SELECT * FROM Employee
WHERE Contains(resume, ’Oracle’)=1 AND Contains(location, :bay_area)=1;
```

The invocation of the operator `Contains(resume, ’Oracle’)` is transformed into the execution of the function `text.contains(resume, ’Oracle’)` since the signature of the function matches the datatypes of the operator arguments. Similarly, the invocation of the operator `Contains(location`, `:bay_area)` is transformed into the execution of the function `spatial.contains(location, :bay_area)`.

The following statement would raise an error since none of the operator bindings satisfy the argument datatypes:

```
SELECT * FROM Employee
WHERE Contains(salary, 10000)=1;
```

Operator Privileges

There are system privileges for operator schema objects. They are:

- CREATE OPERATOR
- CREATE ANY OPERATOR
- DROP ANY OPERATOR

See the *Oracle8i SQL Reference* for details.

To use a user-defined operator in an expression, you must own the operator or have EXECUTE privilege on it.

Operators and Indextypes

An operator can be optionally supported by one or more user-defined indextypes. An indextype can "support" one or more operators. This means that a domain index of this indextype can be used in efficiently evaluating these operators. For example, B-tree indexes can be used to evaluate the relational operators like =, < and >. Operators can also be bound to regular functions. For example, an operator Equal can be bound to a function `eq(number, number)` that compares two numbers. The DDL for this would be:

```
CREATE OPERATOR Equal
BINDING(NUMBER, NUMBER) RETURN NUMBER USING eq;
```

Thus, an indextype designer should first design the set of operators to be supported by the indextype. For each of these operators, a functional implementation should be provided.

The list of operators supported by an indextype are specified when the indextype schema object is created (as described above). The evaluation of operators using indextype is different for operators occurring in WHERE clause compared to operators occurring elsewhere in a SQL statement. Below we consider index-based evaluation of the operators in both these cases.

Operators in WHERE clause

The operators appearing in the `WHERE` clause can be evaluated efficiently by performing an index scan using the scan methods provided as part of indextype implementation. This involves recognizing operator predicates of a certain form, selection of a domain index, setting up of appropriate index scan, and finally, execution of index scan methods. Let's consider each one of these steps in detail.

Operator Predicates

Indextype "supports" efficient evaluation of those operator predicates, which can be represented by a range of lower and upper bounds on the operator return values. Specifically, predicates of the form

```
op(...) relop <value expression>, where relop in {<, <=, =, >=,>}
```

```
op(...) LIKE <value_expression>
```

are possible candidates for index scan based evaluation.

Use of the operators in any expression, for example

```
op(...) + 2 = 3
```

precludes index-scan based evaluation.

Predicates of the form,

```
op() is NULL
```

will not be evaluated using index scan. It will always be evaluated using the functional implementation.

Finally, any other operator predicates which can internally be converted into one of the above forms by Oracle can also make use of the index scan based evaluation.

Operator Resolution

The index scan based evaluation of the operator is a possible candidate for predicate evaluation only if the operator occurring in the predicate (as described above) operates on a column or `OBJECT` attribute indexed using an indextype. The final decision to choose between the indexed implementation and the functional implementation is made by the optimizer. The optimizer takes into account the selectivity and cost while generating the query execution plan.

As an example, consider the query

```
SELECT * FROM Employees WHERE Contains(resume, 'Oracle') = 1;
```

The optimizer can choose to use a domain index in evaluating the `Contains` operator if

- The resume column has an index defined on it.
- The index is of type `TextIndexType`.
- `TextIndexType` supports the appropriate `Contains`() operator.

If any of the above conditions do not hold, a complete scan of the `Employees` table is performed and the functional implementation of `Contains` is applied as a post-filter. If the above conditions are met, the optimizer uses selectivity and cost functions to compare the cost of index-based evaluation with the full table scan and appropriately generates the execution plan.

Consider a slightly different query,

```
SELECT * FROM Employees WHERE Contains(resume, 'Oracle') =1 AND id =100;
```

In this query, the `Employees` table could be accessed through an index on the `id` column or one on the `resume` column. The optimizer estimates the costs of the two plans and picks the cheaper one, which could be to use the index on `id` and apply the `Contains` operator on the resulting rows. In this case, the functional implementation of `Contains`() is used and the domain index is not used.

Index scan Setup

If a domain index is selected for the evaluation of an operator predicate, an index scan is set-up. The index scan is performed by the scan methods (`ODCIIndexStart`(), `ODCIIndexFetch`(), `ODCIIndexClose`()) specified as part of the corresponding indextype implementation. The `ODCIIndexStart`() method is invoked with the operator related information including name and arguments and the lower and upper bounds describing the predicate. After the `ODCIIndexStart`() call, a series of fetches are performed to obtain row identifiers of rows satisfying the predicate, and finally the `ODCIIndexClose`() is called when the SQL cursor is destroyed.

Execution Model for Index Scan Methods

The index scan routines must be implemented with an understanding of how the routines' invocations are ordered and how multiple sets of invocations can be interleaved.

As an example, consider the query

```
SELECT * FROM Emp1, Emp2 WHERE
Contains(Emp1.resume, 'Oracle') =1 AND Contains(Emp2.resume, 'Unix') =1
AND Emp1.id = Emp2.id;
```

If the optimizer decides to use the domain indexes on the resume columns of both tables, the indextype routines may be invoked in the following sequence:

```
start(ctx1, ...); /* corr. to Contains(Emp1.resume, 'Oracle') */
start(ctx2, ...); /* corr. to Contains(Emp2.resume, 'Unix');
fetch(ctx1, ...);
fetch(ctx2, ...);
fetch(ctx1, ...);
...
close(ctx1);
close(ctx2);
```

Thus, the same indextype routine may be invoked but for different instances of operators. At any time, many operators are being evaluated through the same indextype routines. In case of routines that do not need to maintain any state across calls i.e. all the information is obtained through its parameters (like the create routine), this is not a problem. However, in case of routines needing to maintain state across calls (like the fetch routine which needs to know which row to return next), the state should be maintained in the `SELF` parameter that is passed in to each call. The `SELF` parameter (which is an instance of the implementation type) can be used to store either the entire state (if it is not too big) or a handle to the cursor-duration memory that stores the state.

Operators elseWHERE

Using Functional Implementation

Operators occurring in expressions other than in the `WHERE` clause are evaluated using the functional implementation. For example,

```
SELECT Contains(resume, 'Oracle') FROM Employee;
```

would be executed by scanning the `Employee` table and invoking the functional implementation for Contains on each instance of resume. The function is invoked by passing it the actual value of the resume (text data) in the current row. Note that this function would not make use of any domain indexes that may have been built on the resume column.

However, it's possible to have a functional implementation for an operator that makes use of a domain index. The following sections discuss how functions that use domain indexes can be written and how they are invoked by the system.

Creating Index-based Functional Implementation

For many domain-specific operators, such as `Contains`, the functional implementation can work in two ways:

1. If the operator is operating on a column (or `OBJECT` attribute) that has a domain index of a particular indextype, the function can evaluate the operator by looking at the index data rather than the actual argument value.

   For example, when `Contains(resume, 'Oracle')` is invoked on a particular row of the `Employee` table, it is easier for the function to look up the text domain index defined on the resume column and evaluate the operator based on the row identifier for the row containing the resume - rather than work on the resume text data argument.

2. If the operator is operating on a column that does not have an appropriate domain index defined on it or if the operator is invoked with literal values (non-columns), the functional implementation evaluates the operator based on only the argument values. This is the default behavior for all operator bindings.

To achieve both the behaviors of (1) and (2) above, the functional implementation is provided using a regular function which has three additional arguments - in addition to all the original arguments to the operator. The additional arguments are:

- Index context — containing domain index information and the row identifier of the row on which operator is being evaluated and
- Scan context — a context value to share state with subsequent invocations of the same operator (operating on other rows of the table).
- Scan flag — indicates whether the current call is the last invocation during which all clean up operations should be done.

For example, the index-based functional implementation for the Contains operator is provided by the following function.

```
CREATE FUNCTION TextContains (Text IN VARCHAR2, Key IN VARCHAR2,
indexctx IN ODCIIndexCtx, scanctx IN OUT TextIndexMethods, scanflg IN NUMBER)
RETURN NUMBER AS
BEGIN
.......
END TextContains;
```

The `Contains` operator is bound to the above functional implementation as follows:

```
CREATE OPERATOR Contains
BINDING (VARCHAR2, VARCHAR2) RETURN NUMBER
WITH INDEX CONTEXT, SCAN CONTEXT TextIndexMethods
```

```
USING TextContains;
```

The `WITH INDEX CONTEXT` clause specifies that the functional implementation can make use of any applicable domain indexes. The `SCAN CONTEXT` specifies the datatype of the scan context argument. It must be the same as the implementation type of the relevant indextype that supports this operator.

Operator Resolution

Oracle will invoke the functional implementation for the operator if the operator appears `elseWHERE` i.e. anywhere other than the `WHERE` clause. If the functional implementation is index-based (i.e. defined to use an indextype), the additional index information will be passed in as arguments only if the operator's first argument is a column (or `OBJECT` attribute) with a domain index of the appropriate indextype defined on it.

For example, in the query

```
SELECT Contains(resume, 'Oracle & Unix') FROM Employees;
```

the Operator `Contains` will be evaluated using the index-based functional implementation by passing the index information about the domain index on resume column instead of the resume data.

Operator Execution

To execute the index-based functional implementation, Oracle RDBMS will set-up the arguments in the following manner:

- The initial set of arguments are the same as those specified by the user for the operator.
- If the first argument is not a column, the `ODCIIndexCtx` attributes are set to `NULL`.
- If the first argument is a column, the `ODCIIndexCtx` attributes are set up as follows.
  - If there are no applicable domain indexes, the `ODCIIndexInfo` attribute is set to `NULL`, else it is set up with the information about the domain index.
  - The `rowid` attribute holds the row identifier of the row being operated on.
- The scan context is passed as `NULL` to the first invocation of the operator. Since it is an `IN/OUT` parameter, the return value from the first invocation is passed in to the second invocation and so on.
- The scan flag is set to `RegularCall` for all normal invocations of the operator. After the last invocation, the functional implementation is invoked once more

during which any cleanup actions can be performed. During this call, the scan flag is set to `CleanupCall` and all other arguments except the scan context are set to `NULL`.

When index information is passed in, the implementation can compute the operator value by doing a domain index lookup using the row identifier as key. The index metadata is used to identify the index structures associated with the domain index. The scan context is typically used to share state with the subsequent invocations of the same operator.

Ancillary Data

Apart from filtering rows, the operator occurring in `WHERE` clause might need to support returning ancillary data. The ancillary data is modeled as an operator (or multiple operators) with a single literal number argument. It has a functional implementation that has access to state generated by the index-scan based implementation of the primary operator occurring in the `WHERE` clause.

For example, in the following query,

```
SELECT Score(1) FROM Employees
WHERE Contains(resume, 'OCI & UNIX', 1) =1;
```

Contains is the primary operator which can be evaluated using an index-scan which in addition to determining the rows that satisfy the predicate, also computes a score value for each row. The functional implementation for Score operator simply accesses the state generated by the index-scan to obtain score for a given row identified by its row identifier. The literal argument 1 associates the ancillary operator Score to the corresponding primary operator Contains which generates the ancillary data.

In summary, ancillary data is modeled as independent operator(s), which is invoked by the user with a single number argument that ties it with the corresponding primary operator. Its functional implementation makes use of either the domain index or the state generated by the primary operator occurring in `WHERE` clause. The functional implementation is invoked with extra arguments: the index context containing the domain index information and the scan context which provides access to the state generated by the primary operator. The following sections discuss how operators modeling ancillary data are defined and invoked.

Creating Operator Binding that Computes Ancillary Data

An indextype designer needs to specify that an operator binding computes ancillary data. Such a binding is referred to as a *primary* binding. For example, a primary binding for Contains can be defined as follows:

```
CREATE OPERATOR Contains
BINDING (VARCHAR2, VARCHAR2) RETURN NUMBER
WITH INDEX CONTEXT, SCAN TextIndexMethods COMPUTE ANCILLARY DATA
USING TextContains;
```

The above definition registers two bindings for Contains, namely:

- `CONTAINS(VARCHAR2, VARCHAR2)` — This can be used as before.
- `CONTAINS(VARCHAR2, VARCHAR2, NUMBER)` — When ancillary data is required elsewhere in SQL query, the operator can be invoked with the above signature. The `NUMBER` argument is used to associate the corresponding ancillary operator binding.

However, the indextype designer needs to define a single functional implementation:

```
TextContains(VARCHAR2, VARCHAR2, ODCIIndexCtx, TextIndexMethods, NUMBER).
```

Creating Operator Binding that Models Ancillary Data

An indextype designer has to implement the functional implementation for ancillary data operators in a manner similar to the index-based functional implementation. As discussed earlier, the function takes extra arguments. After the function is defined, the indextype designer can bind it to the operator with an additional `ANCILLARY TO` attribute, which indicates that the functional implementation needs to share state with the *primary* operator binding. The binding that is used for modeling ancillary data is referred to as the *ancillary* operator binding.

For example, let `TextScore`() function contain code to evaluate the `Score` ancillary operator.

```
CREATE FUNCTION TextScore (Text IN VARCHAR2, Key IN VARCHAR2,
indexctx IN ODCIIndexCtx, scanctx IN OUT TextIndexMethods, scanflg IN NUMBER)
RETURN NUMBER AS
BEGIN
.......
END TextScore;
```

An ancillary operator binding can be created as follows:

```
CREATE OPERATOR Score
BINDING (NUMBER) RETURN NUMBER
ANCILLARY TO Contains(VARCHAR2, VARCHAR2)
USING TextScore;
```

- The ANCILLARY TO clause specifies that it shares state with the implementation of corresponding primary operator binding CONTAINS(VARCHAR2, VARCHAR2).
- Note that the functional implementation for the ancillary operator binding must have the same signature as the functional implementation for the primary operator binding.
- The ancillary operator binding is invoked with a single literal number argument, e.g Score(1), Score(2), etc.

Operator Resolution

The operators corresponding to ancillary data are invoked by the user with a single number argument.

> **Note:** The number argument must be a literal in both the ancillary operation and the primary operator invocation. This is required so that the operator association can be done at the query compilation time.

The corresponding primary operator invocation in the query is determined by matching it with the number passed in as the last argument to the primary operator. After the matching primary operator invocation is found (it is an error to find zero or more than one matching primary operator invocation):

- The arguments to the primary operator are also made operands to the ancillary operator.
- The ancillary and primary operator executions are passed in the same scan context.

For example, consider the query

```
SELECT Score(1) FROM Employees
WHERE Contains(resume, ' Oracle & Unix', 1) =1;
```

The invocation of Score is determined to be ancillary to Contains based on the number argument "1" and the functional implementation for Score gets the following operands: (resume, 'Oracle&Unix', indexctx, scanctx, scanflg) where scanctx is shared with the invocation of Contains.

Operator Execution

The execution would involve using an index scan to process the Contains operator. For each of the rows returned by the fetch() call of the index scan, the functional implementation of `Score` is invoked by passing it the `ODCIIndexCtx` argument, which contains the index information, row identifier, and a handle to the index scan state. The functional implementation can use the handle to the index scan state to compute the score.

Object Dependencies, Drop Semantics, and Validation

Dependencies

The dependencies between various objects are as follows:

- **Functions, Packages, and Object Types:** Referenced by Operators and Indextypes.
- **Operators:** Referenced by Indextypes, DML and Query SQL Statements.
- **Indextypes**: Referenced by Domain Indexes.
- **Domain Indexes:** Referenced (used implicitly) by DML and Query SQL Statements

Thus, the order in which these objects must be created, or their definitions exported for future Import are:

- Functions, Packages, and Object Types, followed by Operators, followed by Indextypes.

Drop Semantics

The drop behavior for an object is as follows:

- **`RESTRICT` semantics:** If there are any dependent objects the drop operation is disallowed.
- **`FORCE` semantics:** The object is dropped even in the presence of dependent objects and the dependent objects if any are recursively marked invalid.

The table below shows the default and explicit drop options supported for operators and indextypes. The other schema objects are included for completeness and the corresponding drop behavior already available in Oracle8*i*.

Schema Object	Default Drop Behavior	Explicit Options Supported
Function	`FORCE`	None
Package	`FORCE`	None

Schema Object	Default Drop Behavior	Explicit Options Supported
Object Types	`RESTRICT`	`FORCE`
Operator	`RESTRICT`	`FORCE`
Indextype	`RESTRICT`	`FORCE`

Object Validation

Invalid object are automatically revalidated whenever the object is subsequently referenced.

Privileges

- For creating an operator and its bindings, the user must have `EXECUTE` privilege on the function, operator, package, or the type referenced in addition to `CREATE OPERATOR` or `CREATE ANY OPERATOR` privilege.
- For creating an indextype, the user must have `EXECUTE` privilege on the type that implements the indextype in addition to `CREATE INDEXTYPE` or `CREATE ANY INDEXTYPE` privilege. Also, the user must have `EXECUTE` privileges on the operators that the indextype supports.
- For creating domain index the user must `EXECUTE` privilege on the indextype in addition to `CREATE INDEX` or `CREATE ANY INDEX` privilege.
- For using the operators in queries and/or DML statements user must have `EXECUTE` privilege on the operator and the associated function/package/type.

8 Query Optimization

- This chapter describes query optimization, including:
- Overview
- Defining Statistics, Selectivity, and Cost Functions
- Using User-defined Statistics, Selectivity, and Cost
- Predicate Ordering

Overview

Query Optimization is the process of choosing the most efficient way to execute a SQL statement. When the *cost-based optimizer* was offered for the first time with Oracle7, Oracle supported only standard relational data. The introduction of objects with Oracle8*i* extended the supported datatypes and functions. The *Extensible Indexing* feature discussed in the previous chapter, introduces user-defined access methods.

For more information regarding optimization see:

- *Oracle8i Concepts* — for an introduction to optimization
- *Oracle8i Tuning* — for information about using hints in SQL statements

The extensible optimizer feature allows authors of user-defined functions and indexes to create statistics collection, selectivity, and cost functions that are used by the optimizer in choosing a query plan. The optimizer cost model is extended to integrate information supplied by the user. Specifically, you now can:

- Associate cost function and default costs with domain indexes, indextypes, packages, and stand-alone functions.
- Associate selectivity function and default selectivity with methods of object types, package functions, and stand-alone functions.
- Associate statistics collection functions with domain indexes and columns of tables.
- Order predicates with functions based on cost.
- Select a user-defined access method (domain index) for a table based on access cost.
- Use the ANALYZE command to invoke user-defined statistics collection and deletion functions.
- Use new data dictionary views to include information about the statistics collection, cost, or selectivity functions associated with columns, domain indexes, indextypes or functions.
- Add a hint to preserve the order of evaluation for function predicates.

Please note that only the *cost-based* optimizer has been enhanced; Oracle has not altered the operation of the *rule-based* optimizer.

The optimizer generates an execution plan for a SQL DML statement: SELECT, INSERT, UPDATE, or DELETE. For simplicity, we describe the generation of an execution plan in terms of a SELECT statement, but the same process applies to other DML statements.

An execution plan includes an *access method* for each table in the FROM clause, and an ordering, called the *join order*, of the tables in the FROM clause. System-defined access methods include indexes, hash clusters, and table scans. The optimizer chooses a plan by generating a set of join orders, or permutations, by computing the cost of each, and then by selecting the process with the lowest cost. For each table in the join order, the optimizer computes the cost of each possible access method and join method and chooses the one with the lowest cost. The cost of the join order is the sum of the access method and join method costs. The costs are calculated using algorithms which together comprise the *cost model*. The cost model includes varying level of detail about the physical environment in which the query is executed.

The optimizer uses statistics about the objects referenced in the query to compute the selectivity and costs. The statistics are gathered using the ANALYZE command. The selectivity of a predicate is the fraction of rows in a table that is chosen by the predicate. It is a number between 0 and 1.

The *Extensible Indexing* feature allows users to define new operators, indextypes, and domain indexes. For user-defined operators and domain indexes, the *Extensible Optimizer* feature allows you to control the three main components used by the optimizer to select an execution plan:

- Statistics
- Selectivity
- Cost

In the following sections, we describe each of these components in greater detail.

Statistics

Statistics are collected using the ANALYZE command. Statistics can be collected for tables and indexes. In general, the more accurate the statistics, the better the execution plan generated by the optimizer. We call the statistics generated by the current ANALYZE command *standard statistics*. However, with the addition of user-defined domain indexes in Oracle8*i*.release 8.1.5, the standard ANALYZE statement cannot generate any statistics on the domain index since the database does not know the index storage structure.

User-Defined Statistics

The Extensible Optimizer feature lets you define *statistics collection* functions for domain indexes and columns. The extension to the ANALYZE command has the effect that whenever a domain index is analyzed, a call is made to the user-specified statistics collection function. The database does not know the representation and meaning of the user-collected statistics.

In addition to domain indexes, Oracle supports user-defined statistics collection functions for individual columns of a table, and for user-defined datatypes. In the former case, whenever a column is analyzed, the user-defined statistics collection function is called to collect statistics in addition to any standard statistics that the database collects. If a statistics collection function exists for a datatype, it is called for each column of the table being analyzed that has the required type.

Thus, the *Extensible Optimizer* feature extends ANALYZE to allow user-defined statistics collection functions for domain indexes, indextypes, datatypes, and individual table columns.

The cost of evaluating a user-defined function depends on the algorithm and the statistical properties of its arguments. It is not practical to store statistics for all possible combinations of columns that could be used as arguments for all functions. Therefore, Oracle maintains only statistics on individual columns. It is also possible that function costs depend on the different statistical properties of each argument. Every column could require statistics for every argument position of every applicable function. Oracle does not support such a proliferation of statistics and cost functions because it would decrease performance.

A user-defined function to drop statistics is required whenever there is a user-defined statistics collection function; it is called by ANALYZE DELETE.

User-Defined Statistics for Partitioned Objects

Since domain indexes cannot be partitioned in Oracle8*i*, release 8.1.5, a user-defined statistics collection function collects only global statistics on the non-partitioned index.

When an ANALYZE command specifies a list of partitions, this information is not passed to user-defined statistics collection functions.

Selectivity

The optimizer uses statistics to calculate the selectivity of predicates. The selectivity is the fraction of rows in a table that is chosen by the predicate. It is a number between 0 and 1. The selectivity of a predicate is used to estimate the cost of a particular access method; it is also used to determine the optimal join order. A poor choice of join order by the optimizer could result in a very expensive execution plan.

Currently, the optimizer uses a standard algorithm to estimate the selectivity of selection and join predicates. However, the algorithm does not always work well in cases in which predicates contain functions or type methods. In addition, in Oracle8*i*, release 8.1.5, 1 predicates can contain user-defined operators about which the optimizer does not have any information. In that case the optimizer cannot compute an accurate selectivity.

User-defined Selectivity

For greater control over the optimizer's selectivity estimation, this feature lets you specify user-defined selectivity functions for predicates containing user-defined operators, stand-alone functions, package functions, or type methods. The user-defined selectivity function is called by the optimizer whenever it encounters a predicate with one of the following forms:

```
operator(...) relational_operator <constant>

<constant> relational_operator operator(...)

operator(...) LIKE <constant>
```

where

- `operator(...)` is a user-defined operator, stand-alone function, package function, or type method,
- `relational_operator` is one of `{<, <=, =, >=, >}`, and
- `<constant>` is a constant value expression or bind variable.

For such cases, users can define selectivity functions associated with `operator(...)`. The arguments to `operator` can be columns, constants, bind variables, or attribute references. When optimizer encounters such a predicate, it calls the user-defined selectivity function and passes the entire predicate as an argument (including the operator, function, or type method and its arguments, the relational operator `relational_operator`, and the constant expression or bind variable). The return value of the user-defined selectivity function must be expressed as a percent, and be between 0 and 100 inclusive; the optimizer ignores values outside this range.

Wherever possible, the optimizer uses user-defined selectivity values. However, this is not possible in the following cases:

- The user-defined selectivity function returns an invalid value (less than 0 or greater than 100)
- There is no user-defined selectivity function defined for the operator, function, or method in the predicate
- The predicate does not have one of the above forms, e.g., `operator(...) + 3 relational_operator <constant>`

In each of these cases, the optimizer uses heuristics to estimate the selectivity.

Cost

The optimizer estimates the cost of various access paths to choose an optimal plan. For example, it computes the cost of using an index and a full table scan to choose between the two. However, with regard to domain indexes, the optimizer does not know the internal storage structure of the index, and so it cannot compute a good estimate of the cost of a domain index.

User-Defined Cost

For greater flexibility, the cost model has been extended to let you define costs for domain indexes and user-defined stand-alone functions, package functions, and type methods. The user-defined costs can be in the form of default costs that the optimizer looks up, or they can be full-fledged cost functions which the optimizer calls to compute the cost.

As is the case with user-defined selectivity, user-defined cost is optional. If no user-defined cost is available, the optimizer uses heuristics to compute an estimate. However, in the absence of sufficient useful information about the storage structures in user-defined domain indexes and functions, such estimates can be very inaccurate and result in the choice of a sub-optimal execution plan.

User-defined cost functions for domain indexes are called by the optimizer only if a domain index is a valid access path for a user-defined operator (for details regarding when this is true, see the discussion of *user-defined indexing* in the previous chapter). User-defined cost functions for functions, methods and domain indexes are only called when a predicate has one of the following forms:

```
operator(...) relational_operator <constant>

<constant> relational_operator operator(...)
```

```
operator(...) LIKE <constant>
```

where

- `operator(...)` is a user-defined operator, stand-alone function, package function, or type method,
- `relational_operator` is one of {`<, <=, =, >=, >`}, and
- `<constant>` is a constant value expression or bind variable.

This is, of course, identical to the conditions for user-defined selectivity functions.

User-defined cost functions can return three cost values, each value representing the cost of a *single* execution of a function or domain index implementation:

- `CPU` — the number of machine instructions executed by the function or domain index implementation. This does not include the overhead of invoking the function.
- `I/O` — the number of data blocks read by the function or domain index implementation. For a domain index, this does not include accesses to the Oracle table. The multiblock I/O factor is not passed to the user-defined cost functions.
- `NETWORK` — the number of data blocks transmitted. This is valid for distributed queries as well as functions and domain index implementations. For Oracle8*i* this cost component is not used and is ignored; however, as described below, the user is required to stipulate a value so that backward compatibility is facilitated when this feature is introduced.

The optimizer computes a composite cost from these cost values.

Optimizer Parameters

The cost of a query is a function of the cost values discussed above. These values can be combined in one of three ways depending on the settings of optimizer initialization parameters. The setting determines the function that is minimized.

- If `optimizer_mode` is `first_rows`, the resource cost of returning a single row is minimized. The optimizer mode is passed to user-defined cost functions.
- If `optimizer_percent_parallel` is not zero, a combination of throughput and resource costs is minimized.
- If neither of the previous two conditions pertains, the resource cost of returning all rows is minimized.

Defining Statistics, Selectivity, and Cost Functions

You can compute and store user-defined statistics for domain indexes and columns. These statistics are in addition to the standard statistics that are already collected by ANALYZE. User-defined selectivity and cost functions for functions and domain indexes can use standard and user-defined statistics in their computation. The internal representation of these statistics need not be known to Oracle; we only require that you provide methods for their access. You are solely responsible for defining the representation of such statistics and for maintaining them. It is important to note that user-collected statistics are only used by user-defined selectivity and cost functions; the optimizer use s only its standard statistics.

User-defined statistics collection, selectivity, and cost functions must be defined in a user-defined type. This type must have a form similar to a system-defined interface called ODCIStats (**O**racle **D**ata **C**artridge **I**nterface **Stat**istic**s**) defined as follows:

```
CREATE INTERFACE ODCIStats AS (

   -- Function to get current interface
   FUNCTION ODCIGetInterfaces(ifclist OUT ODCIObjectList) return NUMBER,

   -- User-defined statistics functions
   FUNCTION ODCIStatsCollect(col ODCIColInfo, options ODCIStatsOptions,
      statistics OUT RAW) return NUMBER,
   FUNCTION ODCIStatsCollect(ia ODCIIndexInfo, options ODCIStatsOptions,
      statistics OUT RAW) return NUMBER,
   FUNCTION ODCIStatsDelete(col ODCIColInfo) return NUMBER,
   FUNCTION ODCIStatsDelete(ia ODCIIndexInfo) return NUMBER,

   -- User-defined selectivity function
   FUNCTION ODCIStatsSelectivity(pred ODCIPredInfo, sel OUT NUMBER, args
      ODCIArgDescList, start <function_return_type>,
      stop <function_return_type>,
      <list of function arguments>) return NUMBER,

   -- User-defined cost function for functions and type methods
   FUNCTION ODCIStatsFunctionCost(func ODCIFuncInfo, cost OUT ODCICost,
      args ODCIArgDescList, <list of function arguments>) return NUMBER,

   -- User-defined cost function for domain indexes
   FUNCTION ODCIStatsIndexCost(ia ODCIIndexInfo, sel NUMBER,
      cost OUT ODCICost, qi ODCIQueryInfo, pred ODCIPredInfo,
      args ODCIArgDescList, start <operator_return_type>,
      stop <operator_return_type>, <list of operator value arguments>)
      return NUMBER
)
```

You can define a new object type, referred to as a *statistics type*, with a subset of functions from `ODCIStats`. Since user-defined statistics collection, selectivity, and cost functions are all optional, a statistics type need not contain all the functions in `ODCIStats`.

The types of the parameters of statistics type methods are system-defined `ODCI` (**O**racle **D**ata **C**artridge **I**nterface) datatypes. Some of them are described in the reference to *Extensible Indexing*, and the rest are described in the reference chapter detailing the *Extensible Optimizer*.

The selectivity and cost functions must not change any database or package state. To that end, they must be defined with appropriate purity level pragmas, otherwise the optimizer will not call them.

Depending on the object that user-defined statistics are being associated with, not all the functions defined in a statistics type will be used. The table below lists the functions and default statistics that will be used by the optimizer.

Table 8–1 Statistics Type Methods and Default Statistics Used for Various Objects

ASSOCIATE STATISTICS WITH	Statistics Type Methods Used	Default Statistics Used
column	`ODCIStatsCollect`, `ODCIStatsDelete`	
object type	`ODCIStatsCollect`, `ODCIStatsDelete`, `ODCIStatsFunctionCost`, `ODCIStatsSelectivity`	cost, selectivity
function	`ODCIStatsFunctionCost`, `ODCIStatsSelectivity`	cost, selectivity
package	`ODCIStatsFunctionCost`, `ODCIStatsSelectivity`	cost, selectivity
index	`ODCIStatsCollect`, `ODCIStatsDelete`, `ODCIIndexCost`	cost
indextype	`ODCIStatsCollect`, `ODCIStatsDelete`, `ODCIIndexCost`	cost

User-Defined Statistics Functions

There are two user-defined statistics collection functions, one for collecting statistics and the other for deleting them.

The first, `ODCIStatsCollect`, is used to collect user-defined statistics; its interface depends on whether a column or domain index is being analyzed. It is called when analyzing a column of a table or a domain index and takes two parameters:

- `col` for the column being analyzed, or

  `ia` for the domain index being analyzed;
- `options` for options specified in the `ANALYZE` command (e.g., the sample size when `ANALYZE ESTIMATE` is used).

As mentioned, the database does not interpret statistics collected by `ODCIStatsCollect`. You can store output in a user-managed format or in a dictionary table (described in the *Extensible Optimizer* reference) provided for the purpose. The statistics collected by the `ODCIStatsCollect` functions are returned in the output parameter, `statistics`, as a `RAW` datatype.

When an `ANALYZE DELETE` command is issued, user-collected statistics are deleted by calling the `ODCIStatsDelete` function whose interface depends on whether the statistics for a column or domain index are being dropped. It takes a single parameter: `col`, for the column whose user-defined statistics need to be deleted, or `ia`, for the domain index whose statistics are to be deleted.

If a user-defined `ODCIStatsCollect` function is present in a statistics type, the corresponding `ODCIStatsDelete` function must also be present.

The return values of the `ODCIStatsCollect` and `ODCIStatsDelete` functions must be `Success` (indicating success), `Error` (indicating an error), or `Warning` (indicating a warning); these return values are defined in a system package `ODCIConst` (described in the *Extensible Optimizer* reference).

User-defined Selectivity Functions

You will recall that user-defined selectivity functions are used only for predicates of the following forms:

```
operator(...) relational_operator <constant>

<constant> relational_operator operator(...)

operator(...) LIKE <constant>
```

A user-defined selectivity function, `ODCIStatsSelectivity`, takes five sets of input parameters that describe the predicate:

- `pred` describing the function `operator` and the relational operator `relational_operator`;
- `args` describing the start and stop values (i.e., <`constant`>) of the function and the actual arguments to the function `operator`;
- `start` whose datatype is the same as that of the function's return value, describing the start value of the function;
- `stop` whose datatype is the same as that of the function's return value, describing the stop value of the function;
- and a list of function arguments whose number, position, and type must match the arguments of the function `operator`.

The computed selectivity is returned in the output parameter `sel`, in whole numbers, as a percentage, between 0 and 100, inclusive. The optimizer ignores invalid values.

The return value of the `ODCIStatsSelectivity` function must be

- `Success` indicating success, or
- `Error` indicating an error, or
- `Warning` indicating a warning.

As an example, consider a function `myFunction` defined as follows:

```
myFunction (a NUMBER, b VARCHAR2(10)) return NUMBER
```

A user-defined selectivity function for the function `myFunction` would be as follows:

```
ODCIStatsSelectivity(pred ODCIPredInfo, sel OUT NUMBER, args ODCIArgDescList,
   start NUMBER, stop NUMBER, a NUMBER, b VARCHAR2(10)) return NUMBER
```

If the function `myFunction` is called with literal arguments, e.g.,

```
myFunction (2, 'TEST') > 5
```

then the selectivity function is called as follows:

```
ODCIStatsSelectivity(<ODCIPredInfo constructor>, sel,
   <ODCIArgDescList constructor>, 5, NULL, 2, 'TEST')
```

If, on the other hand, the function `myFunction` is called with some non-literals e.g.,

```
myFunction(Test_tab.col_a, 'TEST')> 5
```

where `col_a` is a column in table `Test_tab`, then the selectivity function is called as follows:

```
ODCIStatsSelectivity(<ODCIPredInfo constructor>, sel,
   <ODCIArgDescList constructor>, 5, NULL, NULL, 'TEST')
```

In other words, the start, stop, and function argument values are passed to the selectivity function only if they are literals; otherwise they are `NULL`. The `ODCIArgDescList` descriptor describes all its following arguments.

User-defined Cost Functions for Functions

As already mentioned, user-defined cost functions are only used for predicates of the following forms:

```
operator(...) relational_operator <constant>

<constant> relational_operator operator(...)

operator(...) LIKE <constant>
```

You can define a function, `ODCIStatsFunctionCost`, for computing the cost of stand-alone functions, package functions, or type methods. This function takes three sets of input parameters describing the predicate:

- `func` describing the function `operator`;
- `args` describing the actual arguments to the function `operator`;
- and a list of function arguments whose number, position, and type must match the arguments of the function `operator`.

The `ODCIStatsFunctionCost` function returns its computed cost in the `cost` parameter. As mentioned, the returned cost can have two components — CPU and I/O — which are combined by the optimizer to compute a composite cost. The costs returned by user-defined cost functions must be positive whole numbers. Invalid values are ignored by the optimizer.

The return value of the `ODCIStatsFunctionCost` function must be

- `Success` indicating success, or
- `Error` indicating an error, or

- `Warning` indicating a warning.

Consider a function `myFunction` defined as follows:

```
myFunction (a NUMBER, b VARCHAR2(10)) return NUMBER
```

A user-defined cost function for the function `myFunction` would be coded as follows:

```
ODCIStatsFunctionCost(func ODCIFuncInfo, cost OUT ODCICost,
   args ODCIArgDescList, a NUMBER, b VARCHAR2(10)) return NUMBER
```

If the function `myFunction` is called with literal arguments, e.g.,

```
myFunction(2, ’TEST’) > 5,
```

then the cost function is called as follows:

```
ODCIStatsFunctionCost(<ODCIFuncInfo constructor>, cost,
   <ODCIArgDescList constructor>, 2, ’TEST’)
```

If, on the other hand, the function `myFunction` is called with some non-literals, e.g.,

```
myFunction(Test_tab.col_a, ’TEST’) > 5
```

where `col_a` is a column in table `Test_tab`, then the cost function is called as follows:

```
ODCIStatsFunctionCost(<ODCIFuncInfo constructor>, cost,
   <ODCIArgDescList constructor>, NULL, ’TEST’)
```

In other words, function argument values are passed to the cost function only if they are literals; otherwise they are `NULL`. The `ODCIArgDescList` descriptor describes all its following arguments.

User-defined Cost Functions for Domain Indexes

User-defined cost functions for domain indexes are used for the same type of predicates mentioned previously, except that `operator` must be a user-defined operator for which a valid domain index access path exists.

The `ODCIStatsIndexCost` function takes eight sets of parameters:

- `ia` describing the domain index;
- `sel` representing the user-computed selectivity of the predicate;

- qi containing additional information about the query;
- pred describing the predicate;
- args describing the start and stop values (i.e., <constant>) of the operator and the actual arguments to the operator operator;
- start, whose datatype is the same as that of the operator's return value, describing the start value of the operator;
- stop whose datatype is the same as that of the operator's return value, describing the stop value of the operator; and
- a list of operator value arguments whose number, position, and type must match the arguments of the operator operator. The value arguments of an operator are the arguments excluding the first argument.

The computed cost of the domain index is returned in the output parameter, cost.

ODCIStatsIndexCost returns

- Success indicating success, or
- Error indicating an error, or
- Warning indicating a warning.

Consider an operator

```
Contains(a_string VARCHAR2(2000), b_string VARCHAR2(10))
```

that returns 1 or 0 depending on whether or not the string b_string is contained in the string a_string. Further, assume that the operator is implemented by a domain index. A user-defined index cost function for this domain index would be coded as follows:

```
ODCIStatsIndexCost(ia ODCIIndexInfo, sel NUMBER, cost OUT ODCICost,
   qi ODCIQueryInfo, pred ODCIPredInfo, args ODCIArgDescList,
   start NUMBER, stop NUMBER, b_string VARCHAR2(10)) return NUMBER
```

Note that the first argument, a_string, of Contains does not appear as a parameter of ODCIStatsIndexCost. This is because the first argument to an operator must be a column for the domain index to be used, and this column information is passed in via the ODCIIndexInfo parameter. Only the operator arguments after the first (i.e., the "value" arguments) must appear as parameters to the ODCIStatsIndexCost function.

If the operator is called, e.g.,

```
Contains(Test_tab.col_c,'TEST') <= 1
```

then the index cost function is called as follows:

```
ODCIStatsIndexCost(<ODCIIndexInfo constructor>, sel, cost,
   <ODCIQueryInfo constructor>, <ODCIPredInfo constructor>,
   <ODCIArgDescList constructor>, NULL, 1, 'TEST')
```

In other words, the start, stop, and operator argument values are passed to the index cost function only if they are literals; otherwise they are `NULL`. The `ODCIArgDescList` descriptor describes all its following arguments.

Using User-defined Statistics, Selectivity, and Cost

Statistics types act as interfaces for user-defined functions that influence the choice of an execution plan by the optimizer. However, for the optimizer to be able to use a statistics type requires a mechanism to bind the statistics type to a database object (column, stand-alone function, object type, index, indextype or package). This is the function of the new `ASSOCIATE STATISTICS` command. The following sections describe this command in more detail.

User-defined Statistics

User-defined statistics functions are relevant for columns (both standard SQL datatypes and object types) and domain indexes. Statistics types used to collect user-defined statistics need not have the `ODCIStatsSelectivity`, `ODCIStatsFunctionCost`, and `ODCIStatsIndexCost` functions (they are ignored). The sections below describe how column and index user-defined statistics are collected.

User-collected statistics can either be stored in some predefined dictionary tables or users could create their own tables. The latter approach requires that privileges on these tables be administered properly, backup and restoration of these tables be done along with other dictionary tables, and point-in-time recovery considerations be resolved.

To ease the administration overhead, a predefined table, `USTATS$`, is created where you can store statistics. These statistics are not interpreted by the system; they are used by user-defined selectivity and cost functions. In addition to using these predefined tables, nothing prevents you from creating and administering your own tables to store the statistics. Details on the `USTATS$` table are given in the *Extensible Optimizer* reference.

Column Statistics

Consider a table Test_tab defined as follows:

```
CREATE TABLE Test_tab (
   col_a    NUMBER,
   col_b    typ1,
   col_c    VARCHAR2(2000)
)
```

where typ1 is an object type. Suppose that stat is a statistics type with ODCIStatsCollect and ODCIStatsDelete functions. User-defined statistics are collected by the ANALYZE command for the column col_b if we bind a statistics type with the column as follows:

```
ASSOCIATE STATISTICS WITH COLUMNS Test_tab.col_b USING stat
```

A list of columns can be associated with the statistics type stat. Note that Oracle supports only associations with top-level columns, not attributes of object types; if you wish, the ODCIStatsCollect function can collect individual attribute statistics by traversing the column.

Another way to collect user-defined statistics is to declare an association with a datatype as follows:

```
ASSOCIATE STATISTICS WITH TYPES typ1 USING stat_typ1
```

which declares stat_typ1 as the statistics type for the type typ1. When the table Test_tab is analyzed with this association, user-defined statistics are collected for the column col_b using the ODCIStatsCollect function of statistics type stat_typ1.

Individual column associations always have precedence over associations with types. Thus, in the above example, if both ASSOCIATE STATISTICS commands are issued, ANALYZE would use the statistics type stat (and *not* stat_typ1) to collect user-defined statistics for column col_b. It is also important to note that standard statistics, if possible, are collected along with user-defined statistics.

User-defined statistics are deleted using the ODCIStatsDelete function from the same statistics type that was used to collect the statistics.

Associations defined by the ASSOCIATE STATISTICS command are stored in a new dictionary table called ASSOCIATION$ (details are given in the *Extensible Optimizer* reference).

Only user-defined datatypes can have statistics types associated with them; you cannot declare associations for standard SQL datatypes.

Domain Index Statistics

A domain index has an indextype. A statistics type for a domain index is defined by associating it either with the index or its indextype. Consider the following example using the table Test_tab we defined earlier:

```
CREATE INDEX Test_indx ON Test_tab(col_a)
INDEXTYPE IS indtype PARAMETERS('example');

CREATE OPERATOR userOp BINDING (NUMBER) RETURN NUMBER
USING userOp_func;

CREATE INDEXTYPE indtype
FOR userOp(NUMBER)
USING imptype;
```

Here, indtype is the indextype, userOp is a user-defined operator supported by indtype, userOp_func is the functional implementation of userOp, and imptype is the implementation type of the indextype indtype.

A statistics type stat_Test_indx can be associated with the index Test_indx as follows:

```
ASSOCIATE STATISTICS WITH INDEXES Test_indx USING stat_Test_indx
```

When the domain index Test_indx is analyzed, user-defined statistics for the index are collected by calling the ODCIStatsCollect function of stat_Test_indx.

If a statistics type association is not defined for a specific index, Oracle looks for a statistics type association for the indextype of the index. In the above example, a statistics type stat_indtype can be associated with the indextype indtype as follows:

```
ASSOCIATE STATISTICS WITH INDEXTYPES indtype USING stat_indtype
```

When the domain index Test_indx is analyzed and no statistics type association has been defined for the index Test_indx, then user-defined statistics for the index are collected by calling the ODCIStatsCollect function of stat_indtype.

Thus, individual domain index associations always have precedence over associations with the corresponding indextypes.

Domain index statistics are dropped using the ODCIStatsDelete function from the same statistics type that was used to collect the statistics.

User-defined Selectivity

Selectivity functions are used by the optimizer to compute the selectivity of predicates in a query. The predicates must have one of the appropriate forms and can contain user-defined operators, stand-alone functions, package functions, or type methods. Selectivity computation for each is described below.

User-defined Operators

Consider the example laid out earlier, and suppose that the following association is declared:

```
ASSOCIATE STATISTICS WITH FUNCTIONS userOp_func USING stat_userOp_func
```

Now, if the following predicate

```
userOp(Test_tab.col_a) = 1
```

is encountered, the optimizer calls the `ODCIStatsSelectivity` function (if present) in the statistics type `stat_userOp_func` that is associated with the functional implementation of the `userOp_func` of the `userOp` operator.

Stand-Alone Functions

If the association

```
ASSOCIATE STATISTICS WITH FUNCTIONS myFunction USING stat_MyFunction
```

is declared for a stand-alone function `myFunction`, then the optimizer calls the `ODCIStatsSelectivity` function (if present) in the statistics type `stat_myFunction` for the following predicate (for instance):

```
myFunction(Test_tab.col_a, 'TEST') = 1.
```

Package Functions

If the association

```
ASSOCIATE STATISTICS WITH PACKAGES Demo_pack USING stat_Demo_pack
```

is declared for a package `Demo_pack`, then the optimizer calls the `ODCIStatsSelectivity` function (if present) in the statistics type `stat_Demo_pack` for the following predicate (for instance):

```
Demo_pack.myDemoPackFunction(Test_tab.col_a, 'TEST') = 1
```

where `myDemoPackFunction` is a function in `Demo_pack`.

Type Methods

If the association

```
ASSOCIATE STATISTICS WITH TYPES Example_typ USING stat_Example_typ
```

is declared for a type `Example_typ`, then the optimizer calls the `ODCIStatsSelectivity` function (if present) in the statistics type `stat_Example_typ` for the following predicate (for instance):

```
myExampleTypMethod(Test_tab.col_b) = 1
```

where `myExampleTypMethod` is a method in `Example_typ`.

Default Selectivity

An alternative to selectivity functions is user-defined *default selectivity*. The default selectivity is a value (between 0% and 100%) that is looked up by the optimizer instead of calling a selectivity function. Default selectivities can be used for predicates with user-defined operators, stand-alone functions, package functions, or type methods.

The following command:

```
ASSOCIATE STATISTICS WITH FUNCTIONS myFunction DEFAULT SELECTIVITY 20
```

declares that the following predicate, for instance,

```
myFunction(Test_tab.col_a) = 1
```

always has a selectivity of 20 percent (or 0.2) regardless of the parameters of `myFunction,` or the comparison operator "=", or the constant "1". The optimizer uses this default selectivity instead of calling a selectivity function.

An association can be declared using either a statistics type or a default selectivity, but not both. Thus, the following statement is illegal:

```
ASSOCIATE STATISTICS WITH FUNCTIONS myFunction USING stat_myFunction
   DEFAULT SELECTIVITY 20
```

The following are some more examples of default selectivity declarations:

```
ASSOCIATE STATISTICS WITH PACKAGES Demo_pack DEFAULT SELECTIVITY 20
ASSOCIATE STATISTICS WITH TYPES Example_typ DEFAULT SELECTIVITY 20
```

User-defined Cost

The optimizer uses user-defined cost functions to compute the cost of predicates in a query. The predicates must have one of the forms listed earlier and can contain user-defined operators, stand-alone functions, package functions, or type methods. In addition, user-defined cost functions are also used to compute the cost of domain indexes. Cost computation for each is described below.

User-defined Operators

Consider the example outlined above, and suppose that the following associations are declared:

```
ASSOCIATE STATISTICS WITH INDEXES Test_indx USING stat_Test_indx
ASSOCIATE STATISTICS WITH FUNCTIONS userOp USING stat_userOp_func
```

Consider the following predicate:

```
userOp(Test_tab.col_a) = 1.
```

If the domain index `Test_indx` implementing `userOp` is being evaluated, the optimizer calls the `ODCIStatsIndexCost` function (if present) in the statistics type `stat_Test_indx`. If the domain index is not used, however, the optimizer calls the `ODCIStatsFunctionCost` function (if present) in the statistics type `stat_userOp` to compute the cost of the functional implementation of the operator `userOp`.

Stand-Alone Functions

If the association

```
ASSOCIATE STATISTICS WITH FUNCTIONS myFunction USING stat_myFunction
```

is declared for a stand-alone function `myFunction`, then the optimizer calls the `ODCIStatsFunctionCost` function (if present) in the statistics type `stat_myFunction` for the following predicate (for instance):

```
myFunction(Test_tab.col_a, 'TEST') = 1
```

User-defined function costs do not influence the choice of access methods; they are only used for ordering predicates (described in the *Extensible Optimizer* reference).

Package Functions

If the association

```
ASSOCIATE STATISTICS WITH PACKAGES Demo_pack USING stat_Demo_pack;
```

is declared for a package `Demo_pack`, then the optimizer calls the `ODCIStatsFunctionCost` function (if present) in the statistics type `stat_Demo_pack` for the following predicate (for instance):

```
Demo_pack.myDemoPackFunction(Test_tab.col_a) = 1
```

where `myDemoPackFunction` is a function in `Demo_pack`.

Type Methods

If the association

```
ASSOCIATE STATISTICS WITH TYPES Example_typ USING stat_Example_typ;
```

is declared for a type `Example_typ`, then the optimizer calls the `ODCIStatsFunctionCost` function (if present) in the statistics type `stat_Example_typ` for the following predicate:

```
myExampleTypMethod(Test_tab.col_b) = 1
```

where `myExampleTypMethod` is a method in `Example_typ`.

Default Cost

Like default selectivity, default costs can be used for predicates with user-defined operators, stand-alone functions, package functions, or type methods. So, the following command

```
ASSOCIATE STATISTICS WITH INDEXES Test_indx DEFAULT COST (100, 5, 0)
```

declares that using the domain index `Test_indx` to implement the following predicate (to select one example)

```
userOp(Test_tab.col_a) = 1
```

always has a CPU cost of 100, I/O of 5, and network of 0 (the network cost is ignored in Oracle8*i*) regardless of the parameters of `userOp`, the comparison operator "=", or the constant "1". The optimizer uses this default cost instead of calling an `ODCIStatsIndexCost` cost function.

You can declare an association using either a statistics type or a default cost, not both. Thus, the following statement is illegal:

```
ASSOCIATE STATISTICS WITH INDEXES Test_indx USING stat_Test_indx
   DEFAULT COST (100, 5, 0)
```

The following are some more examples of default cost declarations:

```
ASSOCIATE STATISTICS WITH FUNCTIONS myFunction DEFAULT COST (100, 5, 0)
ASSOCIATE STATISTICS WITH PACKAGES Demo_pack DEFAULT COST (100, 5, 0)
ASSOCIATE STATISTICS WITH TYPES Example_typ DEFAULT COST (100, 5, 0)
ASSOCIATE STATISTICS WITH INDEXTYPES indtype DEFAULT COST (100, 5, 0)
```

Predicate Ordering

In the absence of an `ORDERED_PREDICATES` hint (described on page 16-4), predicates (except those used for index keys) will be evaluated in the order specified by the following rules:

- Predicates without any user-defined functions, type methods, or subqueries are evaluated first, in the order specified in the `WHERE` clause.
- Predicates with user-defined functions and type methods which have user-computed costs are evaluated in increasing order of their cost.
- Predicates with user-defined functions and type methods that have no user-computed cost are evaluated next, in the order specified in the `WHERE` clause.
- Predicates not specified in the `WHERE` clause (e.g., predicates transitively generated by the optimizer) are evaluated next.
- Predicates with subqueries are evaluated last in the order specified in the `WHERE` clause.

Dependency Model

The dependency model reflects the actions that are taken when you issue any of the SQL commands described in the table.

Table 8–2 Dependency Model for DDLs

Command	Action
`DROP statistics_type`	if an association is defined with statistics_type, the command fails, otherwise the type is dropped
`DROP statistics_type FORCE`	calls `DISASSOCIATE FORCE` for all objects associated with the `statistics_type`; drops statistics_type

Table 8–2 Dependency Model for DDLs (Cont.)

Command	Action
DROP object	calls DISASSOCIATE, drops object_type if DISASSOCIATE succeeds
ALTER TABLE DROP COLUMN	if association is present for the column, this calls DISASSOCIATE FORCE with column; if no entry in ASSOCIATION$ but there are entries in type USATS$, then ODCIStatsDelete for the columns is invoked
DISASSOCIATE	if user-defined statistics collected with the statistics type are present, the command fails
DISASSOCIATE FORCE	deletes the entry in ASSOCIATION$ and calls ODCIStatsDelete
ANALYZE TABLE DELETE STATISICS	the ODCIStatsDelete function is invoked; if any errors are raised, ANALYZE fails and the error is reported
ASSOCIATE	if an association or user-defined statistics are present for the associated object, the command fails

Restrictions and Suggestions

A statistics type is defined as a regular object type. Since object types must have at least one attribute, a statistics type also must have at least one attribute. This will be a dummy attribute, however, since it will never be set or accessed.

Parallel Query

In Oracle8*i* domain indexes are non-partitioned and serial. The optimizer computes the composite cost of a domain index access path assuming a serial execution.

Distributed Execution

Oracle's distributed implementation does not support adding functions to the remote capabilities list. All functions referencing remote tables are executed as filters. The placement of the filters occurs outside the optimizer. The cost model reflects this implementation and does not attempt to optimize placement of these predicates.

Since predicates are not shipped to the remote site, you cannot use domain indexes on remote tables. Therefore, the `DESCRIBE` protocol is unchanged, and remote domain indexes are not visible from the local site.

Performance

The cost of execution of the queries remains the same with the extensible optimizer if the same plan is chosen. If a different plan is chosen, the execution time should be better assuming that the user-defined cost, selectivity, and statistics collection functions are accurate. In light of this, you are strongly encouraged to provide statistics collection, selectivity, and cost functions for user-defined structures because the optimizer defaults can be inaccurate and lead to an expensive execution plan.

9 Using Cartridge Services

This chapter describes how to use cartridge services, including:

Cartridge Services — Introduction

This chapter describes a set of services that will help you create data cartridges in the Oracle8*i* Extensibility framework.

Using Oracle Cartridge Services offers you these advantages:

Portability

Oracle Cartridge Services offers you the flexibility to work across different machine architectures

Flexibility Within Oracle Environments

Another type of flexibility is offered to you in terms of the fact that all cartridge services will work with your Oracle Database irrespective of the configuration of operations that has been purchased by your client.

Language Independence

The use of the NLS services lets you internationalize your cartridge. Language independence means that you can have different instances of your cartridge operating in different language environments.

Tight Integration with the Server

Various cartridge services have been designed to facilitate access with Oracle ORDBMS. This offers far superior performance to client -side programs attempting to perform the same operations.

Guaranteed Compatibility

Oracle is a rapidly evolving technology and it is likely that your clients might be operating with different releases of Oracle. The cartridge services will operate with all versions of Oracle database.

Integration of Different Cartridges

The integration of cartridge services lets you produce a uniform integration of different data cartridges.

The following sections provide a brief introduction to the set of services that you can use as part of your data cartridge. The APIs that describe these interfaces are described in Chapter 9, "Using Cartridge Services"

Cartridge Handle

Cartridge services require various handles that are encapsulated inside two types of OCI handles -

- **Environment handle** (`OCIEnv` or `OCI_HTYPE_ENV`).

  Various cartridge services are required at the process level when no session is available. The `OCIInitialize`() should use the `OCI_OBJECT` option for cartridge service.

- **User Session handle** (`OCISession` or `OCI_HTYPE_SESSION`).

  In a callout, the services can be used when the handle is allocated even without opening a connection back to the database.

All cartridge service calls take a `dvoid *` OCI handle as one of the arguments that may be either an environment or a session handle. While most service calls are allowed with either of the handles, certain calls may not be valid with one of the handles. For example, it may be an error to allocate `OCI_DURATION_SESSION` with an environment handle. An error will typically be returned in an error handle.

Client Side Usage

Most of the cartridge service can also be used on the client side code. Refer to individual services for restrictions. To use cartridge service on the client side, the OCI environment has to be initialized with `OCI_OBJECT` option. This is automatically effected in a cartridge.

Cartridge Side Usage

Most of the services listed in this document can be used in developing a database cartridge, but please refer to documentation of each individual service for restrictions. New service calls are available to obtain the session handle in a callout. The session handle is available without opening a connection back to the server.

Service Calls

Before using any service, the OCI environment handle must be initialized. All the services take an OCI environment (or user_session) handle as an argument. Errors are returned in an OCI error handle. The sub handles required for various service calls are not allocated along with the OCI environment handle. Services which need to initialize an environment provide methods to initialize it.

The following example demonstrates the initialization of these handles:

```
{
OCIEnv *envhp;
OCIError *errhp;
(void) OCIInitialize(OCI_OBJECT, (dvoid *)0, 0, 0, 0);
(void) OCIEnvInit(&envhp, OCI_OBJECT, (size_t)0, (dvoid **)0);
(void) OCIHandleAlloc((dvoid *)envhp, (dvoid **)errhp,   OCI_HTYPE_ERROR, (size_
t)0, (dvoid **)0);
/* ... use the handles ... */
(void) OCIHandleFree((dvoid *)errhp, OCI_HTYPE_ERROR);
}
```

Error Handling

Routines that return errors will generally return `OCI_SUCCESS` or `OCI_ERROR`. Some routines may return `OCI_SUCCESS_WITH_INFO`, `OCI_INVALID_HANDLE`, or `OCI_NO_DATA`. If `OCI_ERROR` or `OCI_SUCCESS_WITH_INFO` is returned, then an error code, an error facility, and possibly an error message can be retrieved by calling `OCIErrorGet`:

```
{
OCIError *errhp;
ub4 errcode;
text buffer[512];
(void) OCIErrorGet((dvoid *)errhp, 1, (text *)NULL, &errcode, buffer,
                   sizeof(buffer), OCI_HTYPE_ERROR);
}
```

Memory Services

Memory management is one of the services that is required by cartridge developers.

The memory service allows the client to allocate or free memory chunks. Each memory chunk is associated with a duration. This allows clients to automatically free all memory associated with a duration (at the end of the duration). The duration determines the heap that is used to allocate the memory. The memory service predefines three kinds of durations: call (`OCI_DURATION_CALL`), statement (`OCI_DURATION_STATEMENT`) and session (`OCI_DURATION_SESSION`).

The client can also create a user duration. The client has to explicitly start and terminate a user duration. Thus, the client can control the ’length’ of a user duration. Like the predefined durations, a user duration can be used to specify the allocation duration (e.g., memory chunks are freed at the end of the user duration).

Each user duration has a parent duration. A user duration terminates implicitly when its parent duration terminates. A parent duration can be call, statement, transaction, session or any other user duration. Memory allocated in the user duration comes from the heap of its parent duration.

The Oracle RDBMS memory manager already supports a variety of memory models. Currently callouts support memory for the duration of that callout. With the extension of row sources to support external indexing, there is a need for memory of durations greater than a callout.

The following functionality is supported:

- Allocate (permanent and freeable) memory of following durations
  - call to agent process
  - statement
  - session
  - shared attributes (meta-data) for cartridges
- Ability to re-allocate memory
- Ability to create a subduration memory i.e., a sub heap which gets freed up when the parent heap gets freed up. Memory for this sub heap can be allocated and freed.
- Ability to specify zeroed memory
- Ability to allocate large contiguous memory

Maintaining Context

Context management allows the clients to store values across calls. Cartridge services provide a mechanism for saving and restoring context.

Most operating systems which support threads have the concept of thread context. Threads can store thread specific data in this context (or state) and retrieve it at any point. This provides a notion of thread global variable. Typically a pointer which points to the root of a structure is stored in the context.

When the row source mechanism is externalized, you will need a mechanism to maintain state between multiple calls to the same row source.

There is a need to maintain session, statement and process states. Session state includes information about multiple statements that are open, message files based on sessions NLS settings etc. Process state includes shared metadata, (this can also be system wide shared), message files etc. Depending on whether the cartridge application is truly multi threaded, information sharing can be at a process level or system level.

Since a user can be using multiple cartridges at any time, the state that is maintained has to be per cartridge. This is implemented by requiring the user to supply a key for each duration.

Durations

There are various predefined types of durations supported on memory and context management calls. An additional parameter in all these calls is a context.

- `OCI_DURATION_CALL`. The duration of this operation is that of a callout.
- `OCI_DURATION_STATEMENT`. The duration of this operation is the external row source.
- `OCI_DURATION_SESSION`. The duration of this operation is the user session.
- `OCI_DURATION_PROCESS`. The duration of this is agent process.

National Language Service (NLS)

To support multilingual application, NLS functionality is required for cartridges and callout. NLSRTL is multi-platform and multilingual library current used in RDBMS and provides consistent NLS behavior to all Oracle products.

NLS basic services will provide the following language and cultural sensitive functionality:

- Locale information retrieval.
- String manipulation in the format of Multi-byte and Wide-char.
- Character set conversion including Unicode support.
- Messaging mechanism.

NLS language information retrieval

An Oracle locale consists of language, territory and character set definitions. The locale determines conventions such as native day and month names; and date, time, number, and currency formats. An internationalized application will obey a user's locale setting and cultural convention. For example, in a German locale setting, users will expect to see day and month names in German spelling etc. The following interface provides a simple way to retrieve local sensitive information.

String manipulation

Two types of data structure are supported for string manipulation: multi-byte string and wide char string. Multi-byte string is in native Oracle character set encoding and functions operated on it take the string as a whole unit. Wide char string function provides more flexibility in string manipulation and supports character-based and string-based operations.

The wide char data type we use here is Oracle specific and not to be confuse with the wchar_t defined by ANSI/ISO C standard. The Oracle wide char is always 4 bytes in all the platform, while wchar_t is implementation/platform dependent. The idea of Oracle wide char is to normalize multibyte character to have a fixed-width for easy processing. Round-trip conversion between Oracle wide char and native character set is guaranteed.

The string manipulation can be classified into the following categories:

- Conversion of string between multibyte and wide char.
- Character classifications.
- Case conversion.
- Display length calculation.
- General string manipulation, such as compare, concatenation and searching.

Parameter Manager Interface

The parameter manager provides a set of routines to process parameters from a file or a string. Routines are provided to process the input and to obtain key and value pairs. These key and value pairs are stored in memory and routines are provided which can access the values of the stored parameters.

The input processing routines match the contents of the file or the string against an existing grammar and compare the key names found in the input against the list of known keys that the user has registered. The behavior of the input processing routines can be configured depending on the bits that are set in the flag argument.

The parameters can be retrieved either one at a time or all at once by calling a function that iterates over the stored parameters.

Input Processing

Parameters consist of a key, or parameter name, type, and a value and must be specified in the following format:

```
key = value
```

Parameters can optionally accept lists of values which may be surrounded by parentheses. The following two formats are acceptable for specifying a value list:

```
key = (value1 value2 ... valuen)
key = value1 value2 ... valuen
```

A value can be a string, integer, `OCINumber`, or Boolean. A boolean value starting with '`y`' or '`t`' maps to `TRUE` and a boolean value starting with '`n`' or '`f`' maps to `FALSE`. The matching for boolean values is case insensitive.

The parameter manager views certain characters as "special characters" which are not parsed literally. The special characters and their meanings are indicated below:

Table 9–1 Special Characters and their Meanings

Character	Meaning
#	Comment (only for files)
(	Start a list of values
)	End a list of values
"	Start or end of quoted string
'	Start or end of quoted string
=	Separator of keyword and value
\	Escape character

If a special character must be treated literally, then it must either be prefaced by the escape character or the entire string must be surrounded by single or double quotes.

A key string can contain alphanumeric characters only. A value can contain any characters. However, the value cannot contain special characters unless they are quoted or escaped.

Parameter Manager Behavior Flag

The routines to process a file or a string take a behavior flag that can alter certain default characteristics of the parameter manager. The following bits can be set in the flag to produce the new behavior:

- `OCI_EXTRACT_CASE_SENSITIVE`. All comparisons are case sensitive. The default is to use case insensitive comparisons.
- `OCI_EXTRACT_UNIQUE_ABBREVS`. Unique abbreviations are allowed for keys. The default is that unique abbreviations are not allowed.
- `OCI_EXTRACT_APPEND_VALUES`. If a value or values are already stored for a particular key, then any new values for this key should be appended. The default is to return an error.

Key Registration

Before invoking the input processing routines (`OCIExtractFromFile` or `OCIExtractFromString`), all of the keys must be registered by calling `OCIExtractSetNumKeys` followed by `OCIExtractSetKey`. `OCIExtractSetKey` requires the following information for each key:

- Name of the key
- Type of the key (`integer`, `string`, `boolean`, `OCINumber`)
- `OCI_EXTRACT_MULTIPLE` is set for the flag value if multiple values are allowed (default: only one value allowed)
- Default value to be used for the key (may be `NULL`)
- Range of allowable integer values given by the starting and ending value, inclusive (may be `NULL`)
- List of allowable string values (may be `NULL`)

Parameter Storage and Retrieval

The results of processing the input into a set of keys and values are stored. The validity of the parameters is checked before storing the parameters in memory. The values are checked to see if they are of the proper type. In addition, if you wish, the values can be checked to see if they fall within a certain range of integer values or are members of a list of enumerated string values. Also, if you do not specify that a key can accept multiple values, then an error will be returned if a key is specified more than once in a particular input source. Also, an error will be returned if the key is unknown.

After the processing is completed, the value(s) for a particular key can be queried. Separate routines are available to retrieve a string value, an integer value, an `OCINumber` value, and a boolean value.

It is possible to retrieve all parameters at once. The function `OCIExtractToList` must first be called to generate a list of parameters that is created from the parameter structures stored in memory. `OCIExtractToList` will return the number of unique keys stored in memory, and then `OCIExtractFromList` can be called to return the list of values associated with each key.

Parameter Manager Context

The parameter manager maintains its own context within the `OCI` environment handle. This context stores all the processed parameter information and some internal information. It must be initialized with a call to `OCIExtractInit` and cleaned up with a call to `OCIExtractTerm`.

File I/O

The OCI file I/O package is designed to make it easier for you to write portable code that interacts with the file system by providing a consistent view of file I/O across multiple platforms.

You need to be aware of two issues when using this package in a data cartridge environment. The first issue is that this package does not provide any security when opening files for writing or when creating new files in a directory other than the security provided by the operating system protections on the file and directory. The second issue is that this package will not support the use of file descriptors across calls in a multi-threaded server environment.

String Formatting

The OCI string formatting package facilitates writing portable code that handles string manipulation by means of the `OCIFormatString` routine. This is an improved and portable version of `sprintf` that incorporates additional functionality and error checking that the standard `sprintf` does not. This additional functionality includes:

- Arbitrary argument selection.

- Variable width and precision specification.
- Length checking of the buffer.
- Oracle National Language Support for internationalization.

Part III

Advanced Topics

10 Design Considerations

This chapter describes various design considerations, including:

- Designing the types
- Callouts
- Designing Indexes
- Designing Operators
- Talking to the Optimizer
- Design for maintenance
- Miscellaneous

Designing the types

Structured and Unstructured Data

Structured data is one whose type is expressible to Oracle in the form of an Object Type. Unstructured data is one which is un-interpretable by Oracle, that is, whose type is a `RAW` or a `BLOB`. The choice of modeling cartridge data as structured or unstructured depends on the following considerations:

1. Structured data can be shared by different applications since the structure is published in Oracle.
2. Structured types provide strong type checking whereas unstructured data does not.
3. Structured data is easily queried whereas unstructured data is not. One has to publish user-defined functions to facilitate querying the unstructured data.
4. Constraints are easily supported on structured data but not on unstructured data.
5. Indexes are easily supported on structured data, whereas, on unstructured data indices on user-defined functions would need to be created, or extensible indexes would need to be defined.
6. Structured data needs to be marshalled by Oracle to be retrieved to client as a value, whereas, unstructured data is easily retrievable as a value.

Using Nested Tables or VARRAYs

In deciding whether to use a nested table or a VARRAY type to model a collection, it is important to understand how these are implemented in Oracle to make the right design choice. Logically, nested tables differ from VARRAYs in one fundamental way: VARRAYs represent ordered set of items whereas nested tables do not. But, physically, nested tables can only be represented as tables, whereas VARRAYs can only be represented as raw columns or LOB columns. The implications of their physical representation is the following:

Nested Tables

- Nested tables are better suited for querying since elements are represented as rows.
- Indices may be created on columns of nested tables for faster searches.

- Constraints may be specified for nested tables.
- Clustering of nested elements belonging to a common parent row is possible when the storage table is specified as an Index Organized Table, furthermore, specifying key compression reduces the overhead of the system assigned `NESTED_TABLE_ID` values.
- When stored as a Heap Organized Table, creating an index on the `NESTED_TABLE_ID` column enhances retrieval of nested tables.
- Retrieving the nested table as a value for a given parent incurs the overhead of selecting and marshalling the individual rows to form the collection value.
- Even though parent tables may be partitioned, storage tables corresponding to their nested tables cannot be partitioned.

VARRAYs

- A VARRAYs is better suited for retrieval as a value since that is s how it is stored.
- Support for indexing, specification of constraints on VARRAYs is not available.
- Querying of VARRAYs is sub-optimal since rows have to materialized from collection value.
- Partitioning of VARRAYs stored as `LOB`s is permitted when the parent table is partitioned.

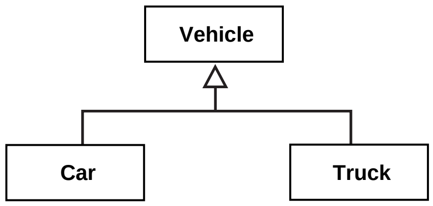
Based on the above implications, if the ability to query of update individual collection elements is important, then nested tables are a better choice to model your collection data. On the other hand, if your application is requires fetching the entire collection as a whole and then operating on it, modeling the collection data as a VARRAY will yield better retrieval performance.

Working Around Inheritance

Inheritance is a technique used in object-oriented development to create objects that contain generalized attributes and behavior for groups of related objects. The more general objects created using inheritance are referred to as a super-types. The objects that "inherit" from the super-types (i.e. are more specific cases of the super-type) are called subtypes.

A common case of inheritance is that of `Person` and `Employee`. Some instances of person are employees. The more general case, `Person`, is the super-type and the special case, `Employee`, the sub-type. Another example could involve a `Vehicle` as super-type and `Car`, `Truck` as its sub-types.

Figure 10–1 Class Diagram: Vehicle as Super-type, Car and Truck as Subtypes



Inheritance Implementation Consequences

Inheritance can imply various levels of encapsulation for super-types. In cases where the super-type should not be exposed to other objects, a subtype should contain the methods and attributes necessary to make the super-type invisible. To understand the implementation consequences of the inheritance, it is also important to remember that Oracle8*i* is a strongly-typed system. A strongly-typed system requires that the type of an attribute is declared when the attribute is declared. Only values of the declared type may be stored in the attribute. For example, the Oracle8*i* collections are strongly-typed. Oracle8*i* does not allow the implementation of heterogeneous collections (collections of multiple types).

See Also:

- WORKING WITH USER-DEFINED TYPES in *Oracle8i Application Developer's Guide - Fundamentals*

Simulating Inheritance

Inheritance can be implemented in Oracle8*i* using one of the following three techniques:

- Subtype Contains Super-type
- Super-type Contains or References All Subtypes
- Dual Subtype / Super-type Reference.

Subtype Contains Super-type

Figure 10–2 Object-Relational Schema — Subtype Contains Super-type

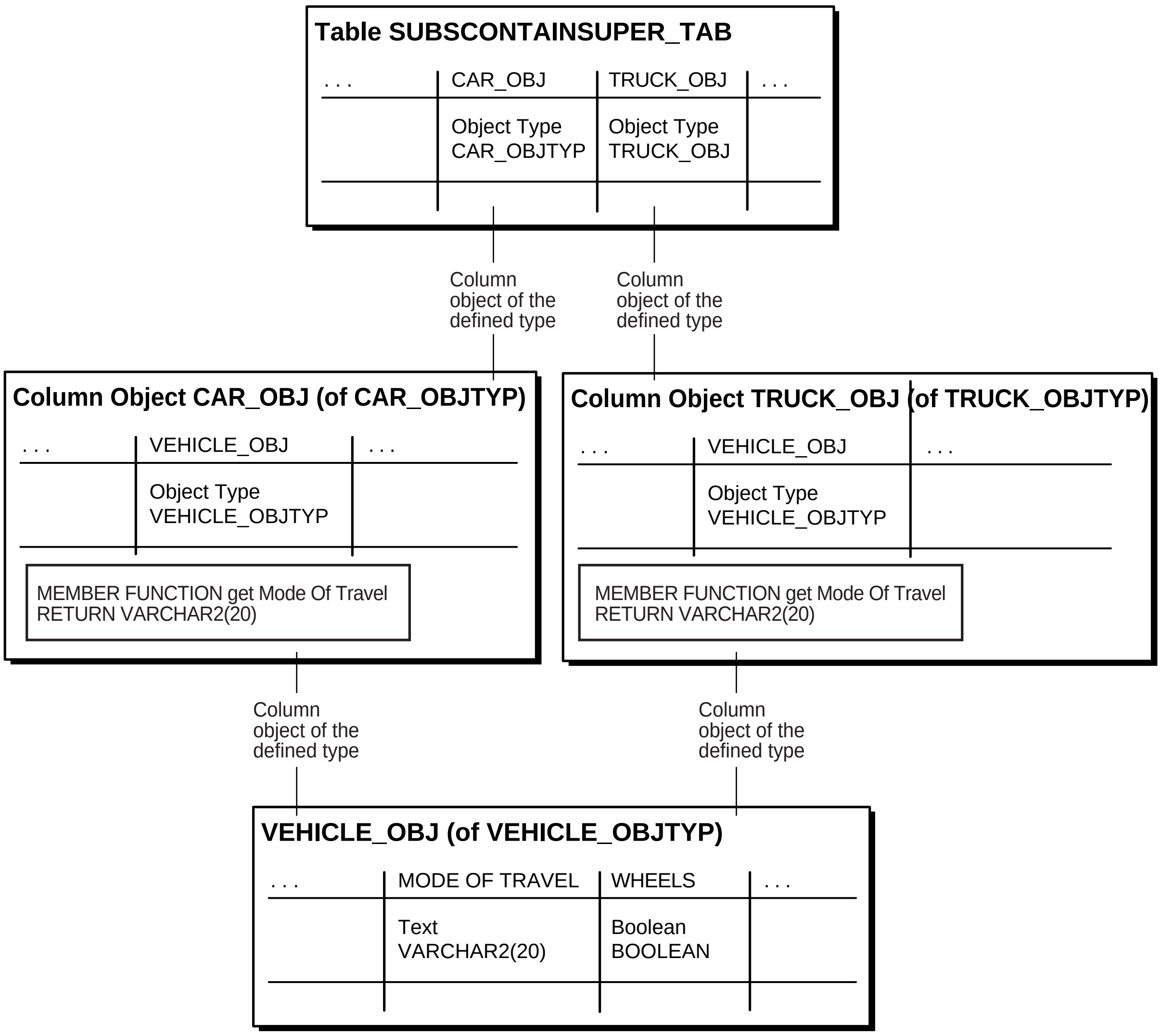


Table SUBSCONTAINSUPER_TAB
. . .
CAR_OBJ
TRUCK_OBJ
. . .
Object Type CAR_OBJTYP
Object Type TRUCK_OBJ
Column object of the defined type
Column object of the defined type
Column Object CAR_OBJ (of CAR_OBJTYP)
VEHICLE_OBJ
Object Type VEHICLE_OBJTYP
MEMBER FUNCTION get Mode Of Travel RETURN VARCHAR2(20)
Column Object TRUCK_OBJ (of TRUCK_OBJTYP)
VEHICLE_OBJ
Object Type VEHICLE_OBJTYP
MEMBER FUNCTION get Mode Of Travel RETURN VARCHAR2(20)
Column object of the defined type
Column object of the defined type
VEHICLE_OBJ (of VEHICLE_OBJTYP)
MODE OF TRAVEL
WHEELS
Text VARCHAR2(20)
Boolean BOOLEAN

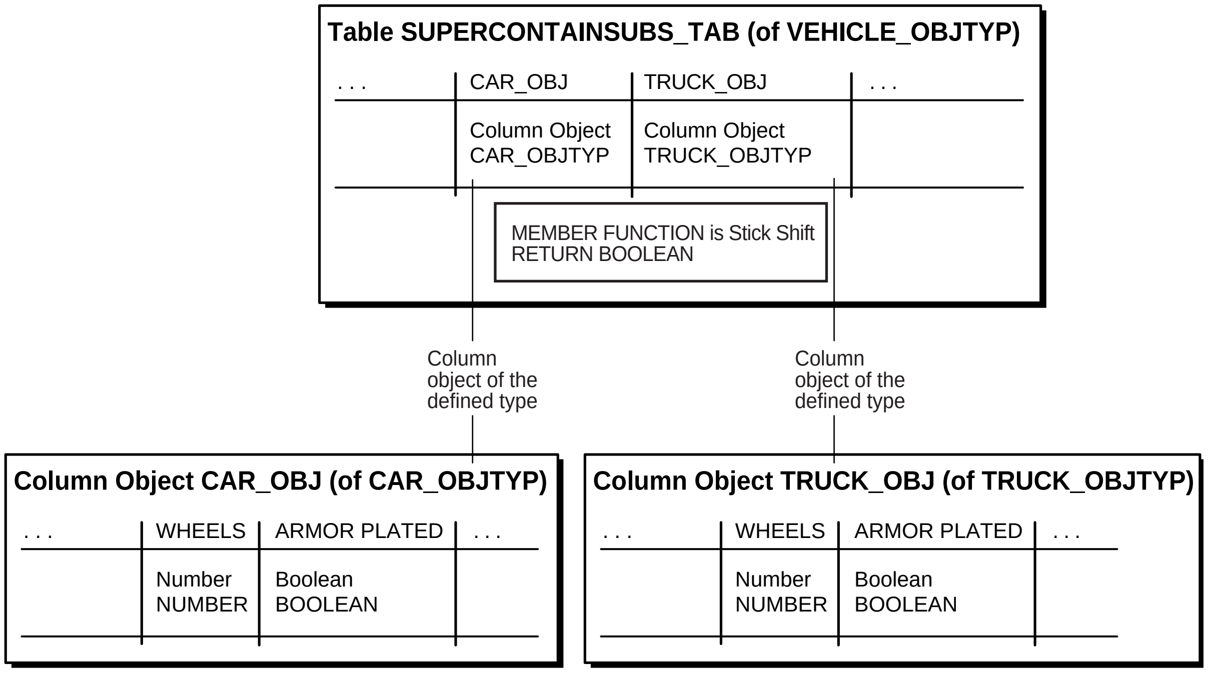
The *Subtype Contains Super-type* technique hides the implementation of the abstractions / generalizations for a subtype. Each of the subtypes are exposed to other types in the object model. The super-types are not exposed to other types. To simulate inheritance, the super-type in the design object model is created as an object type. The subtype is also created as an object type. The super-type is defined as an embedded attribute in the subtype. All of the methods that can be executed for the subtype and it's super-type must be defined in the subtype.

The Subtype Contains Super-type technique is used when each subtype has specific relationships to other objects in the object model. For example, a super-type of `Customer` may have subtypes of `Private Customer` and `Corporate Customer`. `Private Customers` have relationships with the `Personal Banking` objects, while `Corporate Customers` have relationships with the `Commercial Banking` objects. In this environment, the `Customer` super-type is not visible to the rest of the object model.

In the `Vehicle-Car / Truck` example, the `Vehicle` (super-type) is embedded in the sub-types `Car` and `Truck`.

Super-type Contains All Subtypes

Figure 10–3 Object-Relational Schema — Super-type Contains All Subtypes



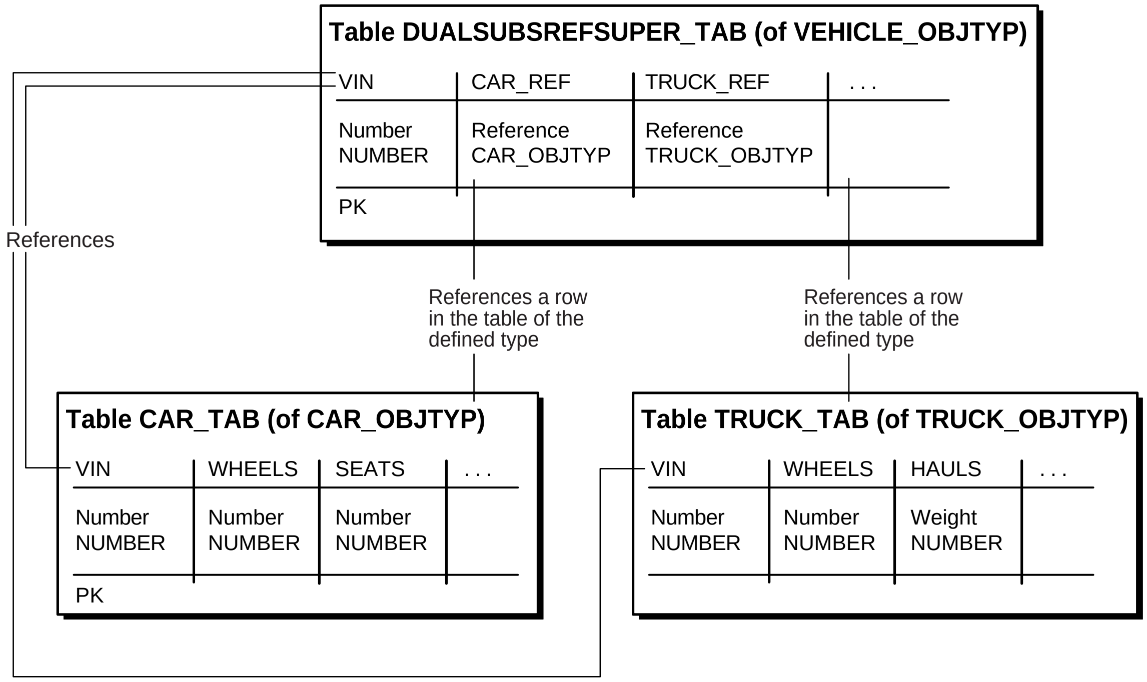
The Super-type Contains All Subtypes technique hides the implementation of the subtypes and only exposes the super-type. To simulate inheritance, all of the subtypes for a given super-type in the design object model are created as object types. The super-type is created as an object type as well. The super-type declares an attribute for each subtype. The super-type also declares the constraints to enforce the one-and-only-one rules for the subtype attributes. All of the methods that can be executed for the subtype must defined in the super-type.

The Super-type Contains All Subtypes technique is used when objects have relationships with other objects that are predominately one-to-many in multiplicity. For example, a `Customer` can have many `Accounts` and a `Bank` can have many `Accounts`. The many relationships require a collection for each subtype if the *Subtype Contains Super-type* technique is used. If the `Account` is a super-type and `Checking` and `Savings` are subtypes, both `Bank` and `Customer` must implement a collection of `Checking` and `Savings` (4 collections). Adding a new account subtype requires that both `Customer` and `Bank` add the collection to support the new account subtype (2 collections per addition). Using the *Super-type Contains All Subtype*s technique means that the customer and bank have a collection of `Account`. Adding a subtype to `Accounts` means that only account changes.

In the case of the `Vehicle-Car`/`Truck`, the `Vehicle` is created with `Car` and `Truck` as embedded attributes of `Vehicle`.

Dual Subtype / Super-type Reference

Figure 10–4 Object-Relational Schema — Dual Subtype / Super-type Reference



In cases where the super-type is involved in multiple object-relationships with many for a multiplicity and the subtypes have specific relationships in the object model, the implementation of Inheritance is a combination of the two inheritance techniques. The super-type is implemented as an object type. Each subtype is implemented as an object type. The super-type implements a referenced attribute for each subtype (zero referenced relationship). The super-type also implements an or-association for the group of subtype attributes. Each subtype implements a referenced attribute for the super-type (one referenced relationship). In this way, both the super-type and sub-type are visible to the rest of the object model.

In the case of the `Vehicle`-`Car`/`Truck`, the `Vehicle` is created as an type. The `Car` and `Truck` are created as types. The `Vehicle` type implements a reference to both `Car` and `Truck`, with the or-constraint on the `Car` and `Truck` attributes. The `Car` implements an attribute that references `Vehicle`. The `Truck` implements an attribute that references `Vehicle`.

Writing Methods: PL/SQL, C or Java?

When writing methods for object types, you have multiple implementation choices – PL/SQL, C/C++ and Java. Of these, PL/SQL and Java methods run within the address space of the server. C/C++ methods are dispatched as external procedures and run outside the address space of the server.

The best implementation choice varies from situation to situation. The following rules of thumb might be of help.

1. A callout involving C or C++ is, in general, the fastest if the nature of processing is substantially CPU-bound. However, callouts incur the cost of dispatch, and if the amount of processing in C/C++ is not large then the cost of dispatch does not amortize very well.
2. PL/SQL tends to offer the best price-performance for methods that are not computation-intensive. The other implementation options are typically favored over PL/SQL if you have a large body of code already implemented in another language that you want to use a part of the data cartridge
3. Java is a relatively open implementation choice. The interpreted nature of Java implies that for high performance applications, some sort of compilation of methods written in Java will be needed.

Invokers Rights — Why, When, How

Until release 8.1.5, stored procedures and SQL methods could only execute with the privileges of the definer. Such definer-rights routines are bound to the schema in which they reside, and this remains the default. Under this condition, a routine executes with the rights of the definer of the function, not the user invoking it. However, this is a limitation if the function statically or dynamically issues SQL statements.

For example, if the function had a static cursor that performs a SELECT from USER_TABLES, the USER_TABLES it would retrieve would be that of the definer irrespective of which user was using the function. For the function to be used against data not owned by the definer, explicit GRANTs had to be issued from the owner to the definer, or the function needed to be defined in the same schema where the data resided. The former course creates security and administration problems; the latter forces the function to be redefined in each schema that needs to use it.

The invoker-rights mechanism, introduced in Orace8*i* release 8.1.5, permits a function to execute with the privileges of the invoker. This permits cartridges to live within a schema dedicated to the cartridge and to be used by other schemas without requiring privileges be granted to operate on objects in the schema where the cartridge resides.

Callouts

When to Callout

You should consider utilizing callouts in the following circumstances:

- When it would be impractical or impossible to code the algorithm you   require in SQL.
- When the performance gains of a compiled language (e.g., C) outweigh the extproc callout overhead
- When you wish to leverage existing 3GL code

When to Callback

You should consider utilizing callbacks in the following circumstances:

- When you need data that was not passed as an argument to the call out.
- When it isn't practical to pass the data to the call out (e.g., the number and size of the parameters exceeds that which is allowed or performs well).

Consider making a single callout which does multiple callbacks rather than multiple callouts (e.g. instead of a factorial callout which takes a single number and computes a the factorial for it, consider making a callout which takes a VARRAY and repeatedly calls back to get next number to compute the factorial for. You always do performance testing to see at what at point the multi-call back approach out-performs the multi-callout approach

Callouts and LOB

- It may be to your advantage to code your callout so that it is independent of LOB type (BFILE/BLOB).
- The PL/SQL layer of your cartridge can "open" your BFILE so that no BFILE-specific logic is required in your callout (other than error recovery from OCILob calls that do not operate on BFILEs).
- With the advent of temporary LOBs in Orace8*i* release 8.1.5, you need to be aware of the deep copy that can occur when assignments and calls are done with temporary LOBs. Use "NOCOPY" (by REF) on BLOB parameters as appropriate.

Saving and Passing State

External procedures under Oracle 8.0 have a "state-less" model. All Statement handles opened during the invocation of an external procedure are closed implicitly at the end of the call.

In Oracle 8.1, we allow "state" (OCI Statement handles etc. and associated state in the DBMS) to be saved and used across invocations of external procedures in a session.B y default cartridges are still stateless, however, `OCIMemory` services and `OCIContext` services can be used with `OCI_DURATION_SESSION` or other appropriate duration to save state. Statement handles created in one external procedure invocation can get re-used in another. The Data Cartridge developer needs to explicitly free these handles. It is recommended that this is done as soon as the statement handle is no longer needed. All state maintained for the statement in the OCI handles and in the DBMS would get freed as a result. This should help in improving the scalability of the Data Cartridge.

Designing Indexes

Influencing Index Performance

It is wrong to assume that creating domain index is always the best course. If, after careful consideration, you determine that you need to create domain index, you should keep the following factors in mind. For one, if the domain index is complex, the functional implementation will work better

- When the data size is small
- When the result is a large percentage of the total data size.

Judicious use of the extensible optimizer can lead to good performance.

Influencing Index Performance

Naming of internal components can be an issue. Naming of internal data objects for a domain index implementation and are typically based on names you provide for table and indexes. The problem is that the derived names for the internal objects should not conflict with any other user defined object or system object. You may have to develop some policy that restricts names, or implement some metadata management scheme to avoid errors during `DROP`, `CREATE` etc.

When to Use IOTs

You can create only one index on IOTs in 8.0.x releases. However, if most of your data is in the index, it's more efficient than storing your data in both the table and then an additional index.

You can create secondary indexes on IOTs in Orace8*i* release 8.1.5 which offers a big advantage if you are accessing the data different ways.

Can Index Structures Be Stored in LOBs

Index structures can be stored in `LOBs` but take care to tune the `LOB` for best performance. If you are accessing a particular `LOB` frequently, create your table with the `CACHE` option and place the `LOB` index in a separate tablespace. If you are updating a `LOB` frequently, `TURN OFF LOGGING` and read / write in multiples of `CHUNK` size. If you are accessing a particular portion of a `LOB` frequently, buffer your reads / writes using `LOB` buffering or your own buffering scheme.

External Index Structures

With the extensible indexing framework, the meaning and representation of a user-defined index is left to the cartridge developer. We do provide basic index implementations such as IOTs. In certain cases, binary or character `LOB`s can also be used to store complex index structures. IOTs, `BLOB`s and `CLOB`s all live within the database. In addition to them, you may also store a user-defined index as a structure external to the database, say in a `BFILE`.

The external index structure gives you the most flexibility in terms of how your index is represented. It is useful if you have already invested in the development of in-memory indexing structures. For example, an operating system file may store index data, which is read into a memory mapped file at run time. Such cases may be handled as BFILEs in the external index routines.

External index structures may provide superior performance. However, this comes at some cost. Index structures external to the database do not participate in the transaction semantics of the database which, in the case of index structures inside the database, make data and concomitant index updates atomic. This means that if update to the data causes an update for the external index to be invoked via the extensible indexing interface, any failures may cause the data updates to be rolled back but not the index updates. The database can only roll back what is internal to it — external index structures cannot be rolled back in synchronization with a database rollback.

External index structures can be very useful for read-only access. Their semantics become complex if updates to data are involved.

Multi-Row Fetch

```
ODCIIndexFetch(self IN [OUT] <impltype>, nrows IN NUMBER, rids OUT ODCIRidList)
RETURN NUMBER
```

When the `ODCIIndexFetch` routine is called, the `ROWID`s of all the rows that satisfy the operator predicate are returned. The maximum number of rows that can be returned by the `ODCIIndexFetch` routine is `nrows` (`nrows` being an argument to the `ODCIIndexFetch` routine). The value of `nrows` is decided by Oracle based on some internal factors. If you have a better idea of the number of rows that ought to be returned to achieve optimal query performance, you can determine that this number of rows is returned in the `ODCIRidList` VARRAY instead of `nrows`. Note that the number of values in the `ODCIRidList` has to be less than or equal to `nrows`.

You, as cartridge designer, are in the best position to make a judgement regarding the number of rows to be returned. For example, if in the index the number of (say 1500) rowids are stored together and `nrows` = 2000, then it may be optimal to return 1500 rows in lieu of 2000 rows. Otherwise the user would have to retrieve 3000 rowids, return 2000 if them and note which 1000 rowids were not returned.

If you not have any specific optimization in mind, you can use the value of `nrows` to determine the number of rows to be returned. Currently the value of `nrows` has been set to 2000.

Anyone implementing indexes which use callouts should use *multirow fetch* to fetch the largest number of rows back to the server. This offsets the cost of making the callout. You can set this using `_DOMAIN_INDEX_BATCH_SIZE` in your init.ora.

Designing Operators

Functional and Index Implementations

All indexes should contain an indexed and functional implementation of the operator, in case the optimizer chooses not to use the indexed implementation. You can, however, use the indexing structures to produce the functional result.

Talking to the Optimizer

Weighing Cost and Selectivity

Estimating Cost

In Orace8*i* release 8.1.5 only the CPU and I/O costs are considered.

Cost for functions The cost of executing a C function can be determined using common profilers or tools. For SQL queries, an explain plan of the query would give a rough estimate of the cost of the query. In addition the `tkprof` utility can be used to gather information about the CPU and the I/O cost involved in the operation. The cost of executing a callout could also be determined by using it in a SQL query which "selects from dual" and then estimating its cost from the `tkprof` utility.

Cost for Indexes The cost of the index is a function of the selectivity of the predicate (which is passed as an argument to the cost function) * the total number of data blocks in the index structures. Hence the index cost function should be one which increases with the increase in selectivity of the predicate. With a selectivity of 100%, the cost of accessing the index should be the cost of accessing all the data in all the structures that comprise the domain index.

The total cost of accessing the index is the cost of performing the `ODCIIndexStart`, N * `ODCIIndexFetch` and `ODCIIndexClose` operators, where N is the number of times the `ODCIIndexFetch` routine will be called based on the selectivity of the predicate. The cost of `ODCIIndexStart`, `ODCIIndexFetch` and `ODCIIndexClose` functions can be determined as discussed above.

Estimating Selectivity

Selectivity for Functions The selectivity of a predicate is the percentage of rows returned by the predicate divided by the total number of rows in the table(s).

The selectivity function should use the statistics collected for the table to determine what percentage of rows of the table will be returned by the predicate with the given list of arguments. For example, to compute the selectivity of a predicate `IMAGE_GREATER_THAN` (`Image SelectedImage`) which determines the images that are greater than the `Image SelectedImage`, a histogram of the sizes of the images in the database can be a useful statistics to compute the selectivity.

Collecting Statistics

Statistics can affect the calculation of selectivity for predicates and also the cost of domain indexes.

Statistics for Tables The statistics collected for a table can affect the computation of selectivity of a predicate. So statistics that can help the user make a better judgement about the selectivity of a predicate should be collected for a table/column. Knowing the predicates that would operate on the data will be helpful to determine what statistics would be good to collect.

Some example of statistics that can be useful in spatial domain for example could be the average/min/max number of elements in a VARRAY that contains the nodes of the spatial objects.

Note that standard statistics are collected in addition to the user defined statistics when the ANALYZE command is invoked.

Statistics for Indexes When a domain index is analyzed statistics for the underlying objects which constitute the domain index should be analyzed. For example if the domain index is comprised of tables, the statistics collection function should ANALYZE the tables when the domain index is analyzed. The cost of accessing the domain index can be influenced by the statistics that have been collected for the index. For example the cost of accessing a domain index could be approximated to the selectivity * the total number of data blocks (in the various tables) being accessed when the domain index is accessed.

To accurately define cost, selectivity and statistics functions, a good understanding of the domain is required. The above guidelines are meant to help you understand some of the issues you need to take into account while working on the cost, selectivity and statistics functions. In general it may be a good idea to start of by using the default cost and selectivity and observe how the queries of interest behave.

Design for maintenance

- Carefully design your object types and methods. Object types are difficult to upgrade once they are in use by applications.
- Use `OIDs` in all of your object types so users can import/export data easily across databases.
- It is easy to add a method to a type; it’s hard to remove it.
- You are likely get more use out of the cartridge and the existing tool stack if you support functions against a traditional relational model in addition to an object model.
- Expose significant and frequently used data from your complex objects in object types as attributes so that you can build an index on them.
- If your cartridge maintains a large number of objects, views, tables, etc., consider making a metadata table to maintain the relationships among the objects for the user. This will ease the complexity of developing and maintaining the cartridge when it is in use.

How to Make Your Cartridge Extensible

- Keep your interface simple, and document it thoroughly.
- Use OO concepts appropriately.
- Ensure that your methods do not have side affects

How to Make Your Cartridge Installable

- Include a `README` with your cartridge to tell users how to install the cartridge
- Make the cartridge installable in one step in the database, if possible:

  ```
  sqlplus @imginst
  ```

- Tell users how to start the `listener` if you are using callouts.
- Tell users how to setup `extproc`. Most users have never heard of `extproc` and many users have never set up a listener. This is the primary problem when deploying cartridges.

- In Orace8*i* release 8.1.5 using the software packager, you can easily create custom SQL install scripts by using the `'instantiate_file'` action. This is a great feature that allows you to substitute variables in your files when they are installed and it leaves your user with scripts and files that are customized for their machine.

Miscellaneous

How to Write Portable Cartridge Code

You should:

- Use the datatypes in oratypes.h
- Use OCI calls where ever possible.
- Use the switches which enforce ANSI C conformance when possible
- Use ANSI C function prototypes
- Build and test on your target platforms as early in your development cycle as possible (flush out platform specific code and allow as much time to redesign as possible).

You should avoid:

- Storing endian (big/little) specific data
- Storing floating point data (IEEE/VAX/other)
- Operating System specific calls (if they can't be avoided, isolate them in an OS specific layer, however the calls you require are not in the OCI, and also are not in POSIX, then you are likely to encounter intractable problems)
- `int` <-> `size_t` implicit casts on a 64 bit platform

Part IV

Scenarios and Examples

This section includes two examples:

- A comprehensive example based on a hypothetical cartridge coded in PL/SQL — Chapter 11, "Power Demand Cartridge Example"
- An example of extensible indexing coded in C — Chapter 12, "SBTREE: An Example of Extensible Indexing"

11

Power Demand Cartridge Example

This chapter explains the power demand sample data cartridge that is included with the Oracle8*i* Data Cartridge Software Development Kit (SDK). The power demand cartridge includes a user-defined object type and extensible indexing. This chapter covers the following topics:

- "Modelling the Application" on page 11-9, including the technical and business scenario
- "Queries and Extensible Indexing" on page 11-13, describing kinds of queries that benefit from domain indexes
- "Creating the Domain Index" on page 11-15, explaining how the index and related structures for the example were created.
- "Testing the Domain Index" on page 11-39, explaining how to test the domain index and see if it is causing more efficient execution of queries than would occur without an index
- "Using the Time Series Cartridge with the Power Demand Cartridge" on page 11-48, showing how to define Time Series cartridge objects and run time series queries with power demand data
- "Using the Spatial Cartridge with the Power Demand Cartridge" on page 11-54, showing how to define Spatial cartridge objects and run spatial queries with power demand data

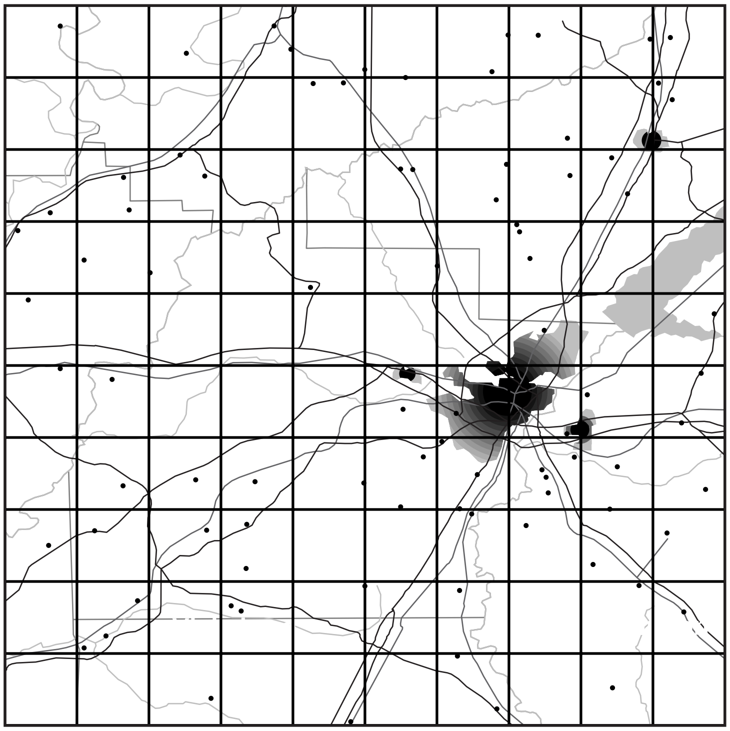
This chapter does not explain in detail the concepts related to the features illustrated. For information about extensible indexing, see Chapter 7, "Building Domain Indexes". For information about cartridge services, see Chapter 9, "Using Cartridge Services"].

This chapter divides the example into segments and provides commentary. The entire cartridge definition is available online in the following location:

```
...directory-path?.../tkqxpwr.sql   [location and name TBS]
```

Feature Requirements

A power utility, *Power-To-The-People*, develops a sophisticated model to decide how to deploy its resources. The region served by the utility is represented by a grid laid over a geographic area.



This region may be surrounded by other regions some of whose power needs are supplied by other utilities. As pictured above, every region is composed of geographic quadrants referred to as "cells" on a 10x10 grid. There are a number of ways of identifying cells — by spatial coordinates (longitude/latitude), by a matrix numbering (1,1; 1,2;...), and by numbering them sequentially:

Figure 11–1 Regional Grid Cells in Numbered Sequence

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50
51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68	69	70
71	72	73	74	75	76	77	78	79	80
81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100

Within the area represented by each cell, the power used by consumers in that area is recorded each hour. For example, the power demand readings for a particular hour might be represented by Table 11–2 (cells here represented on a matrix):

Table 11–1 Sample Power Demand Readings for an Hour

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	23	21	25	23	24	25	27	32	31	30
2	33	32	31	33	34	32	23	22	21	34
3	45	44	43	33	44	43	42	41	45	46
4	44	45	45	43	42	26	19	44	33	43
5	45	44	43	42	41	44	45	46	47	44
6	43	45	98	55	54	43	44	33	34	44
7	33	45	44	43	33	44	34	55	46	34
8	87	34	33	32	31	34	35	38	33	39
9	30	40	43	42	33	43	34	32	34	46
10	43	42	34	12	43	45	48	45	43	32

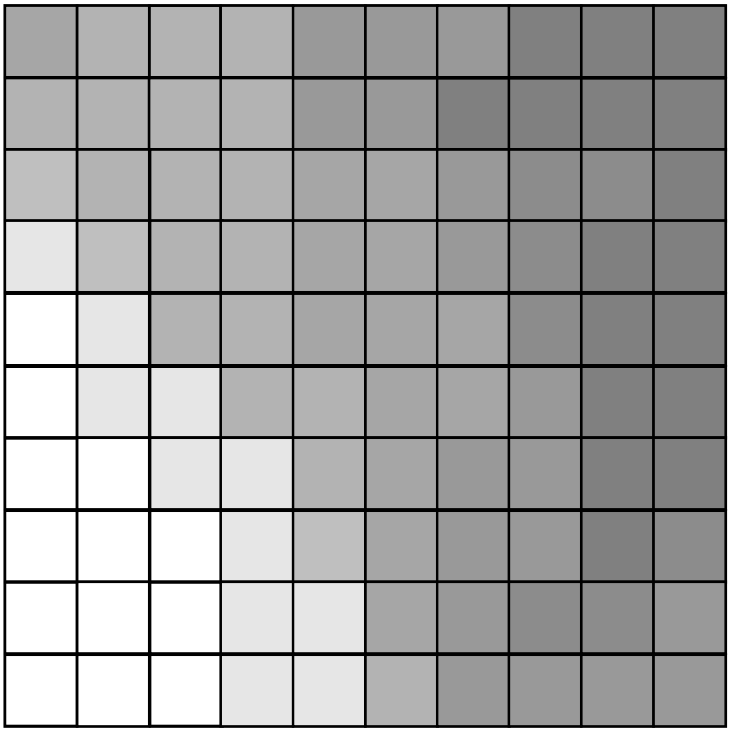
The power stations also receives reports from two other sources:

- *Sensors* on the ground provide temperature readings for every cell

  By analyzing the correlation between historical power demand from cells and the temperature readings for those regions, the utility is able to determine with a close approximation what the demand will be given specific temperatures.

- *Satellite cameras* provide images regarding current conditions that are converted into grey scale images that match the grid:

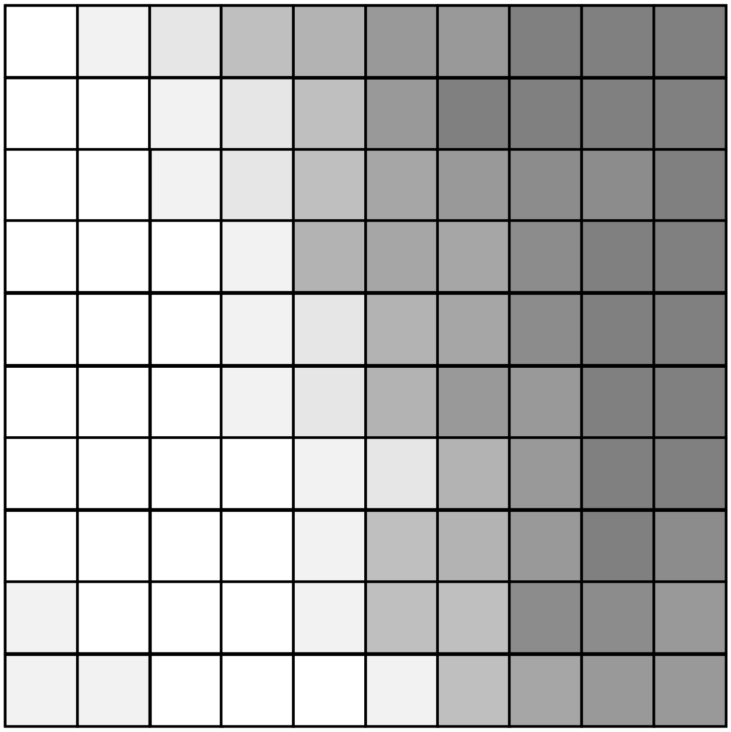
Figure 11–2 Grey Scale Representation of Satellite Image



These images are designed so that ’lighter is colder’. The image above shows a cold front moving into the region from the south-west. By correlating the data provided by the grey scale images with temperature readings taken at the same time, the utility has been able to determine what the power demand is given weather conditions viewed from the stratosphere.

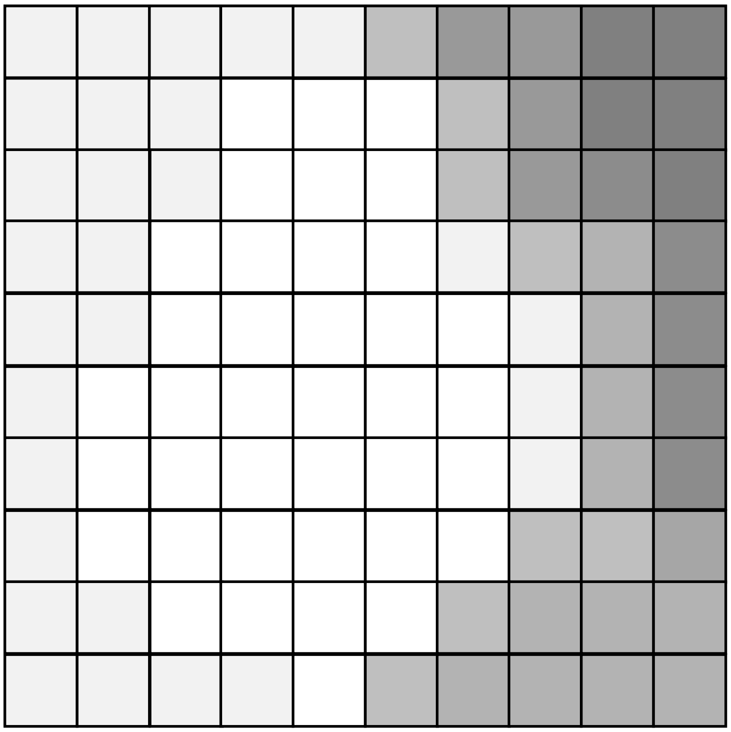
The reason that this is important is that a crucial part of this modeling has to do with noting the rapidity and degree of change in the incoming reports as weather changes and power is deployed. The following diagram shows same cold front at a second recording:

Figure 11–3 Grey-Scale Representation of Weather Conditions at Second Recording



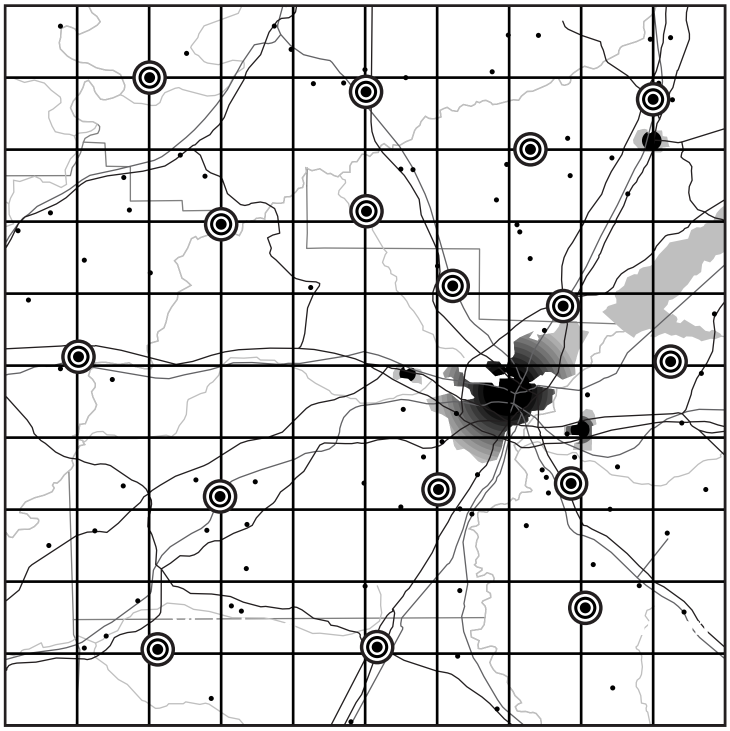
By analyzing the extent and speed of the cold front, the utility is able to project what the conditions are likely to be in the short and medium term:

Figure 11–4 Grey-Scale Representation of Conditions as Projected



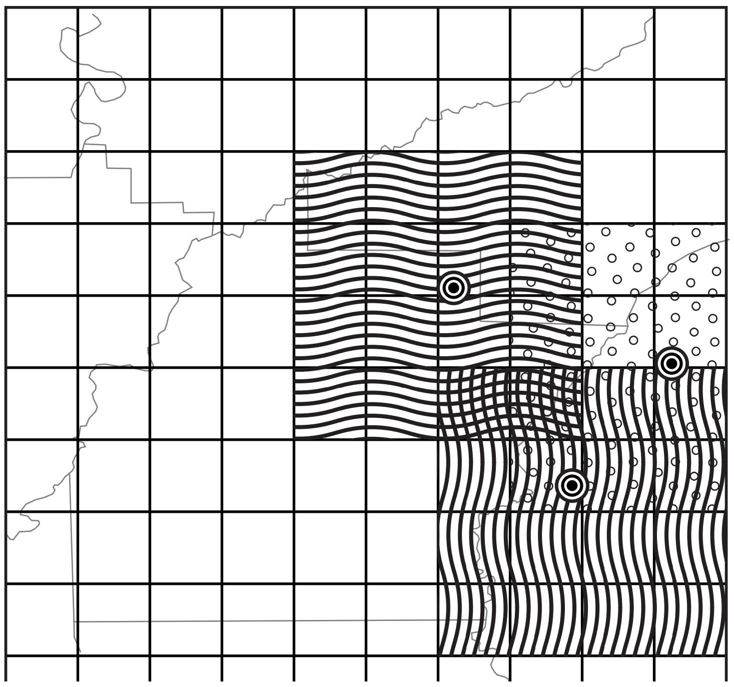
By combing this data about these conditions, and other anomalous situations (such as the failure of a substation) the utility must be able to organize the most optimal deployment of its resources. The following drawing reflects the distribution of substations across the region:

Figure 11–5 Distribution of Power Stations Across the Region



The distribution of power stations means that the utility can redirect its deployment of electricity to the areas of greatest need. The following figure gives a pictorial representation of the overlap between three stations:

Figure 11–6 Areas Served by Three Power Stations

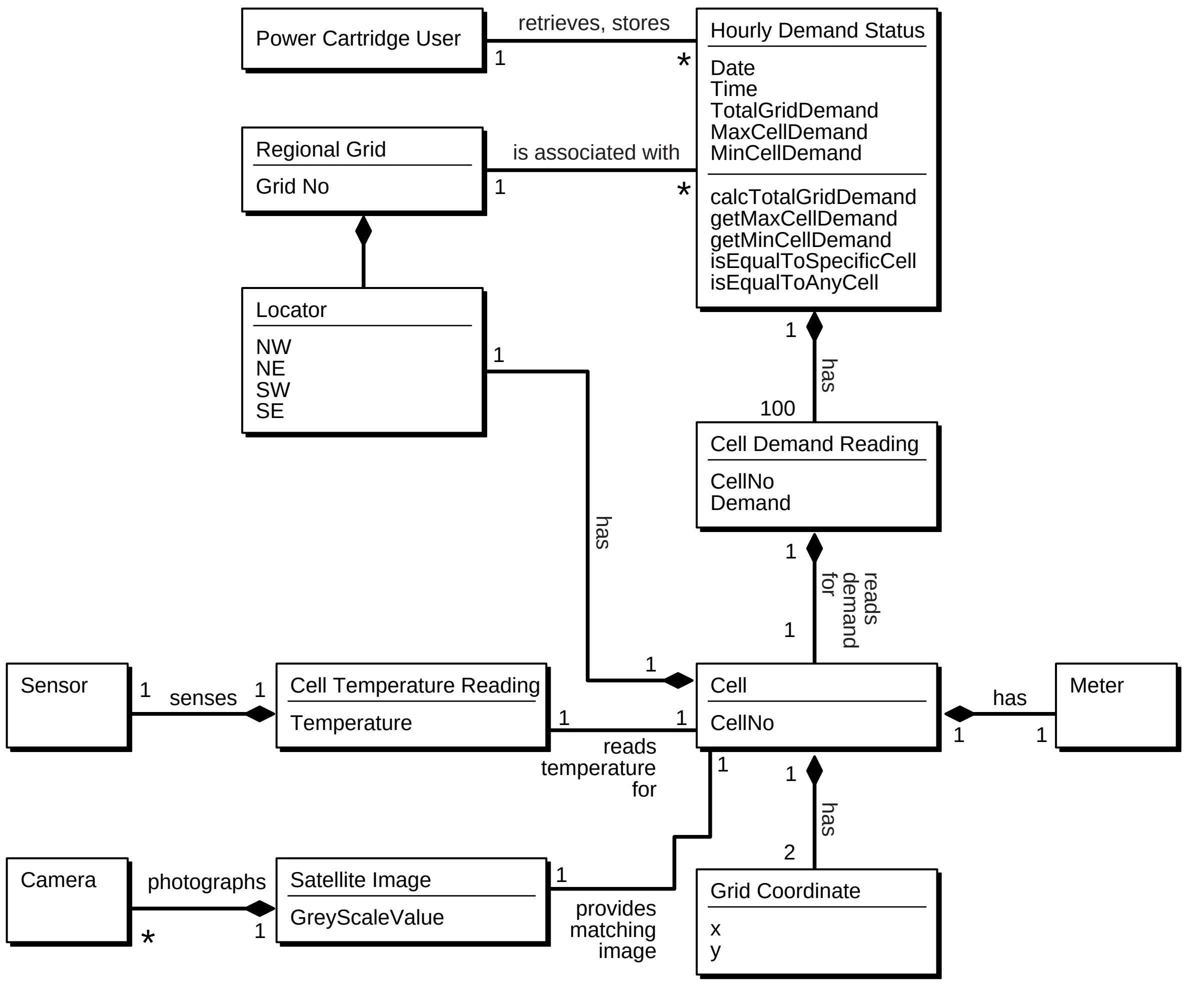


Depending on fluctuating requirements, the utility must be able to decide how to deploy its resources, and even whether to purchase power from a neighboring utility in the event of shortfall.

Modelling the Application

The following Class Diagram describes the application objects using the Unified Modelling Language (UML) notation.

Figure 11–7 Use Case Diagram for Power Demand Cartridge



Sample Queries

Modelling the application in this way, makes possible the following specific queries:

- Find the cell (geographic quadrant) with the highest demand for a specified time-period.

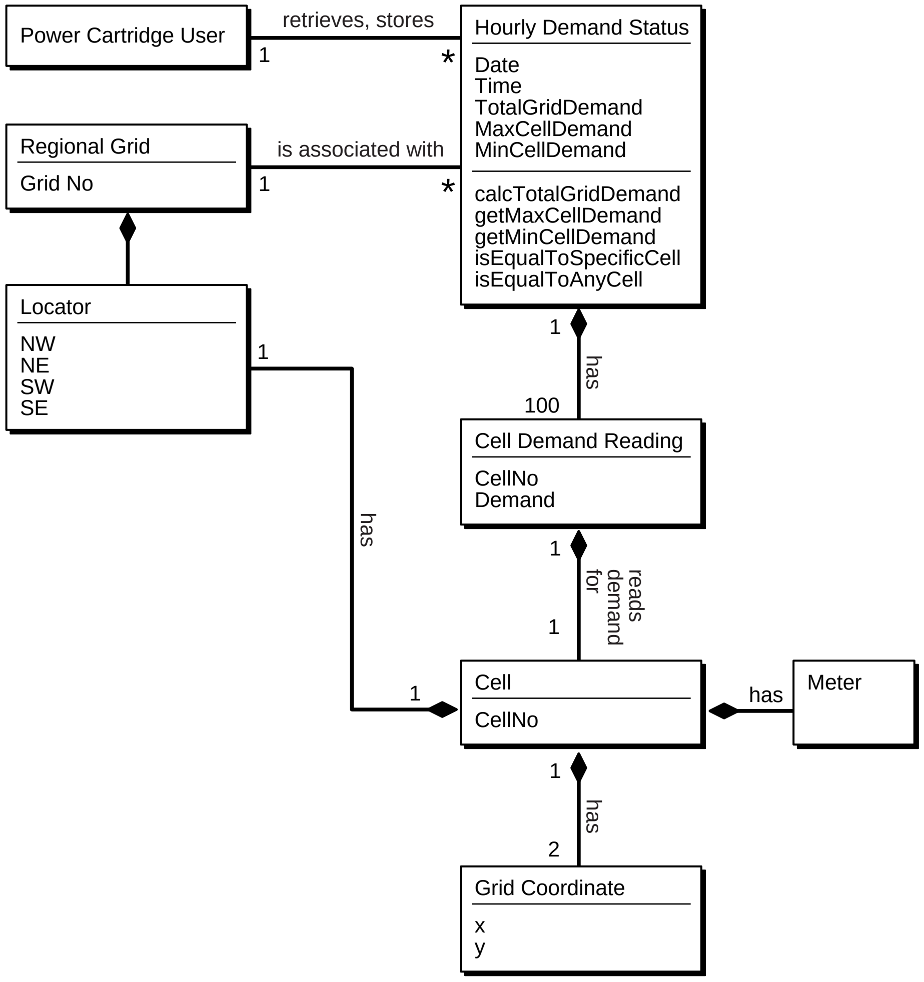
- Find the time-period with the highest total demand.
- Find all cells where demand is greater than some specified value.
- Find any cell at any time where the demand equals some specified value.
- Find any time-period for which 3 or more cells had / have a demand greater than some specified
- Find the time-period for which there was the greatest disparity (difference) between the cell with the minimum demand and the cell with the maximum demand.
- Find the times for which 10 or more cells had demand not less than some specified value.
- Find the times for which the average cell demand was greater than some specified value. (Note: it is assumed that the average is easily computable by TotalPowerDemand / 100.)
- Find the time-periods for which the median cell demand was greater than some specified value. (Note: It is assumed that the median value is not easily computable).
- Find all time-periods for which the total demand rose 10 percent or more over the preceding time's total demand.

These queries are, of course, only a short list of the possible information that could be gleaned from the system. For instance, it is obvious that the developer of such an application would want to build queries that are based on the information derived from prior queries e.g.,

- What is the percentage change in demand for a particular cell as compared to a previous time-period?
- Which cells demonstrate rapid increase / decrease in demand measured as percentages greater / lesser than specified values.

The Power Demand cartridge as implemented is described in the class diagram below.

Figure 11–8 Use Case Diagram for Power Demand Cartridge



The utility gets ongoing reports from weather centers about current conditions and from power stations about ongoing power utilization for specific geographical areas (represented by cells on a 10x10 grid). It then compares this information to historical data in order to predict demand for power in the different geographic areas for given time periods.

Each service area for the utility is considered as a 10x10 grid of cells, where each cell's boundaries are associated with spatial coordinates (longitude/latitude). The geographical areas represented by the cells can be uniform or can have different shapes and sizes. Within the area represented by each cell, the power used by consumers in that area is recorded each hour. For example, the power demand readings for a particular hour might be represented by Table 11–2.

Table 11–2 Sample Power Demand Readings for an Hour

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	23	21	25	23	24	25	27	32	31	30
2	33	32	31	33	34	32	23	22	21	34
3	45	44	43	33	44	43	42	41	45	46
4	44	45	45	43	42	26	19	44	33	43
5	45	44	43	42	41	44	45	46	47	44
6	43	45	98	55	54	43	44	33	34	44
7	33	45	44	43	33	44	34	55	46	34
8	87	34	33	32	31	34	35	38	33	39
9	30	40	43	42	33	43	34	32	34	46
10	43	42	34	12	43	45	48	45	43	32

The numbers in each cell reflect power demand (in some unit of measurement determined by the electric utility) for the hour for that area. For example, the demand for the first cell (1,1) was 23, the demand for the second cell (1,2) was 21, and so on. The demand for the last cell (10, 10) was 32.

The utility uses this data for many monitoring and analytical applications. Readings for individual cells are monitored for unusual surges or decreases in demand. For example, the readings of 98 for (6,3) and 87 for (8,1) might be unusually high, and the readings of 19 for (4,7) and 12 for (10,4) might be unusually low. Trends are also analyzed, such as significant increases or decreases in total, per-neighborhood, and per-station demand over time.

Queries and Extensible Indexing

Before you use extensible indexing, you should first ask whether the users of the table will benefit from having the domain index. That is, will they execute queries that could run just as efficiently using a standard Oracle index (or using no index at all)?

Queries Not Benefiting from Extensible Indexing

A query does not require a domain index if both of the following are true:

- The desired information can be made an attribute (column) of the table and a standard index can be defined on that column.
- The operations in queries on the data are limited to those operations supported by the standard index, such as `equals`, `lessthan`, `greaterthan`, `max`, and `min` for a b-tree index.

In the `PowerDemand_Typ` object type cartridge example, the values for three columns (`TotGridDemand`, `MaxCellDemand`, and `MinCellDemand`) are set by functions, after which the values do not change. (For example, the total grid power demand for 13:00 on 01-Jan-1998 does not change after it has been computed.) For queries that use these columns, a standard b-tree index on each column is sufficient and recommended for operations like `equals`, `lessthan`, `greaterthan`, `max`, and `min`.

Examples of queries that would not benefit from extensible indexing (using the power demand cartridge) include:

- Find the cell with the highest power demand for a specific time.
- Find the time when the total grid power demand was highest.
- Find all cells where the power demand is greater than a specified value.
- Find the times for which the average cell demand or the median cell demand was greater than a specified value.

  To make this query run efficiently, define two additional columns in the `PowerDemand_Typ` object type (`AverageCellDemand` and `MedianCellDemand`), and create functions to set the values of these columns. (For example, `AverageCellDemand` is `TotGridDemand` divided by 100.) Then, create b-tree indexes on the `AverageCellDemand` and `MedianCellDemand` columns.

Queries Benefiting from Extensible Indexing

A query benefits from a domain index if the data being queried against cannot be made a simple attribute of a table or if the operation to be performed on the data is not one of the standard operations supported by Oracle indexes.

Examples of queries that would benefit from extensible indexing (using the power demand cartridge) include:

- Find the first cell for a specified time where the power demand was equal to a specified value.

  By asking for the *first cell*, the query goes beyond a simple true-false check (such as finding out whether *any* cell for a specified time had a demand equal to a specified value), and thus benefits from a domain index.
- Find the time for which there was the greatest disparity (difference) between the cell with the minimum demand and the cell with the maximum demand.
- Find all times for which 3 or more cells had a demand greater than a specified value.
- Find all times for which 10 or more cells had a demand not less than a specified value.
- Find all times for which the total grid demand rose 10 percent or more over the preceding time's total grid demand.

Creating the Domain Index

This section explains the parts of the power demand cartridge as they relate to extensible indexing. Explanatory text and code segments are mixed.

The entire cartridge definition is available online as extdemo1.sql in the standard Oracle demo directory (location is platform-dependent).

Creating the Schema to Own the Index

Before you create a domain index, create a database user (schema) to own the index. In the power demand example, the user `PowerCartUser` is created and granted the appropriate privileges. All database structures related to the cartridge are created under this user (that is, while the cartridge developer or DBA is connected to the database as `PowerCartUser`).

```
set echo on
connect sys/knl_test7 as sysdba;
drop user PowerCartUser cascade;
create user PowerCartUser identified by PowerCartUser;

-------------------------------------------------------------------
-- INITIAL SET-UP
-------------------------------------------------------------------
-- grant privileges --
grant connect, resource to PowerCartUser;
```

```
-- do we need to grant these privileges --
grant create operator to PowerCartUser;
grant create indextype to PowerCartUser;
grant create table to PowerCartUser;
```

Creating the Object Type (PowerDemand_Typ)

The object type `PowerDemand_Typ` is used to store the hourly power grid readings. This type is used to define a column in the table in which the readings are stored.

First, two types are defined for later use:

- `PowerGrid_Typ`, to define the cells in PowerDemand_Typ
- `NumTab_Typ`, to be used in the index-organized table in which the index entries are stored

```
CREATE OR REPLACE TYPE PowerGrid_Typ as VARRAY(100) of NUMBER;
CREATE OR REPLACE TYPE NumTab_Typ as TABLE of NUMBER;
```

The `PowerDemand_Typ` type includes:

- Three attributes (`TotGridDemand`, `MaxCellDemand`, `MinCellDemand`) that are set by three member procedures
- Power demand readings (100 cells in a grid)
- The date/time of the power demand readings. (Every hour, 100 areas transmit their power demand readings.)

```
CREATE OR REPLACE TYPE PowerDemand_Typ AS OBJECT (
  -- Total power demand for the grid
  TotGridDemand NUMBER,
  -- Cell with maximum/minimum power demand for the grid
  MaxCellDemand NUMBER,
  MinCellDemand NUMBER,
  -- Power grid: 10X10 array represented as Varray(100)
  -- using previously defined PowerGrid_Typ
  CellDemandValues PowerGrid_Typ,
  -- Date/time for power-demand samplings: Every hour,
  -- 100 areas transmit their power demand readings.
  SampleTime DATE,
  --
  -- Methods (Set...) for this type:
  -- Total demand for the entire power grid for a
  -- SampleTime: sets the value of TotGridDemand.
  Member Procedure SetTotalDemand,
  -- Maximum demand for the entire power grid for a
  -- SampleTime: sets the value of MaxCellDemand.
  Member Procedure SetMaxDemand,
  -- Minimum demand for the entire power grid for a
  -- SampleTime: sets the value of MinCellDemand.
  Member Procedure SetMinDemand
);
/
```

Defining the Object Type Methods

The `PowerDemand_Typ` object type has methods that set the first three attributes in the type definition:

- `TotGridDemand`, the total demand for the entire power grid for the hour in question (identified by `SampleTime`)
- `MaxCellDemand`, the highest power demand value for all cells for the `SampleTime`
- `MinCellDemand`, the lowest power demand value for all cells for the `SampleTime`

The logic for each procedure is not complicated. `SetTotDemand` loops through the cell values and creates a running total. `SetMaxDemand` compares the first two cell values and saves the higher as the current highest value; it then examines each successive cell, comparing it against the current highest value and saving the higher of the two as the current highest value, until it reaches the end of the cell values. `SetMinDemand` uses the same approach as `SetMaxDemand`, but it continually saves the lower value in comparisons to derive the lowest value overall.

```
CREATE OR REPLACE TYPE BODY PowerDemand_Typ
IS
  --
  -- Methods (Set...) for this type:
  -- Total demand for the entire power grid for a
  -- SampleTime: sets the value of TotGridDemand.
  Member Procedure SetTotalDemand
  IS
  I BINARY_INTEGER;
  Total NUMBER;
  BEGIN
    Total :=0;
    I := CellDemandValues.FIRST;
    WHILE I IS NOT NULL LOOP
   Total := Total + CellDemandValues(I);
        I := CellDemandValues.NEXT(I);
    END LOOP;
    TotGridDemand := Total;
  END;

  -- Maximum demand for the entire power grid for a
  -- SampleTime: sets the value of MaxCellDemand.
  Member Procedure SetMaxDemand
  IS
  I BINARY_INTEGER;
  Temp NUMBER;
  BEGIN
    I := CellDemandValues.FIRST;
    Temp := CellDemandValues(I);
    WHILE I IS NOT NULL LOOP
   IF Temp < CellDemandValues(I) THEN
      Temp := CellDemandValues(I);
   END IF;
        I := CellDemandValues.NEXT(I);
    END LOOP;
    MaxCellDemand := Temp;
  END;

  -- Minimum demand for the entire power grid for a
  -- SampleTime: sets the value of MinCellDemand.
  Member Procedure SetMinDemand
  IS
  I BINARY_INTEGER;
  Temp NUMBER;
  BEGIN
    I := CellDemandValues.FIRST;
    Temp := CellDemandValues(I);
    WHILE I IS NOT NULL LOOP
   IF Temp > CellDemandValues(I) THEN
      Temp := CellDemandValues(I);
   END IF;
        I := CellDemandValues.NEXT(I);
    END LOOP;
    MinCellDemand := Temp;
  END;
END;
/
```

Creating the Functions and Operators

The power demand cartridge is designed so that users can query the power grid for relationships of `equality`, `greaterthan`, or `lessthan`. However, because of the way the cell demand data is stored, the standard operators (=, >, <) cannot be used. Instead, new operators must be created, and a function must be created to define the implementation for each new operator (that is, how the operator is to be interpreted by Oracle).

For this cartridge, each of the three relationships can be checked in two ways:

- Whether a specific cell in the grid satisfies the relationship. (For example, are there grids where cell (3,7) has demand equal to 25?)

  These operators have names in the form `Power_XxxxxSpecific` (such as `Power_EqualsSpecific`), and the implementing functions have names in the form `Power_XxxxxSpecific_Func`.

- Whether any cell in the grid satisfies the relationship. (For example, are there grids where any cell has demand equal to 25?)

  These operators have names in the form `Power_XxxxxAny` (such as `Power_EqualsAny`), and the implementing functions have names in the form `Power_XxxxxAny_Func`.

For each operator-function pair, the function is defined first and then the operator as using the function. The function is the implementation that would be used if there were no index defined. This implementation must be specified so that the Oracle optimizer can determine costs, decide whether the index should be used, and create an execution plan.

Table 11–3 shows the operators and implementing functions:

Table 11–3 Operators and Implementing Functions

Operator	Implementing Function
`Power_EqualsSpecific`	`Power_EqualsSpecific_Func`
`Power_EqualsAny`	`Power_EqualsAny_Func`
`Power_LessThanSpecific`	`Power_LessThanSpecific_Func`
`Power_LessThanAny`	`Power_LessThanAny_Func`
`Power_GreaterThanSpecific`	`Power_GreaterThanSpecific_Func`
`Power_GreaterThanAny`	`Power_GreaterThanAny_Func`

Each function and operator returns a numeric value of 1 if the condition is true (for example, if the specified cell is equal to the specified value), 0 if the condition is not true, or null if the specified cell number is invalid.

The following statements create the implementing functions (`Power_xxx_Func`), first the `specific` and then the `any` implementations.

```
CREATE FUNCTION Power_EqualsSpecific_Func(
  object PowerDemand_Typ, cell NUMBER, value NUMBER)
RETURN NUMBER AS
  BEGIN
  IF cell <= object.CellDemandValues.LAST
  THEN
     IF (object.CellDemandValues(cell) = value) THEN
   RETURN 1;
     ELSE
   RETURN 0;
     END IF;
  ELSE
     RETURN NULL;
  END IF;
  END;
/
CREATE FUNCTION Power_GreaterThanSpecific_Func(
  object PowerDemand_Typ, cell NUMBER, value NUMBER)
RETURN NUMBER AS
  BEGIN
  IF cell <= object.CellDemandValues.LAST
  THEN
     IF (object.CellDemandValues(cell) > value) THEN
   RETURN 1;
     ELSE
   RETURN 0;
     END IF;
  ELSE
     RETURN NULL;
  END IF;
  END;
/
CREATE FUNCTION Power_LessThanSpecific_Func(
  object PowerDemand_Typ, cell NUMBER, value NUMBER)
RETURN NUMBER AS
  BEGIN
  IF cell <= object.CellDemandValues.LAST
  THEN
```

```
     IF (object.CellDemandValues(cell) < value) THEN
   RETURN 1;
     ELSE
   RETURN 0;
     END IF;
  ELSE
     RETURN NULL;
  END IF;
  END;
/
CREATE FUNCTION Power_EqualsAny_Func(
  object PowerDemand_Typ, value NUMBER)
RETURN NUMBER AS
   idx NUMBER;
  BEGIN
    FOR idx IN object.CellDemandValues.FIRST..object.CellDemandValues.LAST LOOP
      IF (object.CellDemandValues(idx) = value) THEN
   RETURN 1;
      END IF;
    END LOOP;
   RETURN 0;
  END;
/
CREATE FUNCTION Power_GreaterThanAny_Func(
  object PowerDemand_Typ, value NUMBER)
RETURN NUMBER AS
   idx NUMBER;
  BEGIN
    FOR idx IN object.CellDemandValues.FIRST..object.CellDemandValues.LAST LOOP
      IF (object.CellDemandValues(idx) > value) THEN
   RETURN 1;
      END IF;
    END LOOP;
   RETURN 0;
  END;
/
CREATE FUNCTION Power_LessThanAny_Func(
  object PowerDemand_Typ, value NUMBER)
RETURN NUMBER AS
   idx NUMBER;
  BEGIN
    FOR idx IN object.CellDemandValues.FIRST..object.CellDemandValues.LAST LOOP
      IF (object.CellDemandValues(idx) < value) THEN
   RETURN 1;
      END IF;
    END LOOP;
   RETURN 0;
  END;
/
```

The following statements create the operators (`Power_xxx`). Each statement specifies an implementing function.

```
CREATE OPERATOR Power_Equals BINDING(PowerDemand_Typ, NUMBER, NUMBER)
  RETURN NUMBER USING Power_EqualsSpecific_Func;
CREATE OPERATOR Power_GreaterThan BINDING(PowerDemand_Typ, NUMBER, NUMBER)
  RETURN NUMBER USING Power_GreaterThanSpecific_Func;
CREATE OPERATOR Power_LessThan BINDING(PowerDemand_Typ, NUMBER, NUMBER)
  RETURN NUMBER USING Power_LessThanSpecific_Func;

CREATE OPERATOR Power_EqualsAny BINDING(PowerDemand_Typ, NUMBER)
  RETURN NUMBER USING Power_EqualsAny_Func;
CREATE OPERATOR Power_GreaterThanAny BINDING(PowerDemand_Typ, NUMBER)
  RETURN NUMBER USING Power_GreaterThanAny_Func;
CREATE OPERATOR Power_LessThanAny BINDING(PowerDemand_Typ, NUMBER)
  RETURN NUMBER USING Power_LessThanAny_Func;
```

Creating the Indextype Implementation Methods

The power demand cartridge creates an object type for the indextype that specifies methods for the domain index. These methods are part of the `ODCIIndex` (Oracle Data Cartridge Interface Index) interface, and they collectively define the behavior of the index in terms of the methods for defining, manipulating, scanning, and exporting the index.

Table 11–4 shows the method functions (all but one starting with `ODCIIndex`) created for the power demand cartridge.

Table 11–4 Indextype Methods

Method	Description
ODCIGetInterfaces	Returns the list of names of the interfaces implemented by the type.

Table 11–4 Indextype Methods

Method	Description
ODCIIndexCreate	Creates the index-organized table to store index data. If the base table containing data to be indexed is not empty, this method builds the index for existing data. This method is called when a CREATE INDEX statement is issued that refers to the indextype. Upon invocation, any parameters specified in the PARAMETERS clause are passed in along with a description of the index.
ODCIIndexDrop	Deletes the index. This method is called when a DROP INDEX statement specifies the index.
ODCIIndexStart	Initializes the scan of the index for the operator predicate. This method is invoked when a query is submitted involving an operator that can be executed using the domain index.
ODCIIndexFetch	Returns the ROWID of each row that satisfies the operator predicate.
ODCIIndexClose	Ends the current use of the index. This method can perform any necessary clean-up.
.ODCIIndexInsert	Maintains the index structure when a record is inserted in a table that contains columns or object attributes indexed by the indextype.
ODCIIndexDelete	Maintains the index structure when a record is deleted from a table that contains columns or object attributes indexed by the indextype.
ODCIIndexUpdate	Maintains the index structure when a record is updated (modified) in a table that contains columns or object attributes indexed by the indextype.
ODCIIndexGet Metadata	Allows the export and import of implementation-specific metadata associated with the index.

Type Definition

The following statement creates the power_idxtype_im object type. The methods of this type are the ODCI methods to define, manipulate, and scan the domain index. The curnum attribute is the cursor number used as context for the scan routines (ODCIIndexStart, ODCIIndexFetch, and ODCIIndexClose).

```
CREATE OR REPLACE TYPE power_idxtype_im AS OBJECT
(
  curnum NUMBER,
  MEMBER FUNCTION ODCIGetInterfaces(ifclist OUT sys.ODCIObjectList)
     RETURN NUMBER,
  MEMBER FUNCTION ODCIIndexCreate (ia sys.odciindexinfo, parms VARCHAR2)
     RETURN NUMBER,
  MEMBER FUNCTION ODCIIndexDrop(ia sys.odciindexinfo) RETURN NUMBER,
  MEMBER FUNCTION ODCIIndexStart(self IN OUT power_idxtype_im,
     ia sys.odciindexinfo,
     op sys.odciPredInfo, qi sys.ODCIQueryInfo,
     strt NUMBER, stop NUMBER,
     cmppos NUMBER, cmpval NUMBER) RETURN NUMBER,
  MEMBER FUNCTION ODCIIndexStart(self IN OUT power_idxtype_im,
     ia sys.odciindexinfo,
     op sys.odciPredInfo, qi sys.ODCIQueryInfo,
     strt NUMBER, stop NUMBER,
     cmpval NUMBER) RETURN NUMBER,
  MEMBER FUNCTION ODCIIndexFetch(nrows NUMBER,
     rids OUT sys.odciridlist)
     RETURN NUMBER,
  MEMBER FUNCTION ODCIIndexClose RETURN NUMBER,
  MEMBER FUNCTION ODCIIndexInsert(ia sys.odciindexinfo, rid VARCHAR2,
     newval PowerDemand_Typ) RETURN NUMBER,
  MEMBER FUNCTION ODCIIndexDelete(ia sys.odciindexinfo, rid VARCHAR2,
     oldval PowerDemand_Typ) RETURN NUMBER,
  MEMBER FUNCTION ODCIIndexUpdate(ia sys.odciindexinfo, rid VARCHAR2,
     oldval PowerDemand_Typ, newval PowerDemand_Typ) RETURN NUMBER,
  MEMBER FUNCTION ODCIIndexGetMetadata(ia sys.odciindexinfo, expversion
     VARCHAR2, newblock OUT PLS_INTEGER) RETURN VARCHAR2
);
/
```

The `CREATE TYPE` statement is followed by a `CREATE TYPE BODY` statement that specifies the implementation for each member function:

```
CREATE OR REPLACE TYPE BODY power_idxtype_im
IS
...
```

Each member function is described in a separate section, but the function definitions (except for `ODCIIndexGetMetadata`, which returns a `VARCHAR2` string) have the following general form:

```
  MEMBER FUNCTION function-name (...)
    RETURN NUMBER
  IS
  ...
```

```
END;
```

ODCIGetInterfaces Method

The `ODCIGetInterfaces` member function returns the list of names of the interfaces implemented by the type. In release 8.1, there is only one set of the extensible indexing interface routines, called `SYS.ODCIINDEX1`. Thus, in release 8.1, the `ODCIGetInterfaces` routine must return `'SYS'.'ODCIINDEX1'` as one of the implemented interfaces.

```
MEMBER FUNCTION ODCIGetInterfaces(ifclist OUT sys.ODCIObjectList)
     return number is
 BEGIN
     ifclist := sys.ODCIObjectList(sys.ODCIObject('SYS','ODCIINDEX1'));
     return ODCIConst.Success;
 END ODCIGetInterfaces;
```

ODCIIndexCreate Method

The `ODCIIndexCreate` member function creates the index-organized table to store index data. If the base table containing data to be indexed is not empty, this method inserts the index data entries for existing data.

The function takes the index information as an object parameter whose type is `SYS.ODCIINDEXINFO`. The type attributes include the index name, owner name, and so forth. The `PARAMETERS` string specified in the `CREATE INDEX` statement is also passed in as a parameter to the function.

```
MEMBER FUNCTION ODCIIndexCreate (ia sys.odciindexinfo, parms VARCHAR2)
   RETURN NUMBER
is
 i INTEGER;
 r ROWID;
 p NUMBER;
 v NUMBER;
 stmt1 VARCHAR2(1000);
 stmt2 VARCHAR2(1000);
 stmt3 VARCHAR2(1000);
 cnum1 INTEGER;
 cnum2 INTEGER;
 cnum3 INTEGER;
 junk NUMBER;
```

The SQL statement to create the index-organized table for the index data is constructed and executed. The table includes the `ROWID` of the base table (`r`), the cell position number (`cpos`) in the grid from 1 to 100, and the power demand value in that cell (`cval`).

```
BEGIN
   -- Construct the SQL statement.
   stmt1 := 'CREATE TABLE ' || ia.IndexSchema || '.' || ia.IndexName ||
           '_pidx' || '( r ROWID, cpos NUMBER, cval NUMBER)';

   -- Dump the SQL statement.
   dbms_output.put_line('ODCIIndexCreate>>>>>');
   sys.ODCIIndexInfoDump(ia);
   dbms_output.put_line('ODCIIndexCreate>>>>>'||stmt1);

   -- Execute the statement.
   cnum1 := dbms_sql.open_cursor;
   dbms_sql.parse(cnum1, stmt1, dbms_sql.native);
   junk := dbms_sql.execute(cnum1);
   dbms_sql.close_cursor(cnum1);
```

The function populates the index by inserting rows into the index-organized table. The function "unnests" the VARRAY attribute and inserts a row for each cell into the index-organized table. Thus, each 10 X 10 grid (10 rows, 10 values per row) becomes 100 rows in the index-organized table (one row per cell).

```
   -- Now populate the table.
   stmt2 := ' INSERT INTO '|| ia.IndexSchema || '.' ||
       ia.IndexName || '_pidx' ||
       ' SELECT :rr, ROWNUM, column_value FROM THE' ||
       ' (SELECT CAST (P.'|| ia.IndexCols(1).ColName||'.CellDemandValues
          AS NumTab_Typ)'||
       ' FROM ' || ia.IndexCols(1).TableSchema || '.' ||
       ia.IndexCols(1).TableName || ' P' ||
       ' WHERE P.ROWID = :rr)';

   -- Execute the statement.
   dbms_output.put_line('ODCIIndexCreate>>>>>'||stmt2);

   -- Parse the statement.
   cnum2 := dbms_sql.open_cursor;
   dbms_sql.parse(cnum2, stmt2, dbms_sql.native);

   stmt3 := 'SELECT ROWID FROM '|| ia.IndexCols(1).TableSchema
     || '.' || ia.IndexCols(1).TableName;
   dbms_output.put_line('ODCIIndexCreate>>>>>'||stmt3);
   cnum3 := dbms_sql.open_cursor;
```

```
  dbms_sql.parse(cnum3, stmt3, dbms_sql.native);
  dbms_sql.define_column_rowid(cnum3, 1, r);
  junk := dbms_sql.execute(cnum3);

  WHILE dbms_sql.fetch_rows(cnum3) > 0 LOOP
     -- Get column values of the row. --
     dbms_sql.column_value_rowid(cnum3, 1, r);
     -- Bind the row into the cursor for the next insert. --
     dbms_sql.bind_variable_rowid(cnum2, ':rr', r);
     junk := dbms_sql.execute(cnum2);
  END LOOP;
```

The function concludes by closing the cursors and returning a success status.

```
  dbms_sql.close_cursor(cnum2);
  dbms_sql.close_cursor(cnum3);
  RETURN ODCICONST.SUCCESS;
 END;
```

ODCIIndexDrop Method

The ODCIIndexDrop member function deletes the index. This method is called when a DROP INDEX statement specifies the index.

```
 MEMBER FUNCTION ODCIIndexDrop(ia sys.odciindexinfo) RETURN NUMBER is
  stmt VARCHAR2(1000);
  cnum INTEGER;
  junk INTEGER;
 BEGIN
   -- Construct the SQL statement.
  stmt := 'drop table ' || ia.IndexSchema || '.' || ia.IndexName
    || '_pidx';

  dbms_output.put_line('ODCIIndexDrop>>>>>');
  sys.ODCIIndexInfoDump(ia);
  dbms_output.put_line('ODCIIndexDrop>>>>>'||stmt);

  -- Execute the statement.
  cnum := dbms_sql.open_cursor;
  dbms_sql.parse(cnum, stmt, dbms_sql.native);
  junk := dbms_sql.execute(cnum);
  dbms_sql.close_cursor(cnum);

  RETURN ODCICONST.SUCCESS;
 END;
```

ODCIIndexStart Method (for `Specific` Queries)

The first definition of the `ODCIIndexStart` member function initializes the scan of the index to return all rows that satisfy the operator predicate. For example, if a query asks for all instances where cell (3,7) has a value equal to 25, the function initializes the scan to return all rows in the index-organized table for which that cell has that value. (This definition of `ODCIIndexStart` differs from the definition in the next section in that it includes the `cmppos` parameter for the position of the cell.)

The `self` parameter is the context that is shared with the `ODCIIndexFetch` and `ODCIIndexClose` functions. The `ia` parameter contains the index information (an object instance of type `SYS.ODCIINDEXINFO`), and the `op` parameter contains the operator information (an object instance of type `SYS.ODCIOPERINFO`). The `strt` and `stop` parameters are the lower and upper boundary points for the operator return value. The `cmppos` parameter is the cell position and `cmpval` is the value in the cell specified by the operator (`Power_XxxxxSpecific`).

```
MEMBER FUNCTION ODCIIndexStart(self IN OUT power_idxtype_im,
      ia sys.odciindexinfo,
      op sys.odciPredInfo, qi sys.ODCIQueryInfo,
      strt NUMBER, stop NUMBER,
      cmppos NUMBER, cmpval NUMBER ) RETURN NUMBER is
  cnum INTEGER;
  rid ROWID;
  nrows INTEGER;
  relop VARCHAR2(2);
  stmt VARCHAR2(1000);
BEGIN
  dbms_output.put_line('ODCIIndexStart>>>>>');
  sys.ODCIIndexInfoDump(ia);
  sys.ODCIPredInfoDump(op);
  dbms_output.put_line('start key : '||strt);
  dbms_output.put_line('stop key : '||stop);
  dbms_output.put_line('compare position : '||cmppos);
  dbms_output.put_line('compare value : '||cmpval);
```

The function checks for errors in the predicate.

```
  -- Take care of some error cases.
  -- The only predicates in which btree operators can appear are
  --    op() = 1     OR    op() = 0
  if (strt != 1) and (strt != 0) then
  raise_application_error(-20101, 'Incorrect predicate for operator');
  END if;
```

```
if (stop != 1) and (stop != 0) then
raise_application_error(-20101, 'Incorrect predicate for operator');
END if;
```

The function generates the SQL statement to be executed. It determines the operator name and the lower and upper index value bounds (the start and stop keys). The start and stop keys can both be 1 (= TRUE) or both be 0 (= FALSE).

```
-- Generate the SQL statement to be executed.
-- First, figure out the relational operator needed for the statement.
-- Take into account the operator name and the start and stop keys.
-- For now, the start and stop keys can both be 1 (= TRUE) or
-- both be 0 (= FALSE).
if op.ObjectName = 'POWER_EQUALS' then
  if strt = 1 then
    relop := '=';
  else
    relop := '!=';
  end if;
elsif op.ObjectName = 'POWER_LESSTHAN' then
  if strt = 1 then
    relop := '<';
  else
    relop := '>=';
  end if;
elsif op.ObjectName = 'POWER_GREATERTHAN' then
  if strt = 1 then
    relop := '>';
  else
    relop := '<=';
  end if;
else
  raise_application_error(-20101, 'Unsupported operator');
end if;

stmt := 'select r from '||ia.IndexSchema||'.'||ia.IndexName||'_pidx'||
          ' where cpos '|| '=' ||''''||cmppos||''''||
          ' and cval '||relop||''''||cmpval||'''';

dbms_output.put_line('ODCIIndexStart>>>>>' || stmt);
cnum := dbms_sql.open_cursor;
dbms_sql.parse(cnum, stmt, dbms_sql.native);
dbms_sql.define_column_rowid(cnum, 1, rid);
nrows := dbms_sql.execute(cnum);
```

The function stores the cursor number in the context, which is used by the `ODCIIndexFetch` function, and sets a success return status.

```
    -- Set context as the cursor number.
    self := power_idxtype_im(cnum);

    -- Return success.
    RETURN ODCICONST.SUCCESS;
  END;
```

ODCIIndexStart Method (for Any Queries)

This definition of the `ODCIIndexStart` member function initializes the scan of the index to return all rows that satisfy the operator predicate. For example, if a query asks for all instances where any cell has a value equal to 25, the function initializes the scan to return all rows in the index-organized table for which that cell has that value. (This definition of `ODCIIndexStart` differs from the definition in the preceding section in that it does not include the `cmppos` parameter.)

The `self` parameter is the context that is shared with the `ODCIIndexFetch` and `ODCIIndexClose` functions. The `ia` parameter contains the index information (an object instance of type `SYS.ODCIINDEXINFO`), and the `op` parameter contains the operator information (an object instance of type `SYS.ODCIOPERINFO`). The `strt` and `stop` parameters are the lower and upper boundary points for the operator return value. The `cmpval` parameter is the value in the cell specified by the operator (`Power_Xxxxx`).

```
  MEMBER FUNCTION ODCIIndexStart(self IN OUT power_idxtype_im,
        ia sys.odciindexinfo,
        op sys.odciPredInfo, qi sys.ODCIQueryInfo,
        strt NUMBER, stop NUMBER,
        cmpval NUMBER ) RETURN NUMBER is
    cnum INTEGER;
    rid ROWID;
    nrows INTEGER;
    relop VARCHAR2(2);
    stmt VARCHAR2(1000);
  BEGIN
    dbms_output.put_line('ODCIIndexStart>>>>>');
    sys.ODCIIndexInfoDump(ia);
    sys.ODCIPredInfoDump(op);
    dbms_output.put_line('start key : '||strt);
    dbms_output.put_line('stop key : '||stop);
    dbms_output.put_line('compare value : '||cmpval);
```

The function checks for errors in the predicate.

```
-- Take care of some error cases.
-- The only predicates in which btree operators can appear are
--    op() = 1     OR    op() = 0
if (strt != 1) and (strt != 0) then
raise_application_error(-20101, 'Incorrect predicate for operator');
END if;

if (stop != 1) and (stop != 0) then
raise_application_error(-20101, 'Incorrect predicate for operator');
END if;
```

The function generates the SQL statement to be executed. It determines the operator name and the lower and upper index value bounds (the start and stop keys). The start and stop keys can both be 1 (= TRUE) or both be 0 (= FALSE).

```
-- Generate the SQL statement to be executed.
-- First, figure out the relational operator needed for the statement.
-- Take into account the operator name and the start and stop keys.
-- For now, the start and stop keys can both be 1 (= TRUE) or
-- both be 0 (= FALSE).
if op.ObjectName = 'POWER_EQUALSANY' then
  relop := '=';
elsif op.ObjectName = 'POWER_LESSTHANANY' then
    relop := '<';
elsif op.ObjectName = 'POWER_GREATERTHANANY' then
    relop := '>';
else
  raise_application_error(-20101, 'Unsupported operator');
end if;

-- This statement returns the qualifying rows for the TRUE case.
stmt := 'select distinct r from '||ia.IndexSchema||'.'||ia.IndexName||
        '_pidx'||' where cval '||relop||''''||cmpval||'''';
-- In the FALSE case, we need to find the  complement of the rows.
if (strt = 0) then
  stmt := 'select distinct r from '||ia.IndexSchema||'.'||
          ia.IndexName||'_pidx'||' minus '||stmt;
end if;

dbms_output.put_line('ODCIIndexStart>>>>>' || stmt);
cnum := dbms_sql.open_cursor;
dbms_sql.parse(cnum, stmt, dbms_sql.native);
dbms_sql.define_column_rowid(cnum, 1, rid);
```

```
    nrows := dbms_sql.execute(cnum);
```

The function stores the cursor number in the context, which is used by the `ODCIIndexFetch` function, and sets a success return status.

```
    -- Set context as the cursor number.
    self := power_idxtype_im(cnum);

    -- Return success.
    RETURN ODCICONST.SUCCESS;
  END;
```

ODCIIndexFetch Method

The `ODCIIndexFetch` member function returns a batch of `ROWIDs` for the rows that satisfy the operator predicate. Each time `ODCIIndexFetch` is invoked, it returns the next batch of rows (`rids` parameter, a collection of type `SYS.ODCIRIDLIST`) that satisfy the operator predicate. The maximum number of rows that can be returned on each invocation is specified by the `nrows` parameter.

Oracle invokes `ODCIIndexFetch` repeatedly until all rows that satisfy the operator predicate have been returned.

```
  MEMBER FUNCTION ODCIIndexFetch(nrows NUMBER, rids OUT sys.odciridlist)
   RETURN NUMBER is
    cnum INTEGER;
    idx INTEGER := 1;
    rlist sys.odciridlist := sys.odciridlist();
    done boolean := FALSE;
```

The function loops through the collection of rows selected by the `ODCIIndexStart` function, using the same cursor number (`cnum`) as in the `ODCIIndexStart` function, and returns the `ROWIDs`.

```
  BEGIN
    dbms_output.put_line('ODCIIndexFetch>>>>>');
    dbms_output.put_line('Nrows : '||round(nrows));

    cnum := self.curnum;

    WHILE not done LOOP
      if idx > nrows then
         done := TRUE;
      else
         rlist.extEND;
         if dbms_sql.fetch_rows(cnum) > 0 then
```

```
          dbms_sql.column_value_rowid(cnum, 1, rlist(idx));
          idx := idx + 1;
       else
          rlist(idx) := null;
          done := TRUE;
       END if;
    END if;
  END LOOP;

  rids := rlist;
  RETURN ODCICONST.SUCCESS;
END;
```

ODCIIndexClose Method

The `ODCIIndexClose` member function closes the cursor used by the `ODCIIndexStart` and `ODCIIndexFetch` functions.

```
MEMBER FUNCTION ODCIIndexClose RETURN NUMBER is
  cnum INTEGER;
BEGIN
  dbms_output.put_line('ODCIIndexClose>>>>>');

  cnum := self.curnum;
  dbms_sql.close_cursor(cnum);
  RETURN ODCICONST.SUCCESS;
END;
```

ODCIIndexInsert Method

The `ODCIIndexInsert` member function is called when a record is inserted in a table that contains columns or `OBJECT` attributes indexed by the indextype. The new values in the indexed columns are passed in as arguments along with the corresponding row identifier.

When an array of rows is inserted into the base table, an array of new values is passed in to the insert routine. This results in better performance than invoking the insert routine with one new row value at a time.

```
MEMBER FUNCTION ODCIIndexInsert(ia sys.odciindexinfo, rid VARCHAR2,
 newval PowerDemand_Typ)
     RETURN NUMBER as
     cid INTEGER;
     i BINARY_INTEGER;
     nrows INTEGER;
     stmt VARCHAR2(1000);
```

```
BEGIN
  dbms_output.put_line(' ');
  dbms_output.put_line('ODCIIndexInsert>>>>>'||
   ' TotGridDemand= '||newval.TotGridDemand ||
   ' MaxCellDemand= '||newval.MaxCellDemand ||
   ' MinCellDemand= '||newval.MinCellDemand) ;
  sys.ODCIIndexInfoDump(ia);

  -- Construct the statement.
  stmt := ' INSERT INTO '|| ia.IndexSchema || '.' || ia.IndexName
         || '_pidx' ||' VALUES (:rr, :pos, :val)';

  -- Execute the statement.
  dbms_output.put_line('ODCIIndexInsert>>>>>'||stmt);
  -- Parse the statement.
  cid := dbms_sql.open_cursor;
  dbms_sql.parse(cid, stmt, dbms_sql.native);
  dbms_sql.bind_variable_rowid(cid, ':rr', rid);

  -- Iterate over the rows of the Varray and insert them.
  i := newval.CellDemandValues.FIRST;
  WHILE i IS NOT NULL LOOP
      -- Bind the row into the cursor for insert.
      dbms_sql.bind_variable(cid, ':pos', i);
      dbms_sql.bind_variable(cid, ':val', newval.CellDemandValues(i));
      -- Execute.
      nrows := dbms_sql.execute(cid);
      dbms_output.put_line('ODCIIndexInsert>>>>>('||
                           'RID' ||' , '||
                           i   || ' , '||
                           newval.CellDemandValues(i)|| ')');
      i := newval.CellDemandValues.NEXT(i);
   END LOOP;
  dbms_sql.close_cursor(cid);
  RETURN ODCICONST.SUCCESS;
END ODCIIndexInsert;
```

ODCIIndexDelete Method

The `ODCIIndexDelete` member function is called when a record is deleted from a table that contains columns or object attributes indexed by the indextype. The old values in the indexed columns are passed in as arguments along with the corresponding row identifier. When an array of rows is deleted, an array of old values and the corresponding row identifiers are passed.

```
  MEMBER FUNCTION ODCIIndexDelete(ia sys.odciindexinfo, rid VARCHAR2,
oldval PowerDemand_Typ)
       RETURN NUMBER as
       cid INTEGER;
       stmt VARCHAR2(1000);
       nrows INTEGER;
   BEGIN
     dbms_output.put_line(' ');
     dbms_output.put_line('ODCIIndexDelete>>>>>'||
      ' TotGridDemand= '||oldval.TotGridDemand ||
      ' MaxCellDemand= '||oldval.MaxCellDemand ||
      ' MinCellDemand= '||oldval.MinCellDemand) ;
     sys.ODCIIndexInfoDump(ia);

     -- Construct the statement.
     stmt := ' DELETE FROM '|| ia.IndexSchema || '.' || ia.IndexName
            || '_pidx' || ' WHERE r=:rr';
     dbms_output.put_line('ODCIIndexDelete>>>>>'||stmt);

     -- Parse and execute the statement.
     cid := dbms_sql.open_cursor;
     dbms_sql.parse(cid, stmt, dbms_sql.native);
     dbms_sql.bind_variable_rowid(cid, ':rr', rid);
     nrows := dbms_sql.execute(cid);
     dbms_sql.close_cursor(cid);

     RETURN ODCICONST.SUCCESS;
   END ODCIIndexDelete;
```

ODCIIndexUpdate Method

The `ODCIIndexUpdate` member function is called when a record is updated in a table that contains columns or object attributes indexed by the indextype. The old and new values in the indexed columns are passed in as arguments along with the row identifier. When an array of rows get updated, arrays of old values, new values and row identifiers are passed.

```
  MEMBER FUNCTION ODCIIndexUpdate(ia sys.odciindexinfo, rid VARCHAR2,
   oldval PowerDemand_Typ, newval PowerDemand_Typ)
       RETURN NUMBER as
       cid INTEGER;
       cid2 INTEGER;
       stmt VARCHAR2(1000);
       stmt2 VARCHAR2(1000);
       nrows INTEGER;
```

```
    i NUMBER;
BEGIN
  dbms_output.put_line(' ');
  dbms_output.put_line('ODCIIndexUpdate>>>>> Old'||
   ' TotGridDemand= '||oldval.TotGridDemand ||
   ' MaxCellDemand= '||oldval.MaxCellDemand ||
   ' MinCellDemand= '||oldval.MinCellDemand) ;
  dbms_output.put_line('ODCIIndexUpdate>>>>> New'||
   ' TotGridDemand= '||newval.TotGridDemand ||
   ' MaxCellDemand= '||newval.MaxCellDemand ||
   ' MinCellDemand= '||newval.MinCellDemand) ;
  sys.ODCIIndexInfoDump(ia);

  -- Delete old entries.
  stmt := ' DELETE FROM '|| ia.IndexSchema || '.' || ia.IndexName
         || '_pidx' || ' WHERE r=:rr';
  dbms_output.put_line('ODCIIndexUpdate>>>>>'||stmt);

  -- Parse and execute the statement.
  cid := dbms_sql.open_cursor;
  dbms_sql.parse(cid, stmt, dbms_sql.native);
  dbms_sql.bind_variable_rowid(cid, ':rr', rid);
  nrows := dbms_sql.execute(cid);
  dbms_sql.close_cursor(cid);

  -- Insert new entries.
  stmt2 := ' INSERT INTO '|| ia.IndexSchema || '.' || ia.IndexName
         || '_pidx' || ' VALUES (:rr, :pos, :val)';
  dbms_output.put_line('ODCIIndexUpdate>>>>>'||stmt2);

  -- Parse and execute the statement.
  cid2 := dbms_sql.open_cursor;
  dbms_sql.parse(cid2, stmt2, dbms_sql.native);
  dbms_sql.bind_variable_rowid(cid2, ':rr', rid);

  -- Iterate over the rows of the Varray and insert them.
  i := newval.CellDemandValues.FIRST;
  WHILE i IS NOT NULL LOOP
      -- Bind the row into the cursor for insert.
      dbms_sql.bind_variable(cid2, ':pos', i);
      dbms_sql.bind_variable(cid2, ':val', newval.CellDemandValues(i));
      nrows := dbms_sql.execute(cid2);
      dbms_output.put_line('ODCIIndexUpdate>>>>>('||
                            'RID' || ' , '||
                            i   || ' , '||
                            newval.CellDemandValues(i)|| ')');
      i := newval.CellDemandValues.NEXT(i);
   END LOOP;
  dbms_sql.close_cursor(cid2);

  RETURN ODCICONST.SUCCESS;
END ODCIIndexUpdate;
```

ODCIIndexUpdate is the last method defined in the CREATE TYPE BODY statement, which ends as follows:

```
END;
/
```

ODCIIndexGetMetadata Method

The optional ODCIIndexGetMetadata member function, if present, is called by the Export utility in order to write implementation-specific metadata (which is not stored in the system catalogs) into the export dump file. This metadata might be policy information, version information, per-user settings, and so on. This metadata is written to the dump file as anonymous PL/SQL blocks that are executed at import time, immediately before the associated index is created.

This method returns strings to the Export utility that comprise the code of the PL/SQL blocks. The Export utility repeatedly calls this method until a zero-length string is returned, thus allowing the creation of any number of PL/SQL blocks of arbitrary complexity. Normally, this method calls functions within a PL/SQL package in order to make use of package-level variables, such as cursors and iteration counters, that maintain state across multiple calls by Export.

For information about the Export and Import utilities, see the *Oracle8i Utilities* manual.

In the power demand cartridge, the only metadata that is passed is a version string of *V1.0*, identifying the current format of the index-organized table that underlies the domain index. The power_pkg.getversion function generates a call to the power_pkg.checkversion procedure, to be executed at import time to check that the version string is *V1.0*.

```
MEMBER FUNCTION ODCIIndexGetMetadata(ia sys.odciindexinfo, expversion
VARCHAR2, newblock OUT PLS_INTEGER)
  RETURN VARCHAR2 is

BEGIN
-- Let getversion do all the work since it has to maintain state across calls.
```

```
  RETURN power_pkg.getversion (ia.IndexSchema, ia.IndexName, newblock);

EXCEPTION
  WHEN OTHERS THEN
      RAISE;

END ODCIIndexGetMetaData;
```

The `power_pkg` package is defined as follows:

```
CREATE OR REPLACE PACKAGE power_pkg AS
  FUNCTION getversion(idxschema IN VARCHAR2, idxname IN VARCHAR2,
      newblock OUT PLS_INTEGER) RETURN VARCHAR2;
  PROCEDURE checkversion (version IN VARCHAR2);
END power_pkg;
/
SHOW ERRORS;

CREATE OR REPLACE PACKAGE BODY power_pkg AS

-- iterate is a package-level variable used to maintain state across calls
-- by Export in this session.

iterate NUMBER := 0;

FUNCTION getversion(idxschema IN VARCHAR2, idxname IN VARCHAR2,
      newblock OUT PLS_INTEGER) RETURN VARCHAR2 IS

BEGIN

-- We are generating only one PL/SQL block consisting of one line of code.
  newblock := 1;

  IF iterate = 0
  THEN
-- Increment iterate so we'll know we're done next time we're called.
    iterate := iterate + 1;

-- Return a string that calls checkversion with a version 'V1.0'
-- Note that export adds the surrounding BEGIN/END pair to form the anon.
-- block... we don't have to.

    RETURN 'power_pkg.checkversion(''V1.0'');';
  ELSE
```

```
-- reset iterate for next index
    iterate := 0;
-- Return a 0-length string; we won't be called again for this index.
    RETURN '';
  END IF;
END getversion;

PROCEDURE checkversion (version IN VARCHAR2) IS

  wrong_version            EXCEPTION;

BEGIN
  IF version != 'V1.0' THEN
     RAISE wrong_version;
  END IF;
END checkversion;

END power_pkg;
```

Creating the Indextype

The power demand cartridge creates the indextype for the domain index. The specification includes the list of operators supported by the indextype. It also identifies the implementation type containing the OCDI index routines.

```
CREATE OR REPLACE INDEXTYPE power_idxtype
FOR
   Power_Equals(PowerDemand_Typ, NUMBER, NUMBER),
   Power_GreaterThan(PowerDemand_Typ, NUMBER, NUMBER),
   Power_LessThan(PowerDemand_Typ, NUMBER, NUMBER),
   Power_EqualsAny(PowerDemand_Typ, NUMBER),
   Power_GreaterThanAny(PowerDemand_Typ, NUMBER),
   Power_LessThanAny(PowerDemand_Typ, NUMBER)
USING power_idxtype_im;
```

Testing the Domain Index

This section explains the parts of the power demand example that perform some simple tests of the domain index. These tests consist of:

- Creating the power demand table (`PowerDemand_Tab`) and populating it with a small amount of data

- Executing some queries before the index is created (and showing the execution plans without an index being used)

  The execution plans show that a full table scan is performed in each case.
- Creating the index on the grid
- Executing the same queries after the index is created (and showing the execution plans with the index being used)

  The execution plans show that Oracle is using the index and not performing full table scans, thus resulting in more efficient execution.

The statements in this section are available online in the example file (tkqxpwr.sql).

Creating and Populating the Power Demand Table

The power demand table is created with two columns:

- `region`, to allow the electric utility to use the grid scheme in multiple areas or states. Each region (for example, New York, New Jersey, Pennsylvania, and so on) is represented by a 10x10 grid.
- `sample`, a collection of samplings (power demand readings from each cell in the grid), defined using the `PowerDemand_Typ` object type.

```
CREATE TABLE PowerDemand_Tab (
  -- Region for which these power demand readings apply
  region NUMBER,
  -- Values for each "sampling" time (for a given hour)
  sample PowerDemand_Typ
);
```

Several rows are inserted, representing power demand data for two regions (1 and 2) for several hourly timestamps. For simplicity, values are inserted only into the first 5 positions of each grid (the remaining 95 values are set to null).

```
-- The next INSERT statements "cheat" by supplying
-- only 5 grid values (instead of 100).

-- First 5 INSERT statements are for region 1 (1 AM to 5 AM on
-- 01-Feb-1998), to get enough timestamps for a moving
-- average using the Time Series cartridge. (Time Series
-- cartridge tests are in a separate file.)

INSERT INTO PowerDemand_Tab VALUES(1,
   PowerDemand_Typ(NULL, NULL, NULL, PowerGrid_Typ(55,8,13,9,5),
   to_date('02-01-1998 01','MM-DD-YYYY HH'))
);

INSERT INTO PowerDemand_Tab VALUES(1,
   PowerDemand_Typ(NULL, NULL, NULL, PowerGrid_Typ(56,8,13,9,3),
   to_date('02-01-1998 02','MM-DD-YYYY HH'))
);

INSERT INTO PowerDemand_Tab VALUES(1,
   PowerDemand_Typ(NULL, NULL, NULL, PowerGrid_Typ(55,8,13,9,3),
   to_date('02-01-1998 03','MM-DD-YYYY HH'))
);

INSERT INTO PowerDemand_Tab VALUES(1,
   PowerDemand_Typ(NULL, NULL, NULL, PowerGrid_Typ(54,8,13,9,3),
   to_date('02-01-1998 04','MM-DD-YYYY HH'))
);

INSERT INTO PowerDemand_Tab VALUES(1,
   PowerDemand_Typ(NULL, NULL, NULL, PowerGrid_Typ(54,8,12,9,3),
   to_date('02-01-1998 05','MM-DD-YYYY HH'))
);

-- Also insert some rows for region 2.

INSERT INTO PowerDemand_Tab VALUES(2,
   PowerDemand_Typ(NULL, NULL, NULL, PowerGrid_Typ(9,8,11,16,5),
   to_date('02-01-1998 01','MM-DD-YYYY HH'))
);

INSERT INTO PowerDemand_Tab VALUES(2,
   PowerDemand_Typ(NULL, NULL, NULL, PowerGrid_Typ(9,8,11,20,5),
   to_date('02-01-1998 02','MM-DD-YYYY HH'))
);
```

Finally, the values for `TotGridDemand`, `MaxCellDemand`, and `MinCellDemand` are computed and set for each of the newly inserted rows, and these values are displayed.

```
DECLARE
CURSOR c1 IS SELECT Sample, Region FROM PowerDemand_Tab FOR UPDATE;
s PowerDemand_Typ;
r NUMBER;
BEGIN
  OPEN c1;
  LOOP
     FETCH c1 INTO s,r;
     EXIT WHEN c1%NOTFOUND;
     s.SetTotalDemand;
     s.SetMaxDemand;
     s.SetMinDemand;
     dbms_output.put_line(s.TotGridDemand);
     dbms_output.put_line(s.MaxCellDemand);
     dbms_output.put_line(s.MinCellDemand);
     UPDATE PowerDemand_Tab SET Sample = s WHERE CURRENT OF c1;
  END LOOP;
  CLOSE c1;
END;
/

-- Examine the values.
SELECT region, P.Sample.TotGridDemand, P.Sample.MaxCellDemand,
   P.Sample.MinCellDemand,
   to_char(P.sample.sampletime, 'MM-DD-YYYY HH')
 FROM PowerDemand_Tab P;
```

Querying without the Index

The queries is this section are executed by applying the underlying function (`PowerEqualsSpecific_Func`) for every row in the table, because the index has not yet been defined.

The example file includes queries that check, both for a specific cell number and for any cell number, for values equal to, greater than, and less than a specified value. For example, the equality queries are as follows:

```
SET SERVEROUTPUT ON
-------------------------------------------------------------------
-- Query, referencing the operators (without index)
-------------------------------------------------------------------
explain plan for
SELECT P.Region, P.Sample.TotGridDemand ,P.Sample.MaxCellDemand,
     P.Sample.MinCellDemand
   FROM PowerDemand_Tab P
   WHERE Power_Equals(P.Sample,2,10) = 1;
@tkoqxpll

SELECT P.Region, P.Sample.TotGridDemand ,P.Sample.MaxCellDemand,
     P.Sample.MinCellDemand
   FROM PowerDemand_Tab P
   WHERE Power_Equals(P.Sample,2,10) = 1;

explain plan for
SELECT P.Region, P.Sample.TotGridDemand ,P.Sample.MaxCellDemand,
     P.Sample.MinCellDemand
   FROM PowerDemand_Tab P
   WHERE Power_Equals(P.Sample,2,8) = 1;
@tkoqxpll

SELECT P.Region, P.Sample.TotGridDemand ,P.Sample.MaxCellDemand,
     P.Sample.MinCellDemand
   FROM PowerDemand_Tab P
   WHERE Power_Equals(P.Sample,2,8) = 1;

explain plan for
SELECT P.Region, P.Sample.TotGridDemand ,P.Sample.MaxCellDemand,
     P.Sample.MinCellDemand
   FROM PowerDemand_Tab P
   WHERE Power_EqualsAny(P.Sample,9) = 1;
@tkoqxpll

SELECT P.Region, P.Sample.TotGridDemand ,P.Sample.MaxCellDemand,
     P.Sample.MinCellDemand
   FROM PowerDemand_Tab P
   WHERE Power_EqualsAny(P.Sample,9) = 1;
```

The execution plans show that a full table scan is performed in each case:

```
OPERATIONS      OPTIONS         OBJECT_NAME
--------------- --------------- ---------------
SELECT STATEMEN
TABLE ACCESS    FULL            POWERDEMAND_TAB
```

Creating the Index

The index is created on the `sample` column in the power demand table.

```
CREATE INDEX PowerIndex ON PowerDemand_Tab(Sample)
   INDEXTYPE IS power_idxtype;
```

Querying with the Index

The queries is this section are the same as those in "Querying without the Index" on page 11-42, but this time the index is used.

The execution plans show that Oracle is using the domain index and not performing full table scans, thus resulting in more efficient execution. For example:

```
SVRMGR> ---------------------------------------------------------------------
SVRMGR> -- Query, referencing the operators (with index)
SVRMGR> ---------------------------------------------------------------------
SVRMGR> explain plan for
     2> SELECT P.Region, P.Sample.TotGridDemand ,P.Sample.MaxCellDemand,
     3>      P.Sample.MinCellDemand
     4>    FROM PowerDemand_Tab P
     5>    WHERE Power_Equals(P.Sample,2,10) = 1;
Statement processed.
SVRMGR> @tkoqxpll
SVRMGR> set echo off
Echo                           OFF
Charwidth                      15
OPERATIONS      OPTIONS        OBJECT_NAME
--------------- -------------- ---------------
SELECT STATEMEN
TABLE ACCESS    BY ROWID       POWERDEMAND_TAB
DOMAIN INDEX                   POWERINDEX
3 rows selected.
Statement processed.
Echo                           ON
SVRMGR>
SVRMGR> SELECT P.Region, P.Sample.TotGridDemand ,P.Sample.MaxCellDemand,
     2>      P.Sample.MinCellDemand
     3>    FROM PowerDemand_Tab P
     4>    WHERE Power_Equals(P.Sample,2,10) = 1;
REGION     SAMPLE.TOT SAMPLE.MAX SAMPLE.MIN
---------- ---------- ---------- ----------
0 rows selected.
ODCIIndexStart>>>>>
ODCIIndexInfo
Index owner : POWERCARTUSER
Index name : POWERINDEX
Table owner : POWERCARTUSER
Table name : POWERDEMAND_TAB
Indexed column : "SAMPLE"
Indexed column type :POWERDEMAND_TYP
Indexed column type schema:POWERCARTUSER
ODCIPredInfo
Object owner : POWERCARTUSER
Object name : POWER_EQUALS
Method name :
```

```
Predicate bounds flag :
     Exact Match
     Include Start Key
     Include Stop Key
start key : 1
stop key : 1
compare position : 2
compare value : 10
ODCIIndexStart>>>>>select r from POWERCARTUSER.POWERINDEX_pidx where cpos ='2'
and cval ='10'
ODCIIndexFetch>>>>>
Nrows : 2000
ODCIIndexClose>>>>>
SVRMGR>
SVRMGR> explain plan for
     2> SELECT P.Region, P.Sample.TotGridDemand ,P.Sample.MaxCellDemand,
     3>      P.Sample.MinCellDemand
     4>    FROM PowerDemand_Tab P
     5>    WHERE Power_Equals(P.Sample,2,8) = 1;
Statement processed.
SVRMGR> @tkoqxpll
SVRMGR> set echo off
Echo                           OFF
Charwidth                      15
OPERATIONS      OPTIONS        OBJECT_NAME
--------------- -------------- ---------------
SELECT STATEMEN
TABLE ACCESS    BY ROWID       POWERDEMAND_TAB
DOMAIN INDEX                   POWERINDEX
3 rows selected.
Statement processed.
Echo                           ON
SVRMGR>
SVRMGR> SELECT P.Region, P.Sample.TotGridDemand ,P.Sample.MaxCellDemand,
     2>      P.Sample.MinCellDemand
     3>    FROM PowerDemand_Tab P
     4>    WHERE Power_Equals(P.Sample,2,8) = 1;
REGION     SAMPLE.TOT SAMPLE.MAX SAMPLE.MIN
---------- ---------- ---------- ----------
         1         90         55          5
         1         89         56          3
         1         88         55          3
         1         87         54          3
         1         86         54          3
         2         49         16          5
         2         53         20          5
7 rows selected.
ODCIIndexStart>>>>>
ODCIIndexInfo
Index owner : POWERCARTUSER
Index name : POWERINDEX
Table owner : POWERCARTUSER
Table name : POWERDEMAND_TAB
Indexed column : "SAMPLE"
Indexed column type :POWERDEMAND_TYP
Indexed column type schema:POWERCARTUSER
ODCIPredInfo
Object owner : POWERCARTUSER
Object name : POWER_EQUALS
Method name :
Predicate bounds flag :
     Exact Match
     Include Start Key
     Include Stop Key
start key : 1
stop key : 1
compare position : 2
compare value : 8
ODCIIndexStart>>>>>select r from POWERCARTUSER.POWERINDEX_pidx where cpos ='2'
and cval ='8'
ODCIIndexFetch>>>>>
Nrows : 2000
ODCIIndexClose>>>>>
SVRMGR>
SVRMGR> explain plan for
     2> SELECT P.Region, P.Sample.TotGridDemand ,P.Sample.MaxCellDemand,
     3>      P.Sample.MinCellDemand
     4>    FROM PowerDemand_Tab P
     5>    WHERE Power_EqualsAny(P.Sample,9) = 1;
Statement processed.
SVRMGR> @tkoqxpll
SVRMGR> set echo off
Echo                            OFF
Charwidth                       15
OPERATIONS      OPTIONS         OBJECT_NAME
--------------- --------------- ---------------
SELECT STATEMEN
TABLE ACCESS    BY ROWID        POWERDEMAND_TAB
DOMAIN INDEX                    POWERINDEX
3 rows selected.
```

```
Statement processed.
Echo                            ON
SVRMGR>
SVRMGR> SELECT P.Region, P.Sample.TotGridDemand ,P.Sample.MaxCellDemand,
     2>      P.Sample.MinCellDemand
     3>    FROM PowerDemand_Tab P
     4>    WHERE Power_EqualsAny(P.Sample,9) = 1;
REGION     SAMPLE.TOT SAMPLE.MAX SAMPLE.MIN
---------- ---------- ---------- ----------
         1         90         55          5
         1         89         56          3
         1         88         55          3
         1         87         54          3
         1         86         54          3
         2         49         16          5
         2         53         20          5
7 rows selected.
ODCIIndexStart>>>>>
ODCIIndexInfo
Index owner : POWERCARTUSER
Index name : POWERINDEX
Table owner : POWERCARTUSER
Table name : POWERDEMAND_TAB
Indexed column : "SAMPLE"
Indexed column type :POWERDEMAND_TYP
Indexed column type schema:POWERCARTUSER
ODCIPredInfo
Object owner : POWERCARTUSER
Object name : POWER_EQUALSANY
Method name :
Predicate bounds flag :
     Exact Match
     Include Start Key
     Include Stop Key
start key : 1
stop key : 1
compare value : 9
ODCIIndexStart>>>>>select distinct r from POWERCARTUSER.POWERINDEX_pidx where
cval ='9'
ODCIIndexFetch>>>>>
Nrows : 2000
ODCIIndexClose>>>>>
```

Using the Time Series Cartridge with the Power Demand Cartridge

This section describes how the Oracle8*i* Time Series Cartridge can be used with the Power Demand cartridge. With the Time Series cartridge, you can apply the many time series and time scaling functions, such as various averages (arithmetic, cumulative, moving) and scaleup, to the power demand data.

This section assumes that you are familiar with time series concepts and basic usage information for the Time Series cartridge. For detailed conceptual and usage information, see the *Oracle8i Time Series User's Guide*.

To use the Time Series cartridge with the power demand data, you must perform the following steps:

1. Identify the timestamp column and other columns of interest in the power demand table.
2. Define the calendars to be used.
3. Create a mapping table to map regions to an hourly calendar.
4. Create a reference-based view.
5. Formulate time series queries.

This section does not discuss creating the underlying table for time series data or loading the data, because these operations were done in "Creating and Populating the Power Demand Table" on page 11-40.

The following operations are not illustrated in this section, but should be included for use in a production environment:

- Creating a security view that uses `INSTEAD OF` triggers for actions that can modify time series data
- Validating the consistency of time series data

Note: The *PowerDemand_Tab* table is not defined as an index-organized table, but as a regular table. Although index-organized tables are recommended for use with the Time Series cartridge for performance reasons, such tables cannot include columns of the VARRAY datatype, which is used to define the power demand grid (`Sample.CellDemandValues`, defined using the `PowerGrid_Typ` object type, which is VARRAY(100) of NUMBER).

Identifying Columns to be Used

The Time Series cartridge requires that each data row include the following:

- A timestamp

  In this example, the timestamp is the `SampleTime` attribute of the `PowerDemand_Typ` object type, which is used to define the `Samples` column of the `PowerDemand_Tab` table.

- A qualifier

  In this example, the qualifier is the `region` column of the `PowerDemand_Tab` table. In a financial time series, the qualifier might be the stock ticker symbol (for example, *ACME* for Acme Corporation.)

- One or more columns with data to be operated on by Time Series cartridge functions.

  In this example, the `TotGridDemand`, `MaxCellDemand`, `MinCellDemand`, and `CellDemandValues` attributes of the `PowerDemand_Typ` object type can be used with Time Series functions. In a financial time series of daily stock market data, the columns to be operated on by Time Series functions might include the opening, closing, high, and low prices, and the total volume of shares traded.

Defining the Calendars

To define the calendars, you must create their definitions in a table of calendars. If the table of calendars does not already exist, create it first. (The calendar table might not exist because this is your first us of the Time Series cartridge; or a calendar table might exist for another application, but you choose to place power demand calendars in a separate table.)

The following statements create a table named `PowerDemand_calendars` and defines the first of three calendars, this one named `PowerReadingsCal_Hourly`. Explanatory notes follow the example.

```
-- Create the table for the calendars.
CREATE TABLE PowerDemand_calendars of ORDSYS.ORDTCalendar;

-- Create three calendars: first one for hourly readings, the
-- other two for daily and monthly scaleup operations.
INSERT INTO PowerDemand_calendars ❶
VALUES(
  ORDSYS.ORDTCalendar(
    0, ❷
    'PowerReadingsCal_Hourly', ❸
    3, ❹
    ORDSYS.ORDTPattern(ORDSYS.ORDTPatternBits(1), ❺
      to_date('01-01-1998 01','MM-DD-YYYY HH')),
    to_date('01-01-1998 01','MM-DD-YYYY HH'), ❻
    to_date('01-01-2008 01','MM-DD-YYYY HH'),
    ORDSYS.ORDTExceptions(), ❼
    ORDSYS.ORDTExceptions()
    )
  );
```

Notes on the preceding example:

❶ `PowerDemand_calendars` is a table of `ORDSYS.ORDTCalendar` objects.

❷ `0` (zero) for calendar type (`caltype`) indicates that this is an exception-based calendar.

❸ `PowerReadingsCal_Hourly` is the name of this calendar.

❹ `3` is the frequency code for `hour`.

❺ The pattern is defined as having all timestamps included (1). Because there are no `off` timestamps (that is, power readings are taken for all hours), any hourly timestamp can be used for the anchor date ('01-01-1998 01' is used in this example).

❻ The calendar begins at 1:00 AM on 01-Jan-1998 and ends at 1:00 AM on 01-Jan-2008

❼ There are no off-exceptions (that is, no hours when readings are not taken) and no on-exceptions (which are impossible in this case anyway, because there are no zeroes in the calendar pattern).

The following statements create two additional calendars, for use with scaleup operations in which hourly power demand readings are scaled up to compute daily and monthly values:

```
INSERT INTO PowerDemand_calendars
VALUES(
  ORDSYS.ORDTCalendar(
    0,
    'PowerReadingsCal_Daily',
    4,
    ORDSYS.ORDTPattern(ORDSYS.ORDTPatternBits(1),
      to_date('01-01-1998','MM-DD-YYYY')),
    to_date('01-01-1998','MM-DD-YYYY'),
    to_date('01-01-2008','MM-DD-YYYY'),
    ORDSYS.ORDTExceptions(),
    ORDSYS.ORDTExceptions()
    )
  );
INSERT INTO PowerDemand_calendars
VALUES(
  ORDSYS.ORDTCalendar(
    0,
    'PowerReadingsCal_Monthly',
    6,
    ORDSYS.ORDTPattern(ORDSYS.ORDTPatternBits(1),
      to_date('01-01-1998','MM-DD-YYYY')),
    to_date('01-01-1998','MM-DD-YYYY'),
    to_date('01-01-2008','MM-DD-YYYY'),
    ORDSYS.ORDTExceptions(),
    ORDSYS.ORDTExceptions()
    )
  );
```

Creating the Mapping Table

Create a table to map regions to calendars, and insert a row for each region. In this example, regions 1 and 2 are associated with the `PowerReadingsCal_Hourly` calendar. This mapping allows the reference-based view to be used.

```
-- Create the metadata table and insert rows for two regions.

CREATE TABLE PowerDemand_metadata (
    region number,
    calendarname varchar2(30),
    constraint  pk_PowerDemand_metadata primary key (region));

INSERT INTO PowerDemand_metadata VALUES(1, 'PowerReadingsCal_Hourly');
INSERT INTO PowerDemand_metadata VALUES(2, 'PowerReadingsCal_Hourly');
```

Creating the Reference-Based View

Create a reference-based view for convenient and efficient access to time series data.

The following statements create a reference-based view for the power demand data:

```
-- Create the reference view.
```

```
CREATE OR REPLACE VIEW PowerDemand_rv(region,TotGridDemand,
     MaxCellDemand,MinCellDemand,CellDemandValues) AS
  SELECT meta.region,
  ORDSYS.ORDTNumSeriesIOTRef(
          'TotGridDemand_ts', Ref(cal), 'PowerCartUser.PowerDemand_Tab T',
          'T.sample.SampleTime',
          'T.sample.TotGridDemand',
          'region', meta.region),
  ORDSYS.ORDTNumSeriesIOTRef(
          'MaxCellDemand_ts', Ref(cal), 'PowerCartUser.PowerDemand_Tab T',
          'T.sample.SampleTime',
          'T.sample.MaxCellDemand',
          'region', meta.region),
  ORDSYS.ORDTNumSeriesIOTRef(
          'MinCellDemand_ts', Ref(cal), 'PowerCartUser.PowerDemand_Tab T',
          'T.sample.SampleTime',
          'T.sample.MinCellDemand',
          'region', meta.region),
  ORDSYS.ORDTNumSeriesIOTRef(
          'CellDemandValues_ts', Ref(cal), 'PowerCartUser.PowerDemand_Tab T',
          'T.sample.SampleTime',
          'T.sample.CellDemandValues',
          'region', meta.region)
  FROM PowerDemand_metadata meta, PowerDemand_calendars cal
  WHERE meta.calendarname = cal.name;
```

Formulating Time Series Queries

Formulating time series queries involves invoking time series or time scaling functions, or both. The power demand example includes SQL and PL/SQL queries that return the following information:

- Hourly power demand for the grid (`TotGridDemand`) for region 1
- Average `TotGridDemand` for region 1
- Cumulative average `TotGridDemand` for region 1
- A time series that leads a specified time series by one day (that is, uses the hourly values for one day to create corresponding hourly values for the next day)
- Moving average of `TotGridDemand` for region 1
- Scaleup of `TotGridDemand` readings for region 1 from hourly to daily

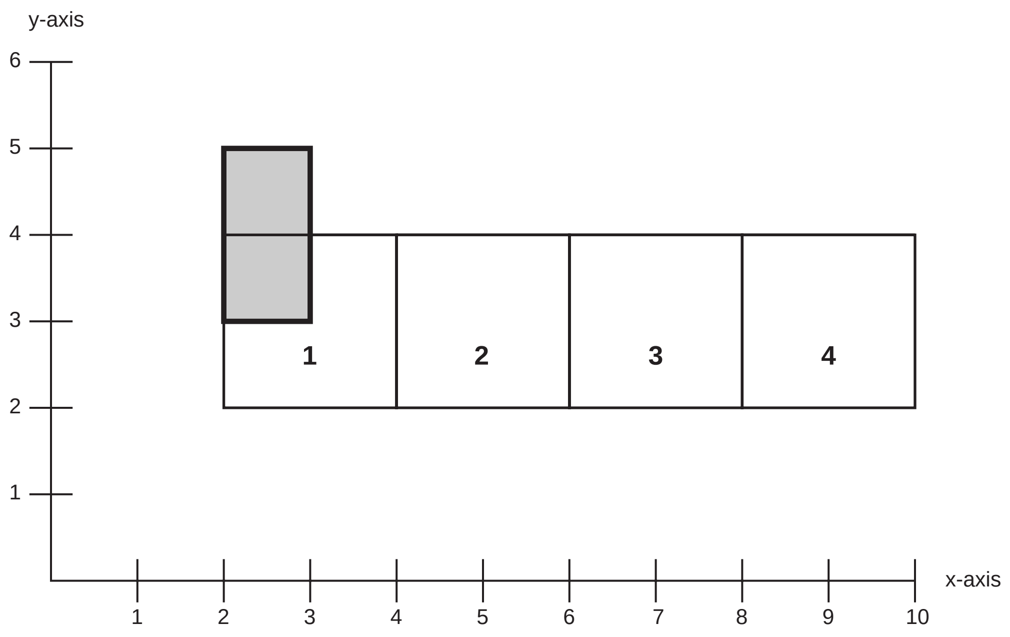
- A time series reflecting the addition of two time series (`MinCellDemand` and `MaxCellDemand`)

The following example shows the execution of the Lead and Moving average functions with power demand data. This example includes the SQL statements and the output with `ECHO` and `SERVEROUTPUT` turned on.

```
SVRMGR> -- Lead: Using timestamps from 1:00 through 5:00 AM on 01-Feb-1998,
SVRMGR> -- create a time series of the number of timestamps 24 hours later.
SVRMGR> -- The result is a time series from 1:00 through 5:00 AM on 02-Feb-1998
SVRMGR> -- containing the same TotGridDemand values as the corresponding
SVRMGR> -- timestamps on 01-Feb-1998.
SVRMGR> --
SVRMGR> SELECT * FROM the
     2>   (SELECT CAST(ORDSYS.TIMESERIES.ExtractTable(
     3>       ORDSYS.TIMESERIES.Lead(ts.TotGridDemand, 24,
     4>         to_date('01-FEB-98 01','DD-MON-YY HH'),
     5>         to_date('01-FEB-98 05','DD-MON-YY HH'))
     6>       ) AS ordsys.ordtNumTab)
     7> FROM PowerCartUser.powerdemand_rv ts
     8> WHERE region = 1);
TSTAMP    VALUE
--------- ----------
02-FEB-98         90
02-FEB-98         89
02-FEB-98         88
02-FEB-98         87
02-FEB-98         86
5 rows selected.
SVRMGR>
SVRMGR> --
SVRMGR> -- Compute a moving average over a window of 3 timestamps
SVRMGR> -- for region 1.
SVRMGR> --
SVRMGR>
SVRMGR> SELECT * FROM the
     2>   (SELECT CAST(ORDSYS.TIMESERIES.ExtractTable(
     3>               ORDSYS.TIMESERIES.Mavg(ts.TotGridDemand,3)
     4>              ) AS ordsys.ordtNumTab)
     5> FROM PowerCartUser.powerdemand_rv ts
     6> WHERE region = 1);
TSTAMP    VALUE
--------- ----------
01-FEB-98
01-FEB-98
```

```
01-FEB-98        89
01-FEB-98        88
01-FEB-98        87
5 rows selected.
```

Figure 11–9 Power Regions and Area of Interest (Spatial Cartridge)



Using the Spatial Cartridge with the Power Demand Cartridge

This section describes how the Oracle8*i* Spatial Cartridge can be used with the Power Demand cartridge. With the Spatial cartridge, you can perform geospatial queries against the power demand regions to select power demand data from areas of interest.

This example defines some regions with rectangular coordinates, and it also defines a rectangular area of interest that partially overlaps region 1 but does not touch regions 2 or 3. This area of interest might reflect the extent of some natural phenomenon, such as a mass of cold air or the path of a tornado (although an actual representation would require more than a simple rectangle). Figure 11–9 shows four regions, each represented as a square on a grid, and the area of interest represented as a gray rectangle. The figure uses a very simple (and arbitrary) coordinate system.

The queries select power demand data from regions that are overlapped in any way by the area of interest. In this example, the queries return data only from region 1. Note that this simple example considers the entire region; it does not provide coordinates for individual cells (neighborhoods), and it does not check which specific cells within region 1 are inside the area of interest.

This section assumes that you are familiar with the concepts and basic usage information for the Spatial cartridge. For detailed conceptual and usage information, see the *Oracle8i Spatial User's Guide and Reference*.

To use the Spatial cartridge with the power demand data, you must perform the following steps:

1. Create a Spatial layer consisting of four tables, with the geometry table related to the `PowerDemand_tab` table by region.
2. Create coordinates (x,y) for the power demand regions.
3. Populate the power demand regions index.
4. Create coordinates (x,y) for the area of interest to be used in queries against the power demand regions.
5. Populate the windows index.
6. Perform spatial queries.

Creating the Spatial Layer (PowerDemandRegions)

To use the Spatial cartridge with power demand data, create a Spatial layer (called `PowerDemandRegions` in this example) consisting of four tables, with the geometry table (`PowerDemandRegions_SDOGEOM`) related to the `PowerDemand_tab` table by the `region` attribute.

The following statements define this layer.

```
-- Simple scenario for integrating Spatial Cartridge.
-- Regions have spatial extent (e.g., states of the U.S.).
-- A person wanting to select data may either want data for
-- predefined regions or data for those units (such as
-- states) that intersect a dynamically created
-- area-of-interest (such as one you would draw when choosing
-- a zoom area from a Web-based mapping service).
-- Create a Spatial layer called PowerDemandRegions. This
-- consists of four tables, and the geometry table is related to
-- the PowerDemand_Tab table by Region.
set serveroutput on
set echo on

CREATE TABLE PowerDemandRegions_SDODIM (
  sdo_dimnum number,
  sdo_dimname varchar2(32),
  sdo_lb number,
  sdo_ub number,
  sdo_tolerance number );

CREATE TABLE PowerDemandRegions_SDOLAYER (
  sdo_ordcnt number,
  sdo_level number,
  sdo_numtiles number );

-- In the following definition of PowerDemandRegions_SDOGEOM,
-- sdo_gid equates to Region in PowerDemand_Tab.
CREATE TABLE PowerDemandRegions_SDOGEOM (
  sdo_gid number,
  sdo_eseq number,
  sdo_etype number,
  sdo_seq number,
  sdo_x1 number,
  sdo_y1 number,
  sdo_x2 number,
  sdo_y2 number,
  sdo_x3 number,
  sdo_y3 number,
  sdo_x4 number,
  sdo_y4 number,
  sdo_x5 number,
  sdo_y5 number ) ;
CREATE TABLE PowerDemandRegions_SDOINDEX (
  sdo_gid number,
  sdo_code raw(255),
  sdo_meta raw(255));

-- Create some coordinates for the example and show how an
-- index is created etc. We will also assume that some windows of
-- interest have been pre-defined and stored in a Window_layer.

CREATE TABLE Windows_SDODIM (
  sdo_dimnum number,
  sdo_dimname varchar2(32),
  sdo_lb number,
  sdo_ub number,
  sdo_tolerance number );

CREATE TABLE Windows_SDOLAYER (
  sdo_ordcnt number,
  sdo_level number,
  sdo_numtiles number );

CREATE TABLE Windows_SDOGEOM (
  sdo_gid number,
  sdo_eseq number,
  sdo_etype number,
  sdo_seq number,
  sdo_x1 number,
  sdo_y1 number,
  sdo_x2 number,
  sdo_y2 number,
  sdo_x3 number,
  sdo_y3 number,
  sdo_x4 number,
  sdo_y4 number,
  sdo_x5 number,
  sdo_y5 number );

CREATE TABLE Windows_SDOINDEX (
  sdo_gid number,
  sdo_code raw(255),
  sdo_meta raw(255));
```

Creating Coordinates for the Power Demand Regions

To enable the Spatial cartridge to recognize and work with the power demand regions, populate the Spatial layer tables with the necessary data. The following statements provide data, including x,y coordinates for region boundary corners, for three regions.

```
-- Populate the tables for power regions.
INSERT INTO PowerDemandRegions_SDODIM VALUES(
 1,
 'x-axis',
 0,
 100,
 0.0005);
INSERT INTO PowerDemandRegions_SDODIM VALUES(
 2,
 'y-axis',
 0,
 100,
 0.0005);
INSERT INTO PowerDemandRegions_SDOLAYER VALUES(
 10,
 5,
 NULL);
INSERT INTO PowerDemandRegions_SDOGEOM VALUES(
 1,
 0,
 3,
 1,
 2,2,
 4,2,
 4,4,
 2,4,
 2,2);
INSERT INTO PowerDemandRegions_SDOGEOM VALUES(
 2,
 0,
 3,
 1,
 4,2,
 6,2,
 6,4,
 4,4,
 4,2);
INSERT INTO PowerDemandRegions_SDOGEOM VALUES(
 3,
 0,
 3,
 1,
 6,2,
 8,2,
 8,4,
 6,4,
 6,2);
```

Populating the Power Demand Regions Index

The following statement populates the index for the Spatial layer `PowerDemandRegions`.

```
-- Populate the index for Spatial layer PowerDemandRegions
EXECUTE sdo_admin.populate_index('POWERDEMANDREGIONS');
```

Creating Coordinates for the Area of Interest

To enable the Spatial cartridge to recognize and work with the area of interest, populate the Windows layer tables with the necessary data. The following statements provide data, including x,y coordinates for the boundary corners, for the area of interest.

```
-- Populate the tables for region of interest.
INSERT INTO Windows_SDODIM VALUES(
 1,
 'x-axis',
 0,
 100,
 0.0005);
INSERT INTO Windows_SDODIM VALUES(
 2,
 'y-axis',
 0,
 100,
 0.0005);
INSERT INTO Windows_SDOLAYER VALUES(
 10,
 5,
 NULL);

-- The next INSERT creates a small rectangle that
-- partially overlaps region 1 but does not touch
-- regions 2 or 3.

INSERT INTO Windows_SDOGEOM VALUES(
 1,
 0,
 3,
 1,
 2,3,
 3,3,
 3,5,
2,5,
2,3);
```

Populating the Windows Index

The following statement populates the index for the `Windows` layer.

```
-- Populate the index for the WINDOWS layer (Windows)
EXECUTE sdo_admin.populate_index('WINDOWS');
```

Performing Spatial Queries

The following queries use the `SDOGEOM.Relate` function to retrieve data from regions that are within or overlapping the area of interest. Because only region 1 overlaps the area of interest, only rows from region 1 are considered. Each row returned reflects power demand data for a particular hourly timestamp (for example, aggregate data for region 1 at 5 AM on 01-Feb-1998).

The first query returns only rows for which the third cell has a power demand reading of 12. Given the actual sample data (see the `INSERT` statements in "Creating and Populating the Power Demand Table" on page 11-40), only one row meets this criterion.

Each of the following statements performs this query, but the second one uses the spatial index for primary filtering (for performance reasons).

```
-- Now some queries.
-- Query 1:
-- Find Regions Within_Or_Overlapping the Area-of-Interest 1
-- whose 3rd Cell has a power demand value of 12.

Select P.Region, P.Sample.TotGridDemand, P.Sample.MaxCellDemand,
P.Sample.MinCellDemand
FROM PowerDemand_Tab P
WHERE Power_Equals(P.Sample, 3, 12) = 1
AND P.Region IN (
Select S.sdo_gid
from powerdemandregions_sdogeom S, windows_sdogeom
where
sdo_geom.Relate('PowerDemandRegions', S.sdo_gid, 'ANYINTERACT', 'WINDOWS', 1) =
'TRUE' );

-- Use the spatial index for primary filtering (for performance reasons)

Select P.Region, P.Sample.TotGridDemand, P.Sample.MaxCellDemand,
P.Sample.MinCellDemand
FROM PowerDemand_Tab P
WHERE Power_Equals(P.Sample, 3, 12) = 1
AND P.Region IN (
Select sdo_gid gid1
from (select distinct s.sdo_gid from powerdemandregions_sdoindex S,
      windows_sdoindex w
      where s.sdo_code = w.sdo_code and w.sdo_gid = 1)
where
sdo_geom.Relate('PowerDemandRegions', sdo_gid, 'ANYINTERACT', 'WINDOWS', 1) =
'TRUE' );
```

Both queries return the following result:

```
REGION     SAMPLE.TOT SAMPLE.MAX SAMPLE.MIN
---------- ---------- ---------- ----------
         1         86         54          3
1 row selected.
```

The second query returns only rows for which `any` cell has a power demand reading of 9. Given the actual sample data (see the `INSERT` statements in "Creating and Populating the Power Demand Table" on page 11-40), five rows meets this criterion.

```
-- Query 2: Same thing for PowerEqualsAny() - in this case where
-- any cell has a power demand value of 9.

Select P.Region, P.Sample.TotGridDemand, P.Sample.MaxCellDemand,
P.Sample.MinCellDemand
FROM PowerDemand_Tab P
WHERE Power_EqualsAny(P.Sample, 9) = 1
AND P.Region IN (
Select S.sdo_gid
from powerdemandregions_sdogeom S, windows_sdogeom
where
sdo_geom.Relate('PowerDemandRegions', S.sdo_gid, 'ANYINTERACT', 'WINDOWS', 1) =
'TRUE' );
```

This query returns the following result:

```
REGION     SAMPLE.TOT SAMPLE.MAX SAMPLE.MIN
---------- ---------- ---------- ----------
         1         90         55          5
         1         89         56          3
         1         88         55          3
         1         87         54          3
         1         86         54           3
5 rows selected.
```

12 SBTREE: An Example of Extensible Indexing

This chapter presents an extensible indexing example in which some of the ODCIIndex interface routines are implemented in C:

Introduction

This example is meant as an illustration of how to implement the interface routines in C, but does not go into the complex domain details of actually implementing an indextype for a specific domain. The code for the example described here is in the demo directory (See file extdemo2.sql).

Design of the indextype

The indextype implemented here, called `sbtree` operates similar to `btree` indexes. It supports the evaluation of three user-defined operators

- `gt(Greater Than)`
- `lt(Less Than)`
- `eq(EQuals).`

These operators can operate on the operands of VARCHAR2 datatype.

The index data consists of records of the form <key, rid> where key is the value of the indexed column and rid is the row identifier of the corresponding row. To simplify the implementation of the indextype, the index data will be stored in a regular table. Thus, the index manipulation routines merely translate operations on the `SBtree` into operations on the table storing the index data. When a user creates a `SBtree` index, a table is created consisting of the indexed column and a `rowid` column. Inserts into the base table will cause appropriate insertions into the index table. Deletes and updates are handled similarly. When the `SBtree` is queried based on a user-defined operator (one of `gt`, `lt` and `eq`), an appropriate query will be issued against the index table to retrieve all the satisfying rows.

Implementing Operators

The `SBtree` indextype supports three operators. Each operator has a corresponding functional implementation. The functional implementations of the `eq`, `gt` and `lt` operators are presented next.

Create Functional Implementations

Functional Implementation of EQ (EQUALS)

The functional implementation for `eq` is provided by a function (`bt_eq`) that takes in two VARCHAR2 parameters and returns 1 if they are equal and 0 otherwise.

```
CREATE FUNCTION bt_eq(a VARCHAR2, b VARCHAR2) RETURN NUMBER AS
BEGIN
  IF a = b then
    RETURN 1;
  ELSE
    RETURN 0;
  END IF;
END;
```

Functional Implementation of LT (LESS THAN)

The functional implementation for `lt` is provided by a function (`lt_eq`) that takes in two `VARCHAR2` parameters and returns 1 if the first parameter is less than the second, 0 otherwise.

```
CREATE FUNCTION bt_lt(a VARCHAR2, b VARCHAR2) RETURN NUMBER AS
BEGIN
  IF a < b then
    RETURN 1;
  ELSE
   RETURN 0;
  END IF;
END;
```

Functional Implementation of GT (GREATER THAN)

The functional implementation for `gt` is provided by a function (`gt_eq`) that takes in two `VARCHAR2` parameters and returns 1 if the first parameter is greater than the second, 0 otherwise.

```
CREATE FUNCTION bt_gt(a VARCHAR2, b VARCHAR2) RETURN NUMBER AS
BEGIN
  IF a > b then
    RETURN 1;
  ELSE
    RETURN 0;
  END IF;
END;
```

Create Operators

To create the operator, you need to specify the signature of the operator along with its return type and also its functional implementation.

Operator EQ

```
CREATE OPERATOR eq
BINDING (VARCHAR2, VARCHAR2) RETURN NUMBER
USING bt_eq;
```

Operator LT

```
CREATE OPERATOR lt
BINDING (VARCHAR2, VARCHAR2) RETURN NUMBER
USING bt_lt;
```

Operator GT

```
CREATE OPERATOR gt
BINDING (VARCHAR2, VARCHAR2) RETURN NUMBER
USING bt_gt;
```

Implementing the Index routines

1. Define an implementation type that implements the ODCIIndex interface routines.

```
CREATE TYPE sbtree_im  AS OBJECT
(
  scanctx RAW(4),
  STATIC FUNCTION ODCIGetInterfaces(ifclist OUT sys.ODCIObjectList)
  RETURN NUMBER,
  STATIC FUNCTION ODCIIndexCreate (ia sys.odciindexinfo, parms VARCHAR2)
  RETURN NUMBER,
  STATIC FUNCTION ODCIIndexDrop(ia sys.odciindexinfo) RETURN NUMBER,
  STATIC FUNCTION ODCIIndexInsert(ia sys.odciindexinfo, rid VARCHAR2,
                                                    newval VARCHAR2)
                                  RETURN NUMBER,
  STATIC FUNCTION ODCIIndexDelete(ia sys.odciindexinfo, rid VARCHAR2,
                                                    oldval VARCHAR2)
                                  RETURN NUMBER,
  STATIC FUNCTION ODCIIndexUpdate(ia sys.odciindexinfo, rid VARCHAR2,
                                  oldval VARCHAR2, newval VARCHAR2)
                                  RETURN NUMBER,
  STATIC FUNCTION ODCIIndexStart(sctx IN OUT sbtree_im, ia sys.odciindexinfo,
                         op sys.odciPredInfo, qi sys.ODCIQueryInfo,
                         strt number, stop number,
                         cmpval VARCHAR2) RETURN NUMBER,
  MEMBER FUNCTION ODCIIndexFetch(nrows number, rids OUT sys.odciridlist)
      RETURN NUMBER,
  MEMBER FUNCTION ODCIIndexClose RETURN NUMBER
);
```

2. Define the implementation type body

You have a choice of implementing the index routines in any of the languages supported by Oracle. For this example, we will implement the get interfaces routine and the index definition routines in PL/SQL. The index manipulation and query routines are implemented in C.

```
CREATE OR REPLACE TYPE BODY sbtree_im
IS
```

The get interfaces routine returns the expected interface name through its `OUT` parameter.

```
   STATIC FUNCTION ODCIGetInterfaces(ifclist OUT sys.ODCIObjectList)
       RETURN NUMBER IS
   BEGIN
       ifclist := sys.ODCIObjectList(sys.ODCIObject('SYS','ODCIINDEX1'));
       RETURN ODCIConst.Success;
   END ODCIGetInterfaces;
```

The `ODCIIndexCreate` routine creates an "index storage" table with two columns. The first column stores the `VARCHAR2` indexed column value. The second column in the index table stores the `rowid` of the corresponding row in the base table. `DBMS_SQL` is used to execute the dynamically constructed SQL statement.

```
  STATIC FUNCTION ODCIIndexCreate (ia sys.odciindexinfo, parms VARCHAR2)
  RETURN NUMBER
  is
   i INTEGER;
   stmt VARCHAR2(1000);
   cnum INTEGER;
   junk INTEGER;
  BEGIN
   -- construct the sql statement
```

```
    stmt := 'create table ' || ia.IndexSchema || '.' ||
      ia.IndexName || '_sbtree'  ||
      '( f1 , f2 ) as select ' ||
      ia.IndexCols(1).ColName || ', ROWID from ' ||
      ia.IndexCols(1).TableSchema || '.' || ia.IndexCols(1).TableName;

  DBMS_OUTPUT.PUT_LINE('CREATE');
  DBMS_OUTPUT.PUT_LINE(stmt);

  -- execute the statement
  cnum := dbms_sql.open_cursor;
  DBMS_SQL.PARSE(cnum, stmt, dbms_sql.native);
  junk := dbms_sql.execute(cnum);
  DBMS_SQL.CLOSE_CURSOR(cnum);

  RETURN ODCIConst.Success;
 END;
```

The ODCIIndexDrop routine drops the index storage table.

```
 STATIC FUNCTION ODCIIndexDrop(ia sys.odciindexinfo) RETURN NUMBER is
  stmt VARCHAR2(1000);
  cnum INTEGER;
  junk INTEGER;
 BEGIN
   -- construct the sql statement
  stmt := 'drop table ' || ia.IndexSchema || '.' || ia.IndexName || '_sbtree';

  DBMS_OUTPUT.PUT_LINE('DROP');
  DBMS_OUTPUT.PUT_LINE(stmt);

  -- execute the statement
  cnum := dbms_sql.open_cursor;
  dbms_sql.parse(cnum, stmt, dbms_sql.native);
  junk := dbms_sql.execute(cnum);
  DBMS_SQL.CLOSE_CURSOR(cnum);

  RETURN ODCIConst.Success;
 END;
```

The index manipulation and query routines are implemented in C. This requires some setup to be done before this statement. Specifically, you need to create a library object called `extdemo2l` for your compiled C code.

After the setup, the `foll`. statements register the implementation of the index manipulation and query routines in terms of their corresponding C functions.

Register the implementation of the ODCIIndexInsert routine.

```
  STATIC FUNCTION ODCIIndexInsert(ia sys.odciindexinfo, rid VARCHAR2,
                                  newval VARCHAR2)
                                  RETURN NUMBER AS external
    name "qxiqtbi"
    library extdemo2l
    WITH context
    parameters (
    context,
    ia,
    ia indicator struct,
    rid,
    rid indicator,
    newval,
    newval indicator,
    RETURN ocinumber
               );
```

Register the implementation of the `ODCIIndexDelete` routine.

```
STATIC FUNCTION ODCIIndexDelete(ia sys.odciindexinfo, rid VARCHAR2,
                                oldval VARCHAR2)
                                RETURN NUMBER AS external
    name "qxiqtbd"
    library extdemo2l
    WITH context
    parameters (
    context,
    ia,
    ia indicator struct,
    rid,
    rid indicator,
    oldval,
    oldval indicator,
    RETURN ocinumber
               );
```

Register the implementation of the `ODCIIndexUpdate` routine.

```
STATIC FUNCTION ODCIIndexUpdate(ia sys.odciindexinfo, rid VARCHAR2,
                                  oldval VARCHAR2, newval VARCHAR2)
                                  RETURN NUMBER AS external
```

```
name "qxiqtbu"
library extdemo2l
WITH context
parameters (
context,
ia,
ia indicator struct,
rid,
rid indicator,
oldval,
oldval indicator,
newval,
newval indicator,
RETURN ocinumber
           );
```

Register the implementation of the ODCIIndexStart routine.

```
STATIC FUNCTION ODCIIndexStart(sctx in out sbtree_im, ia sys.odciindexinfo,
                       op sys.odciPredInfo,
                       qi sys.ODCIQueryInfo,
                       strt number,
                       stop number,
                       cmpval VARCHAR2)
   RETURN NUMBER as external
   name "qxiqtbs"
   library extdemo2l
   with context
   parameters (
     context,
     sctx,
     sctx INDICATOR STRUCT,
     ia,
     ia INDICATOR STRUCT,
     op,
     op INDICATOR STRUCT,
     qi,
     qi INDICATOR STRUCT,
     strt,
     strt INDICATOR,
     stop,
     stop INDICATOR,
     cmpval,
     cmpval INDICATOR,
     RETURN OCINumber
```

```
    );
```

Register the implementation of the `ODCIIndexFetch` routine.

```
  member function ODCIIndexFetch(nrows number, rids OUT sys.odciridlist)
   RETURN NUMBER as external
   name "qxiqtbf"
   library extdemo2l
   with context
   parameters (
     context,
     self,
     self INDICATOR STRUCT,
     nrows,
     nrows INDICATOR,
     rids,
     rids INDICATOR,
     RETURN OCINumber
   );
```

Register the implementation of the ODCIIndexClose routine.

```
  member function ODCIIndexClose RETURN NUMBER as external
   name "qxiqtbc"
   library extdemo2l
   with context
   parameters (
     context,
     self,
     self INDICATOR STRUCT,
     RETURN OCINumber
   );
```

The C Code

General Notes

The C structs for mapping the ODCI types are all defined in the file "`odci.h`". For example, the C struct ODCIIndexInfo is the mapping for the corresponding ODCI object type. Further, the C struct `ODCIIndexInfo_ind` is the mapping for null object.

Common Error Processing Routine

This function is used to check and process the return code from `all OCI` routines. It checks the status code and raises an exception in case of errors.

```
static int qxiqtce(ctx, errhp, status)
OCIExtProcContext *ctx;
OCIError *errhp;
sword status;
{
  text errbuf[512];
  sb4 errcode = 0;
  int errnum = 29400;  /* choose some oracle error number */
  int rc = 0;

  switch (status)
  {
  case OCI_SUCCESS:
    rc = 0;
    break;
  case OCI_ERROR:
    (void) OCIErrorGet((dvoid *)errhp, (ub4)1, (text *)NULL, &errcode,
                       errbuf, (ub4)sizeof(errbuf), OCI_HTYPE_ERROR);
    /* Raise exception */
    OCIExtProcRaiseExcpWithMsg(ctx, errnum, errbuf, strlen((char *)errbuf));
    rc = 1;
    break;
  default:
    (void) sprintf((char *)errbuf, "Warning - some error\n");
    /* Raise exception */
    OCIExtProcRaiseExcpWithMsg(ctx, errnum, errbuf, strlen((char *)errbuf));
    rc = 1;
    break;
  }
  return (rc);
}
```

Implementation Of The ODCIIndexInsert Routine

The insert routine parses and executes a statement that inserts a new row into the index table. The new row consists of the new value of the indexed column and the `rowid` that have been passed in as parameters.

```
OCINumber *qxiqtbi(ctx, ix, ix_ind, rid, rid_ind,
                   newval, newval_ind)
OCIExtProcContext *ctx;
```

```
ODCIIndexInfo     *ix;
ODCIIndexInfo_ind *ix_ind;
char              *rid;
short             rid_ind;
char              *newval;
short             newval_ind;
{
  OCIEnv *envhp = (OCIEnv *) 0;                  /* env. handle */
  OCISvcCtx *svchp = (OCISvcCtx *) 0;            /* service handle */
  OCIError *errhp = (OCIError *) 0;              /* error handle */
  OCIStmt *stmthp = (OCIStmt *) 0;               /* statement handle */
  OCIBind *bndp = (OCIBind *) 0;                 /* bind handle */
  OCIBind *bndp1 = (OCIBind *) 0;                /* bind handle */

  int retval = (int)ODCI_SUCCESS;                /* return from this function */
  OCINumber *rval = (OCINumber *)0;
  ub4 key;                                       /* key value set in "self" */

  char insstmt[2000];                            /* sql insert statement */

  /* allocate memory for OCINumber first */
  rval = (OCINumber *)OCIExtProcAllocCallMemory(ctx, sizeof(OCINumber));

  /* Get oci handles */
  if (qxiqtce(ctx, errhp, OCIExtProcGetEnv(ctx, &envhp, &svchp, &errhp)))
    return(rval);

  /* set up return code */
  if (qxiqtce(ctx, errhp, OCINumberFromInt(errhp, (dvoid *)&retval,
                                         sizeof(retval),
                                         OCI_NUMBER_SIGNED, rval)))
    return(rval);

  /*******************************
   * Construct insert Statement *
   ******************************/

   sprintf(insstmt,
                "INSERT into %s.%s_sbtree values (:newval, :mrid)",
                OCIStringPtr(envhp, ix->IndexSchema),
                OCIStringPtr(envhp, ix->IndexName));
```

```
/****************************************
 * Parse and Execute Create Statement   *
 ****************************************/

/* allocate stmt handle */
if (qxiqtce(ctx, errhp, OCIHandleAlloc((dvoid *)envhp,
                                       (dvoid **)&stmthp,
                                       (ub4)OCI_HTYPE_STMT, (size_t)0,
                                       (dvoid **)0)))
  return(rval);

/* prepare the statement */
if (qxiqtce(ctx, errhp, OCIStmtPrepare(stmthp, errhp, (text *)insstmt,
                                       (ub4)strlen(insstmt), OCI_NTV_SYNTAX,
                                       OCI_DEFAULT)))
  return(rval);



/* Set up bind for newval */
if (qxiqtce(ctx, errhp, OCIBindByPos(stmthp, &bndp, errhp, (ub4)1,
                                     (dvoid *)newval,
                                     (sb4)(strlen(newval)+1),
                                     (ub2)SQLT_STR, (dvoid *)0, (ub2 *)0,
                                     (ub2 *)0, (ub4)0, (ub4 *)0,
                                     (ub4)OCI_DEFAULT)))
  return(rval);

/* Set up bind for rid */
if (qxiqtce(ctx, errhp, OCIBindByPos(stmthp, &bndp, errhp, (ub4)2,
                                     (dvoid *)rid,
                                     (sb4)(strlen(rid)+1),
                                     (ub2)SQLT_STR, (dvoid *)0, (ub2 *)0,
                                     (ub2 *)0, (ub4)0, (ub4 *)0,
                                     (ub4)OCI_DEFAULT)))
  return(rval);


/* Execute statement */
if (qxiqtce(ctx, errhp, OCIStmtExecute(svchp, stmthp, errhp, (ub4)1,
                                       (ub4)0, (OCISnapshot *)NULL,
                                       (OCISnapshot *)NULL,
                                       (ub4)OCI_DEFAULT)))
  return(rval);
  return(rval);
}
```

Implementation of the ODCIIndexDelete Routine

The delete routine constructs a SQL statement to delete a row from the index table corresponding to the row being deleted from the base table. The row in the index table is identified by the value of `rowid` that is passed in as a parameter to this routine.

```
OCINumber *qxiqtbd(ctx, ix, ix_ind, rid, rid_ind,
                   oldval, oldval_ind)
OCIExtProcContext *ctx;
ODCIIndexInfo     *ix;
ODCIIndexInfo_ind *ix_ind;
char              *rid;
short             rid_ind;
char              *oldval;
short             oldval_ind;
{
  OCIEnv *envhp = (OCIEnv *) 0;               /* env. handle */
  OCISvcCtx *svchp = (OCISvcCtx *) 0;         /* service handle */
  OCIError *errhp = (OCIError *) 0;           /* error handle */
  OCIStmt *stmthp = (OCIStmt *) 0;            /* statement handle */
  OCIBind *bndp = (OCIBind *) 0;              /* bind handle */
  OCIBind *bndp1 = (OCIBind *) 0;             /* bind handle */

  int retval = (int)ODCI_SUCCESS;             /* return from this function */
  OCINumber *rval = (OCINumber *)0;
  ub4 key;                                    /* key value set in "self" */

  char delstmt[2000];                         /* sql insert statement */

  /* Get oci handles */
  if (qxiqtce(ctx, errhp, OCIExtProcGetEnv(ctx, &envhp, &svchp, &errhp)))
    return(rval);

  /* set up return code */
  rval = (OCINumber *)OCIExtProcAllocCallMemory(ctx, sizeof(OCINumber));
  if (qxiqtce(ctx, errhp, OCINumberFromInt(errhp, (dvoid *)&retval,
                                          sizeof(retval),
                                          OCI_NUMBER_SIGNED, rval)))
    return(rval);
```

```
/*****************************
 * Construct delete Statement *
 ******************************/

 sprintf(delstmt,
               "DELETE FROM %s.%s_sbtree WHERE f2 = :rr",
               OCIStringPtr(envhp, ix->IndexSchema),
               OCIStringPtr(envhp, ix->IndexName));

/***************************************
 * Parse and Execute delete Statement   *
 ****************************************/

/* allocate stmt handle */
if (qxiqtce(ctx, errhp, OCIHandleAlloc((dvoid *)envhp,
                                       (dvoid **)&stmthp,
                                       (ub4)OCI_HTYPE_STMT, (size_t)0,
                                       (dvoid **)0)))
  return(rval);

/* prepare the statement */
if (qxiqtce(ctx, errhp, OCIStmtPrepare(stmthp, errhp, (text *)delstmt,
                                       (ub4)strlen(delstmt), OCI_NTV_SYNTAX,
                                       OCI_DEFAULT)))
  return(rval);


/* Set up bind for rid */
if (qxiqtce(ctx, errhp, OCIBindByPos(stmthp, &bndp, errhp, (ub4)1,
                                     (dvoid *)rid,
                                     (sb4)(strlen(rid)+1),
                                     (ub2)SQLT_STR, (dvoid *)0, (ub2 *)0,
                                     (ub2 *)0, (ub4)0, (ub4 *)0,
                                     (ub4)OCI_DEFAULT)))
  return(rval);


/* Execute statement */
if (qxiqtce(ctx, errhp, OCIStmtExecute(svchp, stmthp, errhp, (ub4)1,
                                       (ub4)0, (OCISnapshot *)NULL,
                                       (OCISnapshot *)NULL,
                                       (ub4)OCI_DEFAULT)))
  return(rval);

return(rval);
```

```
}
```

Implementation of the ODCIIndexUpdate Routine

The update routine constructs a SQL statement to update a row in the index table corresponding to the row being updated in the base table. The row in the index table is identified by the value of `rowid` that is passed in as a parameter to this routine. The old column value (oldval) is replaced by the new value (newval).

```
OCINumber *qxiqtbu(ctx, ix, ix_ind, rid, rid_ind,
                   oldval, oldval_ind, newval, newval_ind)
OCIExtProcContext *ctx;
ODCIIndexInfo     *ix;
ODCIIndexInfo_ind *ix_ind;
char              *rid;
short             rid_ind;
char              *oldval;
short             oldval_ind;
char              *newval;
short             newval_ind;
{
  OCIEnv *envhp = (OCIEnv *) 0;               /* env. handle */
  OCISvcCtx *svchp = (OCISvcCtx *) 0;         /* service handle */
  OCIError *errhp = (OCIError *) 0;           /* error handle */
  OCIStmt *stmthp = (OCIStmt *) 0;            /* statement handle */
  OCIBind *bndp = (OCIBind *) 0;              /* bind handle */
  OCIBind *bndp1 = (OCIBind *) 0;             /* bind handle */

  int retval = (int)ODCI_SUCCESS;             /* return from this function */
  OCINumber *rval = (OCINumber *)0;
  ub4 key;                                    /* key value set in "self" */

  char updstmt[2000];                         /* sql insert statement */

  /* Get oci handles */
  if (qxiqtce(ctx, errhp, OCIExtProcGetEnv(ctx, &envhp, &svchp, &errhp)))
    return(rval);

  /* set up return code */
  rval = (OCINumber *)OCIExtProcAllocCallMemory(ctx, sizeof(OCINumber));
  if (qxiqtce(ctx, errhp, OCINumberFromInt(errhp, (dvoid *)&retval,
                                          sizeof(retval),
                                          OCI_NUMBER_SIGNED, rval)))
    return(rval);
```

```
/******************************
 * Construct update Statement *
 ******************************/

 sprintf(updstmt,
    "UPDATE %s.%s_sbtree SET f1 = :newval, f2 = :rr WHERE f1 = :oldval",
    OCIStringPtr(envhp, ix->IndexSchema),
    OCIStringPtr(envhp, ix->IndexName));

/****************************************
 * Parse and Execute Create Statement   *
 ****************************************/

/* allocate stmt handle */
if (qxiqtce(ctx, errhp, OCIHandleAlloc((dvoid *)envhp,
                                       (dvoid **)&stmthp,
                                       (ub4)OCI_HTYPE_STMT, (size_t)0,
                                       (dvoid **)0)))
  return(rval);

/* prepare the statement */
if (qxiqtce(ctx, errhp, OCIStmtPrepare(stmthp, errhp, (text *)updstmt,
                                       (ub4)strlen(updstmt), OCI_NTV_SYNTAX,
                                       OCI_DEFAULT)))
  return(rval);


/* Set up bind for newval */
if (qxiqtce(ctx, errhp, OCIBindByPos(stmthp, &bndp, errhp, (ub4)1,
                                     (dvoid *)newval,
                                     (sb4)(strlen(newval)+1),
                                     (ub2)SQLT_STR, (dvoid *)0, (ub2 *)0,
                                     (ub2 *)0, (ub4)0, (ub4 *)0,
                                     (ub4)OCI_DEFAULT)))
  return(rval);

/* Set up bind for rid */
if (qxiqtce(ctx, errhp, OCIBindByPos(stmthp, &bndp, errhp, (ub4)2,
                                     (dvoid *)rid,
                                     (sb4)(strlen(rid)+1),
                                     (ub2)SQLT_STR, (dvoid *)0, (ub2 *)0,
                                     (ub2 *)0, (ub4)0, (ub4 *)0,
                                     (ub4)OCI_DEFAULT)))
  return(rval);
  /* Set up bind for oldval */
  if (qxiqtce(ctx, errhp, OCIBindByPos(stmthp, &bndp, errhp, (ub4)3,
                                       (dvoid *)oldval,
                                       (sb4)(strlen(oldval)+1),
                                       (ub2)SQLT_STR, (dvoid *)0, (ub2 *)0,
                                       (ub2 *)0, (ub4)0, (ub4 *)0,
                                       (ub4)OCI_DEFAULT)))
    return(rval);

  /* Execute statement */
  if (qxiqtce(ctx, errhp, OCIStmtExecute(svchp, stmthp, errhp, (ub4)1,
                                         (ub4)0, (OCISnapshot *)NULL,
                                         (OCISnapshot *)NULL,
                                         (ub4)OCI_DEFAULT)))
    return(rval);

  return(rval);
}
```

Implementation of the ODCIIndexStart Routine

The start routine performs the setup for an `sbtree` index scan. The query information in terms of the operator predicate, its arguments and the bounds on return values are passed in as parameters to this function. The scan context that is shared amongst the index scan routines is an instance of the type `sbtree_im`. We have defined a C struct (`qxiqtim`) as a mapping for the object type. In addition, there is a C struct (`qxiqtin`) for the corresponding null object. Note that the C structs for the object type and its null object can be generated by using the Object Type Translator (OTT).

```
/* The index implementation type is an object type with a single RAW attribute
 * which will be used to store the context key value.
 * C mapping of the implementation type :
 */
struct qxiqtim
{
   OCIRaw *sctx_qxiqtim;
};
typedef struct qxiqtim qxiqtim;

struct qxiqtin
{
  short atomic_qxiqtin;
  short scind_qxiqtin;
};
typedef struct qxiqtin qxiqtin;
```

This function sets up a cursor that scans the index table. The scan retrieves the stored rowids for the rows in the index table that satisfy the specified predicate. The predicate for the index table is generated based on the operator predicate information that is passed in as parameters. For example, if the operator predicate is of the form:

```
eq(col, 'joe') = 1
```

the predicate on the index table is set up to be

```
f1 = 'joe'
```

There are a set of OCI handles that need to be cached away and retrieved on the next fetch call. A C struct `qxiqtcx` is defined to hold all the necessary scan state. This structure is allocated out of `OCI_DURATION_STATEMENT` memory to ensure that it persists till the end of `fetch`. After populating the structure with the required info, a pointer to the structure is saved in OCI context. The context is identified by a 4-byte key that is generated by calling an OCI routine. The 4-byte key is stashed away in the scan context - `exiting`. This object is returned back to the Oracle server and will be passed in as a parameter to the next fetch call.

```
/* The index scan context - should be stored in "statement" duration memory
 * and used by start, fetch and close routines.
 */
struct qxiqtcx
{
  OCIStmt *stmthp;
  OCIDefine *defnp;
  OCIBind *bndp;
  char ridp[19];
};

typedef struct qxiqtcx qxiqtcx;

OCINumber *qxiqtbs(ctx, sctx, sctx_ind, ix, ix_ind, pr, pr_ind, qy, qy_ind,
                   strt, strt_ind, stop, stop_ind, cmpval, cmpval_ind)
OCIExtProcContext *ctx;
qxiqtim           *sctx;
qxiqtin           *sctx_ind;
ODCIIndexInfo     *ix;
```

```
dvoid            *ix_ind;
ODCIPredInfo     *pr;
dvoid            *pr_ind;
ODCIQueryInfo    *qy;
dvoid            *qy_ind;
OCINumber        *strt;
short            strt_ind;
OCINumber        *stop;
short            stop_ind;
char             *cmpval;
short            cmpval_ind;
{
  sword status;
  OCIEnv *envhp; /* env. handle */
  OCISvcCtx *svchp; /* service handle */
  OCIError *errhp;  /* error handle */
  OCISession *usrhp; /* user handle */
  qxiqtcx *icx; /* state to be saved for later calls */

  int strtval; /* start bound */
  int stopval;  /* stop bound */

  int errnum = 29400; /* choose some oracle error number */
  char errmsg[512];  /* error message buffer */
  size_t errmsglen;  /* Length of error message */

  char relop[3]; /* relational operator used in sql stmt */
  char selstmt[2000]; /* sql select statement */

  int retval = (int)ODCI_SUCCESS; /* return from this function */
  OCINumber *rval = (OCINumber *)0;
  ub4 key;  /* key value set in "sctx" */

  /* Get oci handles */
  if (qxiqtce(ctx, errhp, OCIExtProcGetEnv(ctx, &envhp, &svchp, &errhp)))
    return(rval);

  /* set up return code */
  rval = (OCINumber *)OCIExtProcAllocCallMemory(ctx, sizeof(OCINumber));
  if (qxiqtce(ctx, errhp, OCINumberFromInt(errhp, (dvoid *)&retval,
                                           sizeof(retval),
                                           OCI_NUMBER_SIGNED, rval)))
    return(rval);

  /* get the user handle */
```

```
if (qxiqtce(ctx, errhp, OCIAttrGet((dvoid *)svchp, (ub4)OCI_HTYPE_SVCCTX,
                                   (dvoid *)&usrhp, (ub4 *)0,
                                   (ub4)OCI_ATTR_SESSION,
                                   errhp)))
  return(rval);


/**********************************************/
/* Allocate memory to hold index scan context */
/**********************************************/
if (qxiqtce(ctx, errhp, OCIMemoryAlloc((dvoid *)usrhp, errhp,
                                       (dvoid **)&icx,
                                       OCI_DURATION_STATEMENT,
                                       (ub4)(sizeof(qxiqtcx)),
                                       OCI_MEMORY_CLEARED)))
  return(rval);

icx->stmthp = (OCIStmt *)0;
icx->defnp = (OCIDefine *)0;
icx->bndp = (OCIBind *)0;

/***********************************/
/* Check that the bounds are valid */
/***********************************/
/* convert from oci numbers to native numbers */
if (qxiqtce(ctx, errhp, OCINumberToInt(errhp, strt,
                                       sizeof(strtval), OCI_NUMBER_SIGNED,
                                       (dvoid *)&strtval)))
  return(rval);
if (qxiqtce(ctx, errhp, OCINumberToInt(errhp, stop,
              sizeof(stopval),
               OCI_NUMBER_SIGNED,
              (dvoid *)&stopval)))
  return(rval);

/* verify that strtval/stopval are both either 0 or 1 */
if (!(((strtval == 0) && (stopval == 0)) ||
      ((strtval == 1) && (stopval == 1))))
  {
    strcpy(errmsg, "Incorrect predicate for sbtree operator");
    errmsglen = (size_t)strlen(errmsg);
    if (OCIExtProcRaiseExcpWithMsg(ctx, errnum, (text *)errmsg, errmsglen)
        != OCIEXTPROC_SUCCESS)
      /* Use cartridge error services here */;
    return(rval);
  }

/*********************************************/
/* Generate the SQL statement to be executed */
/*********************************************/
if (memcmp((dvoid *)OCIStringPtr(envhp, pr->ObjectName), "EQ", 2)
    == 0)
  if (strtval == 1)
    strcpy(relop, "=");
  else
    strcpy(relop, "!=");
else if (memcmp((dvoid *)OCIStringPtr(envhp, pr->ObjectName), "LT",
                2) == 0)
  if (strtval == 1)
    strcpy(relop, "<");
  else
    strcpy(relop, ">=");
else
  if (strtval == 1)
    strcpy(relop, ">");
  else
    strcpy(relop, "<=");

sprintf(selstmt, "select f2 from %s.%s_sbtree where f1 %s :val",
                OCIStringPtr(envhp, ix->IndexSchema),
                OCIStringPtr(envhp, ix->IndexName), relop);

/***********************************/
/* Parse, bind, define and execute */
/***********************************/
/* allocate stmt handle */
if (qxiqtce(ctx, errhp, OCIHandleAlloc((dvoid *)envhp, (dvoid **)
    &(icx->stmthp),
                                       (ub4)OCI_HTYPE_STMT, (size_t)0,
                                       (dvoid **)0)))
  return(rval);
/* prepare the statement */
if (qxiqtce(ctx, errhp, OCIStmtPrepare(icx->stmthp, errhp, (text *)selstmt,
                                       (ub4)strlen(selstmt), OCI_NTV_SYNTAX,
                                       OCI_DEFAULT)))
  return(rval);

/* Set up bind */
if (qxiqtce(ctx, errhp, OCIBindByPos(icx->stmthp, &(icx->bndp), errhp, (ub4)1,
                                     (dvoid *)cmpval,
                                       (sb4)(strlen(cmpval)+1),
                                       (ub2)SQLT_STR, (dvoid *)0, (ub2 *)0,
                                       (ub2 *)0, (ub4)0, (ub4 *)0,
                                       (ub4)OCI_DEFAULT)))
    return(rval);

  /* Set up define */
  if (qxiqtce(ctx, errhp, OCIDefineByPos(icx->stmthp, &(icx->defnp), errhp,
                                         (ub4)1, (dvoid *)(icx->ridp),
                                         (sb4) sizeof(icx->ridp),
                                         (ub2)SQLT_STR, (dvoid *)0, (ub2 *)0,
                                         (ub2 *)0, (ub4)OCI_DEFAULT)))
    return(rval);

  /* execute */
  if (qxiqtce(ctx, errhp, OCIStmtExecute(svchp, icx->stmthp, errhp, (ub4)0,
                                         (ub4)0, (OCISnapshot *)NULL,
                                         (OCISnapshot *)NULL,
                                         (ub4)OCI_DEFAULT)))
    return(rval);

  /************************************/
  /* Set index context to be returned */
  /************************************/
  /* generate a key */
  if (qxiqtce(ctx, errhp, OCIContextGenerateKey((dvoid *)usrhp, errhp, &key)))
    return(rval);

  /* set the memory address of the struct to be saved in the context */
  if (qxiqtce(ctx, errhp, OCIContextSetValue((dvoid *)usrhp, errhp,
                                             OCI_DURATION_STATEMENT,
                                             (ub1 *)&key, (ub1)sizeof(key),
                                             (dvoid *)icx)))
    return(rval);
  /* set the key as the member of "sctx" */
  if (qxiqtce(ctx, errhp, OCIRawAssignBytes(envhp, errhp, (ub1 *)&key,
                                            (ub4)sizeof(key),
                                            &(sctx->sctx_qxiqtim))))
    return(rval);

  sctx_ind->atomic_qxiqtin = OCI_IND_NOTNULL;
  sctx_ind->scind_qxiqtin = OCI_IND_NOTNULL;

  return(rval);
}
```

Implementation of the ODCIIndexFetch Routine

The scan context set up by the start routine is passed in as a parameter to the fetch routine. This function first retrieves the 4-byte key from the scan context. The C mapping for the scan context is `qxiqtim`. Next, the OCI context is looked up based on the key. This gives the memory address of the structure that holds the OCI handles - the `qxiqtcx` structure.

This function returns the next batch of rowids that satisfy the operator predicate. It uses the value of the `nrows` parameter as the size of the batch. It repeatedly fetches rowids from the open cursor and populates the `rowid` list with them. When the batch is full or when there are no more rowids left, the function returns them back to the Oracle server.

```
OCINumber *qxiqtbf(ctx, self, self_ind, nrows, nrows_ind, rids, rids_ind)
OCIExtProcContext *ctx;
qxiqtim           *self;
qxiqtin           *self_ind;
OCINumber         *nrows;
short             nrows_ind;
OCIArray          **rids;
short             *rids_ind;
{
  sword status;
  OCIEnv *envhp;
  OCISvcCtx *svchp;
  OCIError *errhp;
  OCISession *usrhp;  /* user handle */
  qxiqtcx *icx;

  int idx = 1;
  int nrowsval;

  OCIArray *ridarrp = *rids;   /* rowid collection */
  OCIString *ridstr = (OCIString *)0;

  int done = 0;
  int retval = (int)ODCI_SUCCESS;
  OCINumber *rval = (OCINumber *)0;

  ub1 *key;  /* key to retrieve context */
  ub4 keylen;  /* length of key */
  /*******************/
  /* Get OCI handles */
  /*******************/
  if (qxiqtce(ctx, errhp, OCIExtProcGetEnv(ctx, &envhp, &svchp, &errhp)))
      return(rval);

  /* set up return code */
  rval = (OCINumber *)OCIExtProcAllocCallMemory(ctx, sizeof(OCINumber));
  if (qxiqtce(ctx, errhp, OCINumberFromInt(errhp, (dvoid *)&retval,
sizeof(retval),
                                             OCI_NUMBER_SIGNED, rval)))
    return(rval);

  /* get the user handle */
  if (qxiqtce(ctx, errhp, OCIAttrGet((dvoid *)svchp, (ub4)OCI_HTYPE_SVCCTX,
                                   (dvoid *)&usrhp, (ub4 *)0,
                                   (ub4)OCI_ATTR_SESSION, errhp)))
    return(rval);

  /********************************/
  /* Retrieve context from key    */
  /********************************/
  key = OCIRawPtr(envhp, self->sctx_qxiqtim);
  keylen = OCIRawSize(envhp, self->sctx_qxiqtim);

  if (qxiqtce(ctx, errhp, OCIContextGetValue((dvoid *)usrhp, errhp,
                                           key, (ub1)keylen,
                                           (dvoid **)&(icx))))
    return(rval);

  /* get value of nrows */
  if (qxiqtce(ctx, errhp, OCINumberToInt(errhp, nrows, sizeof(nrowsval),
                                         OCI_NUMBER_SIGNED, (dvoid
*)&nrowsval)))
    return(rval);

  /****************/
  /* Fetch rowids */
  /****************/
  while (!done)
  {
    if (idx > nrowsval)
      done = 1;
    else
    {
      status = OCIStmtFetch(icx->stmthp, errhp, (ub4)1, (ub2) 0,
                            (ub4)OCI_DEFAULT);
      if (status == OCI_NO_DATA)
      {
        short col_ind = OCI_IND_NULL;
        /* have to create dummy oci string */
        OCIStringAssignText(envhp, errhp, (text *)"dummy",
                            (ub2)5, &ridstr);
        /* append null element to collection */
        if (qxiqtce(ctx, errhp, OCICollAppend(envhp, errhp,(dvoid *)ridstr,
                                              (dvoid *)&col_ind,
                                              (OCIColl *)ridarrp)))
          return(rval);
        done = 1;
      }
      else if (status == OCI_SUCCESS)
      {
        OCIStringAssignText(envhp, errhp, (text *)icx->ridp,
                            (ub2)18, (OCIString **)&ridstr);
        /* append rowid to collection */
        if (qxiqtce(ctx, errhp, OCICollAppend(envhp, errhp, (dvoid *)ridstr,
                                              (dvoid *)0, (OCIColl *)ridarrp)))
          return(rval);
        idx++;
      }
      else if (qxiqtce(ctx, errhp, status))
        return(rval);
    }
  }

  /* free ridstr finally */
  if (ridstr &&
      (qxiqtce(ctx, errhp, OCIStringResize(envhp, errhp, (ub4)0,
                                           &ridstr))))
    return(rval);

  *rids_ind = OCI_IND_NOTNULL;

  return(rval);
}
```

Implementation of the ODCIIndexClose Routine

The scan context set up by the start routine is passed in as a parameter to the close routine. This function first retrieves the 4-byte key from the scan context. The C mapping for the scan context is `qxiqtim`. Next, the OCI context is looked up based on the key. This gives the memory address of the structure that holds the OCI handles - the `qxiqtcx` structure.

The function closes and frees all the OCI handles. It also frees the memory that was allocated in the start routine.

```
OCINumber *qxiqtbc(ctx, self, self_ind)
OCIExtProcContext *ctx;
qxiqtim           *self;
qxiqtin           *self_ind;
{
  sword status;
  OCIEnv *envhp;
  OCISvcCtx *svchp;
  OCIError *errhp;
  OCISession *usrhp;   /* user handle */

  qxiqtcx *icx;

  int retval = (int) ODCI_SUCCESS;
  OCINumber *rval = (OCINumber *)0;

  ub1 *key; /* key to retrieve context */
  ub4 keylen; /* length of key */

  if (qxiqtce(ctx, errhp, OCIExtProcGetEnv(ctx, &envhp, &svchp, &errhp)))
      return(rval);

  /* set up return code */
  rval = (OCINumber *)OCIExtProcAllocCallMemory(ctx, sizeof(OCINumber));
  if (qxiqtce(ctx, errhp, OCINumberFromInt(errhp, (dvoid *)&retval,
                                           sizeof(retval),
                                           OCI_NUMBER_SIGNED, rval)))
    return(rval);

  /* get the user handle */
  if (qxiqtce(ctx, errhp, OCIAttrGet((dvoid *)svchp, (ub4)OCI_HTYPE_SVCCTX,
                                     (dvoid *)&usrhp, (ub4 *)0,
                                     (ub4)OCI_ATTR_SESSION, errhp)))
    return(rval);
  /********************************/
  /* Retrieve context using key   */
  /********************************/
  key = OCIRawPtr(envhp, self->sctx_qxiqtim);
  keylen = OCIRawSize(envhp, self->sctx_qxiqtim);

  if (qxiqtce(ctx, errhp, OCIContextGetValue((dvoid *)usrhp, errhp,
                                           key, (ub1)keylen,
                                           (dvoid **)&(icx))))
    return(rval);

  /* Free handles and memory */
  if (qxiqtce(ctx, errhp, OCIHandleFree((dvoid *)icx->stmthp,
                                      (ub4)OCI_HTYPE_STMT)))
    return(rval);

  if (qxiqtce(ctx, errhp, OCIMemoryFree((dvoid *)usrhp, errhp, (dvoid *)icx)))
    return(rval);

  return(rval);
}
```

Implementing the Indextype

Create the indextype object and specify the list of operators that it supports. In addition, specify the name of the implementation type that implements the ODCIIndex interface routines.

```
CREATE INDEXTYPE sbtree
FOR
eq(VARCHAR2, VARCHAR2),
lt(VARCHAR2, VARCHAR2),
gt(VARCHAR2, VARCHAR2)
USING sbtree_im;
```

Usage examples

One typical usage scenario is described below. Create a table and populate it.

```
CREATE TABLE t1 (f1 number, f2 VARCHAR2(200));
INSERT INTO t1 VALUES (1, 'adam');
insert into t1 VALUES (3, 'joe');
```

Create a `sbtree` index on column f2. The create index statement specifies the indextype to be used.

```
create index it1 on t1(f2)
indextype is sbtree;
```

Execute a query that uses one of the `sbtree` operators. The explain plan output for the same shows that the domain index is being used to efficiently evaluate the query.

```
SELECT * FROM t1 WHERE eq(f2, 'joe') = 1;
```

Explain Plan Output

```
 OPERATIONS                    OPTIONS                       OBJECT_NAME

 ----------------------------- ----------------------------- -------------
SELECT STATEMENT
 TABLE ACCESS                  BY ROWID                      T1
 DOMAIN INDEX                                                IT1
```

Part V

Reference

The reference section covers four areas:

13 Reference — Cartridge Services

This reference chapter includes the following information:

Cartridge Services — External Procedures

OCIExtProcAllocCallMemory

Syntax

```
dvoid * OCIExtProcAllocCallMemory ( OCIExtProcContext  *with_context,
                                    size_t amount )
```

Remarks

This call allocates `amount` bytes of memory for the duration of the call of the external procedure.

Any memory allocated by this call is freed by PL/SQL upon return from the external procedure. The application must not use any kind of 'free' function on memory allocated by `OCIExtProcAllocCallMemory`*()*. Use this function to allocate memory for function returns.

A zero return value should be treated as an error

Returns

An untyped (opaque) Pointer to the allocated memory.

Table 13–1 OCIExtProcAllocCallMemory Keywords/Parameters

Keyword/Parameter	Meaning
`with_context (IN)`	the with_context pointer that is passed to the C External Procedure
`amount (IN)`	the number of bytes to allocate

Example

```
text *ptr = (text *)OCIExtProcAllocCallMemory(wctx, 1024)
```

OCIExtProcRaiseExcp

Syntax

```
size_t OCIExtProcRaiseExcp ( OCIExtProcContext *with_context, int errnum )
```

Remarks

Calling this function signals an exception back to PL/SQL. After a successful return from this function, the external procedure must start its exit handling and return back to PL/SQL. Once an exception is signalled to PL/SQL, IN/OUT and OUT arguments, if any, are not processed at all.

Returns

- `OCIEXTPROC_SUCCESS` - If the call was successful.
- `OCIEXTPROC_ERROR` - If the call failed.

Table 13–2 OCIExtProcAllocCallMemory Keywords/Parameters

Keyword/Parameter	Meaning
`with_context (IN)`	the `with_context` pointer that is passed to the C external procedure
`errnum (IN)`	Oracle Error number to signal to PL/SQL `errnum` must be a positive number and in the range 1 to 32767

OCIExtProcRaiseExcpWithMsg

Syntax

```
size_t OCIExtProcRaiseExcpWithMsg ( OCIExtProcContext *with_context,
                                    int errnum, char  *errmsg, size_t msglen )
```

Remarks

Raise an exception to PL/SQL. In addition, substitute the following error message string within the standard Oracle error message string. See the description of *OCIExtProcRaiseExcp()* for more information.

Returns

`OCIEXTPROC_SUCCESS` if the call was successful.

`OCIEXTPROC_ERROR` if the call failed.

Table 13–3 OCIExtProcAllocCallMemory Keywords/Parameters

Keyword/Parameter	Meaning
`with_context (IN)`	the with_context pointer that is passed to the C external procedure
`errnum (IN)`	Oracle Error number to signal to PL/SQL; `errnum` must be a positive number and in the range 1 to 32767
`errmsg (IN)`	the error message associated with the errnum
`len (IN)`	the length of the error message; pass zero if `errmsg` is a null terminated string

Cartridge Services — Memory Services

OCIDurationBegin

Syntax

```
sword OCIDurationBegin(OCIEnv *env, OCIError *err, CONST OCISvcCtx *svc,
OCIDuration parent, OCIDuration *dur);
```

Remarks

This call starts a user duration. Note that the environment or service context parameter cannot both be `NULL`.

Returns

An error code.

Table 13–4 OCIDurationBegin Keywords/Parameters

Keyword/Parameter	Meaning
`env (IN)`	the OCI environment handle
`err (IN)`	the error handle
`errhps (IN)`	the OCI error handle stack
`OCISvcCtx (IN)`	the OCI Service Context (this should be passed as `NULL` for cartridge services)

`parent (IN)`	one of the following:
	a previously created user duration
	`OCI_DURATION_STATEMENT`
	`OCI_DURATION_SESSION`

`dur (OUT)`	newly created user duration

OCIDurationEnd

Syntax

```
sword OCIDurationEnd(OCIEnv *env, OCIError *err, OCIDuration dur, CONST
                     OCISvcCtx *svc);
```

Remarks

This call terminates a user duration. All memory allocated for this duration is freed. Note that the environment or service context parameter cannot both be `NULL`.

Returns

Error code.

Table 13–5 OCIDurationEnd Keywords/Parameters

Keyword/Parameter	Meaning
`env (IN)`	the OCI environment handle
`err (IN)`	the error handle
`dur (IN)`	a previously created user duration using `OCIDurationBegin`()
`OCISvcCtx (IN)`	`OCI` Service Context (this should be passed as `NULL` for cartridge services)

OCIMemoryAlloc

Syntax

```
sword OCIMemoryAlloc(dvoid *hndl, OCIError *err, dvoid **mem, OCIDuration dur,
                     ub4 size, ub4 flags);
```

Remarks

This call allocates memory of a given size from a given duration. To allocate memory for duration of callout of agent, i.e., external procedure duration, use `OCIExtProcAllocCallMemory`. If the `hndl` is an OCI environment, the only duration supported is `OCI_DURATION_PROCESS`. If the `hndl` is an OCI user session, the duration cannot be `OCI_DURATION_PROCESS`.

Returns

Error code.

Table 13–6 OCIMemoryAlloc Keywords/Parameters

Keyword/Parameter	Meaning
`hndl (IN)`	the `OCI` environment handle
`err (IN)`	the error handle
`mem (OUT)`	memory allocated

`dur (IN)`	one of the following:
	a previously created user duration
	`OCI_DURATION_STATEMENT`
	`OCI_DURATION_SESSION`
	`OCI_DURATION_PROCESS`

`size (IN)`	size of memory to be allocated
`flags (IN)`	set `OCI_MEMORY_CLEARED` bit to get memory that has been cleared

OCIMemoryResize

Syntax

```
sword OCIMemoryResize(dvoid *hndl, OCIError *err, dvoid **mem, ub4 newsize, ub4
                      flags);
```

Remarks

This call resizes a memory chunk to a new size. Memory must have been allocated before this function can be called to resize.

Returns

Error code.

Table 13–7 OCIMemoryResize Keywords/Parameters

Keyword/Parameter	Meaning
`hndl (IN)`	the `OCI` environment or user session handle
`err (IN)`	the error handle
`mem (IN/OUT)`	pointer to memory pointer allocated previously using `OCIMemoryAlloc`()
`newsize (IN)`	size of memory requested
`flags (IN)`	set `OCI_MEMORY_CLEARED` bit to get memory that has been cleared

OCIMemoryFree

Syntax

```
sword OCIMemoryFree(dvoid *hndl, OCIError *err, dvoid *mem);
```

Remarks

This call frees a memory chunk.

Returns

Error code.

Table 13–8 OCIMemoryFree Keywords/Parameters

Keyword/Parameter	Meaning
`hndl (IN)`	the `OCI` environment or user session handle
`err (IN)`	the error handle
`mem (IN/OUT)`	pointer to a previously allocated memory

Cartridge Services — Maintaining Context

OCIContextSetValue

Syntax

```
sword OCIContextSetValue(dvoid *hndl, OCIError *err, OCIDuration duration,
                         ub1 *key, ub1 keylen, dvoid *ctx_value);
```

Remarks

This call can be used to save a value (or address) for a particular duration. The context value being stored must be allocated out of memory of duration greater than or equal to the duration being passed in. The key being passed in should be unique in this session. Trying to save a context value under the same key and duration again will result in overwriting the old context value with the new one. Typically, a client will allocate a structure, store its address in the context using this call, and get this address in a separate call using `OCIContextGetValue`(). The (key, value) association can be explicitly removed by calling `OCIContextClearValue`() or else it will go away at the end of the duration.

Returns

- If operation succeeds, return `OCI_SUCCESS`.
- If operation fails, return `OCI_ERROR`.

Table 13–9 OCIContextSetValue Keywords/Parameters

Keyword/Parameter	Meaning
`hndl (IN)`	the `OCI` environment or user session handle
`err (IN)`	the error handle

`duration (IN)`	any user created duration
	`OCI_DURATION_STATEMENT`
	`OCI_DURATION_SESSION`

`key (IN))`	unique key value
`keylen (IN)`	length of the above key (maximum length is 64 bits)
`ctx_value (IN)`	pointer that will be saved in the context

OCIContextGetValue

Syntax

```
sword OCIContextGetValue(dvoid *hndl, OCIError *err, ub1 *key, ub1 keylen,
                         dvoid **ctx_value);
```

Remarks

This call is used to return the value that is stored in the context associated with the given key (by calling `OCIContextSetValue`()).

Requires

`ctx_value` — pointer to a preallocated pointer for the stored context to be returned

Returns

- If operation succeeds, return `OCI_SUCCESS`.
- If operation fails, return `OCI_ERROR`.

Table 13–10 OCIContextSetValue Keywords/Parameters

Keyword/Parameter	Meaning
`hndl (IN)`	the `OCI` environment or user session handle
`err (IN)`	the error handle
`key (IN))`	key value previously registered via `OCIContextSetValue`()
`keylen (IN)`	length of the above key (maximum length is 64 bits)
`ctx_value (IN)`	pointer to the value stored in the context or `NULL` if no value was stored

OCIContextClearValue

Syntax

```
sword OCIContextClearValue(dvoid *hndl, OCIError *err, ub1 *key, ub1 keylen);
```

Remarks

This call is used to remove the value that is stored in the context associated with the given key (by calling OCIContextSetValue()). An error is returned when a non-existent key is passed.

Returns

- If operation succeeds, return `OCI_SUCCESS`.
- If operation fails, return `OCI_ERROR`.

Table 13–11 OCIContextClearValue Keywords/Parameters

Keyword/Parameter	Meaning
`hndl (IN)`	the `OCI` environment or user session handle
`err (IN)`	the error handle
`key (IN))`	unique key value
`keylen (IN)`	length of the above key (maximum length is 64 bits)

OCIContextGenerateKey

Syntax

```
sword OCIContextGenerateKey(dvoid *hndl, OCIError *err, ub4 *key);
```

Remarks

This call will return a unique, 4 byte value each time it is called. This value is going to be unique on a per session basis.

Returns

- If operation succeeds, return `OCI_SUCCESS`.
- If operation fails, return `OCI_ERROR`.

Table 13–12 OCIContextGenerateKey Keywords/Parameters

Keyword/Parameter	Meaning
`hndl (IN)`	the `OCI` environment or user session handle
`err (IN)`	the error handle
`key (OUT))`	pointer to a unique, 4 byte value

Cartridge Services — Parameter Manager Interface

OCIExtractInit

Syntax

```
sword OCIExtractInit(dvoid *hndl, OCIError *err)
```

Remarks

This function initializes the parameter manager. It must be called before calling any other parameter manager routine and it must only be called once. The NLS information is stored inside the parameter manager context and used in subsequent calls to `OCIExtract` routines.

Returns

`OCI_SUCCESS`, `OCI_INVALID_HANDLE`, or `OCI_ERROR.`

Table 13–13 OCIExtractInit Keywords/Parameters

Keyword/Parameter	Meaning
`hndl (IN/OUT)`	the OCI environment or user session handle
`err (IN/OUT)`	the OCI error handle; if there is an error, it is recorded in `err` and this function returns `OCI_ERROR`; diagnostic information can be obtained by calling `OCIErrorGet`()

OCIExtractTerm

Syntax

```
sword OCIExtractTerm(dvoid *hndl, OCIError *err);
```

Remarks

This function releases all dynamically allocated storage and may perform other internal bookkeeping functions. It must be called when the parameter manager is no longer being used and it must only be called once.

Returns

`OCI_SUCCESS`, `OCI_INVALID_HANDLE`, or `OCI_ERROR`.

Table 13–14 OCIExtractTerm Keywords/Parameters

Keyword/Parameter	Meaning
`hndl (IN/OUT)`	the OCI environment or user session handle
`err (IN/OUT)`	the `OCI` error handle. If there is an error, it is recorded in `err` and this function returns `OCI_ERROR`. Diagnostic information can be obtained by calling `OCIErrorGet`().

OCIExtractReset

Syntax

```
sword OCIExtractReset(dvoid *hndl, OCIError *err);
```

Remarks

The memory currently used for parameter storage, key definition storage, and parameter value lists is freed and the structure is reinitialized.

Returns

`OCI_SUCCESS`, `OCI_INVALID_HANDLE`, or `OCI_ERROR`.

Table 13–15 OCIExtractReset Keywords/Parameters

Keyword/Parameter	Meaning
`hndl (IN/OUT)`	the OCI environment or user session handle
`err (IN/OUT)`	the OCI error handle; if there is an error, it is recorded in `err` and this function returns `OCI_ERROR`; diagnostic information can be obtained by calling `OCIErrorGet`()

OCIExtractSetNumKeys

Syntax

```
sword OCIExtractSetNumKeys(dvoid *hndl, OCIError *err, uword numkeys);
```

Remarks

Informs the parameter manager of the number of keys that will be registered. This routine must be called prior to the first call of `OCIExtractSetKey()`.

Returns

`OCI_SUCCESS`, `OCI_INVALID_HANDLE`, or `OCI_ERROR`.

Table 13–16 OCIExtractSetNumKeys Keywords/Parameters

Keyword/Parameter	Meaning
`hndl (IN/OUT)`	the OCI environment or user session handle
`err (IN/OUT)`	the `OCI` error handle. If there is an error, it is recorded in `err` and this function returns `OCI_ERROR`. Diagnostic information can be obtained by calling `OCIErrorGet()`.
`numkeys (IN)`	the number of keys that will be registered with `OCIExtractSetKey()`

OCIExtractSetKey

Syntax

```
sword OCIExtractSetKey(dvoid *hndl, OCIError *err, CONST text *name, ub1 type,
                       ub4 flag, CONST dvoid *defval, CONST sb4 *intrange,
                       CONST text *CONST *strlist);
```

Remarks

Registers information about a key with the parameter manager. This routine must be called after calling OCIExtractNumKeys() and before calling OCIExtractFromFile() or OCIExtractFromString().

Returns

OCI_SUCCESS, OCI_INVALID_HANDLE, or OCI_ERROR.

Table 13–17 OCIExtractSetKey Keywords/Parameters

Keyword/Parameter	Meaning
hndl (IN/OUT)	the OCI environment or user session handle
err (IN/OUT)	the OCI error handle; if there is an error, it is recorded in err and this function returns OCI_ERROR; diagnostic information can be obtained by calling OCIErrorGet()
name (IN)	the name of the key
type (IN)	the type of the key (OCI_EXTRACT_TYPE_INTEGER, OCI_EXTRACT_TYPE_OCINUM, OCI_EXTRACT_TYPE_STRING, or OCI_EXTRACT_TYPE_BOOLEAN)
flag (IN)	set to OCI_EXTRACT_MULTIPLE if the key can take multiple values or 0 otherwise
defval (IN)	set to the default value for the key; may be NULL if there is no default; a string default must be a (text*) type, an integer default must be an (sb4*) type, and a boolean default must be a (ub1*) type.
intrange (IN)	starting and ending values for the allowable range of integer values; may be NULL if the key is not an integer type or if all integer values are acceptable
strlist (IN)	list of all acceptable text strings for the key ended with 0 (or NULL); may be NULL if the key is not a string type or if all text values are acceptable

OCIExtractFromFile

Syntax

```
sword OCIExtractFromFile(dvoid *hndl, OCIError *err, ub4 flag, text *filename);
```

Remarks

The keys and their values in the given file are processed. `OCIExtractSetNumKeys()` and `OCIExtractSetKey()` routines must be called to define all of the keys before calling this routine.

Returns

`OCI_SUCCESS`, `OCI_INVALID_HANDLE`, or `OCI_ERROR`.

Table 13–18 OCIExtractFromFile Keywords/Parameters

Keyword/Parameter	Meaning
`hndl (IN/OUT)`	the OCI environment or user session handle
`err (IN/OUT)`	the OCI error handle; if there is an error, it is recorded in `err` and this function returns `OCI_ERROR`; diagnostic information can be obtained by calling `OCIErrorGet()`
flag (IN)	zero or has one or more of the following bits set: `OCI_EXTRACT_CASE_SENSITIVE`, `OCI_EXTRACT_UNIQUE_ABBREVS`, or `OCI_EXTRACT_APPEND_VALUES`
filename (IN)	`NULL`-terminated filename string

OCIExtractFromStr

Syntax

```
sword OCIExtractFromStr(dvoid *hndl, OCIError *err, ub4 flag, text *input);
```

Remarks

The keys and their values in the given string are processed. `OCIExtractSetNumKeys`() and `OCIExtractSetKey`() routines must be called to define all of the keys before calling this routine.

Returns

`OCI_SUCCESS`, `OCI_INVALID_HANDLE`, or `OCI_ERROR`.

Table 13–19 OCIExtractFromStr Keywords/Parameters

Keyword/Parameter	Meaning
`hndl (IN/OUT)`	the OCI environment or user session handle
`err (IN/OUT)`	the OCI error handle; if there is an error, it is recorded in `err` and this function returns `OCI_ERROR`; diagnostic information can be obtained by calling `OCIErrorGet`().
flag (IN)	zero or has one or more of the following bits set: `OCI_EXTRACT_CASE_SENSITIVE`, `OCI_EXTRACT_UNIQUE_ABBREVS`, or `OCI_EXTRACT_APPEND_VALUES`
input (IN)	`NULL`-terminated input string

OCIExtractToInt

Syntax

```
sword OCIExtractToInt(dvoid *hndl, OCIError *err, text *keyname, uword valno,
sb4 *retval);
```

Remarks

Gets the integer value for the specified key. The `valno`'th value (starting with 0) is returned.

Returns

`OCI_SUCCESS`, `OCI_INVALID_HANDLE`, `OCI_NO_DATA`, or `OCI_ERROR`. `OCI_NO_DATA` means that there is no `valno`'th value for this key.

Table 13–20 OCIExtractToInt Keywords/Parameters

Keyword/Parameter	Meaning
`hndl (IN)`	the OCI environment or user session handle
`err (IN/OUT)`	the OCI error handle; if there is an error, it is recorded in `err` and this function returns `OCI_ERROR`; diagnostic information can be obtained by calling `OCIErrorGet()`
`keyname (IN)`	key name
`valno (IN)`	which value to get for this key
`retval (OUT)`	the actual integer value

OCIExtractToBool

Syntax

```
sword OCIExtractToBool(dvoid *hndl, OCIError *err, text *keyname, uword valno,
                       ub1 *retval);
```

Remarks

Gets the boolean value for the specified key. The `valno`'th value (starting with 0) is returned.

Returns

`OCI_SUCCESS`, `OCI_INVALID_HANDLE`, `OCI_NO_DATA`, or `OCI_ERROR`. `OCI_NO_DATA` means that there is no `valno`'th value for this key.

Table 13–21 OCIExtractToBool Keywords/Parameters

Keyword/Parameter	Meaning
`hndl (IN)`	the OCI environment or user session handle
`err (IN/OUT)`	the OCI error handle; if there is an error, it is recorded in `err` and this function returns `OCI_ERROR`; diagnostic information can be obtained by calling `OCIErrorGet`()
`keyname (IN)`	key name
`valno (IN)`	which value to get for this key
`retval (OUT)`	the actual boolean value

OCIExtractToStr

Syntax

```
sword OCIExtractToStr(dvoid *hndl, OCIError *err, text *keyname, uword valno,
                      text *retval, uword buflen);
```

Remarks

Gets the string value for the specified key. The `valno`'th value (starting with 0) is returned.

Returns

`OCI_SUCCESS`, `OCI_INVALID_HANDLE`, `OCI_NO_DATA`, or `OCI_ERROR`. `OCI_NO_DATA` means that there is no `valno`'th value for this key.

Table 13–22 OCIExtractToStr Keywords/Parameters

Keyword/Parameter	Meaning
`hndl (IN)`	the OCI environment or user session handle
`err (IN/OUT)`	the OCI error handle; if there is an error, it is recorded in `err` and this function returns `OCI_ERROR`; diagnostic information can be obtained by calling `OCIErrorGet`()
`keyname (IN)`	key name
`valno (IN)`	which value to get for this key
`retval (OUT)`	the actual `NULL`-terminated string value
`bufflen (IN)`	the length of the buffer for retval

OCIExtractToOCINum

Syntax

```
sword OCIExtractToOCINum(dvoid *hndl, OCIError *err, text *keyname, uword valno,
                         OCINumber *retval);
```

Remarks

Gets the OCINumber value for the specified key. The `valno`'th value (starting with 0) is returned.

Returns

`OCI_SUCCESS`, `OCI_INVALID_HANDLE`, `OCI_NO_DATA`, or `OCI_ERROR`. `OCI_NO_DATA` means that there is no `valno`'th value for this key.

Table 13–23 OCIExtractToOCINum Keywords/Parameters

Keyword/Parameter	Meaning
`hndl (IN)`	the OCI environment or user session handle
`err (IN/OUT)`	the OCI error handle; if there is an error, it is recorded in `err` and this function returns `OCI_ERROR`; diagnostic information can be obtained by calling `OCIErrorGet`()
`keyname (IN)`	key name
`valno (IN)`	which value to get for this key
`retval (OUT)`	the actual `OCINumber` string value

OCIExtractToList

Syntax

```
sword OCIExtractToList(dvoid *hndl, OCIError *err, uword *numkeys);
```

Remarks

Generates a list of parameters from the parameter structures that are stored in memory. Must be called before `OCIExtractValues`() is called.

Returns

`OCI_SUCCESS`, `OCI_INVALID_HANDLE`, or `OCI_ERROR`.

Table 13–24 OCIExtractToList Keywords/Parameters

Keyword/Parameter	Meaning
`hndl (IN)`	the OCI environment or user session handle
`err (IN/OUT)`	the OCI error handle; if there is an error, it is recorded in `err` and this function returns `OCI_ERROR`; diagnostic information can be obtained by calling `OCIErrorGet`()
numkeys (OUT)	number of distinct keys stored in memory

OCIExtractFromList

Syntax

```
sword OCIExtractFromList(dvoid *hndl, OCIError *err, uword index, text **name,
                         ub1 *type, uword *numvals, dvoid ***values);
```

Remarks

Generates a list of values for the parameter denoted by index in the parameter list. OCIExtractToList() must be called prior to calling this routine to generate the parameter list from the parameter structures that are stored in memory.

Returns

OCI_SUCCESS, OCI_INVALID_HANDLE, or OCI_ERROR.

Table 13–25 OCIExtractFromList Keywords/Parameters

Keyword/Parameter	Meaning
hndl (IN)	the OCI environment or user session handle
err (IN/OUT)	the OCI error handle; if there is an error, it is recorded in err and this function returns OCI_ERROR; diagnostic information can be obtained by calling OCIErrorGet()
index (IN)	which parameter to retrieve from the parameter list
name (OUT)	name of the key for the current parameter
type (OUT)	type of the current parameter (OCI_EXTRACT_TYPE_STRING, OCI_EXTRACT_TYPE_INTEGER, OCI_EXTRACT_TYPE_OCINUM, or OCI_EXTRACT_TYPE_BOOLEAN)
numvals (OUT)	number of values for this parameter
values (OUT)	the values for this parameter

Cartridge Services — File I/O Interface

OCIFileObject

The OCIFileObject data structure holds information about the way in which a file should be opened and the way in which it will be accessed once it has been opened. When this structure is initialized by `OCIFileOpen`(), it becomes an identifier through which operations can be performed on that file. It is a necessary parameter to every function that operates on open files. This data structure is opaque to `OCIFile` clients. It is initialized by `OCIFileOpen`() and terminated by `OCIFileClose`().

OCIFileInit

Syntax

```
sword OCIFileInit(dvoid *hndl, OCIError *err);
```

Remarks

Initializes the `OCIFile` package. It must be called before any other `OCIFile` routine is called.

Returns

`OCI_SUCCESS`, `OCI_INVALID_HANDLE`, or `OCI_ERROR.`

Table 13–26 OCIFileInit Keywords/Parameters

Keyword/Parameter	Meaning
`hndl (IN/OUT)`	the OCI environment or user session handle
`err (IN/OUT)`	the `OCI` error handle. If there is an error, it is recorded in `err` and this function returns `OCI_ERROR`. Diagnostic information can be obtained by calling `OCIErrorGet`().

OCIFileTerm

Syntax

```
sword OCIFileTerm(dvoid *hndl, OCIError *err);
```

Remarks

Terminates the `OCIFile` package. It must be called after the `OCIFile` package is no longer being used.

Returns

`OCI_SUCCESS`, `OCI_INVALID_HANDLE`, or `OCI_ERROR`.

Table 13–27 OCIFileTerm Keywords/Parameters

Keyword/Parameter	Meaning
`hndl (IN/OUT)`	the OCI environment or user session handle
`err (IN/OUT)`	the OCI error handle; if there is an error, it is recorded in `err` and this function returns `OCI_ERROR`; diagnostic information can be obtained by calling `OCIErrorGet`()

OCIFileOpen

Syntax

```
sword OCIFileOpen(dvoid *hndl, OCIError *err, OCIFileObject **filep,
                  OraText *filename, OraText *path, ub4 mode, ub4 create,
                  ub4 type);
```

Remarks

Opens a file.

Returns

OCI_SUCCESS, OCI_INVALID_HANDLE, or OCI_ERROR.

Table 13–28 OCIFileOpen Keywords/Parameters

Keyword/Parameter	Meaning
hndl (IN/OUT)	the OCI environment or user session handle
err (IN/OUT)	the OCI error handle; if there is an error, it is recorded in err and this function returns OCI_ERROR; diagnostic information can be obtained by calling OCIErrorGet()
filep (IN/OUT)	the file identifier
filename (IN)	the file name as a NULL-terminated string
path (IN)	the path of the file as a NULL-terminated string
mode (IN)	the mode in which to open the file. Valid modes are OCI_FILE_READ_ONLY, OCI_FILE_WRITE_ONLY, OCI_FILE_READ_WRITE
create (IN)	indicates if the file be created if it does not exist — valid values are: ■ OCI_FILE_TRUNCATE — create a file regardless of whether or not it exists. If the file already exists overwrite the existing file ■ OCI_FILE_EXCL — fail if the file exists, else create. ■ OCI_FILE_CREATE — open the file if it exists, and create it if it doesn't ■ OCI_FILE_APPEND — set the file pointer to the end of the file prior to writing. This flag can be OR'ed with OCI_FILE_CREATE

Table 13–28 OCIFileOpen Keywords/Parameters (Cont.)

Keyword/Parameter	Meaning
`type (IN)`	file type; valid values are `OCI_FILE_TEXT`, `OCI_FILE_BIN`, `OCI_FILE_STDIN`, `OCI_FILE_STDOUT` and `OCI_FILE_STDERR`

OCIFileClose

Syntax

```
sword OCIFileClose(dvoid *hndl, OCIError *err, OCIFileObject *filep);
```

Remarks

Closes a previously opened file. Once this returns, the `OCIFileObject` structure pointed to by filep will have been destroyed. Therefore, you should not attempt to access this structure after this returns.

Returns

`OCI_SUCCESS`, `OCI_INVALID_HANDLE`, or `OCI_ERROR`.

Table 13–29 OCIFileClose Keywords/Parameters

Keyword/Parameter	Meaning
`hndl (IN/OUT)`	the OCI environment or user session handle
`err (IN/OUT)`	the OCI error handle; if there is an error, it is recorded in `err` and this function returns `OCI_ERROR`; diagnostic information can be obtained by calling `OCIErrorGet`()
`filep (IN/OUT)`	a pointer to a file identifier to be closed

OCIFileRead

Syntax

```
sword OCIFileRead(dvoid *hndl, OCIError *err, OCIFileObject *filep, dvoid *bufp,
                  ub4 bufl, ub4 *bytesread);
```

Remarks

Reads from a file into a buffer. As many bytes as possible will be read into the user buffer. The read will end either when the user buffer is full, or when it reaches end-of-file.

Returns

`OCI_SUCCESS`, `OCI_INVALID_HANDLE`, or `OCI_ERROR.`

Table 13–30 OCIFileRead Keywords/Parameters

Keyword/Parameter	Meaning
`hndl (IN/OUT)`	the OCI environment or user session handle
`err (IN/OUT)`	the OCI error handle; if there is an error, it is recorded in `err` and this function returns `OCI_ERROR`; diagnostic information can be obtained by calling `OCIErrorGet`()
`filep (IN/OUT)`	a file identifier that uniquely references the file
`bufp (IN)`	the pointer to a buffer into which the data will be read. The length of the allocated memory is assumed to be `bufl`
`bufl (IN)`	the length of the buffer in bytes
`bytesread (OUT)`	the number of bytes read

OCIFileWrite

Syntax

```
sword OCIFileWrite(dvoid *hndl, OCIError *err, OCIFileObject *filep,
                   dvoid *bufp, ub4 buflen, ub4 *byteswritten);
```

Remarks

Writes buflen bytes into the file.

Returns

`OCI_SUCCESS`, `OCI_INVALID_HANDLE`, or `OCI_ERROR`.

Table 13–31 OCIFileWrite Keywords/Parameters

Keyword/Parameter	Meaning
`hndl (IN/OUT)`	the OCI environment or user session handle
`err (IN/OUT)`	the OCI error handle; if there is an error, it is recorded in `err` and this function returns `OCI_ERROR`; diagnostic information can be obtained by calling `OCIErrorGet`()
`filep (IN/OUT)`	a file identifier that uniquely references the file
bufp (IN)	the pointer to a buffer into which the data will be written; the length of the allocated memory is assumed to be `buflen`
buflen (IN)	the length of the buffer in bytes
byteswritten (OUT)	the number of bytes written

OCIFileSeek

Syntax

```
sword OCIFileSeek(dvoid *hndl, OCIError *err, OCIFileObject *filep,
                  uword origin, ubig_ora offset, sb1 dir);
```

Remarks

Changes the current position in a file. This will allow a seek past the end of the file. Reading from such a position will cause an end-of-file condition to be reported. Writing to such a position will not work on all file systems. This is because some systems do not allow files to grow dynamically. They require that files be preallocated with a fixed size. Note that this function performs a seek to a byte location.

Returns

OCI_SUCCESS, OCI_INVALID_HANDLE, or OCI_ERROR.

Table 13–32 OCIFileSeek Keywords/Parameters

Keyword/Parameter	Meaning
`hndl (IN/OUT)`	the OCI environment or user session handle
`err (IN/OUT)`	the OCI error handle; if there is an error, it is recorded in `err` and this function returns `OCI_ERROR`; diagnostic information can be obtained by calling `OCIErrorGet`()
`filep (IN/OUT)`	a file identifier that uniquely references the file
origin (IN)	the starting point we want to seek from. The starting point may be `OCI_FILE_SEEK_BEGINNING` (beginning), `OCI_FILE_SEEK_CURRENT` (current position), or `OCI_FILE_SEEK_END` (end of file)
offset (IN)	the number of bytes from the origin you want to start reading from
dir (IN)	the direction we want to go from the origin. NOTE: The direction can be either `OCIFILE_FORWARD` or `OCIFILE_BACKWARD`

OCIFileExists

Syntax

```
sword OCIFileExists(dvoid *hndl, OCIError *err, OraText *filename,
                    OraText *path, ub1 *flag);
```

Remarks

Tests to see if the file exists.

Returns

OCI_SUCCESS, OCI_INVALID_HANDLE, or OCI_ERROR.

Table 13–33 OCIFileExists Keywords/Parameters

Keyword/Parameter	Meaning
hndl (IN/OUT)	the OCI environment or user session handle
err (IN/OUT)	the OCI error handle; if there is an error, it is recorded in err and this function returns OCI_ERROR; diagnostic information can be obtained by calling OCIErrorGet().
filename (IN)	the file name as a NULL-terminated string
path (IN)	the path of the file as a NULL-terminated string
flag (OUT)	set to TRUE if the file exists or FALSE if it does not

OCIFileGetLength

Syntax

```
sword OCIFileGetLength(dvoid *hndl, OCIError *err, OraText *filename,
                       OraText *path, ubig_ora *lenp);
```

Remarks

Gets the length of a file.

Returns

OCI_SUCCESS, OCI_INVALID_HANDLE, or OCI_ERROR.

Table 13–34 OCIFileGetLength Keywords/Parameters

Keyword/Parameter	Meaning
hndl (IN/OUT)	the OCI environment or user session handle
err (IN/OUT)	the OCI error handle; if there is an error, it is recorded in err and this function returns OCI_ERROR; diagnostic information can be obtained by calling OCIErrorGet()
filename (IN)	the file name as a NULL-terminated string
path (IN)	the path of the file as a NULL-terminated string
lenp (OUT)	set to the length of the file in bytes

OCIFileFlush

Syntax

```
sword OCIFileFlush(dvoid *hndl, OCIError *err, OCIFileObject *filep);
```

Remarks

Write buffered data to a file.

Returns

`OCI_SUCCESS`, `OCI_INVALID_HANDLE`, or `OCI_ERROR.`

Table 13–35 OCIFileFlush Keywords/Parameters

Keyword/Parameter	Meaning
`hndl (IN/OUT)`	the OCI environment or user session handle
`err (IN/OUT)`	the OCI error handle; if there is an error, it is recorded in `err` and this function returns `OCI_ERROR`; diagnostic information can be obtained by calling `OCIErrorGet`()
`filep (IN/OUT)`	a file identifier that uniquely references the file

Cartridge Services — String Formatting Interface

OCIFormatInit

Syntax

```
sword OCIFormatInit(dvoid *hndl, OCIError *err)
```

Remarks

Initializes the `OCIFormat` package. This routine must be called before calling any other `OCIFormat` routine and it must only be called once.

Returns

`OCI_SUCCESS`, `OCI_INVALID_HANDLE`, or `OCI_ERROR`.

Table 13–36 OCIFormatInit Keywords/Parameters

Keyword/Parameter	Meaning
`hndl (IN/OUT)`	the OCI environment or user session handle
`err (IN/OUT)`	the OCI error handle; if there is an error, it is recorded in `err` and this function returns `OCI_ERROR`; diagnostic information can be obtained by calling `OCIErrorGet`()

OCIFormatTerm

Syntax

```
sword OCIFormatTerm(dvoid *hndl, OCIError *err)
```

Remarks

Terminates the `OCIFormat` package. It must be called after the `OCIFormat` package is no longer being used and it must only be called once.

Returns

`OCI_SUCCESS`, `OCI_INVALID_HANDLE`, or `OCI_ERROR`.

Table 13–37 OCIFormatTerm Keywords/Parameters

Keyword/Parameter	Meaning
`hndl (IN/OUT)`	the OCI environment or user session handle
`err (IN/OUT)`	the `OCI` error handle. If there is an error, it is recorded in `err` and this function returns `OCI_ERROR`. Diagnostic information can be obtained by calling `OCIErrorGet`().

OCIFormatString

Syntax

```
sword OCIFormatString(dvoid *hndl, OCIError *err, text *buffer,
                      sbig_ora bufferLength, sbig_ora *returnLength,
                      CONST text *formatString,...);
```

Remarks

Writes a text string into the supplied text buffer using the argument list submitted to it and in accordance with the format string given. The first call to this routine must be preceded by a call to the `OCIFormatInit` routine that initializes the `OCIFormat` package for use. When this routine is no longer needed terminate the `OCIFormat` package by a call to the `OCIFormatTerm` routine.

Returns

`OCI_SUCCESS`, `OCI_INVALID_HANDLE`, or `OCI_ERROR`.

Table 13–38 OCIFormatString Keywords/Parameters

Keyword/Parameter	Meaning
`hndl (IN/OUT)`	the OCI environment or user session handle
`err (IN/OUT)`	the OCI error handle; if there is an error, it is recorded in `err` and this function returns `OCI_ERROR`; diagnostic information can be obtained by calling `OCIErrorGet`()
buffer (OUT)	the buffer that contains the string
bufferLength (IN)	the length of the buffer in bytes
returnLength (OUT)	the number of bytes written to buffer (excluding the terminating `NULL`)
formatString (IN)	the format string which can be any combination of literal text and format specifications. A format specification is delimited by the '%' character and is followed by any number (including none) of optional format modifiers and terminated by a mandatory format code. If the format string ends with '%', i.e. with no format modifiers or format specifier following it, then no action is taken. The format modifiers and format codes available are described below.

Table 13–38 OCIFormatString Keywords/Parameters (Cont.)

Keyword/Parameter	Meaning

... (IN)	variable number of arguments of the form `<OCIFormat type wrapper>`(`<variable>`) where `<variable>` must be a variable containing the value to be used - no constant values or expressions are allowed as arguments to the `OCIFormat` type wrappers; the `OCIFormat` type wrappers that are available are listed below; the argument list must be terminated with `OCIFormatEnd`
	`OCIFormatUb1(ub1 variable);`
	`OCIFormatUb2(ub2 variable);`
	`OCIFormatUb4(ub4 variable);`
	`OCIFormatUword(uword variable);`
	`OCIFormatUbig_ora(ubig_ora variable);`
	`OCIFormatSb1(sb1 variable);`
	`OCIFormatSb2(sb2 variable);`
	`OCIFormatSb4(sb4 variable);`
	`OCIFormatSword(sword variable);`
	`OCIFormatSbig_ora(sbig_ora variable);`
	`OCIFormatEb1(eb1 variable);`
	`OCIFormatEb2(eb2 variable);`
	`OCIFormatEb4(eb4 variable);`
	`OCIFormatEword(eword variable);`
	`OCIFormatChar (text variable);`
	`OCIFormatText(CONST text *variable);`
	`OCIFormatDouble(double variable);`
	`OCIFormatDvoid(CONST dvoid *variable);`
	`OCIFormatEnd`

Format Modifiers

A format modifier alters or extends the format specification, allowing more specialized output. The format modifiers may be in any order and are all optional.

Flags (in any order)

Flag	Operation
`'-'`	left-justify the output in the field
`'+'`	always print a sign ('+' or '-') for numeric types
`' '`	if a number's sign is not printed then print a space in the sign position
`'0'`	pad numeric output with zeros not spaces

- If both the `'+'` and `' '` flags are used in the same format specification then the `' '` flag is ignored.
- If both the `'-'` and `'0'` flags are used in the same format specification then the `'-'` flag is ignored.

Alternate output:

- For the octal format code add a leading zero.
- For the hexadecimal format code add a leading '0x'.
- For floating point format codes the output will always have a radix character.

Field Width

`<w>` where `<w>` is a number specifying a minimum field width. The converted argument will be printed in a field at least this wide, and wider if necessary. If the converted argument takes up fewer display positions than the field width, it will be padded on the left (or right for left justification) to make up the field width. The padding character is normally a space, but it is a zero if the zero padding flag was specified. The special character `'*'` may be used in place of `<w>` and indicates the current argument is to be used for the field width value, the actual field or precision follows as the next sequential argument.

Precision

`.<p>` specifies a period followed by the number `<p>`**,** specifying the maximum number of display positions to print from a string, or digits after the radix point for a decimal number, or the minimum number of digits to print for an integer type (leading zeroes will be added to make up the difference). The special character `'*'` may be used in place of `<p>` indicating the current argument contains the precision value.

Argument Index

(`<n>`) where `<n>` is an integer index into the argument list with the first argument being 1. If no argument index is specified in a format specification the first argument is selected. The next time no argument index is specified in a format specification the second argument is selected and so on. Format specifications with and without argument indexes can be in any order and are independent of each other in operation.

For example, the format string `"%u %(4)u %u %(2)u %u"` selects the first, fourth, second, second, and third arguments given to `OCIFormatString`.

Format Codes

A format code specifies how to format an argument that is being written to a string.

Note that these codes can appear in upper case, which will cause all alphabetic characters in the output to appear in upper case except for text strings, which are not converted.

Codes	Operation
`'c'`	single-byte character in the compiler character set
`'d'`	signed decimal integer
`'e'`	exponential (scientific) notation of the form `[-]<d><r>[<d>...]e+[<d>]<d><d>` where `<r>` is the radix character for the current language and `<d>` is any single digit; the default precision is given by the constant `OCIFormatDP`. the precision may be optionally specified as a format modifier - using a precision of 0 suppresses the radix character; the exponent is always printed in at least 2 digits, and can take up to 3 e.g. 1e+01, 1e+10, and 1e+100
`'f'`	fixed decimal notation of the form `[-]<d>[<d>...]<r>[<d>...]` where `<r>` is the appropriate radix character for the current language and `<d>` is any single digit; the precision may be optionally specified as a format modifier- using a precision of 0 suppresses the radix character. the default precision is given by the constant `OCIFormatDP`
`'g'`	variable floating-point notation; chooses `'e'` or `'f'`, selecting `'f''` if the number will fit in the specified precision (default precision if unspecified), and choosing `'e'` only if exponential format will allow more significant digits to be printed; does not print a radix character if number has no fractional part
`'i'`	identical to `'d'`
`'o'`	unsigned octal integer
`'p'`	platform specific pointer printout

Codes	Operation
’s’	prints an argument using the default format code for its type: ociformatub<n>, ociformatuword, ociformatubig_ ora, ociformateb<n>, and ociformateword. the format code used is 'u'. ociformatsb<n>, ociformatsword, and ociformatsbig_ ora. the format code used is 'd'. ociformatchar the format code used is 'c'. ociformattext prints text until trailing null is found. ociformatdouble the format code used is 'g'. ociformatdvoid the format code used is 'p'. ' %' - print a '%'.
’u’	unsigned decimal integer
’x’	unsigned hexadecimal integer

Example

```
/* This example shows the power of arbitrary argument    */
/* selection in the context of internationalization.  A  */
/* date is formatted in 2 different ways for 2 different */
/* countries according to the format string yet the      */
/* argument list submitted to OCIFormatString remains    */
/* invariant.                                            */

text      buffer[255];
ub1       day, month, year;
OCIError *err;
dvoid    *hndl;

/* Set the date. */

day   = 10;
month = 3;
year  = 97;

/* Work out the date in United States' style: mm/dd/yy *:/
OCIFormatString(hndl, err,
                buffer, (sbig_ora)sizeof(buffer),
                (CONST text *)"%(2)02u/%(1)02u/%(3)02u",
                OCIFormatUb1(day),
                OCIFormatUb1(month),
                OCIFormatUb1(year),
                OCIFormatEnd);    /* Buffer is "03/10/97". */

/* Work out the date in New Zealand style: dd/mm/yy *:/
OCIFormatString(hndl, err,
                buffer, (sbig_ora)sizeof(buffer),
                (CONST text *)"%(1)02u/%(2)02u/%(3)02u",
                OCIFormatUb1(day),
                OCIFormatUb1(month),
                OCIFormatUb1(year),
                OCIFormatEnd);    /* Buffer is "10/03/97". */
```

14

Reference — Extensibility Constants & Types

System Defined Constants

All the constants referred to in this document are defined in the `ODCIConst` package installed as part of the catodci.sql script. There are equivalent definitions for use within C routines in odci.h.

We strongly recommend that you use these constants instead of hardcoding their underlying values in your routines.

Alter Options Values

- `AlterOptionNone`
- `AlterOptionRename`
- `AlterOptionRebuild`

ODCIArgDesc.ArgType Bits

- `ArgOther`
- `ArgCol`
- `ArgLit`
- `ArgAttr`
- `ArgNull`

ODCIPredInfo.Flag Bits

- `PredExactMatch`
- `PredPrefixMatch`
- `PredIncludeStart`
- `PredIncludeStop`
- `PredObjectFunc`
- `PredObjectPkg`
- `PredObjectType`

ODCIFuncInfo.Flags Bits

- `ObjectFunc`
- `ObjectPkg`
- `ObjectType`

ODCIQueryInfo.Flags Bits

- `QueryFirstRows`
- `QueryAllRows`

ODCIStatsOptions.Flags Bits

- `EstimateStats`
- `ComputeStats`
- `Validate`

DCIStatsOptions.Options Bits

- `PercentOption`
- RowOption

ScnFlg (Function with Index Context) values

- `RegularCall`
- `CleanupCall`

Status Values

- `Success`
- `Error`
- `Warning`

System Defined Types

A number of *system-defined types* are defined by Oracle and need to be created by running the catodci.sql catalog script. The C mappings for these object ytpes are defined odci.h The `ODCIIndex` routines that follow use these types as parameters.

Unless otherwise mentioned, the names pased as type attributes are unquoted identifiers.

ODCIArgDesc

Name

`ODCIArgDesc`

Datatype

Object type.

Purpose

Stores function / operator arguments.

Table 14–1 Function/Operator Argument Description — Attributes

Name	Datatype	Purpose
`ArgType`	`NUMBER`	Argument type - see "ODCICost" on page 14-18
`TableName`	`VARCHAR2(30)`	Name of table
`TableSchema`	`VARCHAR2(30)`	Schema containing the table
`ColName`	`VARCHAR2(4000)`	Name of column. This could be top level column name such as "A", or a nested column "A"."B" Note that the column name are quoted identifiers.

ODCIArgDescList

Name

`ODCIArgDesc`

Datatype

`VARRAY(32767) of ODCIArgDesc`

Purpose

Lists descriptions of arguments.

ODCIRidList

Name

`ODCIRidList`

Datatype

`VARRAY(32767) OF VARCHAR2("M_URID_SZ")`

Purpose

Stores list of rowids. The rowids are stored in their character format.

ODCIColInfo

Name

`ODCIColInfo`

Datatype

Object type.

Purpose

Stores information related column.

Table 14–2 Column Related Information — Attributes

Name	Datatype	Purpose
`TableSchema`	`VARCHAR2(30)`	Schema containing table
`TableName`	`VARCHAR2(30)`	Name of table
`ColName`	`VARCHAR2(4000)`	Name of column. This could be top level column name such as "A", or a nested column "A"."B" Note that the column name are quoted identifiers.
`ColTypeName`	`VARCHAR2(30)`	Datatype of column
`ColTypeSchema`	`VARCHAR2(30)`	Schema containing datatype if user-defined datatype

ODCIColInfoList

Name

`ODCIColInfoList`

Datatype

`VARRAY(32) OF ODCIColInfo`

Purpose

Stores information related to a list of columns.

ODCICost

Name

`ODCICost`

Datatype

Object type.

Purpose

Stores cost information.

Table 14–3 Cost Information — Attributes

Name	Datatype	Purpose
`CPUCost`	`NUMBER`	`CPU cost`
`IOCost`	`NUMBER`	`I/O cost`
`NetworkCost`	`NUMBER`	`Communication cost`

ODCIFuncInfo

Name

`ODCIFuncInfo`

Datatype

Object type.

Purpose

Stores function information.

Table 14–4 Function Information — Attributes

Name	Datatype	Purpose
`ObjectSchema`	`VARCHAR2(30)`	`Object schema name`
`ObjectName`	`VARCHAR2(30)`	`Function/package/type name`
`MethodName`	`VARCHAR2(30)`	`Method name for package/type`
`Flags`	`NUMBER`	`Function flags - see ODCIConst`

ODCIIndexInfo

Name

`ODCIIndexInfo`

Datatype

Object type

Purpose

Stores the metadata information related to a domain index. It is passed as a parameter to all `ODCIIndex` routines.

Table 14–5 Index Related Information — Attributes

Name	Datatype	Purpose
`IndexSchema`	`VARCHAR2(30)`	Schema containing domain index
`IndexName`	`VARCHAR2(30)`	Name of domain index
`IndexCols`	`ODCIColInfoList`	List of indexed columns

ODCIPredInfo

Name

`ODCIPredInfo`

Datatype

Object type

Purpose

Stores the metadata information related to a predicate containing a user-defined operator or function. It is also passed as a parameter to `ODCIIndexStart`() query routine.

Table 14–6 Operator Related Information — Attributes

Name	Datatype	Purpose
`ObjectSchema`	`VARCHAR2(30)`	Schema of operator/function
`ObjectName`	`VARCHAR2(30)`	Name of operator/function
`MethodName`	`VARCHAR2(30)`	Name of method, applies only to package methods type
`Flags`	`NUMBER`	The possible flags that could be set are: PredExactMatch - Exact Match PredPrefixMatch - Prefix Match PredIncludeStart - Bounds include the start key value PredIncludeStop - Bounds include the stop key value PredObjectFunc - Object is a function PredObjectPlg - Object is a package PredObjectType - Object is a type

ODCIIndexCtx

Name

`ODCIIndexCtx`

Datatype

Object type

Purpose

Stores the index context, including the domain index metadata and the `ROWID`. It is passed as parameter to the functional implementation of an operator that expects index context.

Table 14–7 Index Context Related Information — Attributes

Name	Datatype	Purpose
`IndexInfo`	`ODCIIndexInfo`	stores the metadata information about the domain index
`rid`	`VARCHAR2("M_URID_SZ")`	row identifier of the current row

ODCIObject

Name

`ODCIObject`

Datatype

Object type

Purpose

Stores information about a schema object.

Table 14–8 Index Context Related Information — Attributes

Name	Datatype	Purpose
`ObjectSchema`	`VARCHAR2(30)`	Name of schema in which object is located
`ObjectName`	`VARCHAR2(30)`	Name of object

ODCIObjectList

Name

`ODCIObjectList`

Datatype

VARRAY(32) OF ODCIObject

Purpose

Stores information about a list of schema objects.

ODCIQueryInfo

Name

`ODCIQueryInfo`

Datatype

Object type

Purpose

Stores information about the context of a query. It is passed as a parameter to the `ODCIIndexStart` routine.

Table 14–9 Index Context Related Information — Attributes

Name	Datatype	Purpose
`Flags`	`NUMBER`	The following flags can be set: QueryFirstRows — ’`FIRST_ROWS`’ specified in the query QueryAllRows — ’`ALL_ROWS`’ specified in the query
`AncOps`	`ODCIObjectList`	Ancillary operators referenced in the query

ODCIStatsOptions

Name

`ODCIStatsOptions`

Datatype

Object type.

Purpose

Stores options information for ANALYZE.

Table 14–10 Cost Information — Attributes

Name	Datatype	Purpose
`Sample`	`NUMBER`	`Sample size`
`Options`	`NUMBER`	`ANALYZE options - see "ODCICost" on page 14-18`
`Flags`	`NUMBER`	`ANALYZE flags - see "ODCICost" on page 14-18`

15

Reference — Extensible Indexing Interface

The following ODCI (Oracle Data Cartridge Interface) interfaces are described:

- ODCIGetInterfaces
- ODCIIndexAlter
- OCDIIndexCreate
- ODCIIndexClose
- ODCIIndexDelete
- ODCIIndexDrop
- ODCIIndexFetch
- ODCIIndexGetMetadata
- ODCIIndexInsert
- ODCIIndexStart
- ODCIIndexTruncate
- OCIIndexUpdate

Extensible Indexing — System Defined Interface Routines

Caution: These routines are invoked by Oracle at the appropriate times based on SQL statements executed by the end user. The user should not try to invole these routines directly as this may result in corruption of index data.

ODCIGetInterfaces

Syntax

```
ODCIGetInterfaces(ifclist OUT ODCIObjectList) RETURN NUMBER
```

Purpose

The `ODCIGetInterfaces` function is invoked when an `INDEXTYPE` is created by a `CREATE INDEXTYPE...` statement.

Table 15–1 OCDIGetInterfaces Arguments

Argument	Meaning
`ifclist`	Contains information about the list of interfaces it supports

Returns

- `ODCIConst.Success` on success
- `ODCIConst.Error` on error.

Usage Notes

This function should be implemented as a static type method.

This function must return `’SYS.ODCIINDEX1’` in the `ODCIObjectList`. This indicates that the indextype uses the first version of the `ODCIIndex` interface.

ODCIIndexAlter

Syntax

```
ODCIIndexAlter(ia ODCIIndexInfo, parms IN OUT VARCHAR2, alter_option NUMBER)
RETURN NUMBER
```

Purpose

The `ODCIIndexAlter` procedure is invoked when a domain index is altered using an `ALTER INDEX` statement.

Table 15–2 ODCIIndexAlter Arguments

Argument	Meaning
`ia`	Contains information about the indexed column(s)
`parms (IN)`	Parameter string if `ALTER INDEX PARAMETERS` or `ALTER INDEX REBUILD` contains the user specified parameter string if `ALTER INDEX RENAME` contain the new name of the domain index
`parms (OUT)`	Parameter string is only valid if `ALTER INDEX PARAMETERS` or `ALTER INDEX REBUILD`. Contains the resultant string to be stored in system catalogs

`alter_option`	Specifies one of the following options:
	`AlterIndexNone` if `ALTER INDEX PARAMETERS`
	`AlterIndexRename` if `ALTER INDEX RENAME`
	`AlterIndexRebuild` if `ALTER INDEX REBUILD`

Returns

- `ODCIConst.Success` on success
- `ODCIConst.Warning` on warning,
- `ODCIConst.Error` on error.

Usage Notes

- This function should be implemented as a static type method.

- An ALTER INDEX statement can be invoked for domain indexes in multiple ways.

  ```
  ALTER INDEX index_name
  PARAMETERS params;

  or

  ALTER INDEX index_name
  REBUILD PARAMETERS params;
  ```

  The precise behavior in these two cases is defined by the implementor. One possibility is that the first statement would merely reorganize the index based on the parameters while the second would rebuild it from scratch.
- The maximum length of the input parameters string is 1000 characters. The OUT value of the parms argument can be set to resultant parameters string to be stored in the system catalogs.
- The ALTER INDEX statement can also be used to rename a domain index in the following way:

  ```
  ALTER INDEX index_name
  RENAME TO new_index_name
  ```

  In this case, the new name of the domain index is passed to the parms argument.
- If the ODCIIndexAlter routine returns with the ODCIConst.Success, the index is valid and usable. If the ODCIIndexAlter routine returns with ODCIConst.Warning, the index is valid and usable but a warning message is returned to the user. If ODCIIndexAlter returns with an error (or exception), the domain index will be marked FAILED.
- When the ODCIIndexAlter routine is being executed, the domain index is marked LOADING.

OCDIIndexCreate

Syntax

`OCDIIndexCreate(ia ODCIIndexInfo, parms VARCHAR2) RETURN NUMBER`

Purpose

The `OCDIIndexCreate` procedure is invoked when a domain index is created by a `CREATE INDEX` ... `INDEXTYPE IS` .... `PARAMETERS` ... statement issued by the user.

Table 15–3 OCDIIndexCreate Arguments

Argument	Meaning
`ia`	Contains information about the indexed column
`parms`	Is the `PARAMETERS` string passed in uninterpreted by Oracle. The maximum size of the parameter string is 1000 characters.

Returns

- `ODCIConst.Success` on success
- `ODCIConst.Warning` on warning,
- `ODCIConst.Error` on error.

Usage Notes

- This function should be implemented as a static type method.
- The `OCDIIndexCreate` procedure should handle creation of indexes on both empty and non-empty tables. If the base table is not empty, the `OCDIIndexCreate` procedure can scan the entire table and generate index data.
- Every SQL statement executed by `OCDIIndexCreate` is treated as an independent operation. The changes made by `OCDIIndexCreate` are not guaranteed to be atomic.
- When the `OCDIIndexCreate` routine is being executed, the domain index is marked `LOADING`.
- If the `ODCIIndexCreate` routine returns with the `ODCIConst.Success`, the index is valid and usable. If the `ODCIIndexCreate` routine returns with `ODCIConst.Warning`, the index is valid and usable but a warning message is

returned to the user. If the `OCDIIndexCreate` routine returns with an `ODCIConst.Error` (or exception), the domain index will be marked `FAILED.`

- The only operations permitted on `FAILED` domain indexes is `DROP INDEX`, `TRUNCATE INDEX` or `ALTER INDEX REBUILD`.
- If a domain index is crated on an column of object type which contains a `REF` attribute, you should not be dereferencing the `REF`s while building your index. Dereferencing a `REF` fetches data from a different table instance. If the data in the other table is modifieD, you Will not be notified and your domain index will become incorrect.

ODCIIndexClose

Syntax

```
ODCIIndexClose(self IN <impltype>) RETURN NUMBER
```

Purpose

This procedure is invoked to end the processing of an operator.

Table 15–4 ODCIIndexClose Arguments

Argument	Meaning
`self(IN)`	Is the value of the context returned by the previous invocation of `ODCIIndexFetch`

Returns

- `ODCIConst.Success` on success
- `ODCIConst.Error` on error.

Usage Notes

- The index implementor can perform any appropriate actions to finish up the processing of an domain index scan, such as freeing memory and other resources.

ODCIIndexDelete

Syntax

```
ODCIIndexDelete(ia ODCIIndexInfo, rid VARCHAR2, oldval <icoltype>) RETURN NUMBER
```

Purpose

This procedure is invoked when a row is deleted from a table that has a domain index defined on one of its columns.

Table 15–5 ODCIIndexDelete Arguments

Argument	Meaning
`ia`	Contains information about the indexed column
`rid`	Is the row identifier of the deleted row
`oldval`	Is the value of the indexed column in the deleted row. The datatype is the same as that of the indexed column.

Returns

- `ODCIConst.Success` on success
- `ODCIConst.Error` on error.

Usage Notes

- This function should be implemented as a static type method.
- This procedure should delete index data corresponding to the deleted row from the appropriate tables/files storing index data.

ODCIIndexDrop

Syntax

```
ODCIIndexDrop(ia ODCIIndexInfo) RETURN NUMBER
```

Purpose

The `ODCIIndexDrop` procedure is invoked when a domain index is dropped explicitly using a `DROP INDEX` statement, or implicitly through a `DROP TABLE`, or `DROP USER` statement.

Table 15–6 ODCIIndexDrop Arguments

Argument	Meaning
`ia`	Contains information about the indexed column

Returns

- `ODCIConst.Success` on success
- `ODCIConst.Warning` on warning,
- `ODCIConst.Error` on error.

Usage Notes

- This function should be implemented as a static type method.
- This procedure should drop the domain index data.
- Since it is possible that the domain index is marked `FAILED` (due to abnormal termination of some DDL routine), the `ODCIIndexDrop` routine should be capable of cleaning up partially created domain indexes. When the `ODCIIndexDrop` routine is being executed, the domain index is marked `LOADING`.
- It should be noted that if the `ODCIIndexDrop` routine returns with an `ODCIConst.Error` or exception, the `DROP INDEX` statement would fail and the index would be marked `FAILED`. In that case, there is no mechanism to get rid of the domain index except by using the `FORCE` option. If the `ODCIIndexDrop` routine returns with `ODCIConst.Warning` in the case of an explicit `DROP INDEX` statement, the operation succeeds but a warning message is returned to the user.

ODCIIndexFetch

Syntax

```
ODCIIndexFetch(self IN [OUT] <impltype>, nrows IN NUMBER, rids OUT ODCIRidList)
RETURN NUMBER
```

Purpose

This procedure is invoked repeatedly to retrieve the rows satisfying the operator predicate.

Table 15–7 ODCIIndexFetch Arguments

Argument	Meaning
`self(IN)`	Is the value of the context returned by the previous call (to `ODCIIndexFetch` or to `ODCIIndexStart` if this is the first time fetch is being called for this operator instance
`self(OUT)`	The context that is passed to the next query-time call.Note that this parameter does not have to be defined as `OUT` if the value is not modified in this routine.
`nrows`	Is the maximum number of result rows that can be returned to Oracle in this call
`rids`	Is the array of row identifiers for the result rows being returned by this call

Returns

- `ODCIConst.Success` on success
- `ODCIConst.Error` on error.

Usage Notes

- `ODCIIndexFetch` returns rows satisfying the operator predicate. i.e. it returns the row identifiers of all the rows for which the operator return value falls within the specified bounds.
- Each call to `ODCIIndexFetch` can return a maximum of *nrows* number of rows. The value of *nrows* passed in is decided by Oracle based on some internal factors. However, the `ODCIIndexFetch` routine can return lesser than *nrows* number of rows. The row identifiers are returned through the output rids array.

A `NULL ROWID` (as an element of the rids array) indicates that all satisfying rows have been returned.

Assume that there are 3000 rows which satisfy the operator predicate, and that the value of `nrows` = 2000. The first invocation of `ODCIIndexFetch` can return the first 2000 rows. The second invocation can return a `ridlist` consisting of the remaining 1000 rows followed by a `NULL` element. The `NULL` value in `ridlist` indicates that all satisfying rows have now been returned.

- If the context value is changed within this call, the new value will be passed in to the subsequent query-time calls.

ODCIIndexGetMetadata

Syntax

```
FUNCTION ODCIIndexGetMetadata(
            ia          IN    ODCIIndexInfo,
            version     IN    VARCHAR2,
            new_block   OUT   PLS_INTEGER)
        RETURN VARCHAR2;
```

Purpose

This routine is called repeatedly to return a series of strings of PL/SQL code that comprise the non-dictionary metadata associated with the index in `ia`. The routine can pass whatever information is required at import time; that is, policy, version, preferences, and so on. This method on the `ODCIIndex` interface is required in version 8.1.3 and must be implemented by all domain index implementation types. If `ODCIIndexGetMetadata` is not found, export will abort the creation of the index. However, for the final release of 8.1, this method will be optional if no implementation-specific metadata is required.

Table 15–8 ODCIIndexGetMetadata Arguments

Argument	Description
ia	Specifies the index on which export is currently working.
version	Version of export making the call in the form `08.01.03.00.00`.
new_block	Non-zero (`TRUE`): Returned string starts a new PL/SQL block. Export will terminate the current block (if any) with `END`; and open a new block with `BEGIN` before writing strings to the dump file. The routine is called again. `0` (`FALSE`): Returned string continues current block. Export writes only the returned string to the dump file then calls the routine again.

Developers of domain index implementation types in 8.1.3 **must** implement `ODCIIndexGetMetadata` even if only to indicate that no PL/SQL metadata exists or that the index is not participating in fast rebuild.

For informational on the PL/SQL interfaces in `SYS.DBMS` that export will call, see *Oracle8i Supplied Packages Reference.*

Returns

- A null-terminated string containing a piece of an opaque block of PL/SQL code.
- A zero-length string indicates no more data; export stops calling the routine.

Usage Notes

This function should be implemented as a static type method.

The routine will be called repeatedly until the return string length is 0. If an index has no metadata to be exported using PL/SQL, it should return an empty string upon first call.

This routine can be used to build one or more blocks of anonymous PL/SQL code for execution by import.Each block returned will be invoked independently by import. That is, if a block fails for any reason at import time, subsequent blocks will still be invoked. Therefore any dependent code should be incorporated within a single block. The size of an individual block of PL/SQL code is limited only by the size of import's read buffer controlled by its `BUFFER` parameter.

The execution of these PL/SQL blocks at import time will be considered part of the associated domain index's creation. Therefore, their execution will be dependent upon the successful import of the index's underlying base table and user's setting of import's `INDEXES=Y/N` parameter, as is the creation of the index.

The routine should not pass back the `BEGIN/END` strings that open and close the individual blocks of PL/SQL code; export will add these to mark the individual units of execution.

The parameter `version` is the version number of the currently executing export client. Since export and import can be used to downgrade a database to the previous functional point release, it also represents the minimum server version you can expect to find at import time; it may be higher, but never lower.

The cartridge developer can use this information to determine what version of information should be written to the dump file. For example, assume the current server version is `08.02.00.00.00`, but the export version handed in is `08.01.04.00.00`. If a cartridge's metadata changed formats between 8.1 and 8.2, it would know to write the data to the dump file in 8.1 format anticipating an import into an 8.1.4 system. Server versions starting at 8.2 and higher will have to know how to convert 8.1 format metadata.

Some points of caution:

1. The data contained within the strings handed back to export must be completely platform-independent. That is, they should contain no binary

information that may reflect the endian nature of the export platform which may be different from the import platform. Binary information may be passed as hex strings and converted via RAWTOHEX and HEXTORAW.

2. The strings are translated from the export server to export client character set and are written to the dump file as such. At import time, they are translated from export client character set to import client character set, then from import client char set to import server character set when handed over the UPI interface.
3. Specifying a specific target schema in the execution of any of the PL/SQL blocks should be avoided as it will most likely cause an error if you exercise import's FROMUSER -> TOUSER schema replication feature. For example, a procedure prototype such as:

   ```
   PROCEDURE AQ_CREATE ( schema IN VARCHAR2, que_name IN VARCHAR2) ...
   ```
   Should be avoided since this will fail if you have remapped schema A to schema B on import. You can assume at import time that you are already connected to the target schema.
4. Export dump files from a particular version must be importable into all future versions. This means that all PL/SQL routines invoked within the anonymous PL/SQL blocks written to the dump file must be supported for all time. You may wish to encode some version information to assist with detecting when conversion may be required.
5. Export will be operating in a read-only transaction if its parameter CONSISTENT=Y. In this case, no writes are allowed from the export session. Therefore, this method must not write any database state.
6. You can attempt to import the same dump file multiple times, especially when using import's IGNORE=Y parameter. Therefore, this method must produce PL/SQL code that is idempotent, or at least deterministic when executed multiple times.
7. Case on database object names must be preserved; that is, objects named 'Foo' and 'FOO' are distinct objects. Database object names should be enclosed within double quotes ("") to preserve case.

Error Handling

Any unrecoverable error should raise an exception allowing it to propagate back to get_domain_index_metadata and thence back to export. This will cause export to abort the creation of the current index's DDL in the dump file and to move on to the next index.

At import time, failure of the execution of any metadata PL/SQL block will cause the associated index to not be created under the assumption that the metadata creation is an integral part of the index creation.

ODCIIndexInsert

Syntax

```
ODCIIndexInsert(ia ODCIIndexInfo, rid VARCHAR2, newval <icoltype>) RETURN NUMBER
```

Purpose

This procedure is invoked when a new row is inserted into a table that has a domain index defined on one of its columns.

Table 15–9 ODCIIndexInsert Arguments

Argument	Meaning
`ia`	Contains information about the indexed column
`rid`	Is the row identifier of the new row in the table
`newval`	Is the value of the indexed column in the inserted row.

Returns

- `ODCIConst.Success` on success
- `ODCIConst.Error` on error.

Usage Notes

This function should be implemented as a static type method.

This procedure should insert index data corresponding to the new row into the appropriate tables/files storing index data.

ODCIIndexStart

Syntax

```
ODCIIndexStart(scanctx IN OUT <impltype>, ia ODCIIndexInfo, pi ODCIPredInfo, qi
ODCIQueryInfo, strt <opbndtype>, stop <opbndtype>, <valargs>) RETURN NUMBER
```

Purpose

This procedure is invoked to start the evaluation of an operator on an indexed column.

Table 15–10 ODCIIndexStart Arguments

Argument	Meaning
`scanctx(IN)`	Is the value of the context returned by some previous related query-time call (e.g., the corresponding ancillary operator, if invoked before the primary operator), `NULL` otherwise
`scanctx(OUT)`	The context that is passed to the next query-time call; the next query-time call will be to `ODCIIndexFetch`
`ia`	Contains information about the indexed column
`pi`	Contains information about the operator predicate
`qi`	Contains query information (hints plus list of ancillary operators referenced)
`strt`	Is the start value of the bounds on the operator return value. The datatype is the same as that of the operator's return value
`stop`	Is the stop value of the bounds on the operator return value. The datatype is the same as that of the operator's return value.
`valargs`	Are the value arguments of the operator invocation. The number and datatypes of these arguments are the same as those of the value arguments to the operator.

Returns

- `ODCIConst.Success` on success
- `ODCIConst.Error` on error.

Usage Notes

- `ODCIIndexStart` is invoked to begin the evaluation of an operator on a indexed column. In particular, the following conditions hold:

  - The first argument to the operator is a column which has a domain index defined on it.
  - The indextype of the domain index (specified in `ODCIIndexInfo` parameter) supports the current operator.
  - All other arguments to the operator are value arguments (literals) which are passed in through the `<valargs>` parameters.
- The `ODCIIndexStart` procedure should initialize the index scan as needed (using the operator-related information in `pi` argument) and prepare for the subsequent invocations of `ODCIIndexFetch`.
- The `strt`, `stop` parameters together with the `bndflg` value in `ODCIPredInfo` parameter specify the range of values within which the operator return value should lie.
- Bounds for operator return values are specified as follows:
  - If the predicate to be evaluated is of the form `op LIKE val`, the `ODCIIndexPrefixMatch` flag is set. In this case, the start key contains the value `<val>` and the stop key value is irrelevant.
  - If the predicate to be evaluated is of the form `op` = `val`, the `ODCIIndexExactMatch` flag is set. In this case, the start key contains the value `<val>` and the stop key value is irrelevant.
  - If the predicate to be evaluated is of the form `op` > `val`, `startkey` contains the value `<val>` and stop key value is set to `NULL`. If the predicate is of the form `op` >= `<val>`, the flag `ODCIIndexIncludeStart` is also set.
  - If the predicate to be evaluated is of the form `op < val`, stop key contains the value <val> and the start key value is set to `NULL`. If the predicate is of the form `op <= val`, the flag `ODCIIndexIncludeStop` is also set.
- A context value can be returned back to Oracle (through the `SELF` argument) which will then be passed back to the next query-time call. The next call will be to `ODCIIndexFetch`, if the evaluation continues or to `ODCIIndexStart` if the evaluation is restarted. The context value can be used to store the entire evaluation state or just a handle to the memory containing the state.
- Note that if the same indextype supports multiple operators with different signatures, multiple `ODCIIndexStart` methods need to be implemented, one for each distinct combination of value argument datatypes. For example, if an indextype supports three operators:

  1. `op1(number, number)`

2. `op1(varchar2, varchar2)`
3. `op2(number, number)`

two `ODCIIndexStart` routines would need to be implemented:

– `ODCIIndexStart(...., NUMBER)`— handles cases (1) and (3) which has a `NUMBER` value argument

– `ODCIIndexStart(...., VARCHAR2)`— handles case (2) which has a `VARCHAR2` value argument

- The query information in `qi` parameter can be used to optimize the domain index scan, if possible. The query information includes hints that have been specified for the query and the list of relevant anciliary operators referenced in the query block.

ODCIIndexTruncate

Syntax

```
ODCIIndexTruncate(ia ODCIIndexInfo) RETURN NUMBER
```

Purpose

The `ODCIIndexTruncate` procedure is invoked when a `TRUNCATE` statement is issued against a table that has a domain index defined on one of its columns.

Table 15–11   ODCIIndexTruncate Arguments

Argument	Meaning
`ia`	Contains information about the indexed column

Returns

- `ODCIConst.Success` on success
- `ODCIConst.Warning` on warning,
- `ODCIConst.Error` on error.

Usage Notes

- This function should be implemented as a static type method.
- After this function executes, the domain index should be empty (corresponding to the empty base table).
- While the `ODCIIndexTruncate` routine is being executed, the domain index is marked `LOADING`. If the `ODCIIndexTruncate` routine returns with an `ODCIConst.Error` (or exception), the domain index will be marked `FAILED`. The only operation permitted on `FAILED` domain indexes is `DROP INDEX`, `TRUNCATE INDEX` or `ALTER INDEX REBUILD`. If `ODCIIndexTruncate` returns with `ODCIConst.Warning`, the operation succeeds but a warning message is returned to the user.

OCIIndexUpdate

Syntax

```
OCIIndexUpdate(ia ODCIIndexInfo, rid VARCHAR2, oldval <icoltype>, newval
<icoltype>) RETURN NUMBER
```

Purpose

This procedure is invoked when a column is updated that has a domain index defined on it.

Table 15–12 OCIIndexUpdate Arguments

Argument	Meaning
`ia`	Contains information about the indexed column
`rid`	Is the row identifier of the updated row
`oldval`	Is the value of the indexed column before the update. The datatype is the same as that of the indexed column.
`newval`	Is the value of the indexed column after the update. The datatype is the same as that of the indexed column.

Returns

- `ODCIConst.Success` on success
- `ODCIConst.Error` on error.

Usage Notes

- This procedure should update the index data (corresponding to the updated row) in the appropriate tables / files storing index data.
- In addition to a SQL `UPDATE` statement, a LOB value can be updated through a vairety of "`WRITE`" interfaces (see *Oracle8i Application Developer's Guide - Large Objects (LOBs)*). If a domain index is defined on a `LOB` column or an object type containing a `LOB` attribute, the `ODCIIndexUpdate` routine is called when a LOB locator is implicitly or explicitly closed after one or more write operations.

16

Reference — Extensible Optimizer Interface

This chapter describes the interfaces that are visible to the user and specifies the prototypes of all user-defined functions and procedures:

- Extensible Optimizer — Interface

Extensible Optimizer — Interface

EXPLAIN PLAN

`EXPLAIN PLAN` has been enhanced to show the user-defined CPU and I/O costs for domain indexes in the `OTHER` column of `PLAN_TABLE`. For example, suppose we have a table `Emp_tab` and a user-defined operator `Contains`. Further, suppose that there is a domain index `EmpResume_indx` on the `Resume_col` column of `Emp_tab`, and that the indextype of `EmpResume_indx` supports the operator `Contains`. Then, the query

```
SELECT * FROM Emp_tab WHERE Contains(Resume_col, 'Oracle') = 1
```

might have the following plan:

OPERATION	OPTIONS	OBJECT_NAME	OTHER
SELECT STATEMENT			
TABLE ACCESS	BY ROWID	EMP_TAB	
DOMAIN INDEX		EMPRESUME_INDX	CPU: 300, I/O:4

INDEX Hint

The index hint will apply to domain indexes. In other words, the index hint will force the optimizer to use the hinted index for a user-defined operator, if possible.

ORDERED_PREDICATES Hint

A new hint, called `ORDERED_PREDICATES`, will be introduced. This hint will force the optimizer to preserve the order of predicate evaluation (except those used for index keys) as specified in the `WHERE` clause of a SQL DML statement.

Example

Consider an example of how the statistics functions might be used. Suppose, in the schema `SCOTT`, we define the following:

```
CREATE OPERATOR Contains binding (VARCHAR2(4000), VARCHAR2(30))
   RETURN NUMBER USING Contains_fn;

CREATE TYPE stat1 (
   ...,
   STATIC FUNCTION ODCIStatsSelectivity(pred ODCIPredInfo, sel OUT NUMBER,
      args ODCIArgDescList, start NUMBER, stop NUMBER, doc VARCHAR2(4000),
      key VARCHAR2(30)) return NUMBER,
   STACTIC FUNCTION ODCIStatsFunctionCost(func ODCIFuncInfo, cost OUT
      ODCICost, args ODCIArgDescList, doc VARCHAR2(4000), key VARCHAR2(30))
      return NUMBER,
   STATIC FUNCTION ODCIStatsIndexCost(ia ODCIIndexInfo, sel NUMBER,
      cost OUT ODCICost, qi ODCIQueryInfo, pred ODCIPredInfo,
      args ODCIArgDescList, start NUMBER, stop NUMBER,
      key VARCHAR2(30)) return NUMBER,
   ...
);

CREATE TABLE T (resume VARCHAR2(4000));

CREATE INDEX T_resume on T(resume) INDEXTYPE IS indtype;

ASSOCIATE STATISTICS WITH FUNCTIONS Contains_fn USING stat1;

ASSOCIATE STATISTICS WITH INDEXES T_resume USING stat1;
```

When the optimizer encounters the query

```
SELECT * FROM T WHERE Contains(resume, 'ORACLE') = 1,
```

it will compute the selectivity of the predicate by invoking the user-defined selectivity function for the functional implementation of the `Contains` operator. In this case, the selectivity function is `stat1.ODCIStatsSelectivity`. It will be called as follows:

```
stat1.ODCIStatsSelectivity (
   ODCIPredInfo('SCOTT', 'Contains_fn', NULL, 29),
   sel,
   ODCIArgDescList(
      ODCIArgDesc(ODCIConst.ArgLit, NULL, NULL, NULL),
      ODCIArgDesc(ODCIConst.ArgLit, NULL, NULL, NULL),
      ODCIArgDesc(ODCIConst.ArgCol, 'T', 'SCOTT', '"resume"'),
      ODCIArgDesc(ODCIConst.ArgLit, NULL, NULL, NULL)),
      1,
      1,
      NULL,
      'ORACLE')
```

Suppose the selectivity function returns a selectivity of 3 (percent). When the domain index is being evaluated, then the optimizer will call the user-defined index cost function as follows:

```
stat1.ODCIStatsIndexCost (
   ODCIIndexInfo('SCOTT', 'T_resume',
      ODCIColInfoList(ODCIColInfo('SCOTT', 'T', '"resume"', NULL, NULL))),
      3,
      cost,
      NULL,
      ODCIPredInfo('SCOTT', 'Contains', NULL, 13),
      ODCIArgDescList( ODCIArgDesc(ODCIConst.ArgLit, NULL, NULL, NULL),
                       ODCIArgDesc(ODCIConst.ArgLit, NULL, NULL, NULL),
                       ODCIArgDesc(ODCIConst.ArgLit, NULL, NULL, NULL)),
      1,
      1,
      'ORACLE')
```

Suppose that the optimizer decides not to use the domain index because it is too expensive. Then it will call the user-defined cost function for the functional implementation of the operator as follows:

```
stat1.ODCIStatsFunctionCost (
   ODCIFuncInfo('SCOTT', 'Contains_fn', NULL, 1),
   cost,
   ODCIArgDescList(  ODCIArgDesc(ODCIConst.ArgCol, 'T', 'SCOTT', '"resume"'),
                     ODCIArgDesc(ODCIConst.ArgLit, NULL, NULL, NULL)),
   NULL,
   'ORACLE')
```

The following sections describe each statistics type function in greater detail.

User-Defined ODCIStats Functions

User-defined `ODCIStats` functions are used for table columns, functions, package, type, indextype or domain indexes. These functions are described below.

ODCIStatsCollect

User-defined statistics are collected by defining a function with the prototypes:

```
FUNCTION ODCIStatsCollect(col ODCIColInfo, options ODCIStatsOptions,
   statistics OUT RAW) return NUMBER
FUNCTION ODCIStatsCollect(ia ODCIIndexInfo, options ODCIStatsOptions,
   statistics OUT RAW) return NUMBER
```

Table 16–1 ODCIStatsCollect Parameters

Parameter	Meaning
`col`	column for which statistics are being collected
`ia`	domain index for which statistics are being collected
`options`	options passed to `ANALYZE`
`statistics`	user-defined statistics collected

The function returns `ODCIConst.Success`, `ODCIConst.Error`, or `ODCIConst.Warning.`

Usage Notes

This function should be implemented as a static type method.

ODCIStatsDelete

User-defined statistics are deleted by the ANALYZE command by calling the following user-defined functions:

```
FUNCTION ODCIStatsDelete(col ODCIColInfo) return NUMBER
FUNCTION ODCIStatsDelete(ia ODCIIndexInfo) return NUMBER
```

Table 16–2 ODCIStatsDelete Parameters

Parameter	Meaning
`col`	column for which statistics are being deleted
`ia`	domain index for which statistics are being deleted

The function returns `ODCIConst.Success`**,** `ODCIConst.Error`**, or** `ODCIConst.Warning.`

Usage Notes

This function should be implemented as a static type method.

ODCIStatsSelectivity

A user-defined selectivity function can be specified for a user-defined function or type method. The prototype for a user-defined selectivity function is as follows:

```
FUNCTION ODCIStatsSelectivity(pred ODCIPredInfo, sel OUT NUMBER, args
   ODCIArgDescList, start <function_return_type>, stop <function_return_type>,
   <list of function arguments>) return NUMBER
```

Table 16–3 ODCIStatsSelectivity Parameters

Parameter	Meaning
`pred`	predicate for which the selectivity is being computed
`sel`	the computed selectivity, expressed as a percent, in whole numbers between (and including) 0 and 100
args	descriptor of `start`, `stop`, and actual arguments with which the function, type method, or operator was called. If the function has *n* arguments, the `args` array will contain *n+2* elements, the first element describing the start value, the second element describing the stop value, and the remaining *n* elements describing the actual arguments of the function, method, or operator
start	lower bound of the function (e.g., 2 for a predicate `fn(...) > 2`)
stop	upper bound of the function (e.g., 5 for a predicate `fn(...) < 5`)
`<list of function arguments>`	list of actual parameters to the function or type method; the number, position, and type of each argument must be the same as in the function, type method, or operator

The function returns `ODCIConst.Success`**,** `ODCIConst.Error`**, or** `ODCIConst.Warning.`

Usage Notes

This function should be implemented as a static type method.

ODCIStatsFunctionCost

The cost of a function is computed by a function with the following prototype:

```
FUNCTION ODCIStatsFunctionCost(func ODCIFuncInfo, cost OUT ODCICost,
   args ODCIArgDescList, <list of function arguments>) return NUMBER
```

Table 16–4 ODCIStatsFunctionCost Parameters

Parameter	Meaning
`func`	function or type method for which the cost is being computed
`cost`	computed cost (must be positive whole numbers)
`args`	descriptor of actual arguments with which the function or type method was called. If the function has *n* arguments, the `args` array will contain *n* elements, each describing the actual arguments of the function or type method
`<list of function arguments>`	list of actual parameters to the function or type method; the number, position, and type of each argument must be the same as in the function or type method

The function returns `ODCIConst.Success`**,** `ODCIConst.Error`**, or** `ODCIConst.Warning`.

Usage Notes

This function should be implemented as a static type method.

ODCIStatsIndexCost

The cost of using a domain index is computed by a function with the following prototype:

```
FUNCTION ODCIStatsIndexCost(ia ODCIIndexInfo, sel NUMBER,
   cost OUT ODCICost, qi ODCIQueryInfo, pred ODCIPredInfo, args
   ODCIArgDescList, start <operator_return_type>,
   stop <operator_return_type>, <list of operator value arguments>)
   return NUMBER
```

Table 16–5 ODCIStatsIndexCost Parameters

Parameter	Meaning
`ia`	domain index for which statistics are being collected
`sel`	the user-computed selectivity of the predicate
`cost`	computed cost (must be positive whole numbers)
`qi`	information about the query
`args`	descriptor of `start`, `stop`, and actual value arguments with which the operator was called. If the operator has *n* arguments, the `args` array will contain *n+1* elements, the first element describing the start value, the second element describing the stop value, and the remaining *n-1* elements describing the actual value arguments of the operator (i.e., the arguments after the first)
`start`	lower bound of the operator (e.g., 2 for a predicate `fn(...) > 2)`
`stop`	upper bound of the operator (e.g., 5 for a predicate `fn(...) < 5)`
`<list of function arguments>`	list of actual parameters to the operator (excluding the first); the number, position, and type of each argument must be the same as in the operator

The function returns `ODCIConst.Success`**,** `ODCIConst.Error`**, or** `ODCIConst.Warning.`

Usage Notes

This function should be implemented as a static type method.

Index