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# An Introduction to the Source Code of the Pyrrho DBMS

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# 1. Introduction

For a general introduction to using the Pyrrho DBMS, including its aims and objectives, see the manual that forms part of the distribution of Pyrrho. The web site pyrrhodb.com includes a set of clickable pages for the SQL syntax that Pyrrho uses. This document is for programmers who intend to examine the source code, and includes (for example) details of the data structures and internal locks that Pyrrho uses.

All of the implementation code of Pyrrho remains intellectual property of the University of the West of Scotland, and while you are at liberty to view and test the code and incorporate it into your own software, and thereby use any part of the code on a royalty-free basis, the terms of the license prohibit you from creating a competing product or from reverse engineering the professional edition.

I am proud to let the community examine this code, which has been available since 2005: I am conscious of how strongly programmers tend to feel about programming design principles, and the particular set of programming principles adopted here will please no one. But, perhaps surprisingly, the results of this code are robust and efficient, and the task of this document is to try to explain how and why.

This document has been updated to version 7 (July 2019) and aims to provide a gentle introduction for the enthusiast who wishes to explored the source code, and see how it works. The topics covered include the workings of all levels of the DBMS (the server) and the structure of the client library PyrrhoLink.dll. Over the years some features of Pyrrho and its client library have been added and others removed. At various times there has been support for Rdf and SPARQL, for Java Persistence, for distributed databases, Microsoft’s entity data models and data adapters, and MongoDB-style $ operators. These have been mostly removed over time: some support for Documents and Mandatory Access Control remains. In particular, the notion of multi-database connections is no longer supported.

Much of the structure and functionality of the Pyrrho DBMS is documented in the Manual. The details provided there include the syntax of the SQL2016 language used, the structure of the binary database files and the client-server protocol. Usage details from the manual will not be repeated here. In a few cases, some paragraphs from the user manual provide an introduction to sections of this document. The current version preserves the language, syntax and file format from previous versions and should be mostly[[1]](#footnote-1) compatible with existing database files (whether from Open Source or professional editions). From this version, there is only one edition of Pyrrho, the executables are called Pyrrho… and use append storage. All of the binaries work on Windows and Linux (using Mono). The EMBEDDED option is for creating a class library called EmbeddedPyrrho, with an embedded Pyrrho engine, rather than a database server.

The basic structure of the engine is completely changed in version 7. Many of the low-level internal details follow the design of StrongDBMS (see strongdbms.com), and all of the upper layers of the Pyrrho engine have been redesigned to use shareable data structures similar to StrongDBMS wherever possible. The implementation of roles is also completely redesigned, so that each role may have its own definition of tables, procedures, types and domains; the database schema role is used for operations on base tables.

The reader of this document is assumed to be a database expert and competent programmer. The DBMS itself has over 600 C# classes, spread over roughly 100 source files in 6 namespaces. The Excel worksheet Classes.xls lists all of the classes together with their location, superclass, and a brief description. The code itself is intended to be quite readable, with the 2019 version (C#7) of the language, notably including its ValueTuple feature.

This document avoids having a section for each class, or for each source file. Either of those designs for this document would result in tedious repetition of what is in the source. Instead, the structure of this document reflects the themes of design, with chapters addressing the role in the DBMS of particular groupings of related classes or methods.

# 2. Overall structure of the DBMS

## 2.1 Architecture

The following diagram shows the DBMS as a layered design. There is basically a namespace for each of four of the layers, and two other namepsaces, Pyrrho and Pyrrho.Common.

|  |  |  |
| --- | --- | --- |
| **Namespace** | **Title in the diagram** | **Description** |
| Pyrrho |  | The top level contains only the protocol management files Start.cs, HttpService.cs and Crypt.cs |
| Pyrrho.Common |  | Basic data structures: Integer, TypedValue, BTree, and the lexical analyzer for SQL. All classes in Common apart from Exception classes[[2]](#footnote-2), including Bookmarks for traversing them, are immutable and shareable[[3]](#footnote-3). |
| Pyrrho.Level1 | Database File, Database File Segments | Binary file management and buffering. |
| Pyrrho.Level2 | Physical Records | The Physical layer: with classes for serialisation of physical records. Physical objects are volatile so that shareable structures cannot contain them. |
| Pyrrho.Level3 | Logical Database | Database.cs, Transaction.cs, Value.cs and classes for database objects. All classes in Level3 (except Scanner and Signal) are immutable and shareable. |
| Pyrrho.Level4 | SQL processing | RowSet.cs, Parser.cs etc. All RowSets and most Cursors[[4]](#footnote-4) are immutable and shareable, and give access to the version of the RowSet that created them. |



## 2.2 Key Features of the Design

The following features are really design principles used in implementing the DBMS. There are important modifications to these principles that apply from v7.

1. Transaction commits correspond one-to-one to disk operations: completion of a transaction is accompanied by a force-write of a database record to the disk. The engine waits for this to complete in every case. Some previous versions of Pyrrho had a 5-byte end-of-file marker which was overwritten by each new transaction, but from version 7, all physical records once written are immutable. Deletion of records or database objects is a matter for the logical database, not the physical database. This makes the database fully auditable: the records for each transaction can always be recovered along with details about the transaction (the user, the timestamp, the role of the transaction).
2. Because data is immutable once recorded, the physical position of a record in the data file (its “defining position”) can be used to identify database objects and records for all future time (as names can change, and update and drop details may have a later file position). The transaction log threads together the physical records that refer to the same defining position but, from version 7, Pyrrho maintains the current state of base table rows in memory (using the TableRow class), and does not follow such non-scalable trails
3. Data structures at the level of the logical database (Level 3) are immutable and shareable. For example, if an entry in a list is to be changed, what happens at the data structure level is that a replacement element for the list is constructed and a new list descriptor which accesses the modified data, while the old list remains accessible from the old list descriptor. In this way creating a local copy or snapshot of the database (which occurs at the start of every transaction) consists merely to making a new header for accessing the lists of database objects etc. As the local transaction progresses, this header will point to new headers for these lists (as they are modified). If the transaction aborts or is rolled back, all of this data can be simply forgotten, leaving the database unchanged. With this design total separation of concurrent transactions is achieved, and local transactions always see consistent states of the database.
4. When a local transaction commits, however, the database cannot simply be replaced by the local transaction object, because other transactions may have been committed in the meantime. If any of these changes conflict with data that this transaction has read (read constraints) or is attempting to modify (transaction conflict), then the transaction cannot be committed. If there is no conflict, the physical records proposed in the local transaction are relocated onto the end of the database.
5. Following a successful commit, the database is updated using these same physical records. Thus all changes are applied twice – once in the local transaction and then after transaction commit – but the first can be usefully seen as a validation step, and involves many operations that do not need to be repeated at the commit stage: evaluation of expressions, check constraints, execution of stored procedures etc.
6. From version 7, database objects such as tables and domains cannot be modified if they hold data. The semantics of such changes in previous versions were not really manageable. There are necessarily several mutable structures: Reader, Writer, Context, and Physical (level 2). Physical objects are used only for marshalling serialisation and associated immutable objects replace Physicals in Level 3.
7. Data recorded in the database is intended to be non-localised (e.g. it uses Unicode with explicit character set and collation sequence information, universal time and date formats), and machine-independent (e.g. no built-in limitations as to machine data precision such as 32-bit). Default value expressions, check constraints, views, stored procedures etc are stored in the physical database in SQL2011 source form, and parsed to a binary form when the database is loaded.
8. The database implementation uses an immutable form of B-Trees throughout (note: B-Trees are *not* binary trees). Lazy traversal of B-Tree structures (using immutable bookmarks) is used throughout the query processing part of the database. This brings dramatic advantages where search conditions can be propagated down to the level of B-Tree traversal.
9. Traversing a rowset recovers rows containing TypeValues, and the bookmark for the current row becomes is accessible from the Context. This matches well with the top-down approach to parsing and query processing that is used throughout Level 4 of the code. In v7, the evaluation stack is somewhat flattened. A new Context is pushed on the context stack for a new procedure block or activation, or when there is a change of role. The new context receives a copy of the previous context’s immutable tree structures, which are re-exposed when the top of the stack is removed.
10. The aim of SQL query processing is to bridge the gap between bottom-up knowledge of traversable data in tables and joins (e.g. columns in the above sense) and top-down analysis of value expressions. Analysis of any kind of query goes through a set of stages: (a) source analysis to establish where the data is coming from, (b) computation of the result data types, (c) conditions analysis which examines which search and join conditions can be handled in table enumeration, (d) ordering analysis which looks not only at the ordering requirements coming from explicit ORDER BY requests from the client but also at the ordering required during join evaluation and aggregation, and finally (e) RowSet construction, which chooses the best enumeration method to meet all the above requirements.
11. Executables and SqlValues are immutable level 3 objects that are constructed by the parser. They are not stored in the database, but reconstructed on creation or loading. Procedure bodies being read from the database can contain SqlValues with positions allocated according to the current Reader position. Objects constructed from the input stream of the transaction can use the position in the input stream provided that this accumulates from the start of the transaction rather than the start of the current input line. This is the responsibility of Server.Execute(sql) and SqlHTTPService parser calls.

## 2.3 Multi-threading, uids, and dynamic memory layout

In accordance with the above notes, each Connection has its own PyrrhoServer instance in a separate thread (Pyrrho has no other threads). There is a static set of immutable copies of databases (as committed) and filenames from which a new server instance will start with the committed version of the database it will work with. This set is initially empty accessible from all server threads and protected by the only lock used by Pyrrho. Initialisation also sets up the \_system database, containing primitive types and system tables. Every database structure includes this immutable information. No other cross-thread access is possible in Pyrrho.

Unique identifiers are central to the v7 design of Pyrrho. At the database level (level 3) of the design, each object (including Database and Transaction) contains an association called mem indexed by 64-bit uids. Importantly, uids are also used at level 4 of the engine for run-time data structures, in Contexts and Activations, which manage a similar association called values. This section outlines a rationale for the allocation of uids and the significance of their ranges of values.

Databases contain committed data, which uses two ranges of uids. A fixed set of approximately 1000 uids<0 are used for a set of system objects (constants, tables, domains), and file positions in range 0..262-1 are used to identify committed objects in the database. Some objects with uids in this range are indexed in the objects tree so they can be referenced elsewhere. The Role object allows object uids to be found by name (objects can be renamed by roles). Apart from such referencing, uids are used in evaluation contexts to manage values and object visibility, and to identify expressions that are equivalent, so the uniqueness of uids is very important in this design.

Transactions contain uncommitted objects, so the uids must be managed differently. A transaction allocates uids above 4×260 for uncommitted objects (e.g. proposed new physical records). These uids are retained until the transaction is committed or rolled back and form a natural stack. On commit, the transaction’s objects are serialised to the data file, whereupon the uids are replaced with the committed file positions.

This means that the transaction works with a mixture of committed and uncommitted database objects (table, column, domain etc). Any query processed by the transaction may contain multiple references to the same tables and columns, which may have different values[[5]](#footnote-5) so that each reference gets a new uid.

So far so good. However, not all uncommitted objects have the same lifetime. Prepared statements are connection based and so persist beyond the end of a transaction, and triggers and stored procedures become dynamic objects with shorter lifetimes (command, statement, etc). If a server is to run for a long time, available memory would be exhausted. It is not attractive to intervene at various stages to avoid exhaustion of the available space, traversing the lists of uncommitted objects to compactify the lists. As an experiment, the current implementation seeks to stratify things by identifying different uid ranges for different treatment. We begin by limiting the range for uncommitted physical records to 4×260..5×260..-1. The lifetime of objects in this range is the duration of the transaction.

During query analysis, transactions allocate space for objects local to the processing of the current Command. Uids in the range 5×260..6×260-1are allocated based on the lexical position of objects in the command text (see worked example in sec 6). The highwatermark for this process is called nextIid (in the Context). Thus, all identifiers that occur in the SQL are replaced during parsing with uids in this range as allocated on the first occurrence in the command text. Columns not referred to will be given temporary uids from the nextHeap range, described below: they cannot use their defining position as this might conflict via a separate reference to the table in the SQL (subqueries, views etc).

As a result of the above considerations, the replacement of identifier-based references with uids proceeds from left to right during parsing. When source identifiers are resolved to column references, a lexical id is given to the column reference. If the resulting DBObjects are serialised to the database (stored procedures, triggers), the source code only is saved in the transaction log, and instead of reparsing, each such lexical or heap uid is replaced by a physical or (respectively) statement uid based on the permanent file position of the lexeme. Finally, we note that several roles may be involved, so that columns in a table may be defined by different roles, and be differently referred to in stored procedures, triggers, and constraints.

Several database object types (e.g. Procedure, Check, Trigger, View) define executable code. The physical records in the transaction log record their definition in source form and are called Compiled objects (see sec 3.4.2). During the load phase the executable fragments are parsed, and the resulting executable structures are relocated in memory into the physical address space so that their uids lie between the start and end of the corresponding record in the log. Such objects are immutable and shareable, so that any derived executables (copies of view definitions, filtered rowsets) will be given new temporary uids in the heap range. This rule also applies to uncommitted compiled objects whose shareable uids are relocated if necessary to the same uid range as the definition.

A “connection” range of uids, 7×260..8×260-1 is for prepared statements, as these accumulate and are shared with future transactions for this connection, but are not committed. Each transaction starts with the current database snapshot and this set of prepared statements (the highwatermark is called db.nextPrep). The temporary uids mentioned above work in reverse for prepared statements as it is the uids in the query analysis range that get relocated to the prepared statement range. In the Context there are twin functions called Unheap and UnLex that deal with these contrary relocations.

Schema changes cannot be introduced during such execution of stored procedures, and so the heap is local to the current Command: the execution context initialises cx.nextHeap using db.nextPrep.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| System objects | -8×260..-1 | Basis.\_uid (downwards) | Global |  |
| File positions | 0.. 4×260-1 | 0 (upwards) | Persisted in file |  |
| New Physicals | 4×260..5×260-1 | Database.nextPos (up) | Local to Transaction | ! |
| Query analysis | 5×260..6×260-1 | Database.nextIid (up) | Local to Statement | # |
| Executables | 6×260..7×260-1 | Database.nextStmt (up) | Local to Database | @ |
| Prepared Stmts | 7×260.. nextPrep | Database.nextPrep (up) | Local to Connection | % |
| Heap storage | nextPrep.. 8×260-1 | Context.nextHeap (up) | Local to Command | % |

The boundaries of these ranges are subject to change in later versions of Pyrrho, as they are internal to the engine and not relevant to durable file contents. Allocation of uids in each ranges need to be independent for the following reasons:

* File positions: audit requires asynchronous writing to the transaction log during a transaction. Such asynchronous writing cannot occur during the transaction commit as this process occupies the thread.
* New Physicals: can be created because of triggers and domain refinement at various points during a transaction step. There is a dependency field that helps to ensure that serialisation duing commit takes place in an orderly way.
* Query analysis objects such as cursors need to be managed within statement processing, but the statement Obey() can cause creation of new physicals.
* Storage for compiled statements is local to a database, is immutable, and can be used by successive steps in a transaction and successive transactions.
* The prepared statement storage is semi-persistent and shared among sequential transactions in a single connection independently of commit. This storage can be shared with heap storage.
* Compiled objects have a framing field, which (even when serialised to the database file) may have uids in any of the above unshareable ranges.

As a result of this design, there are numerous recursive methods in Basis and DBObject for relocating things. All objects have a simple Relocate() object that merely changes the defing position, without considering cross-references, and another

Many of these algorithms operate in two stages: scanning an object and its internal references, and reconstructing the object with different uids for its fields (separate mappings are used for rowset uids and those of other DBObjects).

The following relocation processes are distinguished in the source code:

* At the end of a transaction step, objects with heap uids are relocated to the lexical range. This is triggered by Transaction.Unheap(), which calls Relocate(cx) on each Physical, and this cascades to any referenced DBObjects., using Fix(cx).
* Objects with Lexical positions in a new prepared statement are relocated to above the executable range[[6]](#footnote-6). This is done using framing.Relocate(cx), which relocates objects it contains using ObReloc() and RsReloc(). Then framing.Fix(cx) updates the references.
* Transaction commit relocates proposed object uids to final file positions. This is part of the Physical.Commit() implementation and not a separate process. References are fixed during serialisation to the data file. The associated DBObjects, previously installed during the transaction, are relocated to their new positions using \_Relocate(wr), where wr is the commit’s Writer.
* For Database, Load and Install of the framing field relocates all lexical and executable uids in the framing into the file position range.
* View instancing reverses the framing commit process. First the objects in the framing are Scanned to identify object and rowset references. Each referenced object is relocated to the heap range. Context.FixAll() then calls Fix on each object to fix references.

At most one of these relocation operations is in progress at any one time: a field in Context notes the current relocation operation.

Replacement and review of a DBObject allows for more general changes, and therefore must use different algorithms. There are two of these:

* Replacement of an object during parsing uses a two-stage algorithm with an auxiliary catalogue called depths. The method is at Context.Replace(). In the first stage objects at each are scanned using \_Replace, which adds a new version to cx.done. These are then installed in the Context.
* Review of the RowSets in a context is currently performed using a cascade based on rowset source. The method at Context.Review() calls Review() methods on each RowSet. Context.FixAll()is then called which calls Fix() on each object..

Contexts form a tree-like stack of frames, providing an easy support for recursive procedure execution, and in the SQL programming language, dynamic structures are accessible only by direct reference.

## 2.4 The folder and project structure for the source code

The src folder contains

* Folders for the Pyrrho applications: PyrroCmd, PyrrhoTest, PyrrhoJC, and PyrrhoSQL.
* The Shared folder contains the sources for the PyrrhoDBMS engine and the PyrrhoLink API and this arrangement is described next.

The Shared folder contains files and folders for the two currently supported overlapping solutions PyrrhoLink (PL), and PyrrhoSvr (PS).

* The Properties folder handles Visual Studio project stricture. Unusually, it has subfolders for isolating the AssemblyInfo for each of the 3 solutions.
* The Common, Level1, Level2, Level3, and Level4 folders contain the real code base for the DBMS.
* Transaction instances are also created to validate rename, drop and delete operations before these are executed.

# 3. Basic Data Structures

In this chapter we discuss some of the fundamental data structures used in the DBMS. Data structures selected for discussion in this chapter have been chosen because they are sufficiently complex or unusual to require such discussion. All of the source code described in this section is in the Pyrrho.Common namespace: all of the classes in this namespace are immutable and shareable[[7]](#footnote-7).

## 3.1 B-Trees and BLists

Almost all indexing and cataloguing tasks in the database are done by BTrees. These are basically sorted lists of pairs (key,value), where key is comparable. In addition, sets and partial orderings use a degenerate sort of catalogue in which the values are not used (and are all the single value **true**).

There are several subclasses of BTree used in the database: Some of these implement multilevel indexes. BTree itself is a subclass of an abstract class called ATree. The BTree class provides the main implementation. These basic tree implementations are generic, and require type parameters, e.g. BTree<long,bool> . The supplied type parameters identify the data type used for keys and values. BTree is used when the key type is a IComparable. If the values are also IComparable, CTree is used instead (CTree is then IComparable).

See 3.1.5 for a list of related B-Tree classes used in Pyrrho. All are immutable and shareable. BTree<K,V> is shareable provided K and V are, or provided no nonshareable objects have been inserted.

### 3.1.1 B-Tree structure

The B-Tree is a widely-used, fully scalable mechanism for maintaining indexes. B-Trees as described in textbooks vary in detail, so the following account is given here to explain the code.

A B-Tree is formed of nodes called Buckets. Each Bucket is either a Leaf bucket or an Inner Bucket. A Leaf contains up to N KeyValuePairs. An Inner Bucket contains key-value pairs whose values are pointers to Buckets, and a further pointer to a Bucket, so that an Inner Bucket contains pointers to N+1 Buckets altogether (“at the next level”). In each Bucket the KeyValuePairs are kept in order of their key values, and the key-value pairs in Inner buckets contain the first key value for the next lower-level Bucket, so that the extra Bucket is for all values bigger than the last key. All of these classes take a type parameter to indicate the key type.

The value of N in Pyrrho is currently 8: the performance of the database does not change much for values of N between 4 and 32. For ease of drawing, the illustrations in this section show N=4.

The BTree itself contains a root Bucket and some other data we discuss later.

6

6

Root (Inner)

The BTree dynamically reorganizes its structure so that (apart from the root) all Buckets have at least N/2 key-value pairs, and at each level in the tree, Buckets are either all Inner or all Leaf buckets, so that the depth of the tree is the same at all values.

Leaves

6

8

1

3

4

### 3.1.2 ATree<K,V>

The basic operations on B-Trees are defined in the abstract base class ATree<K,V>:, ATree<K,V>.Add, ATree<K,V>.Remove etc, and associated operators + and -.

For a multilevel index, Key can be an array or row (this is implemented in MTree and RTree, see section 3.2). ATree itself is immutable and shareable (but its subclasses might not be, see footnote).

The following table shows the most commonly-used operations:

|  |  |
| --- | --- |
| **Name** | **Description** |
| long Count | The number of items in the tree |
| object this[key] | Get the value for a given key |
| bool Contains(key) | Whether the tree contains the given key |
| ABookmark<K,V> First() | Provides a bookmark for the first pair in the B-tree |
| ABookmark<K,V>Last() | Provides a bookmark for the last pair in the B-tree |
| static Add(ref T, Key, Value) | For the given tree T, add entry Key,Value . |
| static Remove(ref T, Key) | For the given tree T, remove the association for Key. |

However, in version 7 these fundamental operations are made protected, and modifications to B-Trees uses + and – operators. So, to add a new (key,value) pair to a BTree t, we write code such as

t += (key,value);

and to remove a key we write t -= key; . The current version of Visual Studio colours the operator brown to indicate the use of a custom method. Custom operators are static, and so the implementation chosen depends on the declared type of t .

Some B-Trees have values that are also B-Trees, and for these it is convenient to define addition and removal operators for different tuple types (such as triples). BList<V> is a subclass of BTree<int,V> .

If x is BTree<K,V> and V is a class with a default value d, we can write safe code such as x[k]??d, and this avoids having to check x.Contains(k) . If V is object we currently need to write extra brackets in expressions such as (long)(x[k]??-1L).

### 3.1.3 TreeInfo

There are many different sorts of B-Tree used in the DBMS. The TreeInfo construct helps to keep track of things, especially for multilevel indexes (which are used for multicolumn primary and foreign keys).

TreeInfo has the following structure:

|  |  |
| --- | --- |
| **Name** | **Description** |
| Ident headName | The name of the head element of the key |
| Domain headType | The data type of the head element of the key |
| Domain kType | Defines the type of a compound key. |
| TreeBehaviour onDuplicate | How the tree should behave on finding a duplicate key. The options are Allow, Disallow, and Ignore. A tree that allows duplicate keys values provides an additional tree structure to disambiguate the values in a partial ordering. |
| TreeBehaviour onNullKey | How the tree should behave on finding that a key is null (or contains a component that is null). Trees used as indexes specify Disallow for this field. |
| TreeInfo tail | Information about the remaining components of the key |

### 3.1.4 ABookmark<K,V>

Starting with version 6.0 of Pyrrho, we no longer use .NET IEnumerator interfaces, replacing these with immutable and thread-safe structures. Bookmarks mark a place in a sequence or tree, and allow moving on to the next or previous item if any. Every B-Tree provides method First() and Last() that returns a bookmark for the first (resp. last) element of the tree (or null if the tree is empty).

ABookmark<K,V> has method Next() and Previous() which returns a bookmark for the next (resp. previous) element if any.

|  |  |
| --- | --- |
| **Name** | **Description** |
| ABookmark<K,V> Next() |  |
| ABookmark<K,V> Previous() |  |
| K key() | The key at the current position |
| long position() | The current position (stars at 0) |
| V value() | The value at the current position |

Cursors follow a similar pattern (see section 3.6.10).

### 3.1.5 ATree<K,V> Subclasses

Other implementations provide special actions on insert and delete (e.g. tidying up empty nodes in a multilevel index).

The main implementation work is shared between the abstract BTree<K,V> and Bucket<K,V> classes and their immediate subclasses.

There are just 5 ATree subclasses, all sharing the same base implementation::

|  |  |  |
| --- | --- | --- |
| **Name** | **BaseClass** | **Description** |
| BList<V> | BTree<K,V> | Same as BList<V> with a shortcut for adding to the end |
| CList<V> | BList<V> | Same as BList<V> where V is IComparable, allows comparison of lists |
| BTree<K,V> | ATree<K,V> | The main implementation of B-Trees, where K is IComparable |
| CTree<K,V> | BTree<K,V> | V is also IComparable, and so is the tree |
| SqlTree | CTree<TypedValue,  TypedValue> | For one-level indexes where the keys and values have readonly strong types |
| Idents | BTree<string,  (DBObject,Idents)> | This behaves like a lookup tree for Ident->DBObject where the comparison of Idents is as identifierchains. |

If V is a value such as int or long, it is often convenient to use nullable versions: for example a queue of longs can be conveniently implemented as BList<long?>, and then q -= 0 means “remove the head of the queue” since 0 is an int, the head of the list is x[0], which may be null, and q += k means “add k to the end of the queue” (k is converted to long).

The following related immutable classes are contained in the Level3 and Level4 namespaces. Neither of these is a subclass of ATree.

|  |  |
| --- | --- |
| MTree | For multilevel indexes where the value type is long? |
| RTree | For multilevel indexes where the value type is SqlRow |

## 3.2 Other Common Data Structures

### 3.2.1 Integer

All integer data stored in the database uses a base-256 multiple precision format, as follows: The first byte contains the number of bytes following.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| #bytes (=n, say) | data0 | data1 | … | data(n-1) |

data0 is the most significant byte, and the last byte the least significant. The high-order bit 0x80 in data0 is a sign bit: if it is set, the data (including the sign bit) is a 256s-complement negative number, that is, if all the bits are taken together from most significant to least significant, that data is an ordinary 2s-complement binary number. The maximum Integer value with this format is therefore 22039-1 .

Some special values: Zero is represented as a single byte (0x00) giving the length as 0. -1 is represented in two bytes (0x01 0xff) giving the length as 1, and the data as -1. Otherwise, leading 0 and -1 bytes in the data are suppressed.

Within the DBMS, the most commonly used integer format is long (64 bits), and Integer is used only when necessary.

With the current version of the client library, integer data is always sent to the client as strings (of decimal digits), but other kinds of integers (such as defining positions in a database, lengths of strings etc) use 32 or 64 bit machine-specific formats.

The Integer class in the DBMS contains implementations of all the usual arithmetic operators, and conversion functions.

### 3.2.2 Decimal

All numeric data stored in the database uses this type, which is a scaled Integer format: an Integer mantissa followed by a 32-bit scale factor indicating the number of bytes of the mantissa that represent a fractional value. (Thus strictly speaking “decimal” is a misnomer, since it has nothing to do with the number 10, but there seems no word in English to express the concept required.)

Normalisation of a Decimal consists in removing trailing 0 bytes and adjusting the scale.

Within the DBMS, the machine-specific double format is used.

With the current version of the client library, numeric data is always sent to the client in the Invariant culture string format.

The Decimal class in the DBMS contains implementations of all the usual arithmetic operations except division. There is a division method, but a maximum precision needs to be specified. This precision is taken from the domain definition for the field, if specified, or is 13 bytes by default: i.e. the default precision provides for a mantissa of up to 2103-1 .

### 3.2.3 Character Data

All character data is stored in the database in Unicode UTF8 (culture-neutral) format. Domains and character manipulation in SQL can specify a “culture”, and string operations in the DBMS then conform to the culture specified for the particular operation.

The .NET library provides a very good implementation of the requirements here, and is used in the DBMS. Unfortunately .NET handles Normalization a bit differently from SQL2011, so there are five low-level SQL functions whose implementation is problematic.

### 3.2.4 Documents

From v.5.1 Pyrrho includes an implementation of Documents similar to MongoDB, however the $ operators of MongoDB are not provided from v7.

Document comparison is implemented as matching fields: this means that fields are ignored in the comparison unless they are in both documents (the $exists operator modifies this behaviour). This simple mechanism can be combined with a partitioning scheme, so that a simple SELECT statement where the where-clause contains a document value will be propagated efficiently into the relevant partitions and will retrieve only the records where the documents match. Moreover, indexes can use document field values.

### 3.2.5 Domain

Strong types (Domains) are used internally for all processing. ObInfos are role objects used in the Database layer, in the sense that the role contains details of object names, column ordering, and accessibility for the role: see section 3.5.7. In the Database layer (level 3), objects have uids but not names. In the Transaction layer (level 4), SqlValues and Queries have names for the current role (the current role and user are maintained by the Context).

The Domain provides methods of input and output of data, parsing and formatting of value strings, coercing, checking assignability etc. Domain representations allow for sub-columns defined by uid and Domain, but do not specify a column ordering.

At the Transaction level, ad-hoc domains are supported, and defining position of a Domain is ignored. Domains are equal if they have the same properties (other than the defpos), and there is an arbitrary comparison method based on properties. All queries have row types where each column matches a specific Domain, and during query analysis, the computation of the result type involves many such ad hoc structures, and it is not reasonable to have defining positions for them all.

On the other hand, all level 3 (committed) objects have domains that should have defining positions. In particular user-defined Types are implemented as Domains. For these, and for table-valued functions, the structure of the components of the Domain is given by a list of Domains, in SQL called the representation. In SQL such a representation is given by specifying the columns as in a table definition. In the physical database this table definition is explicit, and there is called the structure definition. When arrays and multisets contain structured objects, the structure is defined in a similar way.

To resolve this dilemma, the Pyrrho engine allows ad-hoc domains to have a defining position of -1. All structured domains have a representation. However, when committing objects to a database the Domain.Create function looks to see if the database already defines a domain with the same structure, and if so, the relevant table definition is referenced as the structure of the Domain. The representation is not separately stored in the physical database.

Then when a Domain is loaded from the physical database, the structure’s table definition is retrieved, and the representation is constructed for internal reference.

The following well-known standard types are defined by the Domain class:

|  |  |
| --- | --- |
| **Name** | **Description** |
| Null | The data type of the null value |
| Wild | The data type of a wildcard for traversing compound indexes |
| Bool | The Boolean data type (see BooleanType) |
| RdfBool | The iri-defined version of this |
| Blob | The data type for byte[] |
| MTree | Multi-level index (used in implementation of MTree indexes) |
| Partial | Partially-ordered set (ditto) |
| Char | The unbounded Unicode character string |
| RdfString | The iri-defined version of this |
| XML | The SQL XML type |
| Int | A high-precision integer (up to 2048 bits) |
| RdfInteger | The iri-defined version of this (in principle unbounded) |
| RdfInt | value>=-2147483648 and value<=2147483647 |
| RdfLong | value>=-9223372036854775808 and value<=9223372036854775807 |
| RdfShort | value>=-32768 and value<=32768 |
| RdfByte | value>=-128 and value<=127 |
| RdfUnsignedInt | value>=0 and value<=4294967295 |
| RdfUnsignedLong | value>=0 and value<=18446744073709551615 |
| RdfUnsignedShort | value>=0 and value<=65535 |
| RdfUnsignedByte | value>=0 and value<=255 |
| RdfNonPositiveInteger | value<=0 |
| RdfNegativeInteger | value<0 |
| RdfPositiveInteger | value>0 |
| RdfNonNegativeInteger | value>=0 |
| Numeric | The SQL fixed point datatype |
| RdfDecimal | The iri-defined version of this |
| Real | The SQL approximate-precision datatype |
| RdfDouble | The iri-defined version of this |
| RdfFloat | Defined as Real with 6 digits of precision |
| Date | The SQL date type |
| RdfDate | The iri-defined version of this |
| Timespan | The SQL time type |
| Timestamp | The SQL timestamp data type |
| RdfDateTime | The iri-defined version of this |
| Interval | The SQL Interval type |
| Collection | The SQL array type |
| Multiset | The SQL multiset type |
| UnionNumeric | A union data type for constants that can be coerced to numeric or real |
| UnionDate | A union of Date, Timespan, Timestamp, Interval for constants |

See also sec 3.5.3.

### 3.2.6 TypedValue

A TypedValue has a Domain and an ordering of columns, and a tree of values. TypedValues are immutable, even TArray, TMultiset and TDocument. As with all immutable objects operators such as + provide a new TypedValue.

The following lists the subclasses of TypedValue:

|  |
| --- |
| Cursor |
| TArray |
| TBlob |
| TBool |
| TChar |
| TContext |
| TDateTime |
| TDocArray |
| TDocument |
| TInt |
| TInterval |
| TMTree |
| TMultiset |
| TNull |
| TNumeric |
| TPartial |
| TPeriod |
| TReal |
| TRow |
| TRvv |
| TTimeSpan |
| TTypeSpec |
| TUnion |
| TXml |

### 3.2.7 Ident

An Ident is a dotted identifier chain, and is used to support the analysis of SQL queries during parsing. This construct appears in multiple places in the syntax (see below). Ident is immutable.

|  |  |
| --- | --- |
| CompareTo(ob) | Support alphanumeric comparison of Ident |
| string ident | The head portion of the Ident |
| *Ident(…)* | *Numerous constructors* |
| long iix | A unique uid, usually obtained from the lexer position |
| int Length | The number of segments in the Ident |
| Ident sub | The tail of the Ident |
| string ToString() | A readable version of the Ident |

There is a special tree structure Ident.Idents for handling definitions during parsing. Formally it is a subclass of BTree<string,(long, Ident.Idents)>. It contains SqlValues and Queries indexed by name for the current role (not ObInfo, Domain, or any sort of TypedValues). During parsing, subobject information is added in the Ident.Idents part to deal with query aliases (but not internal structure of SqlValues). The idea is as follows:

Given an Ident chain, there are three possibilities: (a) the chain identifies a unique SqlValue or query, (b) the first part of the chain identifies a query, document or structured object and the rest of the chain leads to a field or child object, (c) the chain is a reference to something that the parse has not yet reached.

There are two lookup this[] functions: one that takes an Ident and returns the DBObject associated, and another that works on the first part of an ident chain. It takes a pair (Ident, int) and retains a pair (DBObject, Idents) giving the object reached and the subtree from that point. There is also a this[] function that takes a string, inherited from the BTree<(DBObject, Ident.Idents)> superclass.

During join processing, column names that are ambiguous and not referenced in the query may get renamed with a dotted notation, similar to a chain. In this case, the aliased column name is treated a s string containing a dot, not a chain. See an example of this process in section 6.1.

## 3.3 File Storage (level 1)

At this level, the class IOBase manages FileStreams, with ReaderBase and WriterBase for the encoding the data classes defined above. The Reader and Writer classes are for reading from and writing to the transaction log, and contain instantaneous snapshots of the database as it evolves during these operations. At the conclusion of Database.Load(), and Transaction.Commit the final version of the database is recorded in a static database list.

The locking required for transaction management is limited to locking the underlying FileStream during Commit() and managing the static list of databases. The FileStream is also locked during seek-read combinations when Readers are created. The binary file transaction log format is almost unchanged since the earliest versions of Pyrrho: every edition of the user manual has documented the file format as a sequence of physical records[[8]](#footnote-8). It uses 8-bit bytes and Unicode UTF8 for strings, but otherwise is independent of machine architecture, operating system, or location.

There are full details of the file format in the Pyrrho Manual, together with a brief outline of the client-server protocol. Some further details are given below.

### 3.3.1 Client-server protocol

In auto-commit mode (implicit transactions) there is generally no acknowledgement of a successful end of the transaction. If an acknowledged service is important, use the Trace requests, or use explicit transactions: note the options of CommitAndReport and CommitAndReportTrace.

Not all services have a response byte.

Note that the request and response bytes are followed by data (for example, DoneTrace, or Schema). See the Manual.

|  |  |  |  |
| --- | --- | --- | --- |
| **Request** | **Intermediate** | **Final response** |  |
| (Connect/Open) |  | Primary |  |
| (Error) |  | Exception |  |
|  | FatalError |  |
| *Authority* |  | *Done* |  |
| BeginTransaction |  |  | unacknowledged |
| CloseConnection |  |  | unacknowledged |
| CloseReader |  |  | unacknowledged |
| Commit | {Warning} | Done |  |
| CommitAndReport  CommitAndReport1 | {Warning} | TransactionReport |  |
| CommitAndReportTrace  CommitAndReportTrace1 | {Warning} | TransactionReportTrace |  |
| CommitTrace | {Warning} | DoneTrace |  |
| Execute | {Warning} | Done |  |
| Schema |  |
| ExecuteTrace | {Warning} | DoneTrace |  |
| Schema |  |
| ExecuteNonQuery | {Warning} | Done |  |
| ExecuteNonQueryTrace | {Warning} | DoneTrace |  |
| ExecuteReader | {Warning} | Done |  |
| Schema |  |
| Get  Get1 | {Warning} | Schema |  |
| Done |  |
| NoData |  |
| Get2 | {Warning} | Schema1 |  |
| Done |  |
| NoData |  |
| GetFileNames |  | Files |  |
| GetInfo | {Warning} | NoData |  |
| Columns |
| Post | {Warning}  Schema | Done |  |
| Put | {Warning}  Schema | Done |  |
| Prepare |  | Done |  |
| ReaderData |  | NoData |  |
|  | ReaderData |  |
| ResetReader |  | Done |  |
| Rest | {Warning} | Schema |  |
| Rollback |  | Done |  |
| TypeInfo |  | (data) |  |

## 3.4 Physical (level 2)

Physical is the base class used for actual items stored in the database file. Physical subclasses are identified by the Physical.Type enumeration, whose values are actually stored in the database. The defining position of a Physical is given by the Reader or Writer position when reading or writing a database file, and for uncommitted objects has a uid exceeding 4×260. Uncommitted objects are those created during parsing, when the parser creates new Physical structures: and adds them to the Transaction. Since Transaction is immutable this means that each Physical gets installed in a new Transaction with a uid given by the lexical position in the source read by the transaction. This object defpos is replaced on Commit by its position in the transaction log. Every thread has its own sequence of uncommitted uids (see sec 2.3), restarting at 4×260 after Commit. For ease of reading, the resulting temporary defpos are rendered in ToString() as !0, !1, !2 etc.

During Commit, the sequence of Physical records prepared by a Transaction is actually written (serialised) to durable media, and the uncommitted uids are replaced by the file positions.

Each Physical type contributes a part of the serialization and deserialization implementation. For example, an Update Physical contributes some fields, and calls its base class (Record) to continue the serialization, and finally Record calls Physical’s serialization method. The Physical layer is level 2 of Pyrrho.

In version 7 many of the so-called Physical classes in memory are subclasses of Compiled, and these have a framing field structures belonging to level 4: for example, expressions and executable statements. These objects are not serialised to or from disk: as in previous versions of Pyrrho stored procedures, queries, triggers etc are recoded in the log in source (string) form. During database Load these source strings are compiled (see sec 3.4.2 below) into an immutable form that is simply cached in the Context when required.

### 3.4.1 Physical subclasses (Level 2)

The type field of the Physical base class is an enum Physical.Type, as shown here:

|  |  |  |  |
| --- | --- | --- | --- |
| **Code** | **Class** | **Base class** | **Description** |
| 0 | EndOfFile | Physical | Checksum record at end of file |
| 1 | PTable | Physical | Defines a table name |
| 2 | PRole | Physical | A Roleand description |
| 3 | PColumn | Physical | Defines a TableColumn or Type field |
| 4 | Record | Physical | Records an INSERT to a table |
| 5 | Update | Record | Records an UPDATE of a record |
| 6 | Change | Physical | Renaming of non-column objects |
| 7 | Alter | PColumn2 | Modify column definition |
| 8 | Drop | Physical | Forget a database object |
| 9 | Checkpoint | Physical | A synchronization point |
| 10 | Delete | Physical | Forget a record from a table |
| 11 | Edit | PDomain | ALTER DOMAIN details |
| 12 | PIndex | Physical | Entity, unique, references |
| 13 | Modify | Physical | Change proc, method, trigger,check,view |
| 14 | PDomain | Physical | Define a Domain |
| 15 | PCheck | Physical | Check constraint for something |
| 16 | *PProcedure* | *Physical* | *Stored procedure/function (deprecated, see below)* |
| 17 | PTrigger | Physical | Define a trigger |
| 18 | PView | Physical | Define a niew |
| 19 | PUser | Physical | Record a user name |
| 20 | PTransaction | Physical | Record a transaction |
| 21 | Grant | Physical | Grant privileges to something |
| 22 | Revoke | Grant | Revoke privileges |
| 23 | PRole1 | Physical | Record a role name |
| 24 | PColumn2 | PColumn | For more column constraints |
| 25 | PType | PDomain | A user-defined structured type |
| 26 | PMethod | PProcedure | A method for a PType (deprecated, see below) |
| 27 | PTransaction2 | PTransaction | Distributed transaction support |
| 28 | Ordering | Physical | Ordering for a user-defined type |
| 29 | (NotUsed) |  |  |
| 30 | PDateType | PDomain | For interval types |
| 31 | *PTemporalView* | *Physical* | *A View for a Temporal Table (obsolete)* |
| 32 | PImportTransaction | PTransaction | A transaction with a source URI |
| 33 | Record1 | Record | A record with provenance URI |
| 34 | PType1 | PType | A user-defined type with a reference URI |
| 35 | PProcedure2 | Physical | (PProcedure2) Specifies return type information |
| 36 | PMethod2 | PProcedures | (PMethod2) Specifies return type information |
| 37 | PIndex1 | PIndex | Adapter coercing to a referential constraint |
| 38 | Reference | Physical | Adapter coerces to a reference constraint |
| 39 | Record2 | Record | Used for record subtyping |
| 40 | Curated | Physical | Record curation of the database |
| *41* | *Partitioned* | *Physical* | *Record a partitioning of the database* |
| 42 | PDomain1 | PDomain | For OWL data types |
| 43 | Namespace | Physical | For OWL data types |
| 44 | PTable1 | PTable | For OWL row types |
| 45 | Alter2 | PColumn2 | Change column names |
| 46 | AlterRowIri | PTable1 | Change OWL row types |
| 47 | PColumn3 | PColumn2 | Add new column constraints |
| 48 | Alter3 | PColumn3 | Alter column constraints |
| *49* | *PView1* | *Pview* | *Define update rules for a view (obsolete)* |
| 50 | Metadata | Physical | Record metadata for a database object |
| 51 | PeriodDef | Physical | Define a period (pair of base columns) |
| 52 | Versioning | Physical | Specify system or application versioning |
| 53 | PCheck2 | PCheck | Constraints for more general types of object |
| *54* | *Partition* | *Physical* | *Manages schema for a partition* |
| 55 | *Reference1* | *Reference* | *For cross-partition references* |
| 56 | ColumnPath | Physical | Records path selectors needed for constraints |
| 57 | Metadata2 | Metadata | Additional fields for column information |
| 58 | Index2 | Index | Supports deep structure |
| 59 | *DeleteReference1* | *Reference* |  |
| 60 | Authenticate |  | Credential information for web-based login |
| 61 | RestView | View | Views defined over HTTP |
| 62 | TriggeredAction |  | Distinguishes triggered parts of a transaction |
| 63 | *RestView1* | *RestView* | *deprecated* |
| 64 | Metadata3 | Metadata | Additional fields for column information in views |
| 65 | RestView2 | RestView | Support for GET USING |

### 3.4.2 Compiled and Framing

Compiled objects include Triggers, Constraints, Views, Procedures and Methods. Procedures and Methods use the SQL stored persistent modules language as described in the SQL standard, including the handling of conditions (exceptions). When compiled code is invoked, it runs in the definer’s role, as specified by the SQL standard.

Following the design outlined in this document, the transaction log contains only the source form of compiled objects, while the in-memory database contains the compiled version. From version 7, parsing is done only on definition, and following parsing everything is referred to by uid, not by using string identifiers. As their name implies, uids are unique in the database, but they are private to the implementation, and are subject to change is later versions of the DBMS.

There are differences in operation of the different versions, however. Up to version 6.3 of the DBMS (file format 5.1) the source code contained database object positions instead of the definer’s name for database objects. This approach is supported in version 7 of the DBMS for database files created with previous versions. Databases created with version 7 or later (file format >5.1) will contain the source code exactly as given by the definer. This is generally supported by previous versions of the DBMS, but objects will display differently in the Log$ system tables.

There is a subclass of Physical for the associated Level2 objects, to provide helper methods for the compilation process. The in-memory data structures resulting from parsing include SqlValues, Queries, and Executables. Compiled objects exist in one of three forms, as follows:

* OnLoad(), recreates the Framing (see sec 3.5.18) for the compiled object from deserialised source code. so that the compiled data structures naturally use uids based on lexical positions of source identifiers in the database file.
* At the end of parsing, the Framing field of the Compiled class receives the generated DBObjects and RowSets, with any heap uids relocated to transaction locations above 5×260. Other uids will be either those of physical objects, or locations in the source code (from the database file, or the SQL command).
* On Commit(), when the Compiled Physical is being relocated to its final (file) position, the compiled object uids are also relocated within the range of file positions occupied by the new Physical record. This enables the new compiled object to activate in the current Database.

This design means that the uids of the objects in the framing field will be different depending on which of these three stages applies. The uids that differ are not generally visible, and the in-memory compiled code structures are otherwise identical.

When the compiled object is referenced at runtime, the DBObject’s framing field is installed in the Context, sharing its (immutable) objects with the referring queries. During query optimisation, if filters, where-conditions or assignments are applied to shared immutable objects, a new non-shared copy must be created: this is important for updatable Views.

Compiled objects have an immutable property called Framing, which holds the results of parsing the object definition. It is a subclass of Basis (see below).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Key** | **Property** | **Type** | **Comment** | **Uid** |
| Data | data | BList<long,RowSet> | RowSet | -450 |
| ObRefs | obrefs | BTree<long,BTree<long,VIC?>> | View Instancing | -451 |
| Obs | obs | BTree<long,DBObject> | DBObjects other than RowSet | -449 |
| RefObs | refobs | BTree<long,BTree<long,VIC?>> | Inverse of obrefs | -460 |
| Resullt | result | long | RowSet | -452 |
| Results | results | BTree<long,long> | Query->RowSet | -453 |

## 3.5 Database Level Data Structures (Level 3)

### 3.5.1 Basis

To ensure shareability and immutability of database objects, the Basis class is used as the base class for most things in Level3 of Pyrrho. Basis contains a flexible way of maintaining object properties in a in a per-object BTree<long,object> called mem. Recall that BTree and its subclasses are themselves immutable.

// negative keys are for system data, positive for user-defined data

public readonly BTree<long, object> mem;

Database, DBObject and Record are direct subclasses of Basis, as are helper level 3 classes such as OrderSpec, WindowBound etc. All subclasses of Basis in the implementation are shareable.

The “user-defined data” for the positive part of mem is defined for the following subclasses of Basis:

|  |  |
| --- | --- |
| **Basis subclass** | **User-defined data** |
| Database, Transaction | DBObjects |
| Role | ObInfos |
| Table | TableRows |
| TableRow | Fields |

Negative uids are for named properties of the different subclasses of Basis and for predefinied system objects (such as standard types, system tables, and their columns). The same API pattern is used for Basis and all its classes. Each subclass defines a set of properties, which are assigned negative uids during engine initialisation. Basis itself defines the Name property.

|  |  |  |  |
| --- | --- | --- | --- |
| **Key** | **Property** | **Type** | **Uid** |
| Name | name | string | -50 |

In the code a key is defined as follows:

internal const long Name = --\_uid; // string

The name property is then accessed by

public string name => (string)mem[Name]??"";

This defines name as a readonly property of Basis[[9]](#footnote-9).

Basis subclasses typically have just two constructors, one public, the other protected: both derive from the single constructor in the abstract class Basis:

protected Basis (BTree<long,object> m) { mem = m; }

Each Basis subclass must define a New method with signature New(BTree<long,object> m). Each Basis subclasses (eg XX) defines an operator for “adding” a property value by creating a new instance:

public static XX operator+(XX b,(long,object)x) {

return b.New(b.mem + x);

}

(See sec 3.1.2 for the definition of ATree’s + operator). For example, given a basis object b, to change its name to ‘xyz’, we can write

b += (Basis.Name, "xyz");

The above coding pattern is used throughout version 7. Some classes define further operators in the same way.

The following sections list other subclasses of Basis (other than Framing, see the previous section).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Key** | **Property** | **Type** | **Subclass** | **Uid** |
| Val | val | long | UpdateAssignment | -237 |
| Vbl | vbl | long | UpdateAssignment | -238 |
| FDConds | conds | BTree<long,bool> | FDJoinPart | -211 |
| FDIndex | index | long | FDJoinPart | -212 |
| FDRefIndex | rindex | long | FDJoinPart | -213 |
| FDRefTable | rtable | long | FDJoinPart | -214 |
| FDTable | table | long | FDJoinPart | -215 |
| Reverse | reverse | bool | FDJoinPart | -216 |
| Items | items | CList<long> | OrderSpec | -217 |
| \_Generation | generation | Generation | GenerationRule | -273 |
| GenExp | exp | SqlValue | GenerationRule | -274 |
| GenString | gfs | string | GenerationRule | -275 |

### 3.5.2 Database

Database is a subclass of Basis. The database class manages all of the database objects and all transactional proposals for updating them. The base class (Database) is used to share databases with a number of connections. Like other level 3 objects, Database is immutable and shareable, so that Reader, Writer and Transaction all have their own version of the database they are working on[[10]](#footnote-10). The current committed state of each database can be obtained from the Database.databases list, and the current state of the transaction logs can be obtained from the Database.databases list. Both of these structures are protected, and accessed using locking in just 2 or 3 places in the code.

The subclasses of Database are described in this section, and are as follows

|  |  |  |
| --- | --- | --- |
| **Class** | **Base Class** | **Description** |
| Database | Basis |  |
| Transaction | Database |  |

The level 3 Database structure maintains the following data:

* Its name, usually just the name of the database file (not including the extension), but see above in this section
* The current position (loadpos) in the associated database file (level 1): at any time this is where the next Commit operation will place a new transaction.
* The id of the user who owns the database
* The list of database objects defined for this database.

All committed DBObjects accessible from the Database class have a defining position given by a fixed position in the transaction log. In v7, the Transaction subclass additionally allows access to its thread-local uncommitted objects, where the defining position is in the range for uncommitted objects, above 262, and this is derived from the lexical position in all SQL read from the client since the start of the transaction.[[11]](#footnote-11)

In v7.0, many DBObject subclasses are for Query and SqlValue objects that do not correspond to physical records but have been constructed on an ad-hoc basis by the Parser. For the Database class this happens with ViewDefinitions and in stored procedures. In such cases the physical records contain source strings for the definitions, and parsing occurs once only for each definition. The defining position of the Query and SqlValue objects is given by the position of the first lexical token in the definition string, and so (for committed objects) is still a fixed position in the transaction log.

The system database \_system contains the predefined types and system tables, and two roles; $Schema and \_public. Every database inherits the objects from \_system including the guest role (this is just \_public).

The properties defined by the Database class are as follows:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Key** | **Property** | **Type** | **Comments** | **Uid** |
| Cascade | cascade | bool | only for Transaction | -227 |
| ColTracker | colTracker | BTree<long,BTree<long,long>> | for Log$ rowsets | -318 |
| \_Connection | conn | BTree<string,string> | the connection string | -261 |
| Curated | curated | long | Point at which the database was archived | -53 |
| Format | format | int | 50 for Pyrrho v5-6, 51 for v7 | -54 |
| Guest | guest | long | Role | -55 |
| LastModified | lastModified | DateTime | UTC last modification | -279 |
| Levels | levels | BTree<Level,long> | classification | -56 |
| LevelUids | cache | BTree<long,Level> |  | -57 |
| Log | log | BTree<long,Physical.Type> | Index to the log | -188 |
| NextPos | nextPos | long[[12]](#footnote-12) | Proposed new Physicals | -395 |
| NextPrep | nextPrep | long | Connection uids, dynamic | -394 |
| NextStmt | nextStmt | long | Uncommitted compiled code | -393 |
| NextId | nextId | long | Offset of next transaction step | -58 |
| Owner | owner | long |  | -59 |
| Public |  | long | -1L | -311 |
| Role | role | long | Role | -285 |
| \_Role | \_role | long | role | -302 |
| Roles | roles | BTree<string,long> |  | -60 |
| \_Schema |  | long | Same as \_system.\_role | -291 |
| SchemaKey | schemakey | long | for POCO | -286 |
| Types | types | BTree<Domain,Domain> | nameless types | -61 |
| TypeTracker | typeTracker | BTree<long,BTree<long,Domain>> | for Alter Type | -315 |
| User | user | long | User | -277 |
| \_User | \_user | long | user | -301 |

The main functionality provided by the Database class is as follows:

|  |  |
| --- | --- |
| **Name** | **Description** |
| Install | Install a Physical record in the level 3 structures |
| Load | Load a database from the database file |
| databases | A static list of Databases by name |
| dbfiles | A static list of FileStreams by database name |
| loadpos | The current position in the file |

### 3.5.3 Transaction

Transaction is implemented as a subclass of Database. It is immutable and shareable/

The Transaction maintains the following additional data:

* The current role and user.
* For checking Drop and Rename, a reference to a DBObject that is affected.
* Information for communication with the client, described next

If a client request results in an exception (other than a syntax error) the transaction will be aborted. Otherwise, following each round-trip from the client, the transaction gives private access to its modified version of the database together with some additional items available for further communication with the client before any further execution requests are made:

* A rowset resulting from ExecuteQuery (RowSet is immutable)
* A list of affected items resulting from ExecuteNonQuery, including versioning information
* A set of warnings (possibly empty) generated during the transaction step
* Diagnostic details accessible using the SQL standard GET DIAGNOSTICS syntax

An ExecuteQuery transaction step isvolves at least two sever round trips. In the first, the RowSet is constructed by the Parser using an ad hoc Query and Domain, and then further round trips progressively compute and return batches of rows from the resulting RowSet.

The database server also has a private long called nextTid that will be used to start the next step of the transaction: this is a number used for generating unique uids within the transaction. At the start of each transaction the generator for this number (tid) is initialised to 262, and the server increments this for each transaction step by the length of the input string (used as described in section 3.5.2 to provide defining positions when parsing). This ensures that each uncommitted object referred to in the transaction has a unique defining position. During the writing of physical records during Commit, all of the corresponding DBObjects are reconstructed and reparsed so that following commjit the resulting Database has only the transaction-log-based defining positions described in 3.5.2. This mechanism ensures that tids do not accumulate from one transaction to the next.

The very strong form of transaction isolation used in Pyrrho means that no transaction can ever see uncommitted objects in another transaction. Similarly although each role can have its own domain for objects granted to it, the role cannot see the domain for another role although the defpos is the same.

The properties defined by the Transaction class are as follows:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Key** | **Property** | **Type** | **Comments** | **Uid** |
| AutoCommit | autoCommit | bool |  | -278 |
| Diagnostics | diagnostics | BTree<Sqlx.TypedValue> | For GET DIAGNOSTICS | -280 |
| ReadConstraint | readConstraint | BTree<long,ReadConstraint> |  | -283 |
| Step | step | long |  | -276 |
| TriggeredAction | triggeredAction | long | role boundary | -288 |

### 3.5.4 Role

In v7, each Role manages ObInfo, the role-based information about DBObjects. In Pyrrho, most objects can be renamed on a per-role basis, and accessibility of objects depends on the role. The Role provides a way of looking up objects by name (such as tables, role, types).

A default role (initially with the same name as the database) is created with definer $Schema.

The first role to be defined in the database sets the name of the default role and immediately becomes the database’s defining role. Nothing else is updated.

However, query processing and procedure execution works at the compiled level, where the definer’s permissions are already built in. So SqlValues and Queries already have the right names and rowTypes.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Key** | **Property** | **Type** | **Comments** | **Uid** |
| DBObjects | dbobjects | BTree<string,long> | domains, tables, views, triggers,  (not TableColumns) | -248 |
|  | infos | BTree<long,ObInfo> | stored in mem |  |
| Procedures | procedures | BTree<string, BTree<int,long>> | name and arity | -249 |

User is a subclass of Role:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Key** | **Property** | **Type** | **Comments** | **Uid** |
| Password | pwd | string | hidden | -303 |
| Clearance | clearance | Level |  | -305 |

If a database uses a predefined domain it acquires a new version of the domain, with a defining position in the database log. However, access to system tables is normally restricted to the database owner.

Before the engine starts to load an existing database, the schemaRole and Owner are given default values of -61 $Schema and -63 the engine account[[13]](#footnote-13). There is also a -57 $Guest role which is empty. If roles and users have not been defined the schemaRole continues to operate the database, but access to the database is limited to the account that started up the server (the engine account). PTransaction markers are not placed in the transaction log until a role and user have been loaded from the database log.

Normally the schemaRole is defined first and then the owner role is defined and given privileges over it. The first role to be defined becomes the SchemaRole (so that the default schema role is forgotten) and inherits all of the system objects. (In previous versions of Pyrrho the schemaRole always had position 5 and had the same name as the database file.) The first user to be defined becomes the Owner of the database, with privileges of Usage and AdminRole on the schemaRole. Access to the database is henceforth determined by these new arrangements, as subsequently modified by grant and revoke.

From this point the Reader uses each PTransaction record to set the defining role and user for installing the details from the log. When a database object (or role) is defined, it records the defining role. The defining user can be determined from the transaction log but is not generally needed.

User and role ids are indexed by the default role, together with all domain and type definitions. Roles inherit naming information for objects granted to them and can modify object names as seen from their role.

### 3.5.5 DBObject

Many Physical records define database objects (e.g. tables, columns, domains, user-defined types etc). For convenience, there is a base class that gathers together three important aspects common to all database objects: (a) a definer and defining position, (b) the classification (for mandatory access control) (c) dependency relationships between objects created during parsing, and (d) the depth of such dependency. We explain these aspects briefly later in this section, but the main discussion of these topics must wait for a later chapter (see Sections 8 and 5 of this document).

Roles can be granted access to many DBObject types, including roles, tables (excluding system tables), views, columns, fields, procedures, methods, domains and user-defined types, so that in v7 the Role object maintains a list (infos) that gives access privileges. The effective row-type of a Table depends on which columns have been granted to the role. In Pyrrho this facility was extended to allow role-based metadata and names[[14]](#footnote-14), so that in v7 the Role becomes responsible for all name lookups for level 3 objects. Level 4 objects contains names directly.

If a DBObject is being renamed or dropped in a role, some action needs to be taken in all the role-based catalogues structures that refer to this object.

Defining positions of objects are all 64-bit longs and have several ranges as described in sec 2.3. Defining positions are allocated by the Reader, and Transaction objects are relocated on Commit.

Basis properties for DBObject are as follows

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Key** | **Property** | **Type** | **Comments** |  |
| \_Alias | alias | string |  | -62 |
| Classification | classification | Level |  | -63 |
| Definer | definer | long | Role | -64 |
| Defpos |  | long | for Rest service $pos | -257 |
| Dependents | dependents | BTree<long,bool> | Objects that must be serialised before the current one | -65 |
| Depth | depth | int | Max depth of Dependents (>=1) | -66 |
| Description | desc | string |  | -67 |
| \_Domain | domain | Domain | Not for Domains | -176 |
| Framing | framing | BTree<long,DBObject> | For compiled objects | -167 |
| LastChange | lastChange | long |  | -68 |
| Sensitive | sensitive | bool |  | -69 |

DBObject has the following subclasses documented in later sections below:

|  |  |  |
| --- | --- | --- |
| **Class** | **Base Class** | **Description** |
| Domain | DBObject | Level 3 domain information: checks, defaults etc |
| Query | DBObject |  |
| Table | DBObject | Level 3 table information: columns, rows, indexes |
| Index | DBObject | Entity, references and unique constraints |
| Procedure | DBObject | Procedure/function parameters and execution |
| Role | DBObject | Level 3 roles have privileges and DBObject lists |
| Check | DBObject |  |
| Trigger | DBObject |  |
| UDType | Domain |  |
| Method | Procedure |  |
| PeriodDef | DBObject |  |
| Query | DBObject |  |
| RowSet | DBObject |  |
| Executable | DBObject |  |

The following subclasses define further key uids:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Key** | **Property** | **Type** | **Subclass** | Uid |
| GroupKind | kind | Sqlx | Grouping | -232 |
| Groups | groups | BList<Grouping> | Grouping | -233 |
| Members | members | BList<long> | Grouping | -234 |
| DistinctGp | distinct | bool | GroupSpecification | -235 |
| Sets | sets | BList<long> | GroupSpecification | -236 |
| Current | current | bool | WindowBound | -218 |
| Distance | distance | TypedValue | WindowBound | -219 |
| Preceding | preceding | bool | WindowBound | -220 |
| Unbounded | unbounded | bool | WindowBound | -221 |
| Exclude | exclude | Sqlx | WindowSpecification | -222 |
| High | high | WindowBound | WindowSpecification | -223 |
| Low | low | WindowBound | WindowSpecification | -224 |
| Order | order | OrderSpec | WindowSpecification | -225 |
| OrderWindow | orderWindow | string | WindowSpecification | -226 |
| OrdType | ordType | Domain | WindowSpecification | -227 |
| Partition | partition | int | WindowSpecification | -228 |
| PartitionType | partitionType | Domain | WindowSpecification | -229 |
| Units | units | Splx | WindowSpecification | -230 |
| WQuery | query | Query | WindowSpecification | -231 |
| Checks | checks | BTree<long,Check> | TableColumn | -268 |
| Generated | generated | GenerationRule (see below) | TableColumn | -269 |
| Table | tabledefpos | long | TableColumn | -270 |
| UpdateAssignments | update | BList<UpdateAssignment> | TableColumn | -271 |
| UpdateString | updateString | string | TableColumn | -272 |
| Prev | prev | TableColumn | ColumnPath | -321 |
| StartCol | startCol | long | PeriodDef | -387 |
| EndCol | endCol | long | PeriodDef | -388 |
| ParamMode | paramMode | Sqlx | ParamInfo | -98 |
| Result | result | Sqlx | ParamInfo | -99 |

### 3.5.6 ObInfo

Role-based information about an object (identified by uid) includes its name, security information and other metadata. The ordering of columns is also a type of metadata, called the rowType as in query processing. All database objects apart from SqlValues have associated ObInfo. (SqlValues always target a single Role, and so directly contain name and column information as appropriate.)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Key** | **Property** | **Type** | **Comment** | **Uid** |
| Columns | columns | Clist<long> |  | -251 |
| MethodInfos | methodInfos | BTree<string,BTree<int,long>> | by name and arity | -252 |
| Privilege | priv | Grant.Privilege |  | -253 |
| Properties | properties | BTree<string,long> | see below | -254 |

Metadata properties have case-sensitive string names and types as follows:

|  |  |  |  |
| --- | --- | --- | --- |
| **Key** | **Property** | **Type** | **Comment** |
| Attribute | Attribute | BTree<string,bool> | Columns can be flagged as attributes for Xml output.  BTree placed somewhere in mem |
| Caption | Caption | string | string placed somewhere in mem |
| Csv | Csv | bool |  |
| \_Description | Description | string | Role-based, not necessarily the same as DBObject.description.  string placed somewhere in mem |
| Entity | Entity | bool |  |
| Histogram | Histogram | bool |  |
| Id | Id | long |  |
| Iri | Iri | string | string placed somewhere in mem |
| Json | Json | bool |  |
| Legend | Legend | string | string placed somewhere in mem |
| Line | Line | bool |  |
| Points | Points | bool |  |
| Pie | Pie | bool |  |
| X | X | int | column for X axis |
| Y | Y | int | column for Y axis |

### 3.5.7 Domain

In v7, the Common level SqlDataType has been removed, and instead there is much greater use internally of the Domain and ObInfo classes.

Scalar values are described by a Domain with an empty rowType and representation, as these two properties are reserved for structured types. For more details see section 3.2.5.

Domains are intrinsic to committed objects, while their ObInfo depends on the current Role. The definer’s role is used for procedure and constraint execution, while the transaction’s current role is used for query processing.

The properties of Domain are as follows:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Key** | **Property** | **Type** | **Comments** | **Uid** |
| Abbreviation | abbrev | string |  | -70 |
| Charset | charSet | CharSet | default is UCS | -71 |
| Constraints | constraints | BTree<long,bool> | Evaluate to bool | -72 |
| Culture | culture | CultureInfo | default InvariantCulture | -73 |
| Default | defaultValue | TypedValue |  | -74 |
| DefaultString | defaultString | string |  | -75 |
| Descending | AscDesc | Sqlx | ASC or DESC | -76 |
| Display | display | int | default is rowType.Length | -177 |
| Element | elType | Domain | For derived types | -77 |
| End | end | Sqlx | DAY etc | -78 |
| Iri | iri | string |  | -89 |
| NotNull | notNull | bool |  | -81 |
| NullsFirst | Nulls | bool | Affects ordering | -82 |
| OrderCategory | orderCatgory | OrderCategory |  | -83 |
| OrderFunc | orderFunc | long | DBObjects | -84 |
| Precision | prec | int |  | -85 |
| Provenance | provenance | string | For imports | -86 |
| Representation | representation | BTree<long,Domain> | →obs For anything with columns (even TRow) | -87 |
| RowType | rowType | CList<long> | SqlValue or TableColumn | -187 |
| Scale | scale | int |  | -88 |
| Start | start | Sqlx (YEAR etc) |  | -89 |
| Structure | structdef | BList<long> | DBObjects | -391 |
| Under | super | long | Domains | -90 |
| UnionOf | unionOf | BList<long> | Domains | -91 |

### 3.5.8 Table

The name of the table and its columns are role-specific, and are retrieved for a From instance (From is a subclass of Query). This slightly indirect mechanism works well since tables can occur multiple times in a query, and the From instances distinguish between them.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Key** | **Property** | **Type** | **Comments** | **Uid** |
| ApplicationPS | appPS | long | PeriodSpecification | -262 |
| Enforcement | enforcement | Grant.Privilege | For mandatory access control | -263 |
| Indexes | indexes | BTree<CList<long>,  long> | Key cols, Index | -264 |
| LastData | lastData | long | Ppos of most recent insert, update or delete | -258 |
| SystemPS | sysPS | long | PeriodSpecification | -265 |
| TableChecks | tableChecks | BTree<long,bool> | Checks | -266 |
| TableCols | tblCols | BTree<long,bool> | TableColumns or type fields | -332 |
| TableRows | tableRows | BTree<long,TableRow> | see note below | -181 |
| Triggers | ptriggers | BTree<PTrigger.TrigType, BTree<long,bool>> | Triggers | -267 |

SystemTable has an additional property:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Key** | **Property** | **Type** | |  | **Uid** |
| Cols | tableCols | | BTree<long,TableColumn> |  | -175 |

TableRow is immutable but is not a Basis subclass. It has some similarities to TRow but is role-independent and therefore has no Domain.

### 3.5.9 Query

From v7, Query is a subclass of DBObject, and it is immutable and shareable to facilitate being a component of SqlValues and Executables stored in the database. The nature of DBObject is inherited by Tables and Views.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Key** | **Property** | **Type** | **Comments** | **Uid** |
| \_Aggregates | aggregates | bool |  | -191 |
| Assig | assig | BTree<UpdateAssignment,bool> | For update | -174 |
| FetchFirst | fetchFirst | int |  | -179 |
| Filter | filter | BTree<long,TypedValue> |  | -180 |
| Matches | matches | BTree<long,TypedValue> |  | -182 |
| OrdSpec | ordSpec | OrderSpec |  | -184 |
| Periods | periods | BTree<long,PeriodSpecl> |  | -185 |
| \_Repl | replace | BTree<string,string> |  | -186 |
| SimpleQuery | simpleQuery | From |  | -189 |
| Where | where | BTree<long,bool> | SqlValue | -190 |

Query subclasses define some additional properties:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Key** | **Property** | **Type** | **Subclass** | **Uid** |
| RVQSpecs | rVqSpecs | BList<long> | CursorSpecification | -192 |
| RestGroups | restGroups | BTree<string,int> | CursorSpecification | -193 |
| RestViews | restViews | BTree<long,bool> | CursorSpecification | -194 |
| \_Source | \_source | string | CursorSpecification | -195 |
| Union | union | long | CursorSpecification | -196 |
| UsingFrom | usingFrom | long | CursorSpecification | -197 |
| Assigns | assigns | BList<UpdateAssignment> | From | -150 |
| Source | source | long | From | -151 |
| Static |  | long | From | -152 |
| \_Target | target | long | From | -153 |
| \_FDInfo | FDInfo | FDJoinPart | JoinPart | -202 |
| JoinCond | joinCond | BTree<long,bool> | JoinPart | -203 |
| JoinKind | kind | Sqlx | JoinPart | -204 |
| LeftOrder | leftOrder | OrderSpec | JoinPart | -205 |
| LeftOperand | leftOperand | long | JoinPart | -206 |
| NamedCols | namedCols | BList<long> | JoinPart | -207 |
| Natural | natural | Sqlx | JoinPart | -208 |
| RightOrder | rightOrder | OrderSpec | JoinPart | -209 |
| RightOperand | rightOperand | long | JoinPart | -210 |
| Distinct | distinct | bool | QueryExpression | -243 |
| \_Left | left | long | QueryExpression | -244 |
| Op | op | Sqlx | QueryExpression | -245 |
| \_Right | right | long | QueryExpression | -246 |
| SimpleTableQuery | simpleTableQuery | bool | QueryExpression | -247 |
| Distinct | distinct | bool | QuerySpecification | -239 |
| RVJoinType | rvJoinType | Domain | QuerySpecification | -240 |
| Scope | scope | BTree<long,Domain> | QuerySpecification | -241 |
| TableExp | tableExp | TableExpression | QuerySpecification | -242 |
| \_Table | table | From | SqlInsert | -154 |
| Provenance | provenance | string | SqlInsert | -155 |
| Value | value | SqlValue | SqlInsert | -156 |
| From | from | long | TableExpression | -198 |
| Group | group | long | TableExpression | -199 |
| Having | having | BTree<long,bool> | TableExpression | -200 |
| Needed | needed | BTree<long,bool> | TableExpression | -178 |
| Windows | windows | BTree<long,bool> | TableExpression | -201 |

### 3.5.10 Index

Indexes are constructed when required to implement integrity constraints.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Key** | **Property** | **Type** | **Comments** | **Uid** |
| Adapter | adapter | Procedure | Given an index key returns an index key | -157 |
| IndexConstraint | flags | ConstraintType | primary, foreign , unique etc | -158 |
| Keys | keys | CList<long> | The key columns | -159 |
| References | references | BTree<long,  BList< TypedValue>> | A list of keys formed by the adapter if any | -160 |
| RefIndex | refindexdefpos | long | The index referred to by a foreign key | -161 |
| RefTable | reftabledefpos | long | The table referred to by a foreign key | -162 |
| TableDefPos | tabledefpos | long | The table whose rows are indexed | -163 |
| Tree | rows | MTree | The multi-level index key->long | -164 |

### 3.5.11 SqlValue

From v7, SqlValue is a subclass of DBObject, whose defpos is assigned by the transaction or reader position, or during compilation.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Key** | **Property** | **Type** | **Comments** | **Uid** |
| \_Columns | columns | CList<long> | SqlValue | -299 |
| \_From | from | long | Directs to a Query | -306 |
| Left | left | long | DBObject or SqlValue | -308 |
| \_Meta | meta | MetaData |  | -307 |
| Right | right | long | SqlValue | -309 |
| Sub | sub | long | SqlValue | -310 |

SqlValue has the following virtual Methods:

|  |  |  |  |
| --- | --- | --- | --- |
| **Method** | **Returns** | **Signatures** | **Description** |
| RowSet |  | From | Installs a computed rowset for VALUES, subquery etc. The base implementation is for a singleton. |
| StartCounter |  | Query | Precedes an aggregation calculation |
| AddIn |  | Query | For the aggregation calculation |
| Compare | Int | Context | A base for join conditions |
| Constrain |  | Context, Domain | Used during query analysis |
| Check |  | Context, List of groups | For checking grouping constructs during query analysis |
| \_Setup |  | Domain | Compute nominal types during query analysis |
| Conditions |  | Context | For computing joins etc in query analysis. Also used for searched case statements |
| MatchExpr |  | SqlValue | Compare SqlValues for structural equality |
| IsFrom |  | Query | For analysing joins |
| IsConstant |  |  | For optimising filters |
| JoinConidition | SqlValue | JoinPart | Gets for condition for a join |
| DistributeConditions |  | Query | For optimising filters in query analysis |
| WhereEquals | bool | List of exprs | Collecting AND wheres |
| HasDisjunction | Bool | SqlValue | Detecting ORs |
| LVal | Target | Context | Used for computing the left side of an assignment, e.g. subscript |
| Invert | SqlValue |  | For optimising predicates |
| Lookup | SqlValue | Ident | Field selector for Rvalue |
| FindType | Domain | Domain | Helper for nominal type analysis in exprs |
| Eval | TypedValue | Context |  |

The base SqlValue class has methods that can be used in aggregations (count, sum etc).

There are over 30 subclasses of SqlValue some of which provide machinery specific to particular syntactic constructs that can occur inside the SELECT clause (e.g. SqlMultiset, SqlValueArray, SqlDocArray).

SqlValue subclasses have the following additional properties:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Key** | **Property** | **Type** | **Subclass** | **Uid** |
| Bits | bits | BList<long> | ColumnFunction | -333 |
| Escape | escape | long | LikePredicate | -358 |
| \_Like | like | bool | LikePredicate | -359 |
| Found | found | bool | MemberPredicate | -360 |
| Lhs | lhs | long | MemberPredicate | -361 |
| Rhs | rhs | long | MemberPredicate | -362 |
| NIsNull | isnull | bool | NullPredicate | -364 |
| NVal | val | long | NullPredicate | -365 |
| All | all | bool | QuantifiedPredicate etc | -348 |
| Between | between | bool | QuantifiedPredicate etc | -349 |
| Found | found | bool | QuantifiedPredicate etc | -350 |
| High | high | long | QuantifiedPredicate etc | -351 |
| Low | low | long | QuantifiedPredicate etc | -352 |
| Op | op | Sqlx | QuantifiedPredicate etc | -353 |
| Select | select | long | QuantifiedPredicate etc | -354 |
| Vals | vals | BList<long> | QuantifiedPredicate etc | -355 |
| What | what | long | QuantifiedPredicate etc | -356 |
| Where | where | long | QuantifiedPredicate etc | -357 |
| QExpr | expr | long | QueryPredicate | -363 |
| Call | call | long | SqlCall | -335 |
| TableCol | tableCol | long | SqlTableCol | -322 |
| CopyFrom | copyFrom | long | SqlCopy | -284 |
| Sce | sce | SqlRow | SqlConstructor  DqlDefaultConstructor | -336 |
| Udt | ut | Domain | SqlConstructor  SqlDefaultConstructor | -337 |
| Spec | spec | long | SqlCursor | -334 |
| Field | field | string | SqlField | -314 |
| Filter | filter | long | SqlFunction | -338 |
| Mod | mod | Sqlx | SqlFunction | -340 |
| Monotonic | monotonic | bool | SqlFunction | -341 |
| Op1 | op1 | long | SqlFunction | -342 |
| Op2 | op2 | long | SqlFunction | -343 |
| Query | query | long | SqlFunction | -344 |
| \_Val | val | long | SqlFunction | -345 |
| Window | window | long | SqlFunction | -346 |
| WindowId | windowId | long | SqlFunction | -347 |
|  |  |  |  |  |
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|  |  |  |  |  |
| \_Val | val | TypedValue | SqlLiteral | -317 |
| TransitionRowSet | trs | long | SqlOldTable,  SqlOldRowCol | -318 |
| Rows | rows | BList<long> | SqlRowArray | -319 |
| ArrayValuedQE | aqe | long | SqlSelectArray | -327 |
| TableRow | rec | TableRow | SqlTableRowStart | -311 |
| TreatExpr | val | long | SqlTreatExpr | -313 |
| TreatType | type | long | SqlTypeExpr | -312 |
| Array | array | BList<long> | SqlValueArray | -328 |
| Svs | svs | long | SqlValueArray | -329 |
| Modifier | mod | Sqlx | SqlValueExpr | -316 |
| Expr | expr | long | SqlValueSelect | -330 |
| Source | source | string | SqlValueSelect | -331 |
| Attrs | attrs | BTree<int,  (XmlName,SqlValue)> | SqlXmlValue | -323 |
| Children | children | BList<long> | SqlXmlValue | -324 |
| Content | content | long | SqlXmlValue | -325 |
| Element | element | XmlName | SqlXmlValue | -326 |

### 3.5.12 Check

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Key** | **Property** | **Type** | **Comments** | **Uid** |
| Condition | condition | SqlValue |  | -51 |
| Source | source | string |  | -52 |

### 3.5.13 Procedure

Functions are procedures with a return type. The \_Domain for the Procedure gives the return type.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Key** | **Property** | **Type** | **Comments** | **Uid** |
| Body | body | long | Executable | -168 |
| Clause | clause | string |  | -169 |
| Inverse | inverse | long | For transformations | -170 |
| Monotonic | monotonic | bool | For adapters | -171 |
| Params | ins | Blist<long> | ParamInfo | -172 |

### 3.5.14 Method

Method is a subclass of Procedure. \_Domain gives the return type. The owning UDT is TypeDef.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Key** | **Property** | **Type** | **Comments** | **Uid** |
| MethodType | methodType | MethodType | Instance, Overriding, Static, Constructor | -165 |
| TypeDef | udType | Domain | The user-defined type for this method | -166 |

### 3.5.15 Trigger

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Key** | **Property** | **Type** | **Comments** | **Uid** |
| Action | action | WhenPart |  | -290 |
| NewRow | newRow | long | if specified | -293 |
| NewTable | newTable | long | if specified | -294 |
| OldRow | oldRow | long | if specified | -295 |
| OldTable | oldTable | long | if specified | -296 |
| TrigType | tgType | TrigType | insert/update before/after etc | -297 |
| UpdateCols | updateCols | BList<long> | if specified | -298 |

Section 4.44 of the SQL standard ISO9075 is quite complex. Any given table can have any number of triggers defined, and more than one of any type. For example, if a table has more than one Update trigger each can refer to the old row or the new row using different identifiers (and may have different definers and hence may access different columns[[15]](#footnote-15)). As the transition row set is traversed, each row must be acted on by each of these triggers in turn (but in an implementation-defined order). Within the trigger definition a column of the row may be referenced directly or via the old row or new row, For each statement affecting a table, an old table is constructed if required for any trigger, consisting of the rows that will be accessed by the statement. For each row, an old row and a new row are constructed if required for an update trigger. These belong to the TableActivation (sec 3.6.2 below) and are used to install the relevant structures in each TriggerActivation that needs them.

In this implementation, the following interpretation is made of this section of the standard: Trigger statements may update old and new rows and tables with some obvious restrictions about existence. Changes made by assignment to new row or new table or directly to a column of the table[[16]](#footnote-16) are seen by other triggers in the implementation-defined order mentioned above. But changes made within a trigger definition to an old table or old row are not seen by other triggers.

Worked examples to illustrate aspects of trigger operation are to be found in section 6.5 below.

### 3.5.16 Executable

From v7, Executable is a subclass of DBObject. It has dozens of subclasses as detailed below.

Many Executables can provide a result value, which is placed in the Context on execution, using Context’s row or ret field depending on whether the result type is described by a Selection or a Domain. The desired result of an Executable is therefore provided to the runtime system as a (Domain,Selection) to cover these cases.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Key** | **Property** | **Type** | **Class** | **Uid** |
| Label | label | string | Executable | -92 |
| Stmt | stmt | string | Executable | -93 |
| \_Type | type | Executable.Type | Executable | -94 |
| \_Table | from | long | SqlInsert | -154 |
| Provenance | provenance | string | SqlInsert | -155 |
| Value | value | long | SqlInsert | -156 |
| Val | val | long | AssignmentStatement | -105 |
| Vbl | vbl | long | AssignmentStatement | -106 |
| Parms | parms | BList<long> | CallStatement | -133 |
| Proc | proc | long | CallStatement | -134 |
| Var | var | long | CallStatement | -135 |
| Stmts | stmts | BList<long> | CompoundStatement | -96 |
| CS | cs | long | CursorDeclaration | -129 |
| Cursor | cursor | long | FetchStatement | -129 |
| How | how | Sqlx | FetchStatement | -130 |
| Outs | outs | Blist<long> | FetchStatement | -131 |
| Where | where | long | FetchStatement | -132 |
| Cursor | cursor | string | ForSelectStatement | -124 |
| ForVn | forvn | string | ForSelectStatement | -125 |
| Loop | loop | long | ForSelectStatement | -126 |
| Sel | sel | long | ForSelectStatement | -127 |
| Stms | stms | BList<long> | ForSelectStatement | -128 |
| List | list | BTree<long,Sqlx> | GetDiagnostics | -141 |
| HDefiner | hdefiner | Activation | Handler | -103 |
| Hdlr | hdlr | HandlerStatement | Handler | -104 |
| HType | htype | Sqlx | HandlerStatement | -102 |
| Conds | conds | BList<string> | HandlerStatement | -101 |
| Action | action | long | HandlerStatement | -100 |
| CredPw | pw | long | HttpREST | -143 |
| CredUs | us | long | HttpREST | -144 |
| Mime | mime | string | HttpREST | -145 |
| Posted | data | long | HttpREST | -146 |
| Url | url | long | HttpREST | -147 |
| Verb | verb | string | HttpREST | -148 |
| Where | wh | long | HttpREST | -149 |
| Else | els | BList<long> | IfThenElse | -116 |
| Elsif | elsif | BList<long> | IfThenElse | -117 |
| Search | search | long | IfThenElse | -118 |
| Then | then | BList<long> | IfThenElse | -119 |
| Init | init | long | LocalVariableDec | -97 |
| LhsType | lhsType | Domain | MultipleAssignment | -107 |
| List | list | BList<long> | MultipleAssignment | -108 |
| Rhs | rhs | long | MultipleAssignment | -109 |
| Ret | ret | long | ReturnStatement | -110 |
| CS | cs | long | SelectStatement | -95 |
| Outs | outs | BList<long> | SelectSingle | -142 |
| Else | els | BList<long> | SimpleCaseStatement, SearchedCaseStatement | -111 |
| Operand | operand | long | SimpleCaseStatement | -112 |
| Whens | whens | BList<long> | SimpleCaseStatement, SearchedCaseStatement | -113 |
| Exception | exception | Execption | Signal | -136 |
| Objects | objects | BList<object> | Signal | -137 |
| \_Signal | signal | string | Signal | -138 |
| SetList | setlist | BTree<Sqlx,long> | Signal | -139 |
| SType | stype | Sqlx | Signal | -140 |
| Cond | cond | long | WhenPart | -114 |
| Stms | stms | BList<long> | WhenPart, LoopStatement | -115 |
| Loop | loop | long | WhileStatement, RepeatStatement, LoopStatement | -121 |
| Search | search | long | WhileStatement, RepeatStatement | -122 |
| What | what | BList<long> | WhileStatement | -123 |
| Nsps | nsps | BTree<string,string> | XmlNameSpaces | -120 |
| QMarks | qMarks | CList<long> | PreparedStatement | -396 |
| Target | target | Executable | PreparedStatement | -397 |

### 3.5.17 View

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Key** | **Property** | **Type** | **Comments** | **Uid** |
| Targets | targets | CList<long> |  | -154 |
| ViewCols | viewCols | CTree<string,long> |  | -378 |
| ViewDef | viewdef | string |  | -379 |
| ViewQuery | viewQry | QueryExpression |  | -380 |

RestView is a subclass of View

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Key** | **Property** | **Type** | **Comments** | **Uid** |
| ClientName | nm | string | Deprecated | -381 |
| ClientPassword | pw | string | Deprecated | -382 |
| Mime | mime | string |  | -255 |
| SqlAgent | sqlAgent | string |  | -256 |
| UsingTablePos | usingTable | long | Table | -385 |
| ViewStruct | viewStruct | Domain |  | -386 |
| ViewTable | viewTable | long | Table | -371 |

Where views are constructed by a simple query (a filter, or a selection of columns) there might seem to be a direct match between view column uids and table column uids, so that the usual SqlCopy mechanism would suffice. The domain representation of the view would simply be a subset of that of the target table, and this is true enough for handling insert and update operations for the view. The different SqlCopy uids for each reference of the view will distinguish the different references during query analysis (if there is more than one), so that a row containing (for example) sender and receiver address would have different column uids for the sender and receiver address fields. Certainly, we might like all the references of the view (all the addresses in this example) to have the same domain: but they will at least be compatible with each other, and, for a different example, could be coerced to match the first one in a merge.

But in general, the cursor specification for the view might be complex, so that the columns of the view bear little or no relationship to the columns of the table(s) it references. (In such cases the view will not be updatable.) In v7, the view’s definition is compiled, and relocated into the query context. Presumably, this should happen separately for each reference to the view. Thus, in the above example, values for the sender’s and receiver’s address will have different domains.

In RestViews it is not possible for the remote generated during RestRowSet evaluation to contain more than one reference to the same view. Although each reference to the restview may have different filters and aggregations, the RestRowSets’ remote queries are passed to separate remote connections (even if they are to the same contributor). It might be possible to form a remote join of contributions that use the same restview, with aliases for the two instances, but such an idea does not generalise comfortably, and it would be better in such cases to agree on a new restview to specify the remote join.

## 3.6 Level 4 Data Structures

Level 4 handles transactions, including Parsing, the execution context, activations etc.

### 3.6.1 Context

A Context contains the main data structures for analysing the meaning of SQL. Activations are the only subclasses of Context. Context and its subclasses are mutable, but all of the other structures mentioned above are immutable.

During parsing and execution of a command, the Context caches database objects it needs, RowSets it is working on, the TypedValues of local variables and open Cursors, and the lookup tables used during parsing. All objects cached are for the context’s role, so that the name and column properties of SqlValues and Queries are correct for the current role. Definitions for new objects are parsed with the help of an ad-hoc table of new ObInfos passed into the parsing routines. This architecture means that ObInfos are never required for cached objects.

During evaluation of expressions, Activations are added to the Context stack when procedure or trigger code is executed, and their cache initialised to the current one before the activation’s schema objects are cached for the definer’s role. This means that all data is passed in, but the schema objects are for the right Role. At the end of an Activation, the caller’s local data is copied back into the calling context together with the return values and out parameters It is important that in SQL there is no concept of reference parameters, so, at any time during expression evaluation, only the top activation is accessible. An apparent exception is with a complex expression on the left-hand side of an assignment, such as f(x).y = z; or even f(x)[y]=z, but even with these, expression f(x) and z can be computed before the assignment is completed. Activations provide for complex Condition and Signal handling, similar to the operation of exceptions.

In Pyrrho, we use lazy traversal of rowsets, frequently delivering an entire rowset to the client interface before computing even one row. The client request for the first or next row begins the evaluation of rows. Each new row bookmark computes a list of (defpos,TypedValue) pairs called vals. While sorting, aggregating or DISTINCT result sets often requires computation of intermediate rowsets, many opportunities for deferring traversal remain and Pyrrho takes every opportunity. To assist this process, Pyrrho uses immutable bookmarks for traversal instead of the more usual iterators. Window functions need the computation of adjacent groups of rows.

Procedural code can reference SqlValues, in complex select list expressions and conditions, in triggers, and in structured programming constructs such as FOR SELECT. Activations can return tables as rowsets: as mentioned above, these are immutable typedvalues.

The data maintained by any kind of Context (for any of the above sorts) is as follows:

* The current transaction snapshot **tr**.
* A set of DBObjects called **obs** consisting of the SqlValues and Queries in the current evaluation. During parsing, there are also (a) a set of definitions called **defs**, which helps with looking up identifier chains, and (b) a structure called **depths**, which organises the set of objects by nesting depth to help with the evolution of queries and sqlValues during parsing analysis.
* A set of RowSets called **data**, one of which is the current **result**, and an association from Queries to RowSets called **results**. The construction of these items completes the compilation process (see sec 3.4.2).
* Volatile lists of TypedValues by uids: Cursors (**cursors**), variables (**values**), a return value (**val**) a top-level Cursor (**rb**) and an association (**from**) between SqlValues and RowSets. This last is copied from a RowSet’s **finder** during Cursor evaluation. These things enable SqlValues to be evaluated given the context. See sec 3.6.4.

Comtexts form a stack and they may have different roles and therefore permissions. Generally on exit from a context, the values and result are slid down the stack to the parent. More interesting cases arise for Activations (see below) as these are special sorts of Context for procedural code, including triggers and constraints.

### 3.6.2 Activation

Activation is a subclass of Context. It has the following subclasses:

|  |  |  |
| --- | --- | --- |
| **Class** | **Base Class** | **Description** |
| Activation | Context | A context for execution of procs, funcs, and methods: local variables, labels, exceptions etc |
| CalledActivation | Activation | An activation for a procedure or method call, managing a Variables stack |
| RESTActivation | TargetActivation | Manage REST operation for remote view |
| TableActivation | TargetActivation | An activation for managing trigger execution |
| HTTPActivation | TargetActivation | Manage HTTP operation for remote view |
| TargetActivation | Activation | An activation for controlling insert/update/delete actions |
| TriggerActivation | Activation | Host for trigger execution |

|  |  |  |
| --- | --- | --- |
| **Property** | **Type** | **Comments** |
| brk | long | An Activation to break to |
| cont | long | An Activation to continue to |
| exceptions | BTree<string,Handler> |  |
| execState | ExecState | saved Transaction and Activation state |
| ret | TypedValue |  |
| saved | ExecState |  |
| signal | Signal |  |
| locals | BTree<long,object> |  |

Activations form a stack, using the next field of Contexts. Local variables are held in the values tree (identified by uid) and the val field of Context holds the return value if any. Many statements are labelled, and these run in new Activation with a matching label. The break statement allows execution to break out of a loop to a named Activation..

Activations provide an exception handling mechanism.Signals cause a change of Context, and the behaviour depends on the kind of Handler defined for that condition. Thus the loop in a CompoundStatement will check the Context that results from Obeying and Executable. If the context has not changed, the next statement in the CompoundStatement is Obeyed. Otherwise we break out of the loop.

When an Activation initializes, it starts with values and other information copied from the parent context. A CalledActivation will set up local variables corresponding to parameters (and, for methods, target fields).A TriggerActivation installs a cursor for the current row from the TransitionRowSet, adding cursors for oldRow and oldTable if these are defined. TargetActivations assist with insert/update/delete operations. The subclass TableActivation also manages Triggers, which operate with the help of TriggerActivations. see the worked example ins section 6.5. A table can define multiple triggers, so modifications to a row may involve the operation of a number of TriggerActivations. During such activity, the transaction state is passed between the different activations, as required by the semantics defined in the SQL standard.

At the end of the activation (e.g. a return statement), the SlideDown method deals with how changes to non-local values should affect the parent context. A number of cases can be distinguished, depending on the type of the parent Context:

Activation: The base SlideDown behaviour is just to copy the changed *non-local* values into the values list.

CalledActivation: A called activation may be for a structured type, in which case updates may be for fields of the target object; while other local variables and parameters will be handled by the ProcedureCall semantics. There is no need for an override of SlideDown.

TriggerActivation: Values assigned to columns of the target table are passed down to the TableActivation (as TargetActivation) and target cursor. Then the base Activation.SlideDown version is called.

TargetActivation: Values assigned to columns of the target table are installed in the target, but this is dealt with by the target’s class (in Insert/Update/Delete). There is no need for an override of SlideDown.

Note that in other circumstances, fields of structured objects can only be updated by SqlValueExpr where the operator is dot (e.g. an assignment to x.y), and in that case the whole object value is considered altered as above.

### 3.6.3 RowSet

RowSets are DBObjects that deliver the result of query processing. RowSets are immutable and shareable, and constructed in a Context when requested. There is an evaluation pipeline for rowsets, starting with the base tables, applying sorting and joins, aggregation, merging and selection etc, according to a strategy determined during parsing. From January 2021, RowSets do not need access to the query that they are built from, and this allows an optimisation process for RowSets (previous versions of Pyrrho used query optimisation only).

Some rowsets operate directly on database objects: tables, views, procedures or supplied values (TrivialRowSet, ExplicitRowSet). TransitionRowSets (or insert, update and delete) operate directly on predefined tables or views, and allow for manipulation of column values by triggers.

Other rowset types (derived tables) have one or more source rowsets, traversed before or during traversal of the result. As far as possible, traversal of the resulting rowset proceeds recursively: a request for a row of a rowset recursively requests a row of the source from which it can be computed. This approach is worthwhile because it is very likely that not all rows will be traversed. JoinRowSets and MergeRowSets use possibly sorted rowset operands, which are built before traversal, but the columns are simple to compute. Aggregation and ordering require the evaluation pipeline to be broken up with Trivial or ExplicitRowSets constructed for intermediate results. Subqueries require the construction of auxiliary source rowsets during parsing, and window functions and lateral joins require rebuilding of the source rowset when needed during traversal.

All of these are constructed on completion of parsing of the SQL statement that contains them, by method RowSets()[[17]](#footnote-17). For example, at the end of parsing the intermediate selection, ordering and filtering operations can be distributed into a pipeline of RowSets, whose rowTypes have finders that keep track of which rowSet has a copy of the current value of each for its column uids. Formally thr finder is a pair RowSet,Column, and associations (uid,Finder) identify the location of the current value of a base column by uid in the current set of cursors. At any stage during traversal, the context maintains the current set of cursors.

Several compiled objects, such as views and procedures, contain rowsets that are constructed during compilation and are referred to in all references to the compiled object. These can be referenced in different future contexts, possibly with several separate references to a single view. This handled by the Instance method, and in addition to using fresh column uids for each instance, the compiled rowset pipeline can be improved by propagating filters, groupings and aggregations from the referencing query to deeper levels of the pipeline (in the Apply method), and removing unnecessary steps (in the Review method).

There are numerous subclasses of RowSet. Each RowSet subclass has one or more associated Cursor subclasses with a similar name. Each Cursor subclass has its own implementations of Next and Previous[[18]](#footnote-18).

|  |  |
| --- | --- |
| **SubClass** | **Role in pipeline** |
| DistinctRowSet | Remove duplicate rows in the source rowset |
| DocArrayRowSet | A rowset whose source is a JSON document. |
| EmptyRowSet |  |
| EvalRowSet | The rowType includes aggregate functions for all rows in the source. |
| ExplicitRowSet | A rowset whose source is an array of rows |
| GroupingRowSet | A rowset for computing a GROUP BY operation |
| IndexRowSet | A rowset whose source is a table with a suitable index |
| JoinRowSet | Form the join of two rowsets |
| MergeRowSet | Form the union, intersection or EXCEPT of two compatible rowsets |
| OldTableRowSet | The rowset accessed by OLD TABLE during trigger operation |
| OrderedRowSet | A rowset formed by reordering the rows in the source |
| RoutineCallRowSet | A rowset whose source is a call to a procedure or method |
| RowSetSection | A rowset forned by selection from the source by row sequence |
| SelectRowSet | A rowset formed by selection or rows using SQL expressions |
| SelectedRowSet | A rowset formed by selection of certain columns from the source |
| SqlRowSet | A rowset whose source is a list of row-valued SQL expressions |
| SystemRowSet | A rowset constructed from data structures in the server |
| TableRowSet | A rowset whose source is a base table |
| TransitionRowSet | For input/update/delete operations (constructed by TargetActivation) |
| TrivialRowSet | A rowset consisting of a single SQL row |
| ValueRowSet | A list of rows provided elementwise |
| WindowRowSet | A rowset from application of a window function to the source rowset |

As with other DBObjects, properties of these immutable classes have uids that allow them to be stored in the BTree<long,object> mem structure inherited from Basis. Many of these properties were first defined for Queries and other parsed entities, so many of the entries below are defined in earlier sections of this manual. For better readability and convenience, their names and descriptions are repeated here.

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Type** | **Definition** | **Uid** |
| \_tgt | PTrigger.TrigType | TransitionRowSet.TriggerType | -421 |
| \_trs | TransitionRowSet | TransitionTableRowSet.Trs | -431 |
| actuals | BList<long> | RoutineCallRowSet.Actuals | -435 |
| adapters | Adapters | TransitionRowSet.\_Adapters | -429 |
| built | bool | RowSet.Built | -402 |
| data | BTree<long,TableRow> | TransitionTableRowSet.Data | -432 |
| defaultURL | string | RestRowSet.DefaultURL | -379 |
| defaults | BTree<long,TypedValue> | TransitionRowSet.Defaults | -415 |
| distinct | bool | QuerySpecification.Distinct | -239 |
| docs | BList<SqlValue> | DocArrayRowSet.Docs | -440 |
| domain | Domain | DBObject.\_Domain | -176 |
| explRows | BList<(long,TRow)> | ExplicitRowSet.ExplRows | -414 |
| filter | PRow | FilterRowSet.IxFilter | -411 |
| finder | BTree<long,Finder> | RowSet.\_Finder | -403 |
| first | long | JoinRowSet.Jfirst | -447 |
| from | From | TransitionRowSet,TrsFrom | -416 |
| groupings | BList<long> | GroupingRowSet.Groupings | -406 |
| groupSpec | GroupSpecification | TableExpression.Group | -199 |
| having | BTree<long,bool> | TableExpression.Having | -200 |
| index | long | IndexRowSet.\_Index | -410 |
| indexdefpos | long | TransitionRowSet.IxDefPos | -420 |
| join | JoinPart | JoinRowSet.\_Join | -446 |
| joinCols | BTree<string,int> | RestRowSet.JoinCols | -383 |
| keys | CList<long> | Index.Keys | -159 |
| lastData | long | Table.LastData | -258 |
| map | BTree<long,Finder> | TransitionTableRowSet.Map | -433 |
| matches | BTree<long,TypedValue> | Query.\_Matches | -182 |
| mtree | MTree | Index.Tree | -164 |
| needed | BTree<long,Finder> | RowSet.\_Needed | -401 |
| offset | int | RowSetSection.Offset | -438 |
| proc | Procedure | RoutineCallRowSet.Proc | -436 |
| ra | TriggerContext | TransitionRowSet.Ra | -424 |
| rb | TriggerContext | TransitionRowSet.Rb | -422 |
| remoteAggregates | bool | RestRowSet.RemoteAggregates | -384 |
| remoteCols | BTree<string,long> | RestRowSet.RemoteCols | -373 |
| remoteGroups | GroupSpecification | RestRowSet.RemoteGroups | -374 |
| restValue | TArray | RestRowSet.RestValue | -457 |
| restView | long | RestRowSet.RestView | -459 |
| result | RowSet | RoutineCallRowSet.Result | -437 |
| ri | TriggerContext | TransitionRowSet.Ri | -423 |
| rmap | BTree<long,Finder> | TransitionTableRowSet.RMap | -434 |
| row | TRow | TrivialRowSet.Singleton | -405 |
| rowOrder | CList<long> | RowSet.RowOrder | -404 |
| rows | Blist<TRow> | RowSet.\_Rows | -407 |
| rt | CList<long> | (domain.rowType) |  |
| second | long | JoinRowSet.Second | -448 |
| size | int | RowSetSection.Size | -439 |
| source | long | From.Source | -151 |
| sqlRows | BList<long> | SqlRowSet.SqlRows | -413 |
| sQMap | BTree<long,Finder> | SelectedRowSet.SQMap | -408 |
| ta | TriggerContext | TransitionRowSet.Ta | -426 |
| table | long | IndexRowSet.IxTable | -409 |
| tabledefpos | long | SqlInsert.\_Table | -154 |
| targetAc | Activation | TransitionRowSet.TargetAc | -430 |
| targetInfo | ObInfo | TransitionRowSet.TargetInfo | -417 |
| targetTrans | BTree<long,Finder> | TransitionRowSet.TargetTrans | -418 |
| tb | TriggerContext | TransitionRowSet.Tb | -425 |
| td | TriggerContext | TransitionRowSet.Td | -428 |
| transTarget | TriggerContext | TransitionRowSet.TransTarget | -419 |
| tree | RTree | OrderedRowSet.\_RTree | -412 |
| usingCols | BTree<string,long> | RetRowSet.UsingCols | -259 |
| usingTable | long | RESTRowSet.UsingTable | -260 |
| values | Tmultiset | WindowRowSet.Multi | -441 |
| wf | SqlFunction | WindowRowSet.Window | -442 |
| where | BTree<long,bool> | Query.Where | -190 |

#### Modifying rowsets

Some rowsets can be used to make changes to their base tables, and this feature is useful for views. As a rule of thumb this requires rowsets whose results expose simple rows and coloumns, possibly with a monotonic adapter function, and thus all Yes entries in this table depend on this additional requirement and the need to satisfy constraints and authorisation requirements. Such an operation adds to the transaction results a set of modifications for each of the individual tables involved. There are no entries below for rowsets with 0 or 1 base table:

|  |  |  |  |
| --- | --- | --- | --- |
| **SubClass** | **Insert** | **Update** | **Delete** |
| DistinctRowSet | No | No | No |
| DocArrayRowSet | No | No | No |
| EmptyRowSet |  |  |  |
| EvalRowSet | No | No | No |
| ExplicitRowSet |  |  |  |
| GroupingRowSet | No | No | Yes |
| IndexRowSet |  |  |  |
| JoinRowSet | Yes | Yes | Yes |
| MergeRowSet | Intersection only | Yes | Yes |
| OldTableRowSet |  |  |  |
| OrderedRowSet | Yes | Yes | Yes |
| RoutineCallRowSet |  |  |  |
| RowSetSection | No | Yes | Yes |
| SelectRowSet | Yes | Yes | Yes |
| SelectedRowSet | Yes | Yes | Yes |
| SqlRowSet |  |  |  |
| SystemRowSet |  |  |  |
| TableExpRowSet | \* | \* | \* |
| TableRowSet |  |  |  |
| TransitionRowSet |  |  |  |
| TrivialRowSet |  |  |  |
| ValueRowSet |  |  |  |
| WindowRowSet | No | No | No |

\* delegates to the source of the Table Expression.

### 3.6.4 Cursor

Previously called RowBookmark, this is an abstract and immutable subclass of TRow for traversing rowSets. All RowSets offer a First() that returns a Cursor at position 0, or null, and a Last() that returns a Cursor at the end of the rowset, or null. Cursors are immutable, but their values can be updated (as usual giving a new cursor, stored in the appropriate context). Note however that an updated cursor continues to traverse the rowset as it was at the start of traversal.

The Context remembers the current Cursor for each RowSet it defines: it contains the values for the current row as defined in the row’s representation. The construction of some rowsets (e.g. grouped and windowed) uses a temporary context. Each RowSet has a finder listing all of the uids for which it provides values directly or indirectly.

The interface offered includes the following:

|  |  |
| --- | --- |
| long \_defpos | The row uid (or 0) |
| int display | The number of columns |
| TRow key | *Abstract* The current key |
| Cursor Last(Context cx) | *Abstract:* Returns a bookmark for the last row, or returns null if there is none |
| BTree<long,TypedValue> \_needed | Ambient data required for evaluation |
| Cursor Next(Context cx) | *Abstract:* Returns a bookmark for the next row, or returns null if there is none |
| int \_pos | The current position: starts at 0 for First() cursor in a traversal |
| long \_ppos | The log position for the current row (or 0) |
| Cursor PositionAt(pos) | Returns a bookmark for the given position, or null if there is none. |
| TableRow Rec() | *Abstract* The current table row if defined for this rowset |
| long \_rowsetpos | The rowset uid |

There are numerous subclasses of Cursor, many of which are local to RowSets.

From the above interface, it is clear that the most important property of a cursor is its role in traversing a RowSet (Next() and Previous(). But cursors also play a cricial role in SqlValue evaluation. Recal that an SqlValue by uid refers to a cell in a row. The cursor is the row: so most evaluations of SqlValue use the current cursor of the appropriate rowset. The Context maintains the current set of Cursors in that context. and both contexts and rowsets manage a set of Finders to get the correct cursor and column to evaluate any currently accessible uid.

This is important because most rowsets are built from their source rowsets, and this this sequence is one of the last things to be established in parsing (see Context.Review()). Many rowsets require building at traversal time (DistinctRowSet, GroupRowSet etc, even lateral joins) and the same evaluation mechanism needs to be used consistently at every stage. To make this work, the context contains a finder field (Contexts are not immutable), which is fixed for each cursor evaluation step.

All rowsets have cursors that can be built from their source rowsets, using a static New method (in case the source is exhausted, New can return null): with this normal method of constructing cursors, the cursor constructor is protected or private. There are just a few cursors that can be built from their targets, in order to perform Insert operations: these are the cursors for TransitionRowSet, SelectedRowSet, RestRowSet, OrderedRowSet, and JoinRowSet (!), and so these have constructors that are internal. EvalRowSet and TrivialRowSet also have Cursors with internal constructors.

Two important Cursor subclasses: TargetCursor and TriggerCursor are not used for traversal but are used as part of this evaluation machinery, as explained in section 6.5. The TriggerCursor is constructed from a targetCursor for each row trigger and ensures that the TriggerActivation has the right finder for trigger execution.

# 4. Locks, Integrity and Transaction Conflicts

Pyrrho's transaction model uses an optimistic 3-stage Commit protocol, as follows:

* Commit1: For each connected database that has work to commit, we first check any recently committed information from the database file for conflicts with data that this transaction has accessed. Then we lock the DataFile and do this again. Conflicts at this stage may cause the transaction to fail (for example, alteration of a record we have accessed).
* Commit2: For each connected database, flush the physical records to the database (the datafile is still locked). The local transaction structure is now discarded.
* Commit3: For each connected database, get the base Level 3 Database instance to install the physicals that have just been committed to the DataFile, and unlock the datafile.

Pyrrho's optimistic transaction model means that the client is unable to lock any data. The database engine uses DataFile locks internally to ensure correct operation of concurrent transactions.

## 4.2 Transaction conflicts

This section examines the verification step that occurs during the first stage of Commit. For each physical record P that has been added to the database file since the start of the local transaction T, we

* check for conflict between P and T: conflict occurs if P alters or drops some data that T has accessed, or otherwise makes T impossible to commit
* install P in T.

Let D be the state of the database at the start of T. At the conclusion of Commit1, T has installed all of the P records, following its own physical records P': T=DP'P. But, if T now commits, its physical records P' will follow all the P records in the database file. The database resulting from Commit3 will have all P' installed after all P, ie. D'=DPP'. Part of the job of the verification step in Commit1 is to ensure that these two states are equivalent: see section 4.2.2.

Note that both P and P' are sequences of physical records: P=p0p1…pn etc.

### 4.2.1 ReadConstraints (level 4)

The verification step goes one stage beyond this requirement, by considering what data T took into account in proposing its changes P'. We do this by considering instead the set P" of operations that are read constraints C' or proposed physicals P' of T. We now require that DP"P = DPP" .

The entries in C' are called ReadConstraints (this is a level 4 class), and there is one per base table accessed during T (see section 3.8.1). The ReadConstraint records:

* The local transaction T
* The table concerned
* The constraint: CheckUpdate or its subclasses CheckSpecific, BlockUpdate

CheckUpdate records a list of columns that were accessed in the transaction. CheckSpecific also records a set of specific records that have been accessed in the transaction. If all records have been accessed (explicitly or implicitly by means of aggregation or join), then BlockUpdate is used instead.

ReadConstraints are applied during query processing by code in the From class.

The ReadConstraint will conflict with an update or deletion to a record R in the table concerned if

* the constraint is a BlockUpdate or
* the constraint is a CheckSpecific and R is one of the specific rows listed.

This test is applied by Participant.check(Physical p) which is called from Commit1.

### 4.2.2 Physical Conflicts

The main job of Participant.check is to call p.Conflict(p) to see of two physical records conflict. The operation is intended to be symmetrical, so in this table the first column is earlier than the second in alphabetical sequence:

|  |  |  |
| --- | --- | --- |
| **Physical** | **Physical** | **Conflict if** |
| Alter | Alter | to same column, or rename with same name in same table |
| Alter | PColumn | rename clashes with new column of same name |
| Alter | Record | record refers to column being altered |
| Alter | Update | update refers to column being aletered |
| Alter | Drop | Alter conflicts with drop of the table or column |
| Alter | PIndex | column referred to in new primary key |
| Alter | Grant | grant or revoke for object being renamed |
| Change | PTable | rename of table or view with new table of same name |
| Change | PAuthority | rename of authority with new authority of same name |
| Change | PDomain | rename of domain with new domain of same name |
| Change | PRole | rename of role with new role of same name |
| Change | PView | rename of table or view with new view of same name |
| Change | Change | rename of same object or to same name |
| Change | Drop | rename of dropped object |
| Change | PCheck | a check constraint and a rename of the table or domain |
| Change | PColumn | new column for table being renamed |
| Change | PMethod | method for type being renamed |
| Change | PProcedure | rename to same name as new proc/func |
| Change | PRole | rename to same name as new role |
| Change | PTable | rename to same name as new table |
| Change | PTrigger | trigger for renamed table |
| Change | PType | rename with same name as new type |
| Change | PView | rename of a view with new view |
| Delete | Drop | delete from dropped table |
| Delete | Update | update of deleted record, or referencing deleted record |
| Delete | Record | insert referencing deleted record |
| Drop | Drop | drop same object |
| Drop | Record | insert in dropped table or with value for dropped column |
| Drop | Update | update in dropped table or with value for dropped column |
| Drop | PColumn | new column for dropped table |
| Drop | PIndex | constraint for dropped table or referencing dropped table |
| Drop | Grant | grant or revoke privileges on dropped object |
| Drop | PCheck | check constraint for dropped object |
| Drop | PMethod | method for dropped Type |
| Drop | Edit | alter domain for dropped domain |
| Drop | Modify | modify dropped proc/func/method |
| Drop | PTrigger | new trigger for dropped table |
| Drop | PType | drop of UNDER for new type |
| Edit | Record | alter domain for value in insert |
| Edit | Update | alter domain for value in update |
| Grant | Grant | for same object and grantee |
| Grant | Modify | grant or revoke for or on modified proc/func/method |
| Modify | Modify | of same proc/func/method or rename to same name |
| Modify | PMethod | rename to same name as new method |
| PColumn | PColumn | same name in same table |
| PDomain | PDomain | domains with the same name |
| PIndex | PIndex | another index for the same table |
| PProcedure | PProcedure | two new procedures/funcs with same name |
| PRole | PRole | two new roles with same name |
| PTable | PTable | two new tables with same name |
| PTable | PView | a table and view with same name |
| PTrigger | PTrigger | two triggers for the same table |
| PView | PView | two new views with the same name |
| Record | Record | conflict because of entity constraint |
| Record | Update | conflict because of entity or referential constraint |
| PeriodDef | Drop | Conflict if the table or column is dropped during period definition |
| Versioning | Drop | Conflict if the table or period is dropped during versioning setup |

### 4.2.3 Entity Integrity

The main entity integrity mechanism is contained in Participant. However, a final check needs to be made at transaction commit in case a concurrent transaction has done something that violates entity integrity. If so, the error condition that is raised is “transaction conflict” rather than the usual entity integrity message, since there is no way that the transaction could have detected and avoided the problem.

Concurrency control for entity integrity constraints are handled by IndexConstraint (level 2). It is done at level 2 for speed during transaction commit, and consists of a linked list of the following data, which is stored in (a non-persisted field of) the new Record

* The set of key columns
* The table (defpos)
* The new key as an array of values
* A pointer to the next IndexConstraint.

During Participant.AddRecord and Participant.UpdateRecord a new entry is made in this list for the record for each uniqueness or primary key constraint in the record.

When the Record is checked against other records (see section 4.2.2) this list is tested for conflict.

### 4.2.4 Referential Integrity (Deletion)

The main referential integrity mechanism is contained in Participant. However, a final check needs to be made at transaction commit in case a concurrent transaction has done something that violates referential integrity. If so, the error condition that is raised is “transaction conflict” rather than the usual referential integrity message, since there is no way that the transaction could have detected and avoided the problem.

Concurrency control for referential constraints for Delete records are handled by ReferenceDeletionConstraint (level 2). It is done at level 2 for speed during transaction commit, and consists of a linked list of the following data, which is stored in (a non-persisted field of) the Delete record

* The set of key columns in the referencing table
* The defining position of the referencing table (refingtable)
* The deleted key as an array of values
* A pointer to the next ReferenceDeletionConstraint.

During Participant.CheckDeleteReference a new entry is made in this list for each foreign key in the deleted record.

When the Record is checked against other records (see section 4.2.2) this list is tested for conflict. An error has occurred if a concurrent transaction has referenced a deleted key.

### 4.2.5 Referential Integrity (Insertion)

The main referential integrity mechanism is contained in Participant. However, a final check needs to be made at transaction commit in case a concurrent transaction has done something that violates referential integrity. If so, the error condition that is raised is “transaction conflict” rather than the usual referential integrity message, since there is no way that the transaction could have detected and avoided the problem.

Concurrency control for referential constraints for Record records are handled by ReferenceInsertionConstraint (level 2). It is done at level 2 for speed during transaction commit, and consists of a linked list of the following data, which is stored in (a non-persisted field of) the Record record

* The set of key columns in the referenced table
* The defining position of the referenced table (reftable)
* The new key as an array of values
* A pointer to the next ReferenceInsertionConstraint.

During Participant.AddRecord a new entry is made in this list for each foreign key in the deleted record.

When the Record is checked against other records (see section 4.2.2) this list is tested for conflict. An error has occurred if a concurrent transaction has deleted a referenced key.

## 4.4 System and Application Versioning

With version 4.6 of Pyrrho versioned tables are supported as suggested in SQL2011. PeriodDefs are database objects that are stored in the Table structure similarly to constraints ad triggers. PeriodSpecs are query constructs that are stored in the Context: e.g. FOR SYSTEM\_TIME BETWEEN .. and .. ,

The GenerationRule enumeration in PColumn allows for RowStart and RowEnd autogenerated columns (as required by SQL2011) and also RowNext, as required for Pyrrho’s implementation of application-time versioning.

a system or application period is defined for a table, Pyrrho constructs a special index called versionedRows whose key is a physical record position, and whose value is the start and end transaction time for the record. This versionedRows structure is maintained during CRUD operations on the database. If a period is specified in a query, versionedRows is used to create an ad-hoc index that is placed in the Context (there is a BTree called versionedIndexes that caches these) and used in constructing the rowsets for the query.

If system or application versioning is specified for a table with a primary index, new indexes with special flags SystemTimeIndex and ApplicationTimeIndex respectively are created: these are primary indexes for the pseudotables T FOR SYSTEM\_TIME and T FOR P which are accessible for and “open” period specification.

# 5. Parsing

Pyrrho uses LL(1) parsing for all of the languages that it processes. The biggest task is the parser for SQL2011. There is a Lexer class, that returns a Sqlx or Token class, and there are methods such as Next(), Mustbe() etc for moving on to the next token in the input.

From version 7, parsing of any code is performed only in the following circumstances[[19]](#footnote-19):

* The transaction has received SQL from the client.
* SQL code is found in a Physical being loaded from the transaction log (when the databse is opened, or after each commit)

The top-level calls to the Parser all create a new instance of the Transaction, containing the newly constructed database objects as described in 3.5.3 above. They begin by creating a Context for parsing.

Within the operation of these calls, the parser updates its own version of the Transaction and Context. The Context is not immutable, so update-assignments are mostly not required for the Context. The recursive-descent parsing routines return the new database objects constructed (Query, SqlValue, Executable) for possible incorporation into the transaction.

## 5.1 Connection

The server is multi-threaded, and a new thread is created for each Connection. The connection string gives the user identity and can request an initial role for the connection.

1. If the database has no users, the system account has all privileges on the database. There is no need to record the user id of the system account, and there is no auditing or mandatory access control. The system account has the identity of the account that starts the server.

2. Otherwise the database has users, and:

a. The log can be read only by the database owner and the system account and is not subject to audit.

b. All other use of the database must have a valid user id and session role and the need for audit is determined by object properties. Guest/Public is a role not a user id.

i. The user’s identity must be defined (a User database object) for the current transaction, so that we can audit their activities if necessary. An ad-hoc user object must be installed if a matching user id cannot be found, initially with a transaction-local uid..

1. If this object is committed (including by an audit record), it is then a defined user, and will be re-used next time this account connects to the database.

ii. If the user is only allowed to use one role, this is supplied by default on connection.

iii. If the role is not set or the current user cannot use any other role, the session role will be the Guest/Public role.

iv. There is no way to set the session role to $Schema.

These rules are sufficient in all cases to ensure that every connection is immediately equipped with a session user and a session role.

## 5.2 Lexical analysis

The Lexer is defined in the Pyrrho.Common namespace, and features the following public data:

* char[] input, for the sequence of Unicode characters being parsed
* pos, the position in the input array
* start, the start of the current lexeme
* tok, the current token (e.g. Sqlx.SELECT, Sqlx.ID, Sqlx.COLON etc)
* val, the value of the current token, e.g. an integer value,the spelling of the Sqlx.ID etc.

The Lexer checks for the occurrence of reserved words in the input, coding the returned token value as the Sqlx enumeration. These Sqlx values are used throughout the code for standard types etc, and even find their way into the database files. There are two possible sources of error here (a) a badly-considered change to the Sqlx enumeration might result in database files being incompatible with the DBMS, (b) the enumeration contains synonyms such as Sqlx.INT and Sqlx.INTEGER and it is important for the DBMS to be internally consistent about which is used (in this case for integer literal values).

The following table gives the details of these issues:

|  |  |  |
| --- | --- | --- |
| **Sqlx id** | **Fixed Value** | **Synonym issues** |
| ARRAY | 11 |  |
| BOOLEAN | 27 |  |
| CHAR | (37 recode) | Always recode CHARACTER to CHAR |
| CLOB | 40 |  |
| CURSOR | 65 |  |
| DATE | 67 |  |
| INT | (128 recode) | Always recode INT to INTEGER |
| INTEGER | 135 |  |
| INTERVAL | 137 |  |
| MULTISET | 168 |  |
| NCHAR | 171 |  |
| NCLOB | 172 |  |
| NULL | 177 |  |
| NUMERIC | 179 |  |
| REAL | 203 |  |
| TIME | 257 |  |
| TIMESTAMP | 258 |  |
| TYPE | 267 |  |
| XML | 356 |  |

Apart from these fixed values, it is okay to change the Sqlx enumeration, and this has occurred so that in the code reserved words are roughly in alphabetical order to make them easy to find.

## 5.3 Parser

The parser retains the following data:

* The Lexer
* The current token in the Lexer, called tok (1 token look ahead)
* The current Context, including the current Database or Transaction

In addition there are lists for handling parameters, but these are for Java, and are described in chapter 11. Apart from parsing routines, the Parser class provides Next(), Match and Mustbe routines.

### 5.3.1 Execute status and parsing

Many database objects such a stored procedures and view contain SQL2011 source code, so that database files actually can contain some source code fragments. Accordingly parsing of SQL code occurs in several cases, discriminated by the execute status (see 3.10.1) of the transaction:

|  |  |
| --- | --- |
| **Execute Status** | **Purpose of parsing** |
| Parse | Parse or reparse of stored procedure body etc. Execution of procedure body uses the results of the parse (Execute class) |
| Obey | Immediate execution, e.g. of interactive statement from client |
| Drop | Parse is occurring to find references to a dropped object (see sections 5.3-4) |
| Rename | Parse is occurring to find references affected by renaming (sections 5.3-4) |

### 5.3.3 Parsing routines

There are dozens of parsing routines (top-down parsing) for the various syntax rules in SQL2011. The context is provided to the Parser constructor, to enable access to the execute status, Nearly all of these are private to the Parser.

The routines accessible from other classes are as follows:

|  |  |
| --- | --- |
| **Signature** | **Description** |
| Parser(cx) | Constructor |
| void ParseSql(sql) | Parse an SqlStatement followed by EOF. |
| SqlValue ParseSqlValue(sql,type) | Parse an SQLTyped Value |
| SqlValue ParseSqlValueItem(sql) | Parse a value or procedure call |
| CallStatement ParseProcedureCall(sql) | Parse a procedure call |
| WhenPart ParseTriggerDefinition(sql) | Parse a trigger definition |
| SelectStatement  ParseCursorSpecification(sql) | Parse a SELECT statement for execution |
| QueryExpression ParseQueryExpression(t,sql) | Parse a QueryExpression for execution |

All the above methods with sql parameters set up their own Lexer for parsing, so that

new Parser(cx).ParseSql(sql)

and similar calls work.

# 6. Query Processing and Code Execution

In section 2.2 a very brief description of query processing was given in term of bridging the gap between bottom-up knowledge of traversable data in tables and joins (e.g. columns in the above sense) and top-down analysis of value expressions.

From v.7 Queries are fully-fledged DBObjects, and are only parsed once. During parsing the Context give access to objects created by the parse, which initially have transaction-local defining positions Some of these will be committed to disk as part of some other structure (e.g. a view or in a procedure body), when of course they will get a new defining position given by the file position.

I would like the context to have lists of queries, executables and rowsets (similarly to the lists of TypedValues). At every point starting a new transaction simply inherits the current context state, but the old context becomes accessible once more when the stack is popped.

## 6.1 Overview of Query Analysis

Pyrrho handles the challenge that identifiers in SQL queries are of several types and subject to different rules of persistence, scope and visibility. Some identifiers are names of database objects (visible in the transaction log, possibly depending on the current role), queries can define aliases for tables, views, columns and even rows, that can be referred to in later portions of the query, user defined types can define fields, documents can have dynamic content, and headers of compound statements and local variables can be defined in SQL routines. Added to all of this is the fact that ongoing transactions proceed in a completely isolated way so that anything they have created is hidden from other processes and never written to disk until the transaction commits.

In addition, Pyrrho operates a very lazy approach to rowSet traversal. RowSet traversal is required when the client requests the results of a query, and as required for source rowSets when an ordering or grouping operation is required by a result traversal. A significant number of rowSet classes is provided to manage these processes. RowSet traversal always uses bookmarks as described elsewhere in this booklet.

In previous versions of Pyrrho, the above considerations led to a lookup process in which identifiers were looked up at runtime, using lists created during a runtime parse of the relevant source codes. Intermediate results were all some kind of Query. Version 7 and later handles this differently, and executables mostly work with rowsets istead of queries. All SQL query text, whether coming from the database file or from an interactive user, is immediately parsed into structures in which all the above identifiers have been replaced by a long defpos, which for database objects is (or is changed during object relocation to) the defining position in the transaction log. It remains true that different roles can have different names for database objects, and this is handled by keeping the naming of objects in the role. The defining role owns this ObInfo, and it is added to other roles that are granted access to the object. So expressions, queries and rowSets may be database-objects (in db.objects) while objects also have role-based ObInfos (in role.infos), stored with the same defpos but in the Role’s mem tree. Several non-immutable structures (Reader, Writer, Context) have their own local copies of the database to speed things up, and queries and sqlValues contain naming and ObInfo information for the current role. The Pyrrho manual in section 9.2 gives a list of all the different object types in the database file, and it is important that this list does not include sqlValues, queries or rowsets, even though these are subclasses of DBObject. Instead, queries, sqlValues and rowsets and many executables associated with compiled objects in the database file are constructed in memory on creation of an entry in the database file, and reconstructed when this is loaded from disk (the set of such associated in-memory objects is managed by the Framing class) .

The SQL parsing process is recursive. During the lexical (left-to-right) phase of analysis the lexer supplies defining positions for unknown SqlValue it encounters. When a FROM clause in the query enables targets of any of these selectors to be identified, the defining position is updated to match the target. In previous versions of Pyrrho, this was referred to as the Sources stage of analysis. In v7 there is no separate analysis stage: the query is progressively rewritten during the parse, so that at the end of parsing all object uids still in use identify specific objects.

QuerySpecifications have SqlValue select items and maintain a scope consisting of all referenceable DBObjects from the containing query or domain if any, and all references created within it to the left for the current position (for example, join operands and their columns). Select items may refer ahead to objects brought into scope by the from clause: until they are resolved they will simply be new SqlValues with the undefined domain Content.

For example, in a query such as “Select b+c as d from a” , the defining positions for the selectors b and c will be replaced by those of columns in a, and the query will have a single selector whose defining position is that of the + operator as the column in the row type for the query and name d. In “Select a.c from t a” the first occurrence of a in the dotted expression will be replaced by t, and c by the column of t, so that the rowType will have a selector “a.c” whose defining position is that of the dotted expression[[20]](#footnote-20).

Parsing proceeds from left to right, and objects are replaced one at a time when further information about them is known. For example, replacing a single select item by uid, affects all objects that refer to it including the containing queries (rowType and domain). Queries can also be replaced (with the same uid) when conditions and filters are moved within the resulting structure. The context uses a special structure called *done* that records the new version for each uid that has been scanned. If a part of the query contains more than one reference to the item being replaced, the enclosing structure may be replaced more than once (overwriting its entry in *done*), but when the scan reaches a reference to the changed uid it will not be rescanned.

As the name implies, these uids need to be unique within the thread. The uniqueness is guaranteed by using the lexical position of the starting token of the query or sqlvalue, offset from the transaction identifier tid. The first step in a transaction for a given thread starts at 0x4000000000000000. An explicit transaction may have several steps and one step can define uncommitted database objects that are used in later steps, so that each step gets a new tid (transaction-uid), incremented by the length of the sql used in the previous step.

Expressions are given uids simply by their lexical position of the first character, or for complex expressions by the position of the top operator (e.g. + < or .).

CursorSpecifications always start with SELECT, so the SELECT position is used for its uid (uids on the heap are supplied for columns not mentioned explicitly in the select list). QueryExpression will have as uid the position of the second character of the SELECT (or UNION etc) that introduces it and the QuerySpecification will use the last character of the corresponding token (so that it gets a different uid from its first selector). FROM introduces a TableExpression, and Joins have uids given by the position of the join operator. Later parts of the query may mention object columns not previously mentioned, allowing their heap uids to be replaced by uids based on lexical positions.

Thus during parsing, there are many replacements of one SqlValue (e.g. an alias placeholder) with another (e.g. the expression, column or subquery that it refers to). Such replacements extend to expressions in subqueries, parameter lists (including those of row constructors), grouping and ordering specifications. When parsing reaches the end of the sql statement, the process of query analysis is complete. Then the RowSets() method will consider definitions of other objects referenced in FROM clauses (that is, base tables, view instances, procedures, etc) and perform some retrieval optimisation, such as filtering and aggregation, so that in the end a cursor-specification can be evaluated by traversing a single rowset[[21]](#footnote-21).

An example will help to explain the process. Consider the following (not clever SQL but has enough features to illustrate the process). Suppose the database defines (only)

create table author(id int primary key,aname char)

create table book(id int primary key,aid int references author,title char)

Then the following uids are defined in the database, as can be verified from the log:

23 AUTHOR a Table

34 INTEGER

48 ID for 23

70 an Index (ID) for 23

91 CHAR

104 ANAME for 23

148 BOOK a Table

158 ID for 148

182 an Index (ID) for 148

204 AID for 148

230 an Index (AID) referencing 70

249 TITLE for 148

Now consider the following query:

1 2 3 4 5 6

123456789012345678901234567890123456789012345678901234567890123456789

SELECT b.title AS c FROM author a, book b WHERE a.id=b.aid AND c>'M'

The uid for a database object cached from the database will be its defining position in the database (position in the transaction log (e.g. 22 for AUTHOR), while the uid for a new object will be its lexical position in the command (e.g. #8 for the identifier b), or its transaction id, (e.g. '0 for the first object created in the transaction), or a heap uid (e.g. %0 for the first object not in any of these categories).

The keyword SELECT introduces a QuerySpecification which is given the uid #7. Following SELECT we start to parse the select items. When the parser reaches lexical position #8, it parses b.title as an identifier chain and looks it up in the context. As the context is empty, it is not known whether b is an object name or an alias, though the dot allows us to infer that it will have structure. ParseVarOrColumn() builds a SqlValueExp #9 whose operator is DOT, and #9 and #11 are unknown SqlValues whose names are b and title respectively. After also noting that alias C at position #19 refers to #9, ParseSelectItem returns the updated QuerySpecification #7 and the SqlValue #9 as a tuple. Here we will show the current state of the parse as

QuerySpecification #7 (#9(B #8.TITLE #10) as C) from ?

B and TITLE are unknown at this stage. At position 26, we lookup author in the database’s metadata for the context’s Role, find it is a table (with file position 22), and add the alias at position 33. The parser returns this as a From object with lexical position #26 in case the command later has another reference to this table. The From is a subclass of Query, and so has a row type. Its constructor is passed the select list, and assigns heap uids for any columns that are so far unreferenced, which is all of them in this case:

From AUTHOR #26 (%0,%1) target=23

The context notes the definitions of both AUTHOR and A as #26.

The comma at position #34 indicates a join. We look up the BOOK table as another From object, and this allows us to resolve the unknown B.TITLE as a simple column (to be copied from the table). So ParseTableReferenceItem returns

From BOOK #36 (#10,%2,%3) target=148

TITLE is now resolved as an SqlCopy and its query, domain and tableColumn are known:

SqlCopy TITLE #10 From #36 Domain: 91 CHAR copy from 249

and the context has noted that B refers to #36.

The next step in ParseFromClause is to construct the JoinPart for these two From objects, whose row type and domain are now known:

JoinPart #34 (#9) #26 CROSS join #36

Next, ParseWhereClause returns a disjunction list (#53,#65):

SqlValueExpr #53(#49=%3)

SqlValueExpr #65(#9>#66)

We have reached the end of the query (no grouping, or further joins) so ParseTableExpression returns

TableExpression #21 (#9) Where:(#53,#65) From: #34

and this completes the QuerySpecification:

QuerySpecification #7 (#9) from #21

As there are no unions/intesections in this query, it is a simple query expression

QueryExpression #2 (#9) Left: #7

there is no order clause, and the cursor specification is now complete:

CursorSpecification #1 (#9) union #2

The next stage is the construction of RowSets, which are gathered in the Context in a list called data::

{(70=IndexRowSet 70(48,104) targets: 23=70 Keys: (48,104),

182=IndexRowSet 182(158,204,249) targets: 148=182 Keys: (158,204,249),

#7=SelectRowSet #7(#10) targets: 23=70,148=182 Source: #21,

#21=TableExpRowSet #21(%0,%1,#10|%2,%3) key (%0,%1,#10) where (#53,#65)

targets: 23=70,148=182 Source: #34,

#26=SelectedRowSet #26(%0,%1) targets: 23=70 Source: 70,

#34=JoinRowSet #34(%0,%1,#10|%2,%3) where (#53,#65) targets: 23=70,148=182

First: #26 Second: #36,

#36=SelectedRowSet #36(#10|%2,%3) where (#65) targets: 148=182 Source: 182)}

The cursor supplied at the top level in this case will contain a single column e.g. {(#10=Nostromo)}. Further information about RowSets and Cursors follows in the next sections.

## 6.2 RowSets and Context

In v7 executables that operate on tables and views (such as SelectStatement, or InsertStatement) are generally associated with rowsets rather than queries. In previous versions, the rowset associated with a query often had the same defining position (uid) and the Context maintained separate lists for object uids and rowset uids. This departure from uniqueness of uids persists in v7. The top-level query in an SQL statement (usually a CursorSpecification) thus typically has the same defpos or uid as the SelectRowSet that contains its result, and a From that targets a base table or view has the same defpos as the TransitionRowSet that manages an associated CRUD operation (this common uid is now called Nuid, while the table or view is called Target).

RowSets give access to a Cursor for traversing a set of rows. Unless an operation such as sorting requires all its data, the rowset rows are not computed until traversal begins. Recall that queries, rowsets and cursors are all immutable data structures, rowsets and queries are nested structures, with SQL commands and results at the top level, and base table references at the bottom: each level contains a reference to an immuable structure at the next level down. A cursor contains a reference to its own rowset. This arrangement requires rowsets to have uids, which for IndexRowSet and TableRowSet can be the same as the index and table, and contain nothing related to the current command, role or user. SystemRowSets are the same for all databases.

|  |  |
| --- | --- |
| **RowSet class** | **Comments** |
| IndexRowSet | Primary or unique index for any user and role |
| SystemRowSet | System Tables as defined in Manual sec 8. Many Cursor types |
| TableRowSet | Accesses base table for any user and role |

Some RowSets have uids given by the lexical position in the command, as shown in the following table.

|  |  |  |
| --- | --- | --- |
| **Syntax** | **RowSet class** | **Comments** |
| From | TrivialRowSet | Static results: rowType from command |
| From | SelectedRowSet | Accesses base table: |
| JoinPart | JoinRowSet | Cursor classes for different join types |
| QueryExpression | MergeRowSet |  |
| QuerySearch | TransitionRowSet | TransitionRowSet has defpos #0 |
| QuerySpecification | SelectRowSet |  |
| QuerySpecification | EvalRowSet | EvalRowSet has just one row |
| QuerySpecification | GroupingRowSet |  |
| SqlInsert | TransitionRowSet | TransitionRowSet has defpos #0 |
| TableExpression | TableExpRowSet |  |
| UpdateSearch | TransitionRowSet | TransitionRowSet has defpos #0 |
| VALUES | ExplicitRowSet |  |

Other RowSets are given uids as required from the different volatile uid ranges (see section 2.3). GroupingRowSet is particularly complex and discussed later in this section.

The Context keeps track of the structures required for computing results. A new Context must be created for each procedure stack frame, but the new stack frame can start off with all the previous frame’s values still visible. SQL does not allow values in statically enclosing frames to be updated. When a procedure returns, the upper context is removed exposing the previously accessible data even if the procedure used the same identifiers for its local data.

The context contains the result of parsing SQL, as a collection of DBObjects (Queries and SqlValues, arranged by depth). During rowset traversal the context contains a set of current rowsets (data) and their cursors. During cursor evaluation, the context contains an association between SqlValues and the rowset used to access its current value. Each rowset contains two versions of this assocation, one (\_finder) for constructing its cursors, and another (finder) for use by clients. These relate to the rowset hierarchy in an obvious way: the internal \_finder at one level is the external finder for level below. For some rowsets such as OrderedRowSet, the finders are changed after building.

In aggregated, grouped and windowed operations, the context contains a set of Registers for accumulating aggregated values for each SqlFunction and any appropriate group or window keys. To facilitate this, the StartCounter and AddIn functions are called with their own Cursor, even through all such will use the same transaction and context.

To compute a join, it is often the case that join columns have been defined and the join requires equality of these join columns (inner join). If the two row sets are ordered by the join columns, then computing the join costs nothing (i.e. O(N)): a join bookmark simply advances the left and right rows returns rows where the join columns have matching values. If the join columns are not in the right order for the join, a sorted rowset is interposed during parsing. The cost of ordering is O(NlogN+MlogM) if both sets need to be ordered. Cross joins cost O(MN) of course.

The above transformations of row sets motivate what happens during query processing in Pyrrho.

### 6.2.1 Grouped aggregations

SQL(2008-) allows a query to specify groupings by columns (or more generally by SqlValue expressions built from columns). Each grouping can be on a single column or lists of columns (as with indexes), called grouping keys. Columns (or expressions) in the source rowset that are not directly used for grouping are called data columns. The select list of the grouped query can contain SqlValues built from grouping keys and aggregation expressions directly or in combination: data columns cannot be referenced directly, The grouped rowset is built by traversing the source rowset, to compute partial sums of data columns for each value of the grouping keys.

## 6.3 SqlValue vs TypedValue

As discussed in the above section, during Query analysis it is quite common for queries to be combined (e.g. in Joins) or have additional columns added (e.g. derived or computed columns in the results).

The parser creates SqlValues, which in v7 are immutable and only need to be constructed once. SqlValues do not have exposed values: the value of an SqlValue is only found by evaluation. During query processing all structured types (normally based on TypedValues) have SqlValue analogues built from SqlTypeColumn. To see the difference consider the following examples of an array of NUMERIC

[INTEGER(1),34.5,0] TypedValues (the first one here has a subtype of NUMERIC)

[A,B,36] SqlValues (36 is an SqlLiteral)

So for example we have Row and SqlRow etc. As has been mentioned, evaluation Contexts are used as general containers, and are important for creating scopes during Parsing.

During rowset traversal, each Cursor computes the TypedValue for its current row. In complex queries, some query columns may depend on derived tables defined later in the query syntax, complicating the normal process of left-to-right evaluation. The evaluation of an SqlValue in these circumstances may temporarily result in a null TypedValue indicating the imcompleteness of evaluation (not a TNull.Value indicating a computed SQL NULL value), and causes the computation of such columns to be retried. This code is contained in Cursor.Value().

Activations form stacks during execution, local variables are defined by giving their activation and name (this is a Target). Variables identified by a dotted sequence of names will be searched for by unwinding the stack to find the appropriate context.

## 6.4 Persistent Stored Modules

A big change in this version of Pyrrho is that code modules (triggers, stored procedures etc) are only parsed once per cold start. The uids given to DBObjects generated by the parser during Load are all in the range of file positions occupied by the corresponding source code in the transaction log. As with all parsing in this version, during the parsing process the resulting objects are added to the parser’s context. These generated objects are not added to the Database objects tree, but stored (in Framing) in the trigger or procedure DBObject. When execution is required, these objects can simply be added to the activation context (by the line of code cx.obs += ob.framing) to make them available to the execution engine. The latter does not need access to the other transient parsing structures (such as defs), since ObInfo information is now added to each SqlValue and Query.

This brings a need to manage cx.obs during the construction of such frames. Each new Parser instance creates a Context where these structures are empty. A complex SQL statement might result in a number of Compiled objects (for example, a table whose column definitions include inline Check constraints), but we cannot simply construct a new Context for each to accumulate the framing for each one. But we can and should control the growth of cx.obs: once the framing property of the compiled object has been collected, we should restore cx.obs (and cx.defs amd cx.depths) to their values at the start of parsing the compiled object. Other parts of the context, such as cx.db, cx.nextPos, cx.nextId continue to accumulate the parsing results.

## 6.5 Trigger Implementation

As elsewhere in Pyrrho, parsing of executable SQL takes place on definition or grant of a database object. Definition is within the command processing that creates the object, or the database load on server start-up, and the associated private uids of compiled objects will differ for these two cases. The compiled objects are placed in the framing property of the associated DBObject, and these are added to the context when required.

Trigger code can refer to new row and table, or old row and table. For simplicity, the new row and table use the same uid as the target table, while different uids refer to the old row and table, which are cached at the start of trigger execution.

This section presents a worked example, based on Test16 in the PyrrhoTest program. This test has a table XA with three triggers defined, which modify two other tables XB and XC. The working below will deal with the second modification to XA, which is an update. The relevant declarations in the test are:

create table xa(b int,c int,d char)

create table xb(tot int)

insert into xb values (0)

[create trigger ruab before update on xa referencing old as mr new as nr

for each row begin atomic update xb set tot=tot-mr.b+nr.b; set d='changed' end]

[create trigger riab before insert on xa

for each row begin atomic set c=b+3; update xb set tot=tot+b end]

At this point, the log contains:

|  |  |  |
| --- | --- | --- |
| **Pos** | **Record Type** | **Contents** |
| 23 | PTable XA |  |
| 30 | PDomain INTEGER |  |
| 44 | PColumn3 B |  |
| 65 | PColumn3 C |  |
| 87 | PDomain CHAR |  |
| 100 | PColumn3 D |  |
| 140 | PTable XB |  |
| 147 | PColumn3 TOT |  |
| 189 | Record 189[140] | 147=0 |
| 221 | Trigger RUAB | Trigger RUAB Update, Before, EachRow on 23  begin atomic update xb set tot=tot-mr.b+nr.b; set d='changed' end |
| 331 | Trigger RIAB | Trigger RIAB Insert, Before, EachRow on 23: begin atomic set c=b+3; update xb set tot=tot+b end |

The Trigger definitions are stored in the log in source form, but an initial version of the compiled contents are now in memory in a field called framing on the Trigger object. The following “readable” version of this field (for RIAB, following a server restart[[22]](#footnote-22)) is from the debugger, and contains the items that will be cached in the context when the trigger is used. They have uids in the physical range starting at 331 and below the next entry in the transaction log, together with a sequence in the executable range notated above with @s Notice that the relevant tables and columns are included:

{Framing B=(@0,);C=(@1,);D=(@2,);RIAB=(331,);TOT=(@3,);XA=(333,B=(@0,);C=(@1,);D=(@2,););

XB=(363,TOT=(@3,);); Obs:

(23 Table Name=XA 23 Definer=-502 Ppos=23

Domain TABLE (44,65,100)([44,Domain INTEGER],[65,Domain INTEGER],[100,Domain CHAR])

Triggers:(Update, Before, EachRow=(221=True)) KeyCols: ,

44 TableColumn 44 Definer=-502 Ppos=44 Domain INTEGER Table=23,

65 TableColumn 65 Definer=-502 Ppos=65 Domain INTEGER Table=23,

100 TableColumn 100 Definer=-502 Ppos=100 Domain CHAR Table=23,

140 Table Name=XB 140 Definer=-502 Ppos=140

Domain TABLE (147)([147,Domain INTEGER]) KeyCols: ,

147 TableColumn 147 Definer=-502 Ppos=147 Domain INTEGER Table=140,

331 Trigger Name=RIAB 331 Definer=-502 Ppos=331 TrigType=Insert, Before, EachRow On=23

From: 333 Action:383 UpdateCols:,

333 From Name=XA 333 RowType:(@0,@1,@2) Target=23,

338 CompoundStatement 338(345,356),

345 AssignmentStatement 345 @1=352,

352 SqlValueExpr Name= 352 Left:@0 Domain INTEGER Right:353 352(@0+353),

353 3,

356 UpdateSearch 356 Nuid=363 Target: 140,

363 From Name=XB 363 RowType:(@3) Assigs:(UpdateAssignment Vbl: @3 Val: 377=True)

Target=140,

377 SqlValueExpr Name= 377 Left:@3 Domain INTEGER Right:@0 377(@3+@0),

383 WhenPart 383\_ Stms: (338),

@0 SqlCopy Name=B @0 From:333 Domain INTEGER copy from 44,

@1 SqlCopy Name=C @1 From:333 Domain INTEGER copy from 65,

@2 SqlCopy Name=D @2 From:333 Domain CHAR copy from 100,

@3 SqlCopy Name=TOT @3 From:363 Domain INTEGER copy from 147) Data:

(140 TableRowSet 140(147) targets: 140=140 Source: \_,

363 SelectedRowSet 363(@3) targets: 140=363 Assigs:(UpdateAssignment Vbl: @3 Val: 377=True)

Source: 140)

Results: (,363 363)}

These implement “set c=b+3; update xb set tot=tot+b”. However, this trigger is not loaded into the main Context, nor even the TableActivation. It will be Installed in the TriggerActivation.

Meantime, the next step in the test is an insert command:

insert into xa(b,d) values (7,'inserted')

Let us trace through everything that happens here. Recall that several sorts of insert triggers can be defined on a table, and possibly more than one of any kind, possible defined by different roles. So the trigger implementation must take into account the command context (with the session role), the target conext (using the table definer’s role) and maybe several different trigger contexts (the trigger definers’ roles). After parsing, we have the following rowsets in the command context #1, whose result is #13:

{(23=TableRowSet 23(44,65,100) targets: 23=23 Source: \_,

#13=SelectedRowSet #13(#16,#18|%0) targets: 23=#13 Source: #21,

#21=SqlRowSet #21(#16,#18))}

The command to be executed is

{SqlInsert #1 Nuid=#13 Target: 23 Value: #13}

This quickly leads to 23.Insert() for Table XA, and the creation of a TableActivation 33, which includes the definition of a TransitionRowSet %1 to manage the insert operation, and associated triggers, in this case the single trigger 331 RIAB is found and TriggerActivation 34 is set up for it. The trigger’s in-memory objects and rowsets, shown above, are installed now.

In the discussion we need to remember that although the column names B, C, D in the table definition are used throughout the source of this example (in table definition, trigger definition and command) it is not necessarily a good idea to use these identifiers in implementation (as they were in previous versions of Pyrrho). The reasons for using uids instead in v7 are (a) such identifiers are valid in different (possibly overlapping scopes) in which case they need more complex identifier chains to disambiguate, (b) different roles are allowed to use different vocabularies, and roles are implemented in the physical layer in Pyrrho for good security reasons. So we we note that in this example the table definer role gives XA the rowType (B[44],C[65],D[100]), the insert command has the anonymous row type (B[#16],D[#18]|C[%0]) where C is not mentioned and will have the default null value, and the trigger definition has rowType (B[@0],C[@1],D[@2]). The current row is described by three cursors, a TransitionCursor, a TargetCursor and a TriggerCursor[[23]](#footnote-23), with these different datatypes, for the three different execution contexts (#1, 33, and 34). Since each context always has its own idea of its cursors, both cursors will be identified by the uid of the TransitionRowSet, %1 in this case (the command might in general have several instances of the table XA).

There were no statement-level triggers for Insert on table XA, so traversal begins with the construction of the first TransitionCursor {(#16=7,#18=inserted,%0= Null) %1} for the TransitionRowSet, and its associated TargetCursor {(44=7,65= Null,100=inserted) %1}. The TableActivation holds the set of row values {(44=7,65= Null,100=inserted,%2=(44=7,65= Null,100=inserted) %1)} for the triggers to work on, and the TargetCursor has set up a proposed TableRow using its current values.

The 33.Triggers(Before|EachRow) method now calls the insert-before triggers, here just the one: 34.Exec() is called for the current row, and begins by setting up the TriggerCursor {(@0=7,@1= Null,@2=inserted) %1} in the TriggerActivation 34. The trigger does not specify a when expression. so the next step (deep in the Exec() method) is 338.Obey(): from above we see this is a CompoundStatement. Compound statements can have exception handlers, so they need a further activation: here Activation 35. The first step at 345 is an assignment statement @1=352, @1 is just C. while 352 is @0+353, i.e. B+3. The latter is evaluated to give 10, and the assignment results in the 35’s value list becoming {(65=10,@0=7,@1=10, @2=inserted)}. We recognise the last three as being for the transition cursor, while the first records a direct assignment to a column (something of a special case in the SQL standard, cf note 116 in section 4.44 of ISO9075(2016)).

The next statement in the action is 356 UpdateSearch 356 Nuid=363 Target: 140, where 363 refers to the above SelectedRowSet. When this is obeyed, 140.Update() is called, which creates a new TableActivation 36 with a {TransitionRowSet %2(@3) targets: 140=363 From: 140 Data: 363} but no triggers as XB has none defined. 363’s only update assignment is noted {UpdateAssignment Vbl: @3 Val: 377}. Traversal leads to its transition cursor {(@3=0) %2} and target cursor {(147=0) %2}.

The update assignment leads to 35.values now becoming {(65=10,147=7,189=(147=0) %2,@0=7,@1=10,@2=inserted)} as we have “inherited” the values from above. Importantly, we see the new value for 147 TOT. The next step ts to update the TableRow in table XB in method 189.\_Update(), which constructs an Update entry for the transaction log {Update 189[140]: 147=7 Prev:189}.

On exit from activations 36, 35, and 34, the new values slide down the stack as appropriate, and the command context adopts the changes made so far: {(!0=TriggeredAction 331,!1=Update 189[140]: 147=7 Prev:189)} replaces the corresponding entries in the caller’s context 32. The changes to the trigger cursors have also modified the TargetCursor and TransitionCursor, so that the details for the new row are {(44=7,65=10,100=inserted) %1} and {(#16=7,#18=inserted,%0=10) %1} respectively, while the TableRow now contains the updated values.

This completes execution of each-row-before triggers, and now the insert of the new row can take place. This gives a new Record for the transaction: {Record !2[23]: 44=7,65=10,100=inserted}.

The command is finished, and the following records are committed along with the triggeredAction note at 421:

|  |  |  |
| --- | --- | --- |
| 428 | Update 189[140] | 147=7 Prev:189 |
| 449 | Record 449[23]: | 44=7,65=10,100=inserted |

The next step in the test is a similar insert operation, that adds some more entries in the log, notably:

|  |  |  |
| --- | --- | --- |
| 505 | Update 189[140] | 147=16 Prev:428 |
| 526 | Record 526[23]: | 44=9,65=12,100=Nine |

Next se have an update statement. From definition of the update trigger above we see that this will demonstrate the operation of OLD ROW and NEW ROW:

update xa set b=8,d='updated' where b=7

In these notes we again assume the server has been restarted (if not the activation identifiers will be different). When TriggerActivation 33.Exec() is called, this is how things stand. (We don’t show the greyed-out entries, which are the same as above. Recall that the TriggerActivation contains the compiled objects of the trigger, shown in blue here. The default colour is for the objects coming from the above SQL statement.)

RowSets:

{(23=TableRowSet 23(44,65,100) matches (44=7) targets: 23=23 Source: \_,

140=TableRowSet 140(147) targets: 140=140 Source: \_,

242=SelectedRowSet 242(@3) targets: 140=242 Assigs:(UpdateAssignment Vbl: @3 Val: 261=True)

Source: 140,

#8=SelectedRowSet #8(%0,%1,%2) where (#38) matches (%0=7) targets: 23=#8

Assigs:(UpdateAssignment Vbl: %0 Val: #17=True,UpdateAssignment Vbl: %2 Val: #21=True)

Source: 23,

%3=TransitionRowSet %3(%0,%1,%2) where (#38) targets: 23=#8 From: 23 Data: #8)}

Objects:

{(221=Trigger Name=RUAB 221 Definer=-502 Ppos=221 TrigType=Update, Before, EachRow On=23

From: 223 Action:287 UpdateCols: OldRow=233 NewRow=237,

223=From Name=XA 223 RowType:(@0,@1,@2) Target=23,

228=CompoundStatement 228(235,268),

233=SqlOldRow Name=MR 233 From:223 Domain TABLE (@0,@1,@2)

([@0,Domain INTEGER],[@1,Domain INTEGER],[@2,Domain CHAR]) [@0,@1,@2],

235=UpdateSearch 235 Nuid=242 Target: 140,

237=SqlNewRow Name=NR 237 From:223 Domain TABLE (@0,@1,@2)

([@0,Domain INTEGER],[@1,Domain INTEGER],[@2,Domain CHAR]) [@0,@1,@2],

242=From Name=XB 242 RowType:(@3) Assigs:(UpdateAssignment Vbl: @3 Val: 261=True)

Target=140,

256=SqlValueExpr Name= 256 Left:@3 Domain INTEGER Right:257 256(@3-257),

257=SqlValueExpr Name=MR.B 257 From:223 Left:233 Domain INTEGER Right:@0 257(233.@0),

261=SqlValueExpr Name= 261 Left:256 Domain INTEGER Right:262 261(256+262),

262=SqlValueExpr Name=NR.B 262 From:223 Left:237 Domain INTEGER Right:@0 262(237.@0),

268=AssignmentStatement 268 @2=274,

274=changed,

287=WhenPart 287\_ Stms: (228),

#1=UpdateSearch #1 Nuid=#8 Target: 23,

#8=From Name=XA #8 RowType:(%0,%1,%2)

Assigs:(UpdateAssignment Vbl: %0 Val: #17=True,UpdateAssignment Vbl: %2 Val: #21=True)

Filter:(%0=7) Where:(#38=True) Target=23,

#17=8,

#21=updated,

#38=SqlValueExpr Name= #38 From:#8 Left:%0 BOOLEAN Right:#39 #38(%0=#39),

#39=7,

@0=SqlCopy Name=B @0 From:223 Domain INTEGER copy from 44,

@1=SqlCopy Name=C @1 From:223 Domain INTEGER copy from 65,

@2=SqlCopy Name=D @2 From:223 Domain CHAR copy from 100,

@3=SqlCopy Name=TOT @3 From:242 Domain INTEGER copy from 147,

%0=SqlCopy Name=B %0 From:#8 Domain INTEGER copy from 44,

%1=SqlCopy Name=C %1 From:#8 Domain INTEGER copy from 65,

%2=SqlCopy Name=D %2 From:#8 Domain CHAR copy from 100)}

Cursors:

{(23=(44=7,65=10,100=inserted) 23,

#8=(%0=7,%1=10,%2=inserted) #8,

%3=(@0=7,@1=10,@2=inserted) %3)}

Recall there are three contexts involved at this point, all dealing with the TransitionRowSet %3: we have TriggerActivation 33, TableActivation 32 and the context below, each with their own idea of what the columns are. The trigger cursor is shown above as %3=(@0=7,@1=10,@2=inserted) %3). The TransitionCursor is two levels down: {(%0=7,%1=10,%2=inserted) %3}, and the TargetCursor one level down is {(44=7,65=10,100=inserted) %3}. The Update method has primed the TableActivation values with its versions of this for old row[[24]](#footnote-24) and new row, (-295=(44=7,65=10,100=inserted) %3,

-293=(44=8,65=10,100=updated), along with the current row 449’s column and row values 44=8,65=10,100=updated,449=(44=7,65=10,100=inserted) %3)}.

33.Exec() prepares for execution on the current row by constructing its idea of oldrow and new row, since these have been referenced. Its values thus become {(233=(@0=7,@1=10,@2=inserted),237=(@0=8,@1=10,@2=updated),449=(@0=7,@1=10,@2=inserted) %3,@0=7,@1=10,@2=inserted)}. This completes Exec() as there is no when-condition specified on the trigger.

The first step in executing the trigger is the UpdateSearch 235, and it calls the Update method on SelectedRowSet 242 targeting XB. The first step is to create TableActivation 35 with its TransitionRowSet %4 for 242.Update(). The traversal begins, and creates the TargetCursor {(147=16) %4}. At this point TableActivation 35’s relevant values are {(147=16,189=(147=16) %4, 233=(@0=7,@1=10,@2=inserted),237=(@0=8,@1=10,@2=updated),449=(@0=7,@1=10,@2=inserted) %3,@0=7,@1=10,@2=inserted)}.

Table XB has no triggers to refer to its old or new row, so the UpdateAssignment for SqlCopy @3 is considered next. If we write [n] for the n.Eval(35), we are evaluating [261] which is [256]+[262] and so on. The evaluation proceeds as follows:

[261]=[256+262]:

[256]=[@3]-[257]:

[@3]={147}=16

[257]=[233].[@0]=7

:=9

[262]=[237].[@0]=8

:=17

So in 35.values, we get {147}:=17, an this completes the calculation of the values of XB’s new row. The new TableRow is now constructed, and \_Update() generates the Update record for XB [140] in the transaction commit: {(!1=Update 189[140]: 147=17 Prev:189)}. This completes the UpdateSearch 235.

The second step in the trigger is an Assignment statement in Activation 34. This updates 34’s values for 100 changed, so 34’s relevant values are {(100=changed, 233=(@0=7,@1=10,@2=inserted),237=(@0=8,@1=10,@2=updated),449=(@0=7,@1=10,@2=inserted) %3,@0=7,@1=10,@2=changed,@3=16)}. The SlideDown method for Activation 34, updates the TriggerActivation 33 to these values. As mentioned in Note 116 in the SQL standard, the assignment to a column of the target table has is recorded, so that the ttrasitioncursor becomes {(%0=7,%1=10,%2=changed) %3}.

Back in 23.Update(), it remains to merge the updates into the new TableRow . As before the \_Update method does this, and generates a further items for the Transaction Commit: {(!2=Update 449[23]: 44=8,65=10,100=changed Prev:449)}

In the transaction log, this shows as

|  |  |  |
| --- | --- | --- |
| 578 | Update 189[140] | 147=17 Prev:505 |
| 599 | Update 449[23]: | 44=8,65=10,100=changed Prev: 449 |

This completes the discussion of the Update trigger demonstration.

In the test a third table XC and a third trigger for XA are defined, and the next step is a Delete operation, demonstrating an INSTEAD OF statement-level trigger and the use of the OLD TABLE feature of SQL. (See section 3.4.2.)

create table xc(totb int,totc int)

[create trigger sdai instead of delete on xa referencing old table as ot for each statement begin atomic insert into xc (select b,c from ot) end]

|  |  |  |
| --- | --- | --- |
| 653 | PTable XC |  |
| 661 | PColumn3 TOTB | for 653(0)[30] |
| 687 | PColumn3 TOTC | for 653(1)[30] |
| 732 | PTrigger SDAI | Delete, Instead, EachStatement on 23,OT=old table : begin atomic insert into xc (select b,c from ot) end |

The framing for 732 is as follows:

{Framing B=(@3,);C=(@4,);D=(@5,); OT=(747,);SDAI=(732,);TOTB=(@6,);TOTC=(@7,);

XA=(734,B=(@0,);C=(@1,);D=(@2,););

XC=(758,TOTB=(@6,);TOTC=(@7,););

Obs:

(23 Table Name=XA 23 Definer=-502 Ppos=23 Domain TABLE (44,65,100)

([44,Domain INTEGER],[65,Domain INTEGER],[100,Domain CHAR])

Triggers:(Insert, Before, EachRow=(331=True),Update, Before,

EachRow=(221=True)) KeyCols: ,

44 TableColumn 44 Definer=-502 Ppos=44 Domain INTEGER Table=23,

65 TableColumn 65 Definer=-502 Ppos=65 Domain INTEGER Table=23,

100 TableColumn 100 Definer=-502 Ppos=100 Domain CHAR Table=23,

653 Table Name=XC 653 Definer=-502 Ppos=653

Domain TABLE (661,687)([661,Domain INTEGER],[687,Domain INTEGER]) KeyCols: ,

661 TableColumn 661 Definer=-502 Ppos=661 Domain INTEGER Table=653,

687 TableColumn 687 Definer=-502 Ppos=687 Domain INTEGER Table=653,

732 Trigger Name=SDAI 732 Definer=-502 Ppos=732 TrigType=Delete, Instead,

EachStatement On=23 From: 734 Action:785 UpdateCols: OldTable=747,

734 From Name=XA 734 RowType:(@0,@1,@2) Target=23,

739 CompoundStatement 739(746),

746 SqlInsert 746 Nuid=758 Target: 653 Value: 758,

747 TransitionTable Name=OT 747 RowType:(@3,@4,@5) Target=23 old for 732 from 23,

758 From Name=XC 758 RowType:(@6,@7) Target=653,

761 SqlValueSelect 761 Domain TABLE (@3,@4)([@3,Domain INTEGER],[@4,Domain INTEGER]) (762),

762 CursorSpecification 762 RowType:(@3,@4) Source={select b,c from ot} Union: 763,

763 QueryExpression 763 RowType:(@3,@4) Left: 768 ,

768 QuerySpecification 768 RowType:(@3,@4) TableExp 773,

773 TableExpression 773 Nuid=747 RowType:(@3,@4,@5) Target: 747,

785 WhenPart 785\_ Stms: (739),

@0 SqlCopy Name=B @0 From:734 Domain INTEGER copy from 44,

@1 SqlCopy Name=C @1 From:734 Domain INTEGER copy from 65,

@2 SqlCopy Name=D @2 From:734 Domain CHAR copy from 100,

@3 SqlCopy Name=B @3 From:747 Domain INTEGER copy from 44,

@4 SqlCopy Name=C @4 From:747 Domain INTEGER copy from 65,

@5 SqlCopy Name=D @5 From:747 Domain CHAR copy from 100,

@6 SqlCopy Name=TOTB @6 From:758 Domain INTEGER copy from 661,

@7 SqlCopy Name=TOTC @7 From:758 Domain INTEGER copy from 687)

Data:

(23 TableRowSet 23(44,65,100) targets: 23=23 Source: \_,

653 TableRowSet 653(661,687) targets: 653=653 Source: \_,

747 SelectedRowSet 747(@3,@4,@5) targets: 23=747 Source: 23,

758 SelectedRowSet 758(@6,@7) targets: 653=758 Source: 768,

762 SelectRowSet 768(@3,@4) targets: 23=747 Source: 773,

768 SelectRowSet 768(@3,@4) targets: 23=747 Source: 773,

773 TableExpRowSet 773(@3,@4,@5) key (@3,@4,@5) targets: 23=747 Source: 747)

Results: (,747 747,758 758,763 768,768 768,773 773)}

We see the old table reference has defined a TransitionTable 747 and a TableExpression 773, along with SqlCopy for the columns. Again for the purpose of these notes we restart the server so that the activation numbers are the same for a reader following the steps with the debugger:

delete from xa where d='changed'

23.Delete() sets up a TableActivation 33 which creates a TriggerAction 34, a TransitionRowSet %4, and a TransitionTableRowSet %5 for the old table, so that the TableActivation 33 has the following rowsets:

{(-296=TransitionTableRowSet -296(%0,%1,%2) targets: 23=#13,

23=TableRowSet 23(44,65,100) matches (100=changed) targets: 23=23 Source: \_,

#13=SelectedRowSet #13(%0,%1,%2) where (#23) matches (%2=changed) targets: 23=#13

Source: 23,

%4=TransitionRowSet %4(%0,%1,%2) where (#23) targets: 23=#13 From: 23 Data: #13)}

The statement-level instead trigger SDAI is now executed 34.Exec(). Before we execute the trigger action we need to create the TransitionTableRowSet OT. Once this is done we have all the rowets for the TriggerActivation 34:

{(23=TableRowSet 23(44,65,100) targets: 23=23 Source: \_,

653=TableRowSet 653(661,687) targets: 653=653 Source: \_,

747=TransitionTableRowSet 747(@3,@4,@5) targets: 23=#13 OLD,

758=SelectedRowSet 758(@6,@7) targets: 653=758 Source: 768,

762=SelectRowSet 768(@3,@4) targets: 23=747 Source: 773,

768=SelectRowSet 768(@3,@4) targets: 23=747 Source: 773,

773=TableExpRowSet 773(@3,@4,@5) key (@3,@4,@5) targets: 23=747 Source: 747,

#13=SelectedRowSet #13(%0,%1,%2) where (#23) matches (%2=changed) targets: 23=#13

Source: 23,

%4=TransitionRowSet %4(%0,%1,%2) where (#23) targets: 23=#13 From: 23 Data: #13)}

The first and only statement to be executed by the trigger is the insert statement for XC 653. {SqlInsert 746 Nuid=758 Target: 653 Value: 758}. XC has no triggers, and 758 is a select statement from the old table, so we check that traversal gets what expect. For XC we have TableActivation 36 and {TransitionRowSet %5(@6,@7) targets: 653=758 From: 653 Data: 768}. The transitioncursor returnsed is {(@6=8,@7=10) %5}, the targetcursor is {(661=8,687=10) %5}, and this gives the new Record for the transaction commit: (!1=Record !1[653]: 661=8,687=10).

Because this is an INSTEAD OF trigger, Exec() returns true, and the actual Delete statement is not executed. Following Commit, the log shows

|  |  |  |
| --- | --- | --- |
| 834 | Record 834[653] | 661=8,687=10 |

This completes this demonstration.

## 6.6 View Implementation

Because of the use case of virtual data warehousing, where (possibly behind the scenes) tables are virtual and mediated by views, it is interesting to enable views to be modifiable. We cover modifiable views in this section. Not all views are modifable, but a great many should be.

A View is a compiled object (class PView is a subclass of Compiled) and a view definition is compiled as soon as the server sees it,, i.e. on creation by a CREATE VIEW SQL statement, or on initial Load of the database. The compiled parts of the View are held in a Framing object.

In this section we follow the execution of the parts of test 12 that deal with views.. For simplicity we omit the earlier steps, and start with an empty database t12, and the definitions

create table p(q int primary key,r char,a int)

create view v as select q,r as s,a from p

In the transaction log these are:

|  |  |  |
| --- | --- | --- |
| 23 | PTable P |  |
| 29 | Domain INTEGER |  |
| 43 | PColumn3 Q | for 23(0)[29] |
| 64 | PIndex P | on 23(43) PrimaryKey |
| 80 | Domain CHAR |  |
| 93 | PColumn3 R | for 23(1)[80] |
| 115 | PColumn3 A | for 23(2)[29] |
| 155 | PView V 155 | select q,r as s,a from p |

The Framing for the View is

{Framing A=(173,);P=(180,A=(173,);Q=(164,);R=(166,););Q=(164,);R=(166,);S=(166,); Obs:

(23 Table Name=P 23 Definer=-502 Ppos=23 Domain TABLE (43,93,115)

([43,Domain INTEGER],[93,Domain CHAR],[115,Domain INTEGER])

Indexes:((43)64) KeyCols: (43=True),

43 TableColumn 43 Definer=-502 Ppos=43 Domain INTEGER Table=23,

93 TableColumn 93 Definer=-502 Ppos=93 Domain CHAR Table=23,

115 TableColumn 115 Definer=-502 Ppos=115 Domain INTEGER Table=23,

156 SelectStatement 156 CS=157,

157 CursorSpecification 157 RowType:(164,166,173) Source={select q,r as s,a from p}

Union: 158,

158 QueryExpression 158 RowType:(164,166,173) Left: 163 ,

163 QuerySpecification 163 RowType:(164,166,173) TableExp 175,

164 SqlCopy Name=Q 164 From:180 Domain INTEGER copy from 43,

166 SqlCopy Name=R 166 From:180 Alias=S Domain CHAR copy from 93,

173 SqlCopy Name=A 173 From:180 Domain INTEGER copy from 115,

175 TableExpression 175 Nuid=180 RowType:(164,166,173) Target: 180,

180 From Name=P 180 RowType:(164,166,173) Target=23) Data:

(64 IndexRowSet 64(43,93,115) targets: 23=64 Keys: (43,93,115),

155 TableExpRowSet 175(164,166,173) key (164,166,173) targets: 23=64 Source: 180,

175 TableExpRowSet 175(164,166,173) key (164,166,173) targets: 23=64 Source: 180,

180 SelectedRowSet 180(164,166,173) targets: 23=64 Source: 64 Result 175)

Results: (,158 175,163 175,175 175,180 180)}

This framing is designed for selection, as in most cases a reference to the view will be within a query. In this section, we want to show that the view can just as easily be a target for insert, update and delete.

As usual, we restart the server so that context and activation numbers are reprociable in these notes. The next statement in the test is

insert into v(s) values('Twenty'),('Thirty')

When the transaction is about to execute this statement after parsing. the context has the following objects and rowsets (omitting the entries listed above which have been installed in the context once referenced), the View has been “instanced” giving the following entries in the Context:

{(#1=SqlInsert #1 Nuid=#13 Target: 155 Value: %3,

#13=From Name=V #13 RowType:(#15|%0,%1) Target=%2,

#15=SqlCopy Name=S #15 From:#13 Domain CHAR copy from 93,

#18=#24,#35,

#24=SqlRow #24 Domain ROW (#25)([#25,CHAR]) [#25],

#25=Twenty,

#35=SqlRow #35 Domain ROW (#36)([#36,CHAR]) [#36],

#36=Thirty,

%0=SqlCopy Name=Q %0 From:#13 Domain INTEGER copy from 43,

%1=SqlCopy Name=A %1 From:#13 Domain INTEGER copy from 115,

%2=View Name=V %2 Definer=-502 Ppos=155 Query select q,r as s,a from p Ppos: 155

Cols (A=%1,Q=#15,R=%0,S=%0) Domain TABLE (#15,%0,%1) Display=4

([#15,Domain INTEGER],[%0,Domain CHAR],[%1,Domain INTEGER]) Targets: 23,

%3=TableExpression %3 Nuid=%8 RowType:(#15,%0,%1) Target: %8,

%4=QuerySpecification %4 RowType:(#15,%0,%1) TableExp %3,

%5=QueryExpression %5 RowType:(#15,%0,%1) Left: %4 ,

%6=CursorSpecification %6 RowType:(#15,%0,%1) Source={select q,r as s,a from p}

Union: %5,

%7=SelectStatement %7 CS=%6,

%8=From Name=P %8 RowType:(#15,%0,%1) Target=23,

%9=SqlCopy Name=R %9 From:%8 Alias=S Domain CHAR copy from 93,

%10=SqlCopy Name=A %10 From:%8 Domain INTEGER copy from 115)}

{(64=IndexRowSet 64(43,93,115) targets: 23=64 Keys: (43,93,115),

#13=TableExpRowSet %3(#15,%0,%1) key (#15,%0,%1) targets: 23=64 Source: %8,

#18=SqlRowSet #18(#15),

%3=TableExpRowSet %3(#15|%0,%1) key (#15,%0,%1) targets: 23=64 Source: %8,

%8=SelectedRowSet %8(#15,%0,%1) key (#15,%0,%1) targets: 23=64 Source: #18)}

Here objects %0-%10 are instances of objects from the veiw definition. Instancing is needed in general because a single command might reference a view more than once and these instances need to be distinguished from each other. Instancing creates new objects to ensure the uids are different and to add modifications coming from the command such as where conditions (there is no question of altering the compiled objects 175 etc!).

Here Execute() sets up a new new Activation 30.This calls Obey() for the SqlInsert statement #1. #1.Obey(30) finds the TableExpRowSet %3 and calls %3.Insert (). In turn this calls %8.Insertt() for the SelectedRowSet %8. This finally calls Insert for Table P: 23.Insert(%3). This sets up a TableActivation 31 and {TransitionRowSet %11(#15|%0,%1) targets: 23=64 From: 23 Data: %8}.

We see that the TacbleActivation really doesn’t mention V, so that the insert for the View V has become an Insert for the Table P 23. The TargetCursor for the Table P fills in the key column Q using Pyrrho’s autokey feature, so, following the autoCommit, we have simply

|  |  |  |
| --- | --- | --- |
| 206 | Record 206[23] | 43=1,93=Twenty |
| 233 | Record 233[23] | 43=2,93=Thirty |

The next step in the test is

update v set s='Forty two' where q=1

This will start again with a clean Context. Similarly to the above, this time when Execute is called we have

{(#1=UpdateSearch #1 Nuid=#8 Target: 155,

#8=From Name=V #8 RowType:(%0,%1,%2) Assigs:(UpdateAssignment Vbl: %1 Val: #16=True)

Filter:(%0=1) Where:(#35=True) Target=%3,

#16=Forty two,

#35=SqlValueExpr Name= #35 From:#8 Left:%0 BOOLEAN Right:#36

#35(%0=#36),

#36=1,

%0=SqlCopy Name=Q %0 From:#8 Domain INTEGER copy from 43,

%1=SqlCopy Name=S %1 From:#8 Domain CHAR copy from 93,

%2=SqlCopy Name=A %2 From:#8 Domain INTEGER copy from 115,

%3=View Name=V %3 Definer=-502 Ppos=155 Query select q,r as s,a from p Ppos: 155

Cols (A=%2,Q=%0,R=%1,S=%1) Domain TABLE (%0,%1,%2) Display=4

([%0,Domain INTEGER],[%1,Domain CHAR],[%2,Domain INTEGER]) Targets: 23,

%4=From Name=P %4 RowType:(%0,%1,%2) Target=23,

%5=SqlCopy Name=Q %5 From:%4 Domain INTEGER copy from 43,

%6=CursorSpecification %6 RowType:(%0,%1,%2) Source={select q,r as s,a from p}

Union: %8,

%7=SelectStatement %7 CS=%6,

%8=QueryExpression %8 RowType:(%0,%1,%2) Left: %9 ,

%9=QuerySpecification %9 RowType:(%0,%1,%2) TableExp %10,

%10=TableExpression %10 Nuid=%4 RowType:(%0,%1,%2) Target: %4,

%11=SqlCopy Name=R %11 From:%4 Alias=S Domain CHAR copy from 93,

%12=SqlCopy Name=A %12 From:%4 Domain INTEGER copy from 115)}

{(#8=SelectedRowSet %4(%0,%1,%2) key (%0,%1,%2) matches (%0=1) targets: 23=64

Assigs:(UpdateAssignment Vbl: %1 Val: #16=True) Source: 64,

%4=SelectedRowSet %4(%0,%1,%2) key (%0,%1,%2) matches (%0=1) targets: 23=64 Assigs:(UpdateAssignment Vbl: %1 Val: #16=True) Source: 64,

%10=TableExpRowSet %10(%0,%1,%2) key (%0,%1,%2) targets: 23=64 Source: %4)}

We see that the where condition and UpdateAssignments have been added to the From object and passed down to the RowSets on table P 23 with Index 64. Again this reduces the View update to an ordinary table update. After Commit we just have

|  |  |  |
| --- | --- | --- |
| 278 | Update 206[23] | 43=1,93=Forty two Prev:206 |

Next we have a simple Delete:

delete from v where s='Thirty'

Once again we see the RowSets are just for Table P 23:

{(#13=SelectedRowSet %5(%0,%1,%2) key (%0,%1,%2) matches (%1=Thirty) targets: 23=64

Source: 64,

%5=SelectedRowSet %5(%0,%1,%2) key (%0,%1,%2) matches (%1=Thirty) targets: 23=64

Source: 64,

%11=TableExpRowSet %11(%0,%1,%2) key (%0,%1,%2) targets: 23=64 Source: %5)}

and the Commit gives

|  |  |  |
| --- | --- | --- |
| 332 | Delete Record 233[23] |  |

For the tests on Views that are joins or joins of views, we prepare some further items:

insert into p(r) values('Fifty')

create table t(s char,u int)

insert into t values('Forty two',42),('Fifty',48)

create view w as select \* from t natural join v

|  |  |  |
| --- | --- | --- |
| 359 | Record 359[23] | 43=2,93=Fifty |
| 403 | PTable T |  |
| 410 | PColumn3 S | for 403(0)[80] |
| 433 | PColumn3 U | for 403(1)[29] |
| 475 | Record 475[403] | 410=Forty two,433=42 |
| 505 | Record 505[403] | 407=Fifty,430=48 |
| 549 | PView W 549 | select \* from t natural join v |

After a restart of the server, the Framing for W is as follows (omitting the entries for P and V, which are the same as above):

{Framing \*=(556,);A=(173,);P=(180,);Q=(164,);S=(166,);T=(559,S=(549,);U=(550,););

U=(550,);V=(561,A=(552,);Q=(551,);S=(553,);); Obs:

(400=Table Name=T 400 Definer=-502 Ppos=400 Domain TABLE (407,430)

([407,Domain CHAR],[430,Domain INTEGER]) KeyCols: ,

407=TableColumn 407 Definer=-502 Ppos=407 Domain CHAR Table=400,

430=TableColumn 430 Definer=-502 Ppos=430 Domain INTEGER Table=400,

546=View Name=W 546 Definer=-502 Ppos=546 Query select \* from t natural join v Ppos: 546

Cols (A=@4,Q=@2,S=@0,U=@1) Domain ROW (@0,@1,@2,@4|@3) Display=4

([@0,Domain CHAR],[@1,Domain INTEGER],[@2,Domain INTEGER],[@3,Domain CHAR],

[@4,Domain INTEGER])

Targets: 23,400,

547=SelectStatement 547 CS=548,

548=CursorSpecification 548 RowType:(@0,@1,@2,@4,@3) Source={select \* from t natural join v}

Union: 549,

549=QueryExpression 549 RowType:(@0,@1,@2,@4,@3) Left: 554 ,

554=QuerySpecification 554 RowType:(@0,@1,@2,@4,@3) TableExp 557,

555=SqlStar Name=\* 555 CONTENT From:554 CONTENT,

557=TableExpression 557 Nuid=564 RowType:(@0,@1,@2,@4|@3) Target: 564,

562=From Name=T 562 RowType:(@0,@1) OrdSpec (0=@0) Target=400,

564=JoinPart 564 RowType:(@0,@1,@2,@4|@3)562 NATURAL INNER join577 on @5

matching @0=@3 @3=@0,

577=From Name=V 577 RowType:(@2,@3,@4) OrdSpec (0=@3) Target=@7,

@0=SqlCopy Name=S @0 From:562 Domain CHAR copy from 407,

@1=SqlCopy Name=U @1 From:562 Domain INTEGER copy from 430,

@2=SqlCopy Name=Q @2 From:577 Domain INTEGER copy from 43,

@3=SqlCopy Name=S @3 From:577 Domain CHAR copy from 93,

@4=SqlCopy Name=A @4 From:577 Domain INTEGER copy from 115,

@5=SqlValueExpr Name= @5 Left:@0 BOOLEAN Right:@3 @5(@0=@3),

@7=View Name=V @7 Definer=-502 Ppos=155 Query select q,r as s,a from p Ppos: 155

Cols (A=@4,Q=@2,R=@3,S=@3) Domain TABLE (@2,@3,@4) Display=4

([@2,Domain INTEGER],[@3,Domain CHAR],[@4,Domain INTEGER]) Targets: 23,

@8=From Name=P @8 RowType:(@2,@3,@4) Target=23,

@9=SqlCopy Name=Q @9 From:@8 Domain INTEGER copy from 43,

@10=CursorSpecification @10 RowType:(@2,@3,@4) Source={select q,r as s,a from p}

Union: @12,

@11=SelectStatement @11 CS=@10,

@12=QueryExpression @12 RowType:(@2,@3,@4) Left: @13 ,

@13=QuerySpecification @13 RowType:(@2,@3,@4) TableExp @14,

@14=TableExpression @14 Nuid=@8 RowType:(@2,@3,@4) Target: @8,

@15=SqlCopy Name=R @15 From:@8 Alias=S Domain CHAR copy from 93,

@16=SqlCopy Name=A @16 From:@8 Domain INTEGER copy from 115) Data:

(400=TableRowSet 400(407,430) targets: 400=400 Source: \_,

546=JoinRowSet 564(@0,@1,@2,@4|@3) targets: 23=64,

400=562 JoinCond: (@5) matching @0=@3 @3=@0 First: @6 Second: @17,

557=TableExpRowSet 557(@0,@1,@2,@4|@3) key (@0,@1,@2,@4) targets: 23=64,400=562

Source: 564,

562=SelectedRowSet 562(@0,@1) targets: 400=562 Source: 400,

564=JoinRowSet 564(@0,@1,@2,@4|@3) targets: 23=64,400=562 JoinCond: (@5) matching @0=@3 @3=@0

First: @6 Second: @17,

577=SelectedRowSet %19(%2,%17,%3) key (%2,%17,%3) targets: 23=64 Source: 64,

,@6=OrderedRowSet @6(@0,@1) key (@0) order (@0) targets: 400=562 Source: 562,@8=SelectedRowSet @8(@2,@3,@4) key (@2,@3,@4) targets: 23=64 Source: 64,@14=TableExpRowSet @14(@2,@3,@4) key (@2,@3,@4) targets: 23=64 Source: @8,@17=OrderedRowSet @17(@2,@3,@4) key (@3) order (@3) targets: 23=64 Source: @8,)

Result 558

Results: (,158 175,163 175,175 175,180 180,554 557,555 557,557 557,558 558)}

Note that the view V has been instanced as part of view W (so that the framing contains a copy of V and an instanced version of V. (In the general case the reference to V by W might require more than a straight copy.)

Once again, view W will usually be used in a query, so that the above framing makes this use trivial. We case of inserting into a join is not interesting, but update and delete for joins turn out to work very well.

Let us restart the server once again (for reproducibility of Activation numbers). So consider the next step in the test:

update w set u=50,a=21 where q=2

This should involve updates to both table P and table T. At Execute(), the context contains (other than entries unchanged from above)

{(#1=UpdateSearch #1 Nuid=#8 Target: 546,

#8=From Name=W #8 RowType:(%0,%1,%2,%3)

Assigs:(UpdateAssignment Vbl: %1 Val: #16=True,UpdateAssignment Vbl: %3 Val: #21=True)

Filter:(%2=2) Where:(#31=True) Target=%4,#16=50,#21=21,

#31=SqlValueExpr Name= #31 From:#8 Left:%2 BOOLEAN Right:#32 #31(%2=#32),#32=2,

%0=SqlCopy Name=S %0 From:#8 Domain CHAR copy from 407,

%1=SqlCopy Name=U %1 From:#8 Domain INTEGER copy from 430,

%2=SqlCopy Name=Q %2 From:#8 Domain INTEGER copy from 43,

%3=SqlCopy Name=A %3 From:#8 Domain INTEGER copy from 115,

%4=View Name=W %4 Definer=-502 Ppos=546 Query select \* from t natural join v Ppos: 546

Cols (A=%3,Q=%2,S=%0,U=%1) Domain ROW (%0,%1,%2,%3|%17) Display=4

([%0,Domain CHAR],[%1,Domain INTEGER],[%2,Domain INTEGER],[%3,Domain INTEGER],

[%17,Domain CHAR]) Targets: 23,400,

%5=JoinPart %5 RowType:(%0,%1,%2,%3|%17)%12 NATURAL INNER join%16 on %15

matching %0=%17 %17=%0,

%6=TableExpression %6 Nuid=%5 RowType:(%0,%1,%2,%3|%17) Target: %5,

%7=QuerySpecification %7 RowType:(%0,%1,%2,%3,%17) TableExp %6,

%8=QueryExpression %8 RowType:(%0,%1,%2,%3,%17) Left: %7 ,

%9=CursorSpecification %9 RowType:(%0,%1,%2,%3,%17) Source={select \* from t natural join v}

Union: %8,

%10=SelectStatement %10 CS=%9,

%11=SqlStar Name=\* %11 CONTENT From:%7 CONTENT,

%12=From Name=T %12 RowType:(%0,%1) OrdSpec (0=%0) Target=400,

%13=SqlCopy Name=U %13 From:%12 Domain INTEGER copy from 430,

%15=SqlValueExpr Name= %15 Left:%0 BOOLEAN Right:%17 %15(%0=%17),

%16=From Name=V %16 RowType:(%2,%17,%3) OrdSpec (0=%17) Target=%18,

%17=SqlCopy Name=S %17 From:%5 Domain CHAR copy from 93,

%18=View Name=V %18 Definer=-502 Ppos=155 Query select q,r as s,a from p Ppos: 155

Cols (A=%3,Q=%2,R=%17,S=%17) Domain TABLE (%2,%17,%3) Display=4

([%2,Domain INTEGER],[%3,Domain INTEGER],[%17,Domain CHAR]) Targets: 23,

%19=From Name=P %19 RowType:(%2,%17,%3) Target=23,

%20=SqlCopy Name=Q %20 From:%19 Domain INTEGER copy from 43,

%21=TableExpression %21 Nuid=%19 RowType:(%2,%17,%3) Target: %19,

%22=QuerySpecification %22 RowType:(%2,%17,%3) TableExp %21,

%23=QueryExpression %23 RowType:(%2,%17,%3) Left: %22 ,

%24=CursorSpecification %24 RowType:(%2,%17,%3) Source={select q,r as s,a from p}

Union: %23,

%25=SelectStatement %25 CS=%24,

%26=SqlCopy Name=R %26 From:%19 Alias=S Domain CHAR copy from 93,

%27=SqlCopy Name=A %27 From:%19 Domain INTEGER copy from 115,

%29=SqlCopy Name=A %29 From:%16 Domain INTEGER copy from 115)}

{(#8=JoinRowSet %5(%0,%1,%2,%3|%17) key (%0,%1,%2,%3,%17) matches (%2=2)

targets: 23=64,400=%12

Assigs:(UpdateAssignment Vbl: %1 Val: #16=True,UpdateAssignment Vbl: %3 Val: #21=True)

JoinCond: (%15) matching %0=%17 %17=%0 First: %14 Second: %28,

%5=JoinRowSet %5(%0,%1,%2,%3|%17) key (%0,%1,%2,%3,%17) matches (%2=2)

targets: 23=64,400=%12

Assigs:(UpdateAssignment Vbl: %1 Val: #16=True,UpdateAssignment Vbl: %3 Val: #21=True)

JoinCond: (%15) matching %0=%17 %17=%0 First: %14 Second: %28,

%6=TableExpRowSet %6(%0,%1,%2,%3|%17) key (%0,%1,%2,%3) targets: 23=64,400=%12 Source: %5,

%12=SelectedRowSet %12(%0,%1) key (%0,%1) targets: 400=%12

Assigs:(UpdateAssignment Vbl: %1 Val: #16=True) Source: 400,

%14=OrderedRowSet %14(%0,%1) key (%0) order (%0) targets: 400=%12

Assigs:(UpdateAssignment Vbl: %1 Val: #16=True) Source: %12,

%19=SelectedRowSet %19(%2,%17,%3) key (%2,%17,%3) matches (%2=2) targets: 23=64

Assigs:(UpdateAssignment Vbl: %3 Val: #21=True) Source: 64,

%21=TableExpRowSet %21(%2,%17,%3) key (%2,%17,%3) targets: 23=64 Source: %19,

%28=OrderedRowSet %28(%2,%17,%3) key (%17) order (%17) matches (%2=2) targets: 23=64

Assigs:(UpdateAssignment Vbl: %3 Val: #21=True) Source: %19)}

This starts an Activation 31 to handle the update, and calls #1.Obey(). #1[nuid] is #8, so JoinRowSet %5.Update(%5) is called. It calls Split(), which traverses the Join to make a list of rows on left and right, and these are installed as in local copies a and b of %14 and %28. The list has just one row in each case.

a.explRows <- {(0=(505, (%0=Fifty,%1=48) %14))}

b.explRows<- {(0=(359, (%2=2,%17=Fifty,%3= Null) %28))}

We deal with %14 first. %14.Update(a) calls %12.Update(a), which calls Table T 403.Update(a). This is basically an ordinary Update (no triggers), but the traversal is constrained to the single row in explRows, and adds {(!0=Update 505[403]: 410=Fifty,433=50 Prev:505)} to the Transaction.

Next we deal with %28.Update(b). It calls %28.Update(b), which calls %19.Update(b) which calls Table P 23.Update(b). Again the traversal is constrained to the single row and adds {(!1=Update 359[23]: 43=2,93=Fifty,115=21 Prev:359)} to the Transaction.

After Commit, we see in the log:

|  |  |  |
| --- | --- | --- |
| 606 | Update 505[403] | 410=Fifty.433=50 Prev:359 |
| 638 | Update 359[23] | 32=2,93=Fifty,115=21 Prev:359 |

# 7. Permissions and the Security Model

This chapter considers only the security model of SQL2011, i.e. machinery for access control (GRANT/REVOKE). Pyrrho's model for database permissions follows SQL2011 with the following modifications

* GRANT OWNER TO has been added to allow ownership of objects (or the database) to be transferred
* REVOKE applies to effective permissions held without taking account of how they were granted

The last point is documented in the manual as a set of proposed changes to the SQL2011 standard. The manual provides a significant amount of helpful information about the security model, e.g. in sections 3.5, 4.4, 5.1, 5.5, 13.5.

## 7.1 Roles

Each session in Pyrrho uses just one Role, as defined in the SQL2011 standard. Tables and columns can be granted to roles. However, Pyrrho allows Roles to have different (conceptual, data) models of the database: tables and columns can be renamed, and new generated columns can be defined. Generated columns can be equipped with update rules. Moreover, XML metadata such as declaring a column as an attribute or directing that a foreign key should be auto-navigated, can be specified at the role level.

With this model, database administrators are encouraged to have roles for different business processes, and given these roles privileges over tables etc, and grant roles to users, rather than granting privileges to users direct.

The system database is set up during Pyrrho initialisation and is called Database.\_system .It contains all the primitive domains, system tables and their columns. All databases inherit these objects on creation. But any domain reference committed to a database file must have a uid matching a defining position in the transaction log, and so a suitable local version of the domain is created for that database to use. The Database maintains an index (with key Domain) to keep track of its local domains.

When a database connects it gains a connection string that must specify the current user and may also specify a role. If the user is known and can only access one role, this role is automatically selected. If the current user is unknown, an ad-hoc user is created. Such an ad-hoc user will only be added to the database if auditing requires it[[25]](#footnote-25) (and in that case becomes a known user, initially with no privileges).

### 7.1.1 The schema role for a database

It is good practice to create other roles for all operations on database tables and other objects and to transfer privileges to these roles rather than use the schema role for all operations. Once this is done, it is recommended to revoke privileges from the schema role. Note that without proper care it is easy to lose all ability to update (or even access) the database.

The schema role maintains a list of the known role and user names.

### 7.1.2 The guest role (public)

The guest role is the default one, and cannot be granted, revoked, or administered. Standard types cannot be modified (for example, you cannot ALTER DOMAIN int), since this would require administration of the guest role.

Objects granted to PUBLIC are added to the namespace of all roles.

### 7.1.3 Other roles

On creation, a new role is owned and administered by the creating user (who must have had administrative permission in the session role in order to create a role). All public objects are automatically added to the namespace of the new role.

New database objects are added to the definer’s role only. They are added to other roles on GRANT.

## 7.2 Effective permissions

The current state of the static permissions in a database can be examined using the following system tables: (Only the Database owner can examine these.) By default the defining role is the owner of any orbject.

|  |  |
| --- | --- |
| **Name** | **Description** |
| Role$Domain | Shows the definers of domains |
| Role$Method | Shows the definers of methods of user-defined types |
| Role$Privilege | Shows the current privileges held by any grantee on any object |
| Role$Procedure | Shows the definers of procedures and functions |
| Role$Trigger | Shows the definers of triggers |
| Role$Type | Shows the definers of user defined types |
| Role$View | Shows the definers of views |

The session role gives only the initial authority for the transaction. During the transaction, the effective permissions are controlled by a stack. Stored procedures, methods, and triggers execute using the authority of their definers (and so can make changes to the database schema only if the definer has been granted the schema authority).

The Database owner is the only user allowed to examine database Log tables; and the owner of a Table is the only user allowed to examine the ROWS(..) logs for a table. The transaction user becomes the owner of a new database or new table. The GRANT OWNER syntax supports the changing of ownership on procedure and tables, and even of the whole database.

## 7.3 Implementation of the Security model

The system database has a Role (with uid -502), and this uid is used for the schema role in any database. The system database User has uid -501. An empty database inherits these, and so does every database in the Database.databases list.

The other predefined role is “guest”and has a uid of -55. This role has access to all public data, that is, it contains all grants to PUBLIC (a dummy user with uid -1).

As is almost implied by the table in section 7.2,

* Each Database has an owner
* Each Table, Procedure or Method has an owner
* Each DBObject (including TableColumns) has an ATree which maps grantee to combinations of Grant.Privilege flags.
* Each Role has an ATree which maps database object (defining position) to combinations of Grant.Privilege flags.

### 7.3.1 The Privilege enumeration

These values are actually stored in the database in the Grant/Revoke record, so cannot be changed. This is a flags enumeration, so combinations of privileges are represented by sums of these values:

|  |  |  |  |
| --- | --- | --- | --- |
| **Flag** | **Meaning** | **Flag** | **Meaning** |
| 0x1 | Select | 0x400 | Grant Option for Select |
| 0x2 | Insert | 0x800 | Grant Option for Insert |
| 0x4 | Delete | 0x1000 | Grant Option for Delete |
| 0x8 | Update | 0x2000 | Grant Option for Update |
| 0x10 | References | 0x4000 | Grant Option for References |
| 0x20 | Execute | 0x8000 | Grant Option for Execute |
| 0x40 | Owner | 0x10000 | Grant Option for Owner |
| 0x80 | Role | 0x20000 | Admin Option for Role |
| 0x100 | Usage | 0x40000 | Grant Option for Usage |
| 0x200 | Handler | 0x80000 | Grant Option for Handler |

### 7.3.2 Checking permissions

The main methods and properties for this are as follows:

* CheckPermissions( DBObject ob, Privilege priv) is a virtual method of the Database class, whose override in Participant calls the ob.ObjectPermissions method. There is a shortcut version called CheckSchemaAuthority() for this specific purpose.
* ObjectPermissions( Database db, Privilege priv) has an implementation in DBObject that checks that the current user or the current authority holds the required privilege.
* There is an override of ObjectPermissions in the Table class, which deals with system and log tables: in the open source edition these tables are read-only and public.
* Table.AccessibleColumns computes the columns that the current user and authority can select.

### 7.3.3 Grant and Revoke

The main methods and properties for this are as follows:

* Access (Database db, bool grant, Privilege priv) grants or revokes a privilege on a DBObject. This requires the creation of a copy of the DBObject with a different users tree (a virtual helper method NewUsers handles this).
* Table.AccessColumn applies a Grant or Revoke to a particular column
* Transaction..DoAccess creates a Grant or Revoke record, and is called by Transaction.Access… routines that are called by the Parser.

An annoying aspect of the implementation is that Grant Select (or Insert, Update, or References) or Usage on a Table or Type implies grant select/usage of all its columns or methods, while a Grant on a Column or method implies grant select/usage on the table/type (but only the explicitly granted columns/methods). This behaviour is as specified by the SQL2011 standard (section 12.2 GR 7-10).

REVOKE does not change the list of users or roles. There is nothing to stop a user name being re-used (since there is nothing to stop rights being restored to an existing user or role). It is obviously business process question whether users’ real names are used or not (or whether a proposed new user is checked for a match against and existing one).

### 7.3.4 Permissions on newly created objects

As mentioned above, creation of new database objects requires use of the schema authority. Privileges on the new object are assigned to the schema authority as follows:

|  |  |  |
| --- | --- | --- |
| **Object Type** | **Initial privileges for schema authority** | **with option** |
| Table | Insert, Select, Update, Delete, References | Grant |
| Column | Insert, Select, Update | Grant |
| Domain | Usage | Grant |
| Method | Execute | Grant |
| Procedure | Execute | Grant |
| View | Select | Grant |
| Authority | UseRole | Admin |
| Role | UseRole | Admin |

It is good practice to limit use of the schema authority, for example to a database administrator, and only for changes to the schema.

### 7.3.5 Dropping objects

The main methods and properties for this are as follows:

* When a database object is dropped it must be removed from any Roles that have privileges on it. This is done by Role.RemoveObject.
* Similarly when a grantee is dropped there is a DBObject.RemoveGrantee method to remove all references to it in grantees lists help by database objects.
* All late-parsed data in the schema (view definitions, procecure bodies, triggers, default values etc. are parsed in a DropTransaction: objects holding references to the dropped object either prevent the drop occurring (RESTRICT), or are dropped in a CASCADE, depending on the action specified.

### 7.3.6 Implementation details

During Load() initially \_Role -502

Set by PTransaction for its physicals to ptrole

then back to -502

In Transact() for TCP session (the connection string always specifies a user):

1. initially role is guest. -502 is always the schema role.
2. if the user is unknown in the database
   1. if the schema role has users, make an uncommitted user id for them with no privileges
   2. (schema role has no users)
      1. if the user’s name matches the server account, use the schema role
      2. otherwise deny access
3. if the connection string specifies a role (add it to the new Tx).
   1. If the role is not known, report no such role.
   2. if the role can be used by the public, we are done
   3. otherwise:
      1. if the user is known
         1. if the user can use the role, we are done.
         2. if the user is the database owner and the role is schema role, we are done (owner can always manage security model if nothing else)
         3. otherwise deny access
      2. if the user is unknown report access denied (even if it is the server a/c)
4. if the connection string does not specify a role
   1. if the database has roles
      1. if the user owns the database, use the schema role
      2. if the user is known, 
         1. if there is just one role the user can use, we are done.
         2. otherwise use guest role (user may be intending to select one)
      3. use the guest role: we are done
   2. (the database has no roles). role is guest

Protocol.Authority changes the connection string and db.mem[\_Role] and updates the session role.

In Transaction Commit() we commit nothing if there are no Physicals, or just an ad-hoc PUser. Ar end of Transaction.Commit() remember to add the Connection back in to the new database object.PRole .

In Transaction.Audit() we commit the user if ad-hoc and not defined by a concurrent transaction.

Install() CREATE ROLE gets a new uid unless it’s the first one (-502 is overloaded in that case)

DROP ROLE removes the role’s name from the list (but does not change the list of users)

PUser Install() GRANT role doesn’t care and might grant -502 (GRANT TO PUBLIC is to uid -55

but the first user grantee for the schema role becomes the database owner

During query processing and execution, we do not use cx.db.role but cx.role. This is initialised to cx.db.role but is changed to the definer’s role during code execution (including constraint evaluation). cx.user always directly addresses cx.db.conn.user.

## 7.4 Mandatory Access Control

See section 3.4.2 of the Pyrrho Manual for an introduction to this section.

As usual, implementation of rules throws up unexpected complications. Tables have classifications as do the records they contain, and the interplay between them and user clearances is far from simple. The main purpose of the classification information for a table is to specify the set of groups and references that will apply to records classified above D. It can also specify a minimum clearance level for access to the table. The SA can completely specify or modify the classification of any record in the table (but for best results should use subsets of the groups and references that they have specified for the table).

I have the following for users other than the SA in my first implementation. (As usual in Pyrrho, any exception will roll back the transaction.)

#### Read

1. If the user does not have select privilege on any of the columns selected or select \* has been specified and the user does not have select privilege for any columns, throw an informative exception (such as “User cannot select column x”, or “user cannot access any columns”).

2. If Select is enforced and the user’s clearance level does not exceed the table’s classification level, report that the table does not exist.

Even if the table contains rows to which the user’s clearance would give them access.

3. If Select is enforced by the table and the user’s clearance does not allow access to a given record, skip the record.

4. If Select is enforced and any records with classification above D are accessed, an audit record is added to the database immediately, whether or not the user’s transaction commits.

This cannot be handled within the ReadConstraint mechanism since ReadConstraints only apply in explicit transaction. The context should record what audit records have already been written to avoid repetition within the same context.

#### Insert

Apart from actions by the SA:

1. If Insert is enforced by the table and the user does not have insert privilege or the user’s clearance does not exceed the table’s classification, throw an Access Denied exception.

2. If Insert is enforced by the table and the user has insert privilege, construct a record whose classification is equal to the user’s clearance, and insert it.

The new record’s classification label will have the user’s minimum clearance level: if this is above D, the groups will be the subset of the user’s groups that are in the table classification, and the references will be the same as the table (a subset of the user’s references).

3. If Insert is not enforced and the user has insert privilege, the record inserted will have level D classification.

#### Update

Apart from actions by the SA:

1. If the user does not have update privilege for the table, throw an Access Denied exception.

2. If Update is not enforced the record’s classification will be unaffected (presumably it will be level D).

3. If Update is enforced by the table and the user’s clearance does not allow access to the table, throw an Access Denied exception.

Even if the update would access records that would match the user’s clearance.

4. If Update is enforced by the table, and a record selected for update is not one to which the user has clearance or does not match the user’s clearance level, throw an Access Denied exception.

Even if the user has a higher clearance than the record’s classification.

5. The updated record must have the same classification as the old.

#### Delete

1. If the user does not have delete permission for the table, throw and Access Denied exception.

Even if the user has a high security clearance.

2. If Delete is enforced by the table for the table or the user’s clearance does not exceed the table’s classification, throw an Access Denied exception.

Even if the delete would actually only remove records that match the user’s clearance.

3. If Delete is enforced by the table and the user has delete privilege for the table, but the record to be deleted has a classification level different from the user or the clearance does not allow access to the record, throw an Access Denied exception.

Even if the delete is attempting to remove an unclassified record.

### 7.4.1 An example

In this example, the server is running on MALCOLM2, and the client accounts are all on the MALCOLM1 machine. Apart from Malcolm himself, there are accounts Fred and Student. We start without the database mac: on creation the server automatically adds a role mac and grants it to Malcolm, who becomes the database owner (and therefore the security administrator).

Note that backslash must not be doubled inside double-quoted strings.

#### A. Logged in with MALCOLM1\Malcolm (not the server account)

1. Starting with empty database mac

SQL> **create table A(B int,C char)**

SQL> **create table D(E char primary key) security level D groups Army Navy references Defence scope read**

SQL> **create table F(G char primary key,H char security level C)**

2. Create some users with and without clearance

SQL> **grant "mac" to "MALCOLM1\Student"**

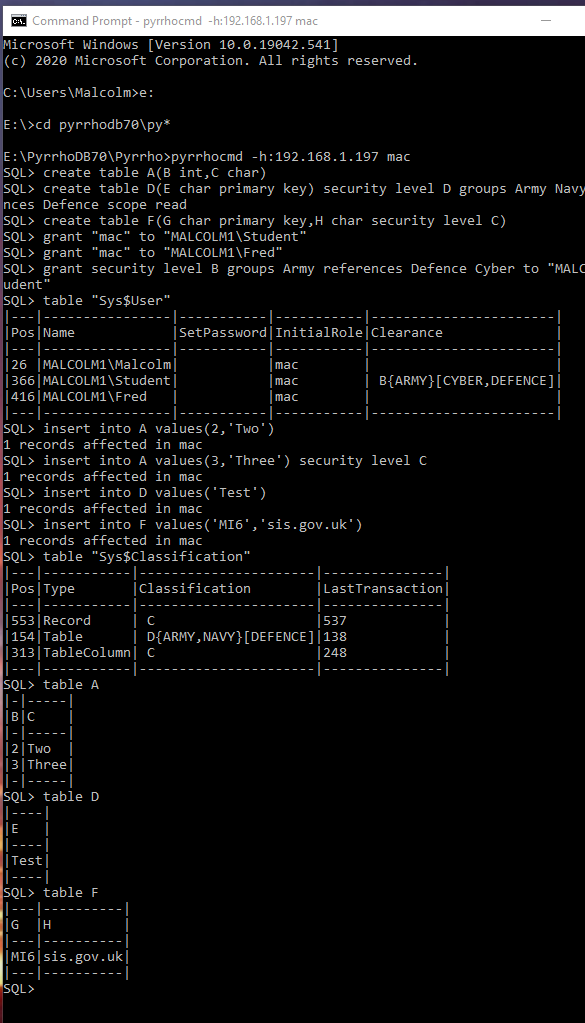
SQL> **grant "mac" to "MALCOLM1\Fred"**

SQL> **grant security level B groups Army references Defence Cyber to "MALCOLM1\Student"**

SQL> **table "Sys$User"**

|---|----------------|-----------|-----------|-----------------------|

|Pos|Name |SetPassword|InitialRole|Clearance |

|---|----------------|-----------|-----------|-----------------------|

|26 |MALCOLM1\Malcolm| |mac | |

|366|MALCOLM1\Student| |mac | B{ARMY}[CYBER,DEFENCE]|

|416|MALCOLM1\Fred | |mac | |

|---|----------------|-----------|-----------|-----------------------|

3. Add some rows with and without classification

SQL> **insert into A values(2,'Two')**

1 records affected in mac

SQL> **insert into A values(3,'Three') security level C**

1 records affected in mac

SQL> **insert into D values('Test')**

1 records affected in mac

SQL> **insert into F values('MI6','sis.gov.uk')**

1 records affected in mac

SQL> **table "Sys$Classification"**

|---|-----------|----------------------|---------------|

|Pos|Type |Classification |LastTransaction|

|---|-----------|----------------------|---------------|

|553|Record | C |537 |

|154|Table | D{ARMY,NAVY}[DEFENCE]|138 |

|313|TableColumn| C |248 |

|---|-----------|----------------------|---------------|

4. Check we can see two rows in A, one row in D and two columns in F

SQL> **table A**

|-|-----|

|B|C |

|-|-----|

|2|Two |

|3|Three|

|-|-----|

SQL> **table D**

|----|

|E |

|----|

|Test|

|----|

SQL> **table F**

|---|----------|

|G |H |

|---|----------|

|MI6|sis.gov.uk|

|---|----------|

#### B. Logged in as Fred

5. Check we can only see one row in A, one column in F, and nothing in D

SQL> **table A**

|-|---|

|B|C |

|-|---|

|2|Two|

|-|---|

SQL> **table D**

Access denied

SQL> **table F**

|---|

|G |

**Graphical user interface, application

Description automatically generated**|---|

|MI6|

|---|

6. Check we can add a row in A, D and F

SQL> **insert into A values(4,'Four')**

1 records affected in mac

SQL> **insert into D values('Fred wrote this')**

1 records affected in mac

SQL> **insert into F values('UWS')**

1 records affected in mac

SQL> **table a**

|-|----|

|B|C |

|-|----|

|2|Two |

|4|Four|

|-|----|

SQL> **table d**

Access denied

SQL> **table f**

|---|

|G |

|---|

|MI6|

|UWS|

|---|

#### C. Logged in as Student

7. Check we can see three rows in A, two rows in D and two columns in F

SQL> **table A**

|-|-----|

|B|C |

|-|-----|

|2|Two |

|3|Three|

|4|Four |

|-|-----|

SQL> **table D**

|---------------|

|E |

|---------------|

|Fred wrote this|

|Test |

|---------------|

SQL> **table F**

|---|----------|

|G |H |

|---|----------|

|MI6|sis.gov.uk|

|UWS| |

|---|----------|

8. Check we can only make changes in table D (enforcement in D is only on read)

SQL> **update A set c = 'No' where b=2**

Access denied

SQL> **update A set c = 'No' where b=3**

Access denied

**Graphical user interface, text

Description automatically generated**SQL> **update A set c = 'No' where b=4**

Access denied

SQL> **update D set E='Fred?' where E<>'Test'**

1 records affected in mac

SQL> **update F set H='www.sis.gov.uk' where G='MI6'**

Access denied

SQL> **update F set H='www.uws.ac.uk' where G='UWS'**

Access denied

9. Check we can add and update our rows in all three tables

SQL> **insert into A values(5,'Fiv')**

1 records affected in mac

SQL> **update A set c='Five' where b=5**

1 records affected in mac

SQL> **insert into D values('Another')**

1 records affected in mac

SQL> **insert into F values('BBC','bbc.co.uk')**

1 records affected in mac

SQL> **update F set H='www.bbc.co.uk' where G='BBC'**

1 records affected in mac

10. Check we can see our rows and changes

SQL> **table A**

|-|-----|

|B|C |

|-|-----|

|2|Two |

|3|Three|

|4|Four |

|5|Five |

|-|-----|

SQL> **table D**

|-------|

|E |

|-------|

|Another|

|Fred? |

|Test |

|-------|

SQL> **table F**

|---|-------------|

|G |H |

|---|-------------|

*![A picture containing text

Description automatically 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|MI6|sis.gov.uk |

|UWS| |

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SQL>

#### D. Logged in as Fred

11. Check Fred can't see the new rows

SQL> **table a**

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|B|C |

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|2|Two |

|4|Four|

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SQL> **table d**

Access denied

SQL> **table f**

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Description automatically generated](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAYABgAAD/4RD0RXhpZgAATU0AKgAAAAgABAE7AAIAAAAOAAAISodpAAQAAAABAAAIWJydAAEAAAAcAAAQ0OocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAE1hbGNvbG0gQ3Jvd2UAAAWQAwACAAAAFAAAEKaQBAACAAAAFAAAELqSkQACAAAAAzQ3AACSkgACAAAAAzQ3AADqHAAHAAAIDAAACJoAAAAAHOoAAAAIAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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q9czaS1/C9pZXsVoMebFLeI8j887XEShePVT+PSi5m0lr+F7SyvYrQY82KW8R5H552uIlC8eqn8elAFGir1zNpLX8L2llexWgx5sUt4jyPzztcRKF49VP49KLmbSWv4XtLK9itBjzYpbxHkfnna4iULx6qfx6UAUaKvXM2ktfwvaWV7FaDHmxS3iPI/PO1xEoXj1U/j0ouZtJa/he0sr2K0GPNilvEeR+edriJQvHqp/HpQBRoq9czaS1/C9pZXsVoMebFLeI8j887XEShePVT+PSi5m0lr+F7SyvYrQY82KW8R5H552uIlC8eqn8elAFGir1zNpLX8L2llexWgx5sUt4jyPzztcRKF49VP49KLmbSWv4XtLK9itBjzYpbxHkfnna4iULx6qfx6UAUa1/FMNxB4juI7y6+1zBY903lhN37tSOBwMDA/CqWoSafJOp0q1ubaLbhlublZmLeoKomB04x+Nanjb/kb7v/AHYv/RSUAYNFFFABRRRQAUUUUAFFFFAHY+LWU6SuFwftC85/2Wrlb6+uNRvHuryTzJnADNtAzgADgcdAKKKufxFS3IKKKKgkKKKKAJ76+uNRvHuryTzJnADNtAzgADgcdAKgoooAKKKKACiiigAooooAKKKKACiiigCe+vrjUbx7q8k8yZwAzbQM4AA4HHQCoKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAqe+vrjUbx7q8k8yZwAzbQM4AA4HHQCiigCCiiigAooooAKKKKACiiigAooooAKKKKACiiigAqe+vrjUbx7q8k8yZwAzbQM4AA4HHQCiigCCiiigAooooAKKKKACiiigD/2Q==)**SQL>

#### E. Logged in as database owner

12. Check all tables including the security information

SQL> **select B,C,security from A**

|-|-----|--------|

|B|C |SECURITY|

|-|-----|--------|

|2|Two | |

|3|Three| |

|4|Four | C |

|5|Five | |

|-|-----|--------|

SQL> **select E,security from D**

|-------|--------|

|E |SECURITY|

|-------|--------|

|Another| |

|Fred? | |

|Test | |

|-------|--------|

SQL> **select G,H,security from F**

|---|-------------|--------|

|G |H |SECURITY|

|---|-------------|--------|

|BBC|www.bbc.co.uk| B |

|MI6|sis.gov.uk | B |

|UWS| | |

|---|-------------|--------|

SQL> **select \* from A where security=level c**

|-|-----|

|B|C |

|-|-----|

|3|Three|

|-|-----|

SQL> **update A set security=level B where security=level C**

1 records affected in mac

SQL> **update F set security=level D where G='BBC'**

1 records affected in mac

SQL> **table "Sys$Classification"**

|----|-----------|----------------------|---------------|

|Pos |Type |Classification |LastTransaction|

|----|-----------|----------------------|---------------|

|553 |Record | B |537 |

|1022|Record | B |1005 |

|154 |Table | D{ARMY,NAVY}[DEFENCE]|138 |

|313 |TableColumn| C |248 |

|----|-----------|----------------------|---------------|

#### F. Logged in as Student

13. Check we can still see our row in A

SQL> **select \* from a where b=5**

|-|----|

*![Text

Description automatically generated](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAYABgAAD/4RDiRXhpZgAATU0AKgAAAAgABAE7AAIAAAAIAAAISodpAAQAAAABAAAIUpydAAEAAAAQAAAQyuocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAFN0dWRlbnQAAAWQAwACAAAAFAAAEKCQBAACAAAAFAAAELSSkQACAAAAAzQ3AACSkgACAAAAAzQ3AADqHAAHAAAIDAAACJQAAAAAHOoAAAAIAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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dzLs29ScJnoOvSt6PW9KEP9jjVFXbozWC6q0Uhj3mbzSMbd+zb+7ztz14xTzqHho6hp9u+oi4t7XRmtfMmSeKF5/Mc7ZBH+8MeGyMdflzjkAe39ef+S+8P6/L/ADf3HPaX4O13VdcbSYtNuYbuNd0qzQOvkjbkFxtJXPbI5yKpS6Fq8GpR6dNpV7HfSjMdq9u4lcc8hMZPQ9u1dhc+JNFj8ZeHLmCeM2djZC1na2jl2REmQHaJCXKgOCMnJHYHgZvhu70rQNW1C2ur6xv4L6weBbnZciFGLA4cBUkwQuDtB+93GRR/wf6+Yf8AAOYvLK60+6e1v7aa1uI8b4p4yjrkZGQeRxVvRdGk1u7lhjube1WGB7iSa437VRBkn5FYn8BV3xXqSahdWccLaa8NnbCCJtOFxsC7mIUmf5yRk+2MCjwlq0OjX1/cTvGrPp88UQkhEqtIy4VSpBBBPqMetC2fzB9PkZV/aw2dz5VvfW9+m0HzrdZAv0/eKpz+FMtLO51C6S2sLea5uJDhIoULu3GeAOTTr6+l1C6M9wkCOQBi3t44V4/2UUL+laHhi8Nlqrubuxto5IHilF/HK8UqMMMh8pSwyD1GMY6ihAyrJomqxaoumy6ZeJfvjbatbuJW4zwmMnj2q7pfg/XNW1xtJh065iu4xmVZoHXyRjILjaSue2RzkVvWGq+GtM8Q30dotsLW+0s2zu32k2yTkqW24xN5Z247tknqOrF8SWcPjXRZ7iXT/sNjB9mEumpcFUjO8c+f87Fd+fpwKO39dw7nJX+m32lXAt9UsriymKhhFcRNG2D3wwBxxUllpc1/Z39zC0apYQiaUMTkqXVOOOuXHXHGaj1C1hs7nyra/t79NufOt1kVfpiRFOfwx71r+Gdai0ax1ss0IuLizWK3Se3WZHbzo2IKspX7oY8jt64oQdV8jMvNLmsbCwu5WjMd/E0sQUnICuyHPHXKnpniobGCO61C3t551t4pZVR5mGRGCcFjkjp16iuul8YWLR6NPd2sN5LBYywzwQWtvEkbmdmGFeB4/u4+6ueevUHntf1W21fUFns7P7GixhDHthGTk8/uoo17/wB3Pv6Gz+YFi08NjUNU1ezsLs3I0+OR4Xii3fatsiooUAn727Ixn8aLHwpqFzd39ndW9zZ3lnam4FtJbsJJDuVQu04Izv44P0qbwdqEFhPqq3GpLprXWnSW8VwwkwrsyHB8tWYZAPat2x17TbZRpsWtLCYNElsU1LZMqPI83mYXahkCgErkqM4PAoei+X46/wDAGtfv/DT/AIJxkuj6nBqa6dNp13HfMQFtXgYSknoAmM8/SmX+nX2l3P2fU7O4s59obyriJo2wehwQDiuxttf0q2mttN/tAlYNHmsF1RI3CLJI7PkAjfsAYpnbnBJC1yjWFlFrEFrJq9vLaO6iW9t4pWWJSeTtdVYkDnGOe1HW39df+HF0uVLe2nvLmO3tIZJ55G2pFEhZnPoAOSatvoWrxaommyaVepfSDKWrW7iVh1yExk9D27VraDd6ZpGvapbjUW+zXFrPaW2pCFl2luFkKDLAEDBAyQGPBpdIk0/TJdV02TWLYpqFj5MeowxzGONt6vtYFA+CF2khT1HUZoD+v+CZS+HtafUJLBdIv2vIgDJbi2fzEB6ZXGRnI/OkXRrqDUrK21eGfTI7tkxLcwlAEY43jdjIHrnHHWu0tPE+labYpYR6o0z21lBb/bEjkUTH7WsrKuQG2qmR8wGcHjpWT4512x1uOyNlcm4kjuLxpGZGBCvOWTlhzlTn2o2a/r+rhumczqFvFZ6ndW1vcLcxQzPGk6gASgEgMME8Hr1NRx288sMs0UMjxQgGV1UlUycDJ7ZPHNR10XhDUdOsZdSi1mXZbT2owhQuJXSVJAhAH8WwrzxzzQttQe+hV0fw3d6vDcyIkyCO1eeDEBb7SVdU2L6nLds88Yqo+i6rHqi6bJpt4l+2Ntq0DCU5GfuYz056V2lx4p0i2jlTR7trdG0aaOMRRuhjnmn8xohgDgL8uenHWo9L8S6PF9kgunhcSaC1hJJcJN5cUnnM4V/Lw5UrgEpn73cZFD3/AK/vf5L7w/r8v839xxz6PqUd/JYyaddpdxDdJbtAwkQcHJXGR1H506TQ9Wh1NNNm0u9jvpBlLVrdxK30TGT0PauuXxVDaaw8sd5YQi20Wazs5tLF0AGO4ouZvnyCTz0AxzxWf4V8TRwyS2euSQvbNp0tlbNcrJ5cW5xJhzERIVJ3AkZPzenFH9fn/kvvD+vyOZvLK60+6e1v7aa1uI8b4p4yjrkZGQeRxVnSNGuNZuZI7dooY4YzLPcTttjhQcFmPJ6kDABJJwATV/xXqSahdWccLaa8NnbCCJtOFxsC7mIUmf5yRk+2MCl8M6jZQ2mraXqU/wBlg1O3VFudhcRSI4ddwGTtJGDgEjOcGhAzL1GxjsZkWC/tb+N03CW1L7epGCHVWB47j0NR2MEd1qFvbzzrbxSyqjzMMiME4LHJHTr1FdfeeINHsbzTpRDYarKlk8d0+n2UMEbSGUlTtmtipITaM7Affrnndf1W21fUFns7P7GixhDHthGTk8/uoo17/wB3Pv6C0YMmtfDi3+s6naWup2q22nrJI17MH2PGjhdwEYc85B4z9asDwZc/2hJA+pWCW6WI1AXpaQxPCSBkAIXzk4wVB4NO8Falbabeal9qu7a0NxYPDDJd25ni3l0IDIEfIwD1Uit+DxHpY1ud/wC07JZ30X7G95JZu1rJNvUjbD5ZwgQAY8sDKk45yR6L5fjr/kgWr+f+X/BOcPg6+/tVbRLmzeBrQXv24SEQLAf+WhyoYAHjG3dngA8VSfSrePVrS2/tazntrh1Vru33bYwWwSVkCMMdeQAfWuqn1/Rrq8ubG6vk23ukpZz6jBbsIVmSQOhSPAKx4VVIVByCQvrxuo2lrZypHaajDqGVy8kEbqgOeg3qrHj/AGR+NGz/AK7sOn9dl+ozULeKz1O6tre4W5ihmeNJ1AAlAJAYYJ4PXqar0UUlsDCiiimAUUUUAFFFFABRRRQAUUUUAFFFFAH3JRRRXrHzIUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFNanU1qAKs33TXhXxj0ybWfGOiWFqyLJNDIN8hIVADkscAnAAJPB6V7rN901498UNS0zSda+06mJpZJNMlt4IYJPLdjI4VyHKMFwm7qO/HthW+BnbhP4qPF7vRb2012TSFiNzdrJ5arbqX809ioxkgjBHHemzaLqltqUenXGm3kV7JjZbPAyyNnphSMnNdj/wkOgz6lFdQXM9jJd6M+nyySlpXtZVGxHZ1QbgyKASq5AJ4rH0GfT9E1i9gl1aF0u7CW3j1C2jl2QO46kMivjAKnCnhuM1wf1+f9fM9n+vy/r5GPJoerQ6mmmzaXex30gylq1u4lb6JjJ6HtSHRtUGq/wBmHTbsX+cfZPIbzemfuYz056dK3/DV3peg6tqFtd3tjfQXtg9utzsuRCjEqcMAElwdu0lR/F3GRVqTX1bxBbCK+8Pw2tvp7We5Yr1reWJi2Ym3qZc/MeRjAxgjFHb+u/8AXzD+vyOXfQ9Wj1RdNk0u9W/cZW1a3cStxnhMZ6c9KbcW+p6JcS2t3Dd6fNJHtlhlVomZDzgg4JBwDz6V0aXmk2PikvoV3p9rayWXlXQuUuXtZWZcSInymYKQeCcEHPPSsbxJ/ZH9qL/YOzyfJTzfKMhi83HzeX5g37On3uc57YpAZ1raXN9dJbWNvLczyHCRQoXZj7AcmtfVfCeo6Zd6bZfZrqW/v7YT/Y/szLKh3Muzb1Jwmeg69Kd4XvbS3Gq2t5drYm/sWt4rt0ZljO9WIYIC2GClcgHr0rpoPEHh+zu7ezS7hvLf+wm09rm4hnSNZfNZzuCYk2EcZXnDDI6iqe39dn/wBLf+vL/g/ccT/Yerf2g9h/Zl59sjAL232d/MXOMZXGRncPzHrViz8N6nP4gi0m5sL63uGZTLH9jkeWJDjL+WBuIAOa6SXxRbxT3qLd2EYTRHsbSTTBdBTmQMEJm+fON3J4xxmqP23Tb+/wDDbSanBarp9nGtxJPHKQGWZ22DYjEnaRjjHvQt1/Xf/JfeD2f9dv8AN/cYM+lTHXp9L01J76RJ3iiVLdlkl2kjPl/eB4zjqKadH1NdUGmNp12L8nAtDA3m5xnGzGenPSuttNX0ex8Z6/LJeWd7aatDOsVw0dwIoy8m8LIFCSYIG07QfvdxmnPr9jPdXNjNe6ZaRvpBsLa9sY7pooh5gfY/mgyHIDLkA4DAdKlXsv67/wBfMp2u/wCu39fI5vX/AA9c+HjYR3yyx3F1ai4eCaExtCS7LtIPP8Oc8dayK6HxZd6dOuj2+k3hvI7LTxBJL5TR5cSOxwG5x8wI9iM4OQOep9X6v8xdF6L8gooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigD7kooor1j5kKKKKACiiigAooooAKKKKACiiigAooooAKKKKACmtTqa1AFWb7prw74xaPNrPiSxSKWGCK3spZ555idkUYYAsdoLHkgYAJ5r3Gb7prxX4rXM9l4w0u4tdag0eRbWQebcJIySAsMoVRH3A9wwwcVhW+A7cJ/FR5VbeHDeX08VnqljNa20Hn3F/+9WGFc453IHJyQAApJJGM1NL4QvUuUSG5tLiCWykvobqJ28uaONSWAyoYMCpGGAOR6c1vvqvh+7kvdJjuLW0fUtPihn1C3geK1a6SQOG8vAKIQApIUDdztAq7cInhmbT9E1d5bS3g06+txqFxazLDNNMpz5fybmQZUbsc8nGMVwPb7/1/4H9M9nr933af8E8+07TbvVrwWmnQme4ZWZYlI3PgZIUHqcDoOT2qqQQcEYIrXt7HTrXXIUuNdia1RfNe6sYpSwIyQih0Q7yQME4AyDmk8S64PEGsNei0jtvkVCQdzy4/jkboznuwAye1AGTRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAfclFFFesfMhRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAU1qKKAKs33TXz98ef8AkOaX/wBcH/8AQhRRXPW+A7cH/FR5RRRRXCeyFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAf//Z)*|B|C |

|-|----|

|5|Five|

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14. Check we can no longer update our rows in A or F

SQL> **delete from A where b=5**

Access denied

SQL> **update F set H='bbc.com' where G='BBC'**

Access denied

#### G. Logged in as Fred

15. Check we can see the row about the BBC

![Text

Description automatically generated](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAYABgAAD/4RDaRXhpZgAATU0AKgAAAAgABAE7AAIAAAAFAAAISodpAAQAAAABAAAIUJydAAEAAAAKAAAQyOocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAEZyZWQAAAAFkAMAAgAAABQAABCekAQAAgAAABQAABCykpEAAgAAAAM4MgAAkpIAAgAAAAM4MgAA6hwABwAACAwAAAiSAAAAABzqAAAACAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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dRW0SQxqsWEjUKBmNSeB7mvXw/8NHNP4jV0zxrZ6PcWcVjo8jabb+e0ttcXm+Sdpo9jEyBFAAAXAC9jzzxBfeLrfWNLsLPWdPnmNvLJLcTw3Yje4Lfd6xsF2jA6HIHauXoroeu5K02NrWdeiv9JsNKsLWa3sbFpHjFzcCeTc5Bb5gqgLwMKFHOSc5o8Xzw3Pim6ltpUmjZYsPGwYHEag8j3FYtbXi+CG28U3UVtEkMarFhI1CgZjUnge5oAxaKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooA/QGiiivnzrCiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKAGt0qrNVpulVZqaA8J/aM/wCQJpP/AF9N/wCgV494ov8AHjGa90y7wyeU0U9vJyrCNeQw7gjtXu/xk0ePXrjQNPnlaKKS6lZ2QfNhYmYgZ6E7cZ5xnOD0rw7RNK0jxN4rsNMsIb2wgl3GZprlJ2IVS3ykRoBwuOQeufavYw/8NHNP4mZNzrmrXl/DfXeqXs93BjyriW4dpI8HI2sTkYJzxRc65q15fw313ql7PdwY8q4luHaSPByNrE5GCc8V1EHhLSdRk8MXNob23tNauZbeWCWZJJIyjAFg4RRyGHBXjHU545rQ9J/trxFaaWJvI+0zCLzdu7bnvjIz+dbkva/9f1oQahquoatOs2q31zfSquxZLmZpGC9cAsTxya0PF88Nz4pupbaVJo2WLDxsGBxGoPI9xWMw2sR6HFJQD31CiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKAP/9k=)SQL> **table F**

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#### H. Logged in as database owner

16. Check that auditing has been happening

SQL> **table "Sys$Audit"**

**|----|----------------|-----|-------------------|**

**|Pos |User |Table|Timestamp |**

**|----|----------------|-----|-------------------|**

**|665 |MALCOLM1\Fred |62 |03/10/2020 10:58:52|**

**|684 |MALCOLM1\Fred |62 |03/10/2020 10:59:08|**

**|824 |MALCOLM1\Fred |62 |03/10/2020 10:59:21|**

**|849 |MALCOLM1\Student|62 |03/10/2020 11:00:28|**

**|868 |MALCOLM1\Student|62 |03/10/2020 11:00:40|**

**|893 |MALCOLM1\Student|62 |03/10/2020 11:00:40|**

**|918 |MALCOLM1\Student|62 |03/10/2020 11:00:40|**

**|986 |MALCOLM1\Student|62 |03/10/2020 11:00:52|**

**|1050|MALCOLM1\Student|62 |03/10/2020 11:00:52|**

**|1273|MALCOLM1\Student|62 |03/10/2020 11:01:02|**

**|1292|MALCOLM1\Fred |62 |03/10/2020 11:01:32|**

**|1424|MALCOLM1\Student|62 |03/10/2020 11:02:42|**

**|1449|MALCOLM1\Student|62 |03/10/2020 11:02:52|**

**|----|----------------|-----|-------------------|**

SQL> **table "Sys$AuditKey"**

|----|---|---|---|

|Pos |Seq|Col|Key|

|----|---|---|---|

|824 |0 |82 |4 |

|868 |0 |82 |2 |

|893 |0 |82 |3 |

|918 |0 |82 |4 |

|1050|0 |82 |5 |

|1424|0 |82 |5 |

|1449|0 |82 |5 |

|----|---|---|---|

17. Finally, here is the complete database log:

SQL> **table "Log$"**

|----|-----------------------------------------------------------------------|------------|-------|

|Pos |Desc |Type |Affects|

|----|-----------------------------------------------------------------------|------------|-------|

|26 |PUser MALCOLM1\Malcolm |PUser |26 |

|46 |PTransaction for 3 Role=5 User=26 Time=10/03/2020 10:56:59 |PTransaction|46 |

|62 |PTable A |PTable |62 |

|68 |Domain INTEGER |PDomain |68 |

|82 |PColumn3 B for 62(0)[68] |PColumn3 |82 |

|103 |Domain CHAR |PDomain |103 |

|116 |PColumn3 C for 62(1)[103] |PColumn3 |116 |

|138 |PTransaction for 5 Role=5 User=26 Time=10/03/2020 10:56:59 |PTransaction|138 |

|154 |PTable D |PTable |154 |

|161 |PColumn3 E for 154(0)[103] |PColumn3 |161 |

|184 |PIndex D on 154(161) PrimaryKey |PIndex |184 |

|203 |Classify 154 D{ARMY,NAVY}[DEFENCE] |Classify |203 |

|239 |Enforcement [154] SCOPE read |Enforcement |239 |

|248 |PTransaction for 5 Role=5 User=26 Time=10/03/2020 10:57:00 |PTransaction|248 |

|264 |PTable F |PTable |264 |

|271 |PColumn3 G for 264(0)[103] |PColumn3 |271 |

|294 |PIndex F on 264(271) PrimaryKey |PIndex |294 |

|313 |PColumn3 H for 264(1)[103] |PColumn3 |313 |

|337 |Classify 313 C |Classify |337 |

|350 |PTransaction for 2 Role=5 User=26 Time=10/03/2020 10:57:08 |PTransaction|350 |

|366 |PUser MALCOLM1\Student |PUser |366 |

|388 |Grant UseRole on 5 to 366 |Grant |388 |

|400 |PTransaction for 2 Role=5 User=26 Time=10/03/2020 10:57:08 |PTransaction|400 |

|416 |PUser MALCOLM1\Fred |PUser |416 |

|435 |Grant UseRole on 5 to 416 |Grant |435 |

|447 |PTransaction for 1 Role=5 User=26 Time=10/03/2020 10:57:08 |PTransaction|447 |

|463 |Clearance 366 B{ARMY}[CYBER,DEFENCE] |Clearance |463 |

|500 |PTransaction for 1 Role=5 User=26 Time=10/03/2020 10:57:18 |PTransaction|500 |

|516 |Record 516[62]: 82=2,116=Two |Record |516 |

|537 |PTransaction for 1 Role=5 User=26 Time=10/03/2020 10:57:18 |PTransaction|537 |

|553 |Record3 553[62]: 82=3,116=Three Classification: C |Record3 |553 |

|580 |PTransaction for 1 Role=5 User=26 Time=10/03/2020 10:57:18 |PTransaction|580 |

|596 |Record 596[154]: 161=Test |Record |596 |

|615 |PTransaction for 1 Role=5 User=26 Time=10/03/2020 10:57:18 |PTransaction|615 |

|631 |Record 631[264]: 271=MI6,313=sis.gov.uk |Record |631 |

|665 |Audit: MALCOLM1\Fred [62] 10/03/2020 10:58:52 |Audit |665 |

|684 |Audit: MALCOLM1\Fred [62] 10/03/2020 10:59:08 |Audit |684 |

|703 |PTransaction for 1 Role=5 User=416 Time=10/03/2020 10:59:08 |PTransaction|703 |

|720 |Record 720[62]: 82=4,116=Four |Record |720 |

|742 |PTransaction for 1 Role=5 User=416 Time=10/03/2020 10:59:08 |PTransaction|742 |

|759 |Record 759[154]: 161=Fred wrote this |Record |759 |

|789 |PTransaction for 1 Role=5 User=416 Time=10/03/2020 10:59:10 |PTransaction|789 |

|806 |Record 806[264]: 271=UWS |Record |806 |

|824 |Audit: MALCOLM1\Fred [62] 10/03/2020 10:59:21 {82='4'} |Audit |824 |

|849 |Audit: MALCOLM1\Student [62] 10/03/2020 11:00:28 |Audit |849 |

|868 |Audit: MALCOLM1\Student [62] 10/03/2020 11:00:40 {82='2'} |Audit |868 |

|893 |Audit: MALCOLM1\Student [62] 10/03/2020 11:00:40 {82='3'} |Audit |893 |

|918 |Audit: MALCOLM1\Student [62] 10/03/2020 11:00:40 {82='4'} |Audit |918 |

|943 |PTransaction for 1 Role=5 User=366 Time=10/03/2020 11:00:40 |PTransaction|943 |

|960 |Update 759[154]: 161=Fred? Prev:759 |Update |759 |

|986 |Audit: MALCOLM1\Student [62] 10/03/2020 11:00:52 |Audit |986 |

|1005|PTransaction for 1 Role=5 User=366 Time=10/03/2020 11:00:52 |PTransaction|1005 |

|1022|Record3 1022[62]: 82=5,116=Fiv Classification: B |Record3 |1022 |

|1050|Audit: MALCOLM1\Student [62] 10/03/2020 11:00:52 {82='5'} |Audit |1050 |

|1075|PTransaction for 1 Role=5 User=366 Time=10/03/2020 11:00:52 |PTransaction|1075 |

|1092|Update 1022[62]: 82=5,116=Five Prev:1022 |Update |1022 |

|1120|PTransaction for 1 Role=5 User=366 Time=10/03/2020 11:00:52 |PTransaction|1120 |

|1137|Record 1137[154]: 161=Another |Record |1137 |

|1159|PTransaction for 1 Role=5 User=366 Time=10/03/2020 11:00:52 |PTransaction|1159 |

|1176|Record3 1176[264]: 271=BBC,313=bbc.co.uk Classification: B |Record3 |1176 |

|1213|PTransaction for 1 Role=5 User=366 Time=10/03/2020 11:00:54 |PTransaction|1213 |

|1230|Update 1176[264]: 271=BBC,313=www.bbc.co.uk Prev:1176 |Update |1176 |

|1273|Audit: MALCOLM1\Student [62] 10/03/2020 11:01:02 |Audit |1273 |

|1292|Audit: MALCOLM1\Fred [62] 10/03/2020 11:01:32 |Audit |1292 |

|1311|PTransaction for 1 Role=5 User=26 Time=10/03/2020 11:02:10 |PTransaction|1311 |

|1327|Update1 553[62]: 82=3,116=Three Classification: B Prev:553 |Update1 |553 |

|1359|PTransaction for 1 Role=5 User=26 Time=10/03/2020 11:02:10 |PTransaction|1359 |

|1375|Update1 1176[264]: 271=BBC,313=www.bbc.co.uk Classification: Prev:1176|Update1 |1176 |

|1424|Audit: MALCOLM1\Student [62] 10/03/2020 11:02:42 {82='5'} |Audit |1424 |

|1449|Audit: MALCOLM1\Student [62] 10/03/2020 11:02:52 {82='5'} |Audit |1449 |

|----|----------------------------------------------------------------

## 7.5 The Type system and OWL support

Pyrrho supports SQL2011 type system and OWL types. It does so using a integrated data type system using the Domain class. The many subclasses of Domain used in previous versions of Pyrrho have been removed as the system had become unworkably complex with the addition of support for OWL classes.

There is now just one Domain class which deals with a large number of situations. In the simplest case, an Domain might be just new Domain(Sqlx.INTEGER), and other versions add precision and scale information, etc. Array and multiset types refer to their element type. Row types are constructed for any result set. Such types can be constructed in an ad hoc way, and may be added to the database by means of a generated domain definition if required when serialising a record.

In a user-defined type, defpos gives the Type definition, which can be accessed for method definitions etc, while the structType field gives the structure type. From v7 the fields of Types are SqlValues, not TableColumns.

In the latest versions of Pyrrho, the type system has been greatly strengthened, with Level 2 (PhysBase) maintaining a catalogue of dataTypes and role-based naming. All data values are typed (the Value class). The Domain has a domaindefpos and a PhysBase name (a PhysBase pointer is not possible because of the way transactions are implemented). There are two local type catalogues maintained: for anonymous types such as INTEGER (or INTEGER NOTNULL etc), and for role-based named domains.

One further complicating aspect in the requirements for the type system is that SQL is very ambiguous about the expected value of different kinds of Subquery. In the SQL standard, subqueries can be scalar, row-valued, or multiset-valued, and row value constructors and table value constructors can occur with the ROW and TABLE keywords. The SQL standard discusses syntactic ambiguities between different kinds of subqueries (Notes 211 and 391). The starting point for such discussion is that users expect to be able to include a scalar query in a select list, and a rowset valued subquery in an insert statement, and both sorts in predicates. From v4.8 of Pyrrho, the type system is strengthened to enable us to distinguish different cases. We introduce the following usage:

1. CursorSpecifications result in a TABLE whose column names are given by the select list.
2. Insert into T values … the data following values will be of type TABLE where the named columns are contextually supplied by T, whereas the column names in the subquery’s select list if any are only used within the subquery.
3. Subqueries can be used as selectors or in simple expressions, in which case we expect a scalar value (the target Domain is initially Null, so to be more specific we can require Sqlx.UnionDateNumeric or Sqlx.CHAR etc)
4. Subqueries can be used as a table reference, in which case the type will be of type TABLE and the column names will be those of the subquery, or the select list has a single element of the table’s row type.
5. Subqueries can be used in predicates that expect them (e.g. IN, EXISTS etc) in which case the type will be MULTISET.
6. Select single row should have type ROW.

In general the type of a subquery result is a UNION of all the possible returned types. There is a step in query processing to Limit the resulting type.

As far as I can tell, all the usages of subqueries in SQL are provided for in Pyrrho’s design. It is an error for such a subquery to have more than one column (unless it is prefixed by ROW so that the column will contain a single row, or TABLE where more than one row is possible) or more than one row (unless the subquery is prefixed by ARRAY, MULTISET, or TABLE as above).

During query analysis of the select lists, selectors have unique SqlName identifiers, and the identity of the corresponding data and types is propagated up and down the query parse tree, using the SqlValue Setup method to supply constraining type information. Selectors are either explicitly in the column lists in select statements, or implicit as in select \* or aggregation operations.

Rows are structured values that can be placed in the datafile: the dataType refers to the Table that defines the structure of the Row from the ordering of columns in the Table, and the data is an array of Column, each is defined by a column in the defining Table. In query processing on the other hand, the columns of a Row type are just values of the appropriate type for the column. The Row type is coerced to the type required for insertion as a row of the table during serialisation: just as when any value (structured or not) is inserted into a column of a table.

From the above discussion we see that Context notions are required at several points in the low levels parts of the DBMS, for parsing, formatting and ordering user-defined types. We need facilities at these lower levels to create role-based parsing and ordering contexts.

# 8. The HTTP service

This section sets out to explain the implementation of the HTTP and HTTPS service aspects of the Pyrrho DBMS.

From version 4.5 this is replaced by a REST service, where the URLs and returned data are role-dependent. The Role is specified as part of the URL, and WS-\* security mechanisms are used to ensure that the access is allowed. Pyrrho supports the Basic authentication model of HTTP, which is sufficient over a secure connection. Support for HTTPS however is beyond the scope of these notes.

To keep the syntax intuitive multiple database connections are not supported. Only constant values can be used in selectors or parameter lists. Joins and other advanced features should be implemented using generated columns, stored procedures etc, which can be made specific to a role. However, the default URL mapping allows navigation through foreign keys.

Most of the implementation described in this section is contained in file HttpService.cs .

## 8.1 URL format

All data segments in the URL are URLencoded so, for example, identifiers never need to be enclosed in double quotes. Matching rules are applied in the order given, but can be disambiguated using the optional $ prefixes. White space is significant (e.g. the spaces in the rules below must be a single space, and the commas should not have adjacent spaces).

**http://***host*:*port*/d*atabase*/*role*{/Selector}{/Processing}[/Suffix]

Selector matches

**[$table** ]*Table*\_id

[**$procedure** ]*Procedure*\_id

**[$where** ]*Column\_*id=string

[**$select** ]*Column\_*id{,*Column\_*id}

[**$key** ]string

Appending another selector is used to restrict a list of data to match a given primary key value or named column values, or to navigate to another list by following a foreign key, or supply the current result as the parameters of a named procedure, function, or method.

Processing matches:

**orderasc** *Column*\_id{, *Column\_*id}

**orderdesc** *Column*\_id{, *Column\_*id}

**skip** *Int\_*string

**count** *Int*\_string

Suffix matches

**$edmx**

**$xml**

**$sql**

The $xml suffix forces XML to be used even for a single value. $edmx returns an edmx description of the data referred to. The $sql suffix forces SQL format. Posted data should be in SQL or XML format.

The HTTP response will be in XML unless it consists of a single value of a primitive type, in which case the default (invariant, SQL) string representation of this type will be used.

For example with an obvious data model, GET http://Sales/Sales/Orders/1234 returns a single row from the Orders table, while http://Sales/Sales/Orders/1234/OrderItem returns a list of rows from the OrderItem table, and http://Sales/Sales/Orders/1234/Customer returns the row from the Customer table

A URL can be used to GET a single item, a list of rows or single items, PUT an update to a single items, POST a new item to a list, or DELETE a single row.

For example, PUT http://Sales/Sales/Orders/1234/DeliveryDate with posted data of 2011-07-20 will update the DeliveryDate cell in a row of the Orders table.

POST http://Sales/Sales/Orders will create a new row in the Orders table: the posted data should contain the XML version of the row. In Pyrrho the primary key can be left unspecified. In all cases the new primary key value will be contained in the Http response.

## 8.2 REST implementation

A described above, the first few segments of the URL are used to create a connection to a database, and set the role. Then the selectors are processed iteratively, at each stage creating a RowSet that will be processed iteratively, with iteration over the final RowSet taking place when sending the results.

It is much simpler to use the facilities in this section as follows:

A single SELECT statement can be send in a GET request to the Role URL,and the returned data will be the entire RowSet that results, together with an ETag as a cache verification token.

If a single row is obtained in this way, a PUT or DELETE with a matching ETag can be used to update the row, provided no conflicting transaction has intervened.

A group of SQL statements can be POSTed as data to the Role URL and will be executed in an explicit transaction. The HTTP request can be made conditional or the continuing validity of previous results by including a set of ETags in the request.

The ETag mechanism is defined in RFC 7232. Its use supports a simple form of transactional behaviour. Very few database products implement ETags at present. The above descriptions can still work in a less secure way in the absence of ETags.

## 8.3 RESTViews

RestViews get their data from a REST service. The parser sets up the restview target in the global From. During Selects, based on the enclosing QuerySpecification, we work out a remote CursorSpecification for the From.source and a From for the usingTable if any, in the usingFrom field of the From.source CS.

Thus there are four Queries involved in RestView evaluation, here referred to as QS,GF,CS and UF. Where example columns such as K.F occur below we understand there there may in general be more than one of each sort.

All columns coming from QS maintain their positions in the final result rowSet, but their evaluation rules and names change: the alias field will hold the original name if there is no alias.

The rules are quite complicated:

If QS contains no aggregation columns, GF and FS have the same columns and evaluation rules: and current values of usingTable columns K are supplied as literals in FS column exps.

If there is no alias for a column expr, an alias is constructed naming K.

Additional (non-grouped) columns will be added to CS,GF for AVG etc.

GS will always have the same grouping columns as QS. For example

QS (AVG(E+K),F) group by F ->

CS (SUM(E+[K]) as C\_2,F COUNT(E+[K]) as D\_2),

[K] is the current value of K from UF

GF (SUM(C\_2) as C2,F,COUNT(D\_2) as D2)

-> QS(C2/D2 as "AVG(E+K)", F)

Crucially, though, for any given QS, we want to minimise the volume D of data transferred. We can consider how much data QS needs to compute its results, and we rewrite the query to keep D as low as possible. Obviously many such queries (such as the obvious select \* from V) would need all of the data. At the other extreme, if QS only refers to local data (no RESTViews) D is always zero, so that all of the following analysis is specific to the RESTView technology.

We will add a set of query-rewriting rules to the database engine aiming to reduce D by recursive analysis of QS and the views and tables it references. As the later sections of this document explain, some of these rules can be very simple, such as filtering by rows or columns of V, while others involve performing some aggregations remotely (extreme cases such as select count(\*) from V needs only one row to be returned). In particular, we will study the interactions between grouped aggregations and joins. The analysis will in general be recursive, since views may be defined using aggregations and joins of other views and local tables.

Any given QS might not be susceptible to such a reduction, or at least we may find that none of our rules help, so that a possible outcome of any stage in the analysis might be to decide not to make further changes. Since this is Pyrrho, its immutable data structures can retain previous successful stages of query rewriting, if the next stage in the recursion is unable to make further progress.

There are two types of RESTView corresponding to whether the view has one single contributor or multiple remote databases. In the simple exercises in this document, V is a RESTview with one contributor, and W has two. In the multiple-contributors case, the view definition always includes a list of contributors (the “using table”, VU here) making it a simple matter to manage the list of contributors.

RESTView often refer to data from other RESTViews so everything needs to work recursively.

The simplest way of reducing the data transferreed is to identiy which columns in a remote view are actually needed by QS, either in the select list or in other expressions in QS such as join conditions.

The first aspect of rewriting we consider is filters. If there are some columns of the RESTView that are not used in the given query, there is an obvious reduction, and if a where-condition can be passed to the remote database, this will also reduce the number of rows returned.

There are two levels for filters in the Pyrrho engine. There is a low-level filter where particular requirements on defining positions and associated values can be specified: this is called match. There is a higher-level filter based on SQL value expressions, corresponding to SQL where and having conditions. To assist with optimisation Pyrrho works with lists of such conditions anded together.

Consider such a where condition E in QS. If both sides of the condition are remote, we can move the where condition to CS to filter the amount of data transferred. On the other hand, we cannot pass a where-condition to the remote database if it references data from a local table.

Similarly with aggregations: if all of the data being aggregated is remote, the aggregation can be done in CS. If some of the select items in QS contain local aggregation or grouping operations, it is often possibly to perform the operations in stages, with some of the agrregations can be done remotely, filtered where appropriate, so that the contributing databases provide partial sums and counts that can be combined in the GF. Most of the work for this is done in SqlValue.ColsForRestView, which is called by RestView.Selects. The base implementation of ColsForRestView examines the given group specification if any and builds lists of remote groups and GF columns. SqlValueExpr.ColsForRestView needs to consider many subcases according as left and right operands are aggregated, local or not, and grouped or not. SqlFunction.ColsForRestView performs complex rewriting for AVG and EXTRACT.

The above analyses and optimisations also need to be available when RESTViews are used in larger SQL queries. The analysis of grouping and filters needs to be applied top down so that as much as possible of the work is passed to the remote systems. Each RESTView target or subquery will receive a different request, and the results will be combined as rowsets of explicit values.

This contrasts with the optimisations used for local (in-memory) data, which instead aims to do as little work as possible until the client asks for successive rows of the results. In addition, detailed knowledge of table sizes, indexes and functional dependencies is available for local data, which helps with query optimisation.

# 9. References

Crowe, M. K. (2005-14): The Pyrrho Database Management System, University of the West of Scotland, [www.pyrrhodb.com](http://www.pyrrhodb.com);

SQL2016: ISO/IEC 9075-2:2016 Information Technology – Database Languages – SQL – Part 2: Foundation (SQL/Foundation); ISO/IEC 9075-4:2016: Information Technology – Database Languages – SQL – Part 4: Persistent Stored Modules;(International Standards Organisation, 2016)

1. An important exception is that from version 7, Pyrrho does not allow schema modifications to objects that contain data. This affects the use of databases from previous versions that record such modifications (see 2.5.6). [↑](#footnote-ref-1)
2. System.Exception is not shareable abd so all its subclasses are not Shareable. [↑](#footnote-ref-2)
3. Shareable classes can have mutable subclasses (shareability is not heritable).BTree<K,V> and BList<V> and their bookmarks are shareable if K and V are; otherwise they are shareable provided all objects placed in them are shareable. Non-shareability and non-immutability are heritable. Shareable classes with no internal subclasses could be made sealed, but this adds nothing for internal classes. [↑](#footnote-ref-3)
4. Cursors used to examine the transaction log directly (LogSystemBookmark and its subclasses, and SysAuditBookmarks) are not shareable. [↑](#footnote-ref-4)
5. Obviously, column references will have different values in different rows. SqlValue evaluation uses the appropriate cursor to obtain the value for a row. During trigger operation the same is true for old/new tables. [↑](#footnote-ref-5)
6. The heap range is then moved to follow the high-watermark of prepared statements. [↑](#footnote-ref-6)
7. Remember that neither immutability nor shareability are heritable. Mutability and non-shareability are. [↑](#footnote-ref-7)
8. Confusingly, one of the Physical subclasses, for inserting data in the database, is called Record. [↑](#footnote-ref-8)
9. For renamable objects, the role’s name for the object is held in an ObInfo structure stored in the Role. [↑](#footnote-ref-9)
10. Reader and Writer both contain Contexts, whose db field is a snapshot of the Database. [↑](#footnote-ref-10)
11. Transactions running in different threads cannot see each other’s data, so concurrent transactions will use the same range of defining positions. [↑](#footnote-ref-11)
12. Many of these properties have type long: such things are uids, and identify DBObjects, SqlValues, Queries, Executables etc. Comments in the source code generally indicate what type of objects is indicated. [↑](#footnote-ref-12)
13. Such negative numbers are assigned more or less arbitrarily in the source code for properties in the lists shown above and elsewhere in Ch 3. For example, the current value of Database.Schema is -61. [↑](#footnote-ref-13)
14. One of the examples in the Pyrrho manual sees a role adding a generated column to a table. This is an extreme case of table metadata! [↑](#footnote-ref-14)
15. Accessibility and visibility of columns in a rowset is managed with the Finder mechanism, see sec 3.6.3. [↑](#footnote-ref-15)
16. See Note 116 in the SQL standard. [↑](#footnote-ref-16)
17. A separate step builds the rows of the rowset. Since RowSet is immutable, the Context contains the current set of rowsets during execution. Building is delayed until traversal, and some rowsets need to be rebuilt if ambient values change. Cursors always continues to traverse the RowSet as it stood at the time of cursor creation (by First() or Last()). [↑](#footnote-ref-17)
18. TransitionRowSet and some system rowsets are unidirectional. [↑](#footnote-ref-18)
19. Versions of Pyrrho prior to v7 reparsed definitions for each role, since roles can rename objects. This was a mistake, since execution of any definition always occurs with the definer’s role. [↑](#footnote-ref-19)
20. The defining position of an expression is that of the top operator, such as + or . . In general, we can’t replace a dotted expression simply with its right hand operand, because the dotted notation is used for disambiguation, not just among columns with the same name, but often between multiple instances of the table (t here). [↑](#footnote-ref-20)
21. In general, subsidiary rowsets may need to be rebuilt during traversal of their parent (e.g. lateral joins, results of procedure calls. [↑](#footnote-ref-21)
22. The uids are different for a newly defined trigger. [↑](#footnote-ref-22)
23. See section 3.4.2. [↑](#footnote-ref-23)
24. Trigger.OldRow is a global constant, currently -293. Such uids are used for the target in TableActivations, leading to trigger-specific versions are used with proper uids in TriggerActivation, where several triggers may be active. [↑](#footnote-ref-24)
25. It is unusual for an auditable object to be accessible to the public. But why not? [↑](#footnote-ref-25)