The Pyrrho Book

Book · May 2015

CITATIONS
0

READS
457

1 author:

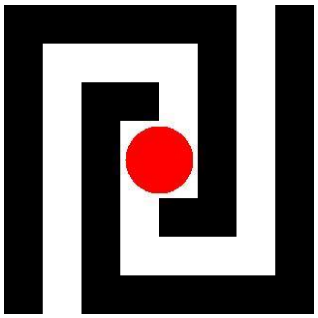
Malcolm Crowe
University of the West of Scotland
88 PUBLICATIONS **333** CITATIONS

SEE PROFILE

The Pyrrho Book

Malcolm Crowe, University of the West of Scotland

www.pyrrhodb.com



ISBN: 978-1-903978-50-4

Paisley: University of the West of Scotland, 2015

Contents

Chapter 1: Introduction to the Book

This book focuses on a number of aspects of database management systems that are important in real life application, but in which current products fall short of what is required. The book will make a contribution to DBMS design by suggesting a number of fundamental improvements to DBMS architecture, and validating them by means of a working proof-of-concept DBMS, Pyrrho, that includes not just the basic relational model, but most of the features of ISO-standard SQL and some other suggestions from the database community. We will discuss the trade-offs in speed and complexity involved in including these features: over the years the set of additional features offered by Pyrrho has changed, with some advanced features (RDF, SPARQL, JPA, client-side data models etc) being removed from Pyrrho where the added complexities have not justified themselves.

In this book, supporting data consistency is a prime concern. In particular it should not be the application's responsibility to maintain consistency or to clean up after errors. The DBMS should have the task of ensuring that data is consistent and constraints as defined in the schema are maintained. While databases should be fast and scalable, 100% accuracy is more important than speed. Alternatives to the relational model are included in this book where relevant: it is a misconception that the failings of database products are somehow the fault of the relational model or SQL.

This book will take for granted the concerns of introductory texts, such as the relational design, SQL, entity-relationship modelling, joins and triggers. One of these concerns, "normal form" data, is notable here in that it contributes to database correctness, since any duplication of data has a potential for inconsistency. It represents an efficiency trade-off since with normal form, the information for the domain needs to be reconstructed by recombining data from these extra tables or selecting columns from larger tables; and where normalisation is reversed for efficiency reasons, it is at the cost of repairing duplicates, for example with the help of triggers. These considerations are of interest, but they come before the starting point for this book: we assume good database design. Our concerns begin with such issues as transaction non-isolation, the suspending of constraints, or inadequate transactional guarantees.[1]

In fact, the most serious criticism of existing commercial products relates to ACID properties and implementation of transactions, wherein many cases they don't follow their own documentation. When this book is used in a university course I would strongly recommend including the Transactions tutorial from DBTechNET.org which provides a useful critique of a range of commercial DBMS from this viewpoint, and supplies a set of interesting exercises to try out on any other supposedly ACID-compliant DBMS. But rather than merely criticise these products, this book offers a set of design proposals for solving the problems of consistency, embodied in the open-source Pyrrho DBMS. In order to show the practicality of these design proposals for advanced database scenarios, this book goes beyond simplified examples to showcase Pyrrho's implementation of distributed and partitioned databases, and strongly typed features of standard SQL.

There are some practical sessions in appendices. Most of these use Pyrrho as the database engine, but the first appendix gives a more general introduction to building database applications, using a number of database products. Shorter practical exercises are included in the chapters as the corresponding topic is presented. Unfortunately no product sticks rigidly to the standard SQL syntax is described in ISO-9075. Pyrrho is closer than most but the SQL syntax appendix is really required reference during practical sessions. A final group of appendices cover some technical details on Pyrrho: the error codes, and system tables.

[1] Some of these difficulties are caused by transaction properties mandated by the ISO standard for SQL. Non-compliance with the SQL standard in these areas is legitimate from the viewpoint of this book: there are other aspects of standard SQL that should never be allowed (for example ineffective REVOKE, ON DROP NO ACTION, "branch transactions").

I expect all readers will have attended at least one course on Databases, but the subject area is quite complex. Actual building of database applications has been a neglected area in most university programmes. The first set of practical exercises in Appendix 1 helps to motivate the discussion by showing some simple approaches to database application development.

1.1 Download Pyrrho

All editions of Pyrrho are available from www.pyrrhodb.org for immediate download. Provided the .NET framework has been installed, it is possible to extract all of the files in the distribution to a single folder, and start to use Pyrrho in this folder without making any system or registry changes.[2] The distribution contains a user manual called Pyrrho.docx: there is some overlap of material between Pyrrho.docx and this book, but the focus in this book is on general principles of databases, while the manual contains more technical details about Pyrrho.

There are several editions of Pyrrho: Professional and Open Source, and the embedded versions of each. They use the same relational engine, API, ACID transactions, integrated security and multi-user access but have a different database format (*.pfl.*.osp) for security reasons. There are corresponding client libraries (PyrrhoLink.dll, OSPLink.dll) and embedded editions (EmbeddedPyrrho.dll, OSP.dll) where an application has one or more private databases[3]. It is very important to understand that the open-source tools cannot be used with the professional server, and vice-versa.

The open-source edition includes some database features omitted from the professional edition for reasons of security. The open-source client OSPLink.dll supports SWI-Prolog and PHP. Otherwise the client API is compatible between the two editions. In the Open Source Edition there is also a client library for Java: OSPJ provides the package org.pyrrhodb.*. There are also some technical explanations of Pyrrho's inner workings in a document called SourceIntro.docx, and there is a catalogue of the C# classes used in the server in Classes.xlsx.

You are allowed to view and test the code, and incorporate it in other software, provided you do not create a competing product. You can redistribute any of the files available on the Pyrrho website in their entirety or embed the dlls or any of the source code in an application. Otherwise, like other editions of Pyrrho, use of this open source edition is subject to the end-user license, and any uses other than those described here requires a license from the University of the West of Scotland.

Database files are generally smaller than those of other database products. Files do not contain any indexes or empty space, so an empty database file is less than 1KB. Database files do grow larger if there are many updates because Pyrrho maintains a full historical record. It is helpful to separate data comprising the historical record from ad-hoc or transient analysis files, so Pyrrho has a multi-database connection mechanism to facilitate connecting to more than one database at a time.

Currently PyrrhoSvr.exe is approximately 870KB, and when running the server process starts out with about 12MB of memory, but requires approximately as much additional memory as the size of the database file. Memory (RAM) is required only for current data, so if many records in the database have been deleted, or much of the database file consists of updates, the working memory required will be less than the size of the database file.

Pyrrho is intellectual property of the University of the West of Scotland, United Kingdom. The associated documentation and source code, where available, are copyright of the University of the West of Scotland. Your use of this intellectual property is governed by a standard end-user license

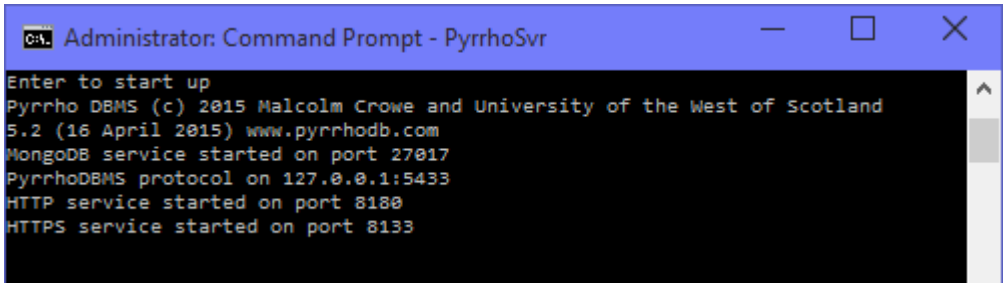
[2] However, it is a good idea to have a separate folder for the databases. It is simplest to copy the server executable to the folder you plan to use. See section 1.2.

[3] It is best to provide exactly one of these four dlls in folders containing client executables. We no longer recommend installing components in the global assembly cache.

agreement, which permits the uses described above without charges. All other use requires a license from the University of the West of Scotland.

1.2 The Pyrrho DBMS server

The server PyrrhoSvr.exe is normally placed in the folder that will also contain the database files. The Professional and Open Source editions of PyrrhoSvr can be started from the command line, by the user who owns this folder. It is a good idea to run the server in a command window, because occasionally this window is used for diagnostic output. (If you are using Embedded Pyrrho only, the database engine is included in the application and so the server does not need to be running.)



Pyrrho provides its client service by default on port 5433, but will find another port if 5433 is already in use. By default Pyrrho will try to set up a REST service on ports http 8180 and https 8133, using Windows authentication, and a MongoDB-like service on port 27017. (You can supply your own server certificate for transport layer security and/or specify different ports.)

On Windows 7 systems and later, if you get Access denied, you can either run the server as administrator, or you can fix the http url reservations. To do this open a command prompt as administrator and issue the following commands (with your full user name where shown):

```
netsh http add urlacl http://127.0.0.1:8180/ user=DOMAIN\user
```

```
netsh http add urlacl https://127.0.0.1:8133/ user=DOMAIN\user
```

If you get other error messages try using different ports using the command line options described below.

1.3 Starting the server

The server is normally started from the command line, in the same folder as the server binary: in the distribution this is in the Pyrrho or OSP folder closest to the root of the distribution. The command line syntax is as follows (for Open Source Pyrrho, the server name is OSP).

PyrrhoSvr [-h:*host*] [-p:*port*] [-s:*port*] [-S:*port*] [-M:*port*] [-d:*path*]

On Linux systems, you will need the Mono runtime installed, and the command line begins **mono PyrrhoSvr.exe** .

The –h and –p arguments are used to set the TCP host name and port number to something other than 127.0.0.1 and 5433 respectively. This can be a useful and simple security precaution. Note that the host IP address used must match the host name given in connection strings. See Appendix 10.

The –s and –S flags modify the ports for the REST service from the defaults of 8180 and 8133.

The –d flag can be used to specify the server's database folder: we will explore the use of this option and some additional flags in the Appendices on Distributed and Partitioned databases when we model the use of multiple servers.

1.4 Database files

PyrrhoSvr.exe, the folder that contains it, and all the database files in this folder are normally owned by the same user, called the server account in the following notes. Note that the "database owner" is different – as described in this section.

If the server creates a database (file) on behalf of a client, the client user's name will be recorded in the very first record of the file: this user is then established as the database owner, and by default has full administrative control over the database.

On the Open Source edition of Pyrrho, database files have extension .osp. For other editions the extension is .pfl. For example, a database called Sales will be contained in a file Sales.pfl or Sales.osp. If a database file grows beyond 4GB it will be split into sections: after the first one their names will be Sales.1.pfl, or Sales.1.osp, etc. (As is suggested by the different extensions, Open Source Pyrrho files cannot be used by other editions and vice versa.)

You can inspect the database folder from time to time to check everything is in order. It is not a good idea to rename a database file, as that is the name of the default database Role, and Pyrrho will infer some sort of partitioning if the two do not match.

For embedded applications, the database file(s) should be installed alongside the application (e.g. as an asset).

1.5 The client programs

There are two client utilities at present: a traditional command-line interpreter PyrrhoCmd, and a Windows client called PyrrhoSQL. As with all Pyrrho clients, the PyrrhoLink.dll or OSPLink.dll assembly is also required. We discuss these first. The distribution also contains a REST client and a transaction profiling utility.

OSPLink.dll (or the Java package org.pyrrhodb.*) is used by any application that wishes to use the Open Source Pyrrho DBMS, and PyrrhoLink.dll is needed by any application that wishes to use the Professional edition of the Pyrrho DBMS. These client libraries have similar functionality. This library includes support for client applications. The simplest possible approach is simply to place PyrrhoLink.dll (or OSPLink.dll) in the same folder as the application that is using it.

PyrrhoCmd is a console application for simple interaction with the Pyrrho server. Basically it allows SQL statements to be issued at the command prompt and displays the results of SELECT statements in a simple form. For most purposes it is best to place the command line utilities such as PyrrhoCmd and the client dll in a different location from the server. They occupy very little disk space: and the databases will be created in the server's folder.

With embedded databases things are different: Databases will be in the same folder as applications using an embedded edition of Pyrrho.

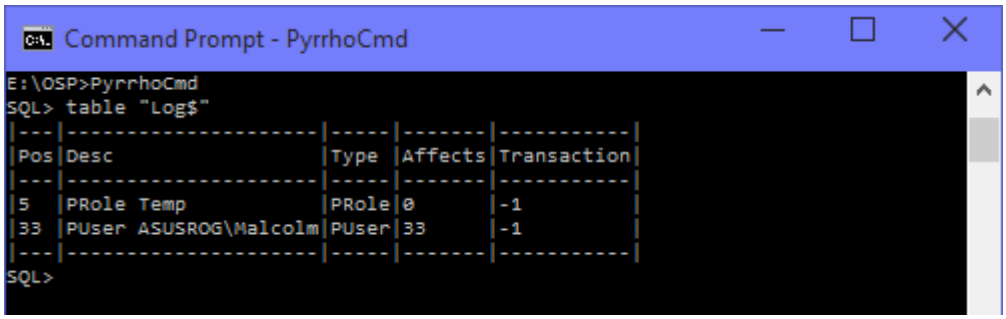
1.6 Checking it works

For simplicity, on the same machine as the server, open a command window and use cd to navigate to the same folder as the client executable. Be sure to use the correct version of PyrrhoCmd: you cannot use the professional version of PyrrhoCmd with the open-source server or vice versa. (It is not usually a good idea to start up PyrrhoCmd or the server by double-clicking, because the command line parameters can be useful.)

PyrrhoCmd

```
SQL> table "Log$"
```

In SQL2011 **table** *id* is the same as **select * from** *id* for base tables and system tables.



Your output will differ in a number of respects from this, (e.g. your folder will probably not be E:\OSP) and some explanations are important here as we can see the Windows identity of the user that started PyrrhoCmd (not the server).

Normally, the PyrrhoCmd command line will have an argument parameter indicating the database(s) to connect to. If none is given, PyrrhoCmd will open (or create) a database called Temp. You can confirm this by looking in the server's folder: you will see a file called Temp.pfl or Temp.osp (it was not there before). Pyrrho creates a default Role for the database with the same name as the database, and records the identity of the creator user (this will be your login ID). All later entries in the log file will have transaction information.

You can use control-C, or close the window, to exit from PyrrhoCmd. (If you want to delete the database file that you have just created, you will need to stop the server.)

When starting up PyrrhoCmd, the following command line arguments are supported:

database ...	One or more database names on the server. The default is Temp. Do not include the .osp or .pfl file extension.
-h:*hostname*	Contact a server on another machine. The default is localhost
-p:*nnnn*	Contact the server listening on this port number. The default is 5433
-s	Silent: suppress warnings about uploads and downloads
-e:*command*	Use the given command instead of taking console input. (Then the SQL> prompt is not used.)
-f:*file*	Take SQL statements from the given file instead of from the console.
-b	No downloads of Blobs
-?	Show this information and exit.

Pyrrho can support locales other than English, but such localisations are not currently included in the distribution. Whether the command prompt (console) window is able to display the localised output will depend on system installation details that are outside Pyrrho's control. Localisation is more effective with Windows Forms or Web Forms applications.

The SQL> prompt

PyrrhoCmd is normally used interactively. At the SQL> prompt you can give a single SQL statement. There is no need to add a semicolon at the end. There is no maximum line length either, so if the command wraps around in PyrrhoCmd's window this is okay.

```
SQL> set role ranking
```

Unless you use multiline command as described below, be careful not to use the return key in the middle of an SQL statement as the end of line is interpreted by PyrrhoCmd as EOF for the SQL statement.

At the SQL command prompt, instead of giving an SQL statement, you can specify a command file using *@filename.* Command files are ordinary text files containing an SQL statement on each line.

If wraparound annoys you, then you can enclose multi-line SQL statements in [ ] . [and] must then enclose the input, i.e. be the first and last non-blank characters in the input.

```
SQL> [ create table directors ( id int primary key,
> surname char,
> firstname char, pic blob ) ]
```

Note that continuation lines are prompted for with > . It is okay to enclose a one-line statement in [ ] .

Note that Pyrrho creates variable length data fields if the length information is missing, as here. This seems strange at first: a field defined as CHAR is actually a string.

Binary data is actually stored inside the database table, and in SQL such data is inserted using hex encoding. But PyrrhoCmd supports a special syntax that uses a filename as a value:

```
SQL> [ insert into directors (id, surname, firstname) values (1,
'Spielberg', 'Steven', ~spielberg.gif) ]
```

The above example shows how PyrrhoCmd allows the syntax `~source` as an alternative to the SQL2011 binary large object syntax `X'474946…'` . PyrrhoCmd searches for the file in the current folder, and embeds the data into the SQL statement before the statement is sent to the server.

As this behaviour may not be what users expect, the first time Pyrrho uploads or downloads a blob, a message is written to the console, e.g.:

```
Note: the contents of source is being copied as a blob to the server
```

`source` can be enclosed in single or double quotes, and may be a URL, i.e. `~source` can be `~"http://something"`. Another use of ~*file*, for importing datafrom spreadsheets, is described in appendix 3 (section A3.3).

Data is retrieved from the database using TABLE or SELECT statements, as indicated above.

If data returned from the server includes blobs, by default PyrrhoCmd puts these into client-side files with new names of form `Blobnn` .

Blobs retrieved to the client side by this method end up in PyrrhoCmd's working directory (which is usually different from the database folder). To view them it is usually necessary to change the file extension, e.g. to Blob1.gif. However, on the server side, such data is actually stored permanently inside database files.

Transactions in Pyrrho are mandatory, and are always serializable. By default, each command is committed immediately unless an error occurs. Alternatively, you can start an explicit transaction at the SQL> prompt:

```
SQL> begin transaction
```

Then the command line prompt changes to SQL-T> to remind you that a transaction is in progress. This will continue until you issue a **`rollback`** or **`commit`** command at the SQL-T> prompt. If an error

is reported by the database engine during an explicit transaction, you will get an additional message saying that the transaction has been rolled back.

Note that this reminder and warning behaviour is generated in the command line client on the basis of naïve text matching (of “begin transaction” etc). The use of comments and other noise may affect these feedback mechanisms. The database engine however is not confused. Serious transactions should use the API instead of the command line.

Chapter 2 Data Consistency, Transparency and Durability

When people speak of databases, consistency, transparency and durability are three of the main properties they ought to expect. But in database software it has very strangely become normal to support inconsistency, and undermine the efforts of software engineers to provide reliable systems, in a mistaken pursuit of speed at all costs. It is not clever to base any decisions on incorrect data, so getting a wrong answer before your competitors is no real advantage. In this book we assume that inconsistency is always bad: since every database starts out in a consistent state it is the job of the DBMS to prevent inconsistencies from creeping in.

Companies almost always store the data for their business processes (customers, employees, accounts etc) in databases. Interestingly, the data in company databases often is retained for decades, long after the computer systems used to create then have ceased to exist. Legacy data still needs to be accessed.

Although computer books often refer to "the corporate database" it is rare now for a company to have just one. But any of these corporate databases can be accessed by numerous other computers and programs in the company or its various branches or customers; and database management systems need to be able to cope with many concurrent connections to the database. Such database systems are said to be server-based (client-server database systems): a program that needs to access the data in the database opens a connection to the server, and uses a standard protocol to send and receive the data it wants. One of the main topics in this course will be the ways that the DBMS ensures consistency and integrity in a busy database system, and is as available as possible.

Some computer programs use local databases: that is, there are no other programs that need to access the data while it is in use. Such database systems are often called embedded. For example, many devices today (phones, cars, fridges etc) have computer systems that use local databases. With HTML5 we have ways for web pages to have local data.

Many important pieces of information in a company are not stored in databases, however. It is fairly rare for spreadsheets, web pages or office documents to be stored in the database. Instead these are stored in the file system as ordinary files. Strangely, although such individual files are commonly security-protected in company computer systems and shared explicitly among user groups, most companies still apply security in an all-or-nothing way the entire database, and not to the separate types of data inside it, despite the availability of security facilities in the database management system. This is yet another aspect we will look at in this module, as it would seem that the security facilities are not currently used because they don't quite match the company's needs.

The database data files are accessed by the database server, so they normally belong to the user account that starts up the database server (often this is a special anonymous account). The database server controls who can connect to the database.

The Pyrrho database management system is named after an ancient Greek philosopher, Pyrrho of Elis (360-272BC), who founded the school of Scepticism. We know of this school from writers such as Diogenes Laertius and Sextus Empiricus, and several books about Pyrrhonism (e.g. by Floridi) have recently appeared.

> And their philosophy was called investigatory, from their investigating or seeking the truth on all sides.
>
> *(Diogenes Laertius p 405)*

Pyrrho's approach was to support investigation rather than mere acceptance of dogmatic or oracular utterance.

Accordingly in this database management system, care is taken to preserve any supporting evidence for data that can be gathered automatically, such as the record of who entered the data, when and (if

possible) why; and to maintain a complete record of subsequent alterations to the data on the same basis. The fact and circumstances of such data entry and maintenance provide some evidence for the truthfulness of the data, and, conversely, makes any unusual activity or data easier to investigate. This additional information is available, normally only to the database owner, via SQL queries through the use of system tables, as described in Chapter 8.2 of this manual. It is of course possible to use such automatically-recorded data in databases and applications.

In other ways Pyrrho supports investigation. For example, in SQL2011 renaming of objects requires copying of its data to a new object, In Pyrrho, by contrast, tables and other database objects can be renamed, so that the history of their data can be preserved. From version 4.5, object naming is role-based (see section 3.6).

The logo on the front cover of this book combines the ancient "Greek key" design, used traditionally in architecture, with the initial letters of Pyrrho, and suggests security in its interlocking elements.

2.1 Durability

Of the trio of topics mentioned in the chapter heading, **Durability** looks the easiest: we assume that we want to keep data in a good form, and our business operations need to be recorded properly. Of course the resulting values of data (account balances etc) will be modified later on as a result of our business processes, so that durability means that we should be able to show later that the data had this value today.

Strangely, very few database systems really have the durability property. When values are deleted or modified there is usually no way to recover the values that were there before. Some commercial systems support a transaction log, but there are no mechanisms to require it to be kept, and in practice such documents are seen as redundant/duplication and deleted as a matter of routine.

As a result, for real durability, database designers need to create special tables (journals, histories etc) when such records are a legal requirement.

In the Pyrrho DBMS the transaction log is precisely the durable record of the database, and so it cannot be deleted without deleting the entire database.[4] The current state of the data (with its indexes etc) is in memory. A similar approach has been reported for in-memory column-oriented DBMS by Wust et al (2012). This architecture brings significant advantages: not only do we have durability of the transaction record, but two other advantages: (a) committing a transaction involves appending the transaction record to the end of the file, and (b) the amount of writing to the disk during operation is reduced (according to benchmark measurements for Pyrrho (Crowe 2005)) by a *factor* of 70.

This large difference in performance arises because in the traditional database architecture it is not only the current state of the data that is held on disk, but also all of the indexes and other data structures, and so any change to the database results in changes to many parts of the disk files. In 2004, when Pyrrho's design was first published, objections from the database community centred on the large amount of memory that would be needed for real commercial databases. In practice databases of 20GB are regarded as reasonable. However, standard DBMS generally use fixed size data fields, while Pyrrho does not, and in 2013, 20GB of memory no longer seems such a large amount.

Pyrrho's approach works best where durability is important, such as customer records, or financial transactions, where data might need to be retrieved years later. There are circumstances where durability may be less important, for example in an enterprise service bus implementation, where the horizon for durability is measured in minutes rather than years. In ESB systems, such messages would normally only be captured for permanent storage as part of a special troubleshooting activity.

[4] This design decision in Pyrrho is discussed further in section 3.7.

2.2 Transparency

Transparency (or accountability) means we should be able to discover why and when data changes: who or what made the change, was it routine or unusual? In this course we will see this is closely tied to the concept of business roles. What becomes important is not just who made the change, but also what role they were playing (e.g. Iyer 2009, Oh and Park 2003): were they carrying out part of their day-to-day role of sales clerk or were they doing something else? Some managers may be authorised to play more than one role, but if they are carrying out a standard procedure it is reasonable for them to say what it is (and not just arbitrary, unaccountable, caprice).

A good database design will build in role-based support for the standard business procedures it supports, but very few do. Most DBMS's simply allow anyone with the power to do something to do it, and don't provide a mechanism to track the roles being played.

In Pyrrho the transaction record includes not only the user identity for a transaction but the role. A user can only use one role at a time for any given database. Roles should capture and restrict to normal business operations. If it becomes necessary for intervention to correct some unusual condition, some administrative role with greater permissions can be used. Auditing will highlight these and they might usefully indicate a need for process improvement (Moorthy et al, 2011).

2.3 Consistency

Consistency means that the data does not contain any contradictions. In good database design a first step in this direction is to minimise copied data: if information is repeated in different places it become hard to ensure consistency when that information changes. Dependent information (e.g. total or count) should be correct when it is accessed. In line with the "no copies" rule, it is actually best if a sum or count is recomputed when required, rather than if an old value is stored somewhere.

As mentioned above, in many DBMS, a single transaction results in many changes to data files, many of which are effectively copies, e.g. a new row in a table would typically have the new primary key value stored in several places, bringing a risk of inconsistency. In the next section we explore the link between transactions and consistency, and examine what this means for constraints.

Another difficult area for consistency is where some data is stored in one database (or one computer) and some elsewhere (in a file, in another database, or on another computer). In such situations it is best if responsibility for ensuring consistency resides somewhere, for example, with (one of?) the DBMS involved, but often there are real difficulties, for example, a transfer from one bank to another. Recent research has revisited this problem, addressing the impact of service oriented architectures (e.g. Lars Frank 2011). We return to this sort of problem below.

2.4 Transactions

The practical way of ensuring consistency is to use transactions. A transaction consists of a set of changes to the database that is logically ATOMIC. That is, although there might be more than one step, the process comprising these steps is indivisible. The classic example is that of a bank transfer. Although there are two steps (taking a sum of money from one account and placing it in another) the process of transfer is logically indivisible. During the process the total amount of money in the bank will be wrong. So while the separate steps are proceeding, nobody else should be able to see any of the changes until the process is complete and the data is consistent. That is, the transaction needs to be ISOLATED until it is either completed (COMMIT) or abandoned (ROLLBACK).

All practical DBMS allow concurrent access so that several clients can be operating on the database at the same time. Not all of them will be making changes to the database, and in any case changes are likely to affect different parts of the database, and so won't affect each other. The theory of database transactions considers each transaction as a sequence of read and write operations each occurring at a particular time. Concurrent transactions are transactions whose operations overlap in time: they are valid as long as they are serialisable, that is, if the reads and writes could have achieved the same

results if all of the operations of the transactions had been moved in time so that the transactions do not overlap. Many DBMS products write changes to disk storage before the transaction commits: in times past this was needed since some transactions might involve too much data to be held in memory. Researchers have examined higher-level disk operations to improve this mechanism, e.g. Ouyang et al (2011). Pyrrho's approach is to assume memory is large enough to avoid doing any writing to non-volatile storage until the transaction commits.

In the database literature transactions are called ACID (atomic, consistent, isolated and durable). All DBMSs provide for transactions, but most allow exceptions to the ACID principles. Allowing exceptions means sacrificing consistency, and in practice many systems then need to introduce notions of compensation activities, to undo changes that may have depended on a transaction that has now been cancelled.[5] For such compensation activities to be automated, they need to be specified in advance for each transaction. In the vast majority of cases, the transaction is not cancelled, and the compensation action is just discarded. It has been estimated that up to 40% of DBMS activity relates to preparation of compensation actions that are never needed, and complex cases have been described that require whole hierarchies of compensation actions.

Dependent systems should not take any consequential action until the database transaction is committed: if this rule is followed there should be no need for compensation. There are several reasons commonly given for not following the rules. One, hinted at above, is that the transaction may involve third parties and the delays involved in using distributed commit protocols seem excessive. This amounts to parties proceeding in the absence of agreement, and must be seen as a risky step. Another reason is that most DBMS using locking for transaction control, and so parts of the database are locked during the distributed transaction protocol, which can be costly. This last point is really quite hard to understand, since robust "optimistic" transaction protocols that minimise locking have been well-documented for decades. Pyrrho uses optimistic concurrency control, and minimises this sort of delay: it also rigorously enforces transaction isolation so that it is impossible to know anything about any ongoing transaction.

The difficulties caused by the bad behaviour of pessimistic (locking) transaction management are far-reaching, and have even led to many businesses deciding that they cannot afford transaction management. Other aspects of RDBMS technology have also been blamed for poor performance, and there are many vendors offering no-SQL databases, or columnar databases. Many commercial DBMS prohibit benchmark testing of their products in their licensing arrangements. Pyrrho positively invites benchmarking (Crowe 2005), and despite its rigour its performance is comparable with commercial products.

2.5 Application programming interfaces: ADO.NET

There are numerous APIs for contacting database servers: the oldest in common use are ODBC and JDBC. Java Persistence had a brief vogue, as did Microsoft's LINQ. The PHP API is like a cut-down version of ADO.NET, and versions of ADO.NET are also used for MySQL and Pyrrho.

We will use some ADO.NET sample code in the lab. The following sequence is typical of standard ADO.NET. The first step uses the database connection string. Every database has its own style of connection string - for lots of examples see www.connectionstrings.com

```
var conn = new XXXConnection("connectionstring");
var cmd = conn.CreateCommand();
cmd.CommandText = "some SQL SELECT string";
```

[5] Compensation mechanisms should be supported by the DBMS if required by business logic. But they should not be introduced merely because the DBMS does not support Web applications or transactions properly. Pyrrho offers row-version checking and other "forensic" methods to explore the dependency of later events on particular transactions, but the use in the literature of phrases such as "automatic compensation" merely indicates poor transaction design or support.

```
var rdr = cmd.ExecuteReader();
while (rdr.Read())
{
…. // access the returned data using rdr[0], rdr[1],..
}
rdr.Close();
conn.Close();
```

This coding pattern is used for SQL strings that do SELECT. You can use cmd.ExecuteNonQuery() for other sorts of SQL commands (update, delete etc).

You can only have one active data reader per connection (you can close one and start another of course). You can have more than one Connection but remember that the DBMS will treat the two connections as completely separate, so that the transaction mechanisms may mean that the two connections see the same or different data.

For this reason, if we need to traverse data from several tables together, we should use SQL joins (this should save a lot of work anyway). We generally keep connections open for as little time as possible, as they can consume resources on the server.

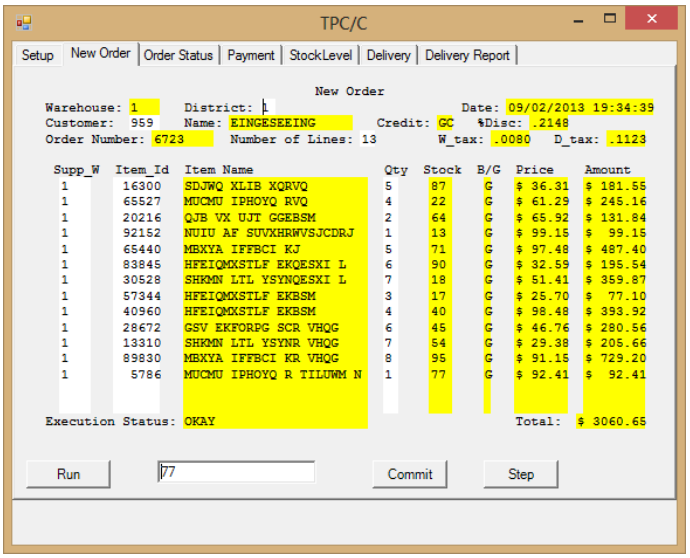
PHP starts the same way:

```
$conn = new COM("connectionObject");
$conn->ConnectionString = connectionString;
$rdr = $conn->Execute(SQLstring);
$row = $rdr->Read();
// Read returns -1 at the end of data, so we continue while $row is not an int:
while(!is_int($row))
{…// $row[0] etc for access to data returned
}
$rdr->Close();
```

2.6 A first benchmark

The C benchmark from the Transaction Processing Council (Raab et al, 2001) is a legendary test of database performance, and models a clerical order-entry OLTP system. In this benchmark (TPCC) each new order transaction involves over 20 round-trips to the database as the information is built up and submitted, and transactional processing is required. On supercomputing clusters transaction rates of 30 million per minute are reported. Thomson et al (2012) report on the different approaches to achieving such high transaction rates: other than using expensive hardware these all sacrifice something important from the above principles.

Results for ACID RDMBS in PCs are more modest, with 1500-2000 per minute being more normal. In the past I have benchmarked Pyrrho at 2000 per minute (on a Dell laptop with Windows 7). On my current 8-core laptop and Windows 8, I get just over 1000 per minute, but the CPU usage is only 14% as the server runs on just one core.



The TPCC benchmark is designed to behave badly with concurrency, since the next-order-number is a bottleneck. Total throughput of the benchmark is lower with 2 terminals because of transaction conflicts, but then increases slowly as more terminals are added. I can use the CPU more by running multiple concurrent terminals (with 5 the CPU usage reaches 57%).

The TPCC application in the open-source distribution has tabs for the various functional tests of Tpcc, but for the purposes of database tuning the two most interesting are Setup and New Order (pictured). The Setup page allows you to decide how many warehouses, and contains buttons for creating the database, its list of products, the districts with their lists of customers, and the warehouses with their stock. The product descriptions and customer names and addresses are all generated according to randomising rules in the TPCC specification: parameters such as tax are also randomised according to the specification. All of this takes around ten minutes on a PC for a single warehouse, and the database is initially 110MB. You can observe the progress of building the database by using a command window: PyrrhoCmd Tpcc, and then at the SQL> prompt, table “Role$Table” shows the number of rows that have been set up in each table. If the server is shut down and restarted, it takes about a minute for the database to be read in from disk, so if you start up the TPCC application you may have to wait this long before the window appears.

The NewOrder page has two useful buttons: Run will run 2000 new orders and this will take one or two minutes. The Step button allows you to see how a single order is built up. Each step models an action of the clerk to select a district, a customer, an item, a quantity, entering them in the white parts of the screen, and shows the responses from the database in the yellow parts of the screen.

It is not wise to use a single benchmark for performance tuning. But since it includes quite large data sets this particular benchmark can be used with a database engine to investigate what happens to network traffic (it is a huge advantage to use fixed size blocks), what is the best size for BTree buckets (this hardly matters), whether minimising disk reads is worthwhile (5%), what enumeration optimisation can be done (3% for a constant-key shortcut), will a specific index class for integer keys work better than a generic one (no), what is the cost of database features such as multiple database connections (1%), whether only using one kind of integer internally would help (no) etc.

2.7 Pyrrho’s internal structure

The database file contains (is) the transaction log, and this gets read in its entirety when the database is loaded following a restart of the database server (cold start). Each database is in a separate file. The database server operates on many database files on behalf of many clients. A single client application can operate many databases at once, by opening connections to one or more databases at a time.

The database file begins with a four-byte “magic cookie” and ends with a five-byte end-of-file marker that contains an encrypted digest of the database file. This marker is a sort of digital signature placed there by the Pyrrho DBMS server, intended to ensure that changes to the database are only made by

legitimate, accountable DBMS operations that form part of the transaction record. There are very few differences between the open-source and professional editions of Pyrrho, but the algorithm for the digest is one of them. If the digest does not match the contents of the database file, Pyrrho refuses to proceed and reports that the database is corrupt.

The first two records after the four-byte marker record the owning role and owning user of the database. All subsequent records in the transaction log record the role and user for the transaction together with a universal-time timestamp. All transaction records are immutable, and can be referred to using their position in the data file, which cannot be changed. The maximum size of the database file is 0x40000000, but big data files are broken into 8GB sections for ease of management.

The data formats used for these transaction records are fully described in the Pyrrho manual: there are about 40 different types of record for specifying domains, columns, tables, procedures, and for setting up and modifying roles and security permissions. Any database object or record can be referred to by its defining position. The name of an object thus becomes metadata and can be changed or made role-dependent, so that the same object can be named differently by different roles.

Most of the records will contain data for the base tables. All of these are binary records that do not depend on the machine data formats for the platform used apart from the basic concept of octet. Character data uses Unicode UTF-8 encoding. Integers are represented in the data file as sequences of octets, corresponding roughly to base-256 arithmetic. The maximum integer allowed has 2048 bits. Numeric data is defined by two such integers, for mantissa and power-of-10 scale. Blobs (binary large objects) are stored in the data file like any other data as an integer (possibly a very large one) followed by the blob data as a list of octets. All dates and times use universal time.

This design brings many benefits as briefly mentioned in the above account: platform and locale independence, the ability to refer to a database object by its defining position. Most importantly this simple transaction log design of the database gives a natural automatic serialisation of transactions.

The data file represents level 1 of the Pyrrho engine. At level 2 (Physical) the design consists of the transaction log records, and the concept of data type is defined at level 2. Transaction isolation is handled in the Pyrrho DBMS engine by using immutable data structures up to level 3 (database) of the design. Up to this level, all fields of data structures are (at least logically) constant, so that for example any change made to a linked list or B-tree results in a new head node. When a transaction is committed, the data is serialised to the data file(s), and the new head nodes for the database(s) affected will be installed in the list of databases connected to the server.

Each ongoing transaction (level 4) uses a separate space of proposed database objects, so that the objects being defined within them have temporary “positions” above 0x40000000 and these numbers are only unique within that ongoing transaction. At the start of transaction copies are made of the head node of each database in the transaction: effectively this takes a snapshot of the database at the start of the transaction, and the transaction proceeds on the basis of this starting database state.

Committing a transaction requires serialising the transaction to the data file/transaction log, and the defining positions of objects are not known until this is done. During serialisation these are relocated to their actual positions in the data file/transaction log.

The actual process of committing a transaction takes place in 3 stages. In stage 1, the connected datafiles are checked for records that conflict with the current transaction. If conflicts are found, the transaction rolls back. In stage 2, the databases are locked, and this check is repeated for even more recent records, and if all is well, the transaction is serialised to the data file. Finally (stage 3), the data just serialised is installed in the (level 3) data structures, and the locks are released.

Transactions that merely read data cannot conflict with any other transaction: it is as if the entire transaction takes place at the begin time. For transactions that make changes to the database,

everything read by the transaction must still be valid at the time the transaction is committed, so it is as if all of the steps of the transaction take place at the commit time.

From this account we see that even with optimistic concurrency, there is always a short time when locks are applied, but locking only occurs at the point of committing the transaction. All of the transaction processing including constraint checking, triggers etc takes place beforehand and all of the data required to commit the transaction has been assembled and is ready for serialisation.

Finally, all of the above discussion needs to be understood in connection with Pyrrho's multi-threading model. Pyrrho DBMS uses multithreading at the level of connections (level 4): each connection runs in a different thread. The transaction mechanism described in the last chapter applies within the connection's thread, collecting the database from the server's (level 3) base thread at the start of each transaction, and synchronising with it when the transaction commits.

In the next chapter we will consider the effects of this approach to transactions and compare with the practice in other DBMS.

The disadvantage of the design is that a cold restart of the database server requires re-reading the entire transaction log: some countervailing measures are (1) using a multi-database design since Pyrrho supports multi-database connections, (2) the technique of partition sequencing discussed in chapter 10.

Key features of Pyrrho's design

In Chapter 9 we will consider an approach to distributed databases where a server can play any or all of three roles in relation to a particular database: storage, transaction serialisation, and query processing. Storage is basically the transaction log or a copy (the physical database or PhysBase), transaction serialisation is when a set of proposed changes are appended to the master copy of the transaction log, and for query processing, the server needs to have the indexes and database objects (implemented in the logical Database class).

During a transaction, the database connection is to a set of LocalTransactions (or proxies) that are based on Database snapshots. Each has access to the physical layer for fetching data from base tables, using a subclass of the PhysBase (for example, the VirtBase class) that also contains the new information that will be added if the transaction commits.

The above considerations lead to the following feature set for Pyrrho.

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. There is a 5-byte end-of-file marker[6] which is overwritten by each new transaction, but otherwise the 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). Needless to say, the current structure of the database object, or the current values of a record, may well depend on subsequent data, which should be examined for relevant alterations and updates (or even drops and deletes). Pyrrho threads together the physical records that refer to the same defining position to facilitate backward searching in the database file and forward searching in the corresponding memory structures.

[6] The end-of-file marker includes a kind of digital signature to guard against tampering with the database contents.

3. Data structures in the higher levels of the database are frequently built from immutable elements. 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 plans 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. Thus the defining positions of any new data will be different from those created in memory for the local transaction: the entire local transaction structure is therefore forgotten even in the case of a successful commit. Instead, the database is updated by reading the new records back from the disk (or disk cache). 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.
5. These approaches to the design have some strange effects. For example, any data structures that are not transaction-specific must avoid maintaining pointers to the logical level structures such as Table, TableColumn, since these may no longer be current for the next transaction. The current versions must be obtained afresh from the Database data structure, either by name or by defining position as appropriate.
6. Because of transaction separation, checking for transaction conflicts cannot be done at the level of the logical database (Level 3). It is done at the physical level (Level 2), with the help of a set of rules for what constitutes a conflict. Data relating to read constraints needs to be passed down to level 2 in a special data structure since these do not correspond to proposed changes to the database.
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 database in SQL2011 source form and reparsed when required. This has the advantage that changes consequential on renaming of objects can be supported at the logical database level, where the edits can be applied to the source forms in memory.
8. The database implementation uses B-Trees throughout (note: B-Trees are *not* binary trees). Lazy traversal of B-Tree structures (enumeration) 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. Database values are strongly typed (TypedValues), but during query processing the server works with SqlValues, which are expressions obtained from the query language. An SqlValue can be evaluated in a Context, to get a TypedValue. Thus a Query is a context whose RowSet is a row of SqlValues (an SqlRow) with a RowEnumerator which modifies the values of the row columns as it moves. This matches well with the top-down approach to parsing and query processing that is used throughout Level 4 of the code.

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) selects analysis to match up references in value expressions with the correct columns in the sources, (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 in many cases can choose the best enumeration method to meet all the above requirements.
11. As a practical matter it is convenient to allow multi-database connections. For example this facilities analysis or modelling of a database using temporary tables, without adding such temporary tables to the business database. However, if a transaction in such a connection causes changes to more than one database, this causes a permanent linkage recorded in both databases: and all linked databases must always continue to be available to any server that is using any of them. While such multi-database transactions are supported, they should be avoided if possible.
12. Despite all of these rich possibilities, it remains the case that almost all servers, databases, transactions and queries will be performed locally with small amounts of data. Most databases will also be small enough to fit comfortably into the 4GB or so RAM available today on PCs, and 1TB RAM is now available on blade servers. Nevertheless, Pyrrho's configuration files allow database tables and their indexes to be partitioned among a set of servers, so that joins and data selected from them can be constructed on other servers. We return to these ideas in chapters 9 and 10.

Chapter 3: Database Design

The physical layer of a relational database consists of a set of named base tables, whose columns contain values drawn from prescribed sets of values (domains). Standard domains include integers, fixed- and floating point numbers, strings of various kinds, dates, times etc. At the layer above this the data in some of these base tables are seen as specifying entities and relations: so that the rows of base tables are seen to give details of unique individual objects identified by primary keys (first normal form), and with relationships to other entities defined in other tables.

At the level above this we have the business model where these entities and their relationships serve a business purpose.

As mentioned in the introduction, the rules of Normal Form are intended to make it easier to maintain the consistency of data in the database as modifications are made to it. For example, if the same information is contained in several rows of a table, it becomes difficult to change any of these rows consistently, and if we are allowed to update some of the repeated data without updating it all at once, there is an obvious danger that some data will be left unchanged (update anomaly). Second and third normal forms ensure at least that such repeated information is no more than coincidence.

If a row of a table aims to provide too much information, it can happen that at the point of inserting a new entry we are unable to provide information in all of the cells (insertion anomaly). And if some information is removed from the database, but is referred to elsewhere, we have a deletion anomaly. Foreign key relationships can help avoid deletion anomalies.

However, it is not really the job of the database engine to be prescriptive about such matters, merely to provide the tools that the database designers want. There are certain expectations about the standard data types that are supported and their interpretation in various cultures: dates can be represented in different timezones, international character sets and collation sequences should be used, national standards for dates, currencies etc. It should be possible for a column to contain values of a user-defined type (e.g. with subfields) or an array. We will return to some of these aspects in later sections.

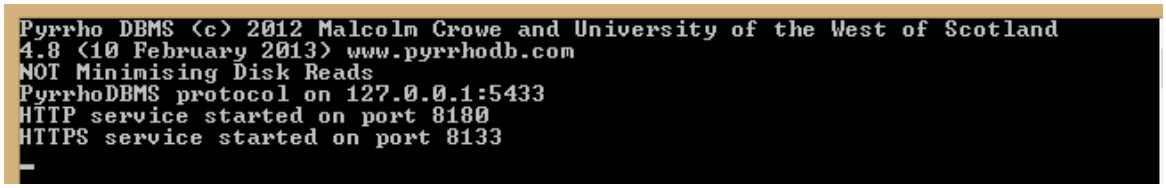
3.1 Constraints

It should be possible to apply a domain constraint, e.g. to specify that a number should be in a certain range, or have a default value. It should be possible in addition to specify a constraint for a column, or an automatic rule to generate the value of a column based on other attributes. Several popular ways of getting the database to generate a primary key for a new row are available. It should be possible to specify a constraint for a table, for example that all values of a particular column are found in the table.

The SQL standard imposes many restrictions on the expressions used to define such constraints, and these are enforced to a greater or lesser degree by different databases. Pyrrho allows any search condition to be used as a column or table constraint, and allows such constraints to be modified later. However, it prevents adding a constraint that is not currently satisfied by data in the table, and does not allow any operation (not even a step in a transaction) that violates any constraint.

Example 1 database

The PyrhoSvr should already be running.



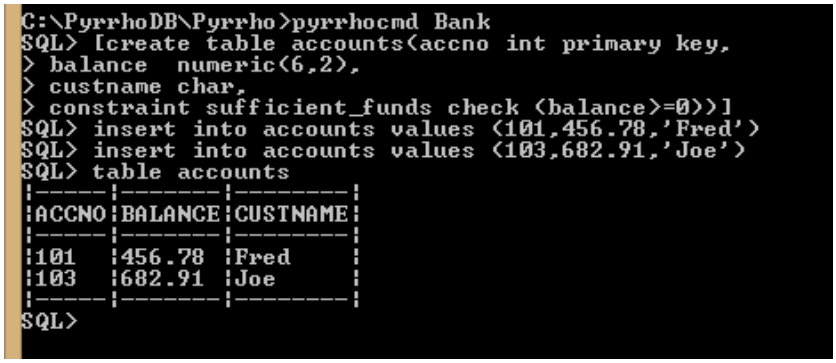
Start up a command window using the command

PyrrhoCmd Bank

Paste the following text into the PyrrhoCmd window at the SQL> prompt (on Windows, right-click the title bar and select Edit>Paste):

```
[create table accounts(accno int primary key,
balance  numeric(6,2),
custname char,
constraint sufficient_funds check (balance>=0))]
insert into accounts values (101,456.78,'Fred')
insert into accounts values (103,682.91,'Joe')
table accounts
```

The output should look similar to the following:



3.2 Pyrrho's logs and system tables

Examine the log.[7] Apart from the DOS window wraparound, it looks like this:

```
SQL> table "Log$"
```

Pos	Desc	Type	Affects	Transaction
4	PRole Bank	PRole	0	-1
32	PUser MALCOLM-NB\Malcolm	PUser	32	-1
55	PTransaction for 9 Role=4 User=32 Time=10/02/2013 16:27:15	PTransaction	0	0
71	PTable ACCOUNTS	PTable	71	55
84	PDomain INTEGER: INTEGER	PDomain	84	55
106	PDomain NUMERIC%6_2: NUMERIC,P=6,S=2	PDomain	106	55
134	PDomain CHAR: CHAR	PDomain	134	55
152	PColumn ACCNO for 71(0)[84]	PColumn3	152	55
174	PIndex U(56) on 71(152) PrimaryKey	PIndex	174	55
195	PColumn BALANCE for 71(1)[106]	PColumn3	195	55
220	PColumn CUSTNAME for 71(2)[134]	PColumn3	220	55
247	Check SUFFICIENT_FUNDS [71]: (balance>=0)	PCheck	71	55
284	PTransaction for 1 Role=4 User=32 Time=10/02/2013 16:27:15	PTransaction	0	0
300	Record for 71 ([152] 101:INTEGER)([195] 456.78:NUMERIC,P=6,S=2)([220] Fred:CHAR)	Record	300	284
334	PTransaction for 1 Role=4 User=32 Time=10/02/2013 16:27:15	PTransaction	0	0
350	Record for 71 ([152] 103:INTEGER)([195] 682.91:NUMERIC,P=6,S=2)([220] Joe:CHAR)	Record	350	334

```
SQL>
```

Pyrrho identifies everything in the database by its defining position Pos. When the database is first created a default "Schema" role and the owner are recorded (here at Pos 4 and 32). These are the only records that do not have transaction information. Then we see 3 transactions corresponding to the three SQL commands issued so far. Each transaction records the use, the role and the timestamp.

The last two transactions are the Insert statements (of type Record). The first transaction defines the accounts table and you can see the steps involved in setting up the three domains and the three columns.

The "Log$" table is one of a great many system tables, that allow the SQL engine to examine the database history. There are tables whose names begin with Log$ that are a historical record, while the system tables, beginning with Sys$ or Role$ show the current database objects.

[7] The idea that all internals of the database engine should be exposed in relational tables is a consequence of Codd's (1985) principles. Since Pyrrho's transaction logs are durable, all their details are exposed in system tables. See Appendix 8.

A particularly useful one is Role$Table:

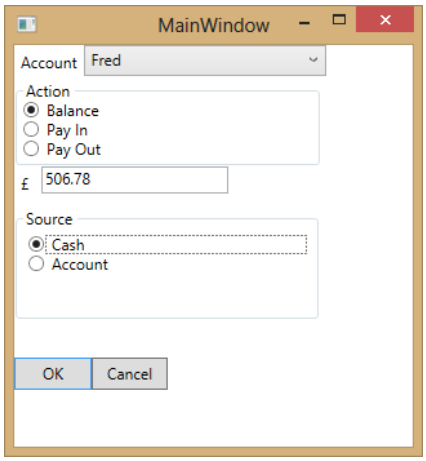
```
SQL> table "Role$Table"
|---|--------|-------|----|--------|----------------|----------|------|-----|
|Pos|Name    |Columns|Rows|Triggers|CheckConstraints|References|RowIri|Owner|
|---|--------|-------|----|--------|----------------|----------|------|-----|
|71 |ACCOUNTS|3      |2   |0       |1               |0         |      |Bank |
|---|--------|-------|----|--------|----------------|----------|------|-----|
SQL>
```

This records the current name of table 71 as ACCOUNTS, and shows it currently has 2 rows.

Note that the script we used for creating the table was all in lower case. The SQL standard says that unquoted identifiers are not case-sensitive. If you want case-sensitivity or special characters you need to double-quote the identifier, as we did with “Log$”.

There are some notes on this aspect of the design of Pyrrho DBMS at the end of this chapter.

Example 2 C# application



Let us write a simple application that uses this database. This one uses Windows Forms for simplicity. To create it from scratch, start up Visual Studio and select New Project>Visual C#>Windows>WPF Application. Add a Reference to PyrrhoLink.dll.

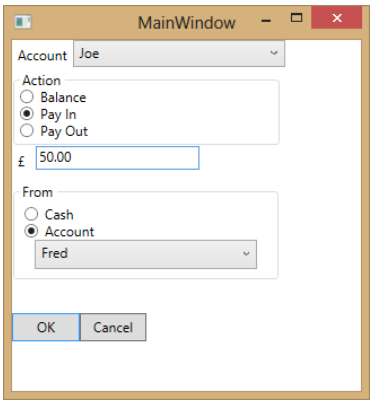
Add user interface elements as shown (I used a StackPanel instead of a Grid for the main window and used horizontal and vertical StackPanels for the detail of the groups). You can see my solution in the resources for this text.

The beginning of the code for the application shows how it works. Note the declaration of the PyrrhoConnection and the code for creating and opening the connection (highlighted in yellow).

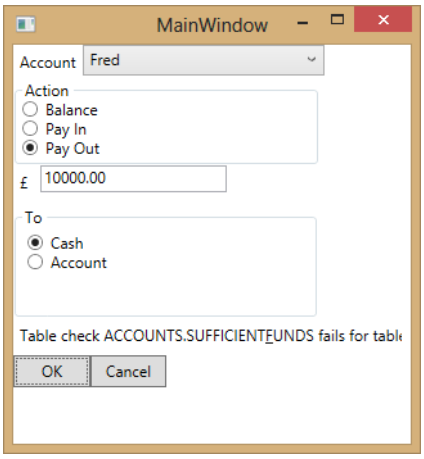
When we need data from the database, we use ADO.NET incantations, one example is highlighted in green. The transaction to do the funds transfer is highlighted in grey, and notice how it is surrounded with an exception handler.

```
using Pyrrho;

namespace WpfApplication2
{
    /// <summary>
    /// Interaction logic for MainWindow.xaml
    /// </summary>
    public partial class MainWindow : Window
    {
        PyrrhoConnect db = null;
        public MainWindow()
        {
            InitializeComponent();
            db = new PyrrhoConnect("Files=Bank");
            db.Open();
            Account2.Visibility = Visibility.Hidden;
        }
        class AcInfo
        {
            public int id;
            public string name;
            public AcInfo(int i, string n) { id = i; name = n; }
            public override string ToString()
            {
                return name;
            }
        }
        AcInfo selected = null,other = null;
        private void Account1_DropDownOpened(object sender, EventArgs e)
        {
            var cmd = db.CreateCommand();
```

```
            cmd.CommandText = "select accno, custname from accounts";
            Account1.Items.Clear();
            var rdr = cmd.ExecuteReader();
            while (rdr.Read())
                Account1.Items.Add(new AcInfo(rdr.GetInt32(0), rdr.GetString(1)));
            rdr.Close();
        }

        private void Account1_SelectionChanged(object sender, SelectionChangedEventArgs e)
        {
            selected = Account1.SelectedItem as AcInfo;
            if (selected != null)
            {
                var cmd = db.CreateCommand();
                cmd.CommandText = "select balance from accounts where accno=" + selected.id;
                var rdr = cmd.ExecuteReader();
                if (rdr.Read())
                    Amount.Text = "" + rdr[0];
                rdr.Close();
            }
            else
                Amount.Text = "0.00";
            CancelButton.IsEnabled = true;

        }
        private void Account2_DropDownOpened(object sender, EventArgs e)
        {
            if (selected != null)
            {
                var cmd = db.CreateCommand();
                cmd.CommandText = "select accno, custname from accounts";
                Account2.Items.Clear();
                var rdr = cmd.ExecuteReader();
                while (rdr.Read())
                    if (rdr.GetInt32(0)!=selected.id)
                        Account2.Items.Add(new AcInfo(rdr.GetInt32(0), rdr.GetString(1)));
                rdr.Close();
            }
        }

        private void OKButton_Click(object sender, RoutedEventArgs e)
        {
            AcInfo sub = ((bool)PayOut.IsChecked) ? selected : ((bool)PayIn.IsChecked) ? other : null;
            AcInfo add = ((bool)PayIn.IsChecked) ? selected : ((bool)PayOut.IsChecked) ? other : null;
            try
            {
                var tr = db.BeginTransaction();
                var cmd = db.CreateCommand();
                if (sub != null)
                {
                    cmd.CommandText = "update accounts set balance = balance-" + Amount.Text + " where
accno=" + sub.id;
                    cmd.ExecuteNonQuery();
                }
                if (add != null)
                {
```



```
                    cmd.CommandText = "update accounts set balance = balance+" + Amount.Text + " where
accno=" + add.id;
                    cmd.ExecuteNonQuery();
                }
                tr.Commit();
                Balance.IsChecked = true;
                Cash.IsChecked = true;
                Account2.SelectedIndex = -1;
                Account1_SelectionChanged(sender, null);
            }
            catch (Exception ex)
            {
                Status.Content = ex.Message;
            }
        }
```



For reasons of space the UI code is omitted here.

Examination of the code above is for most purposes a sufficient introduction to the ADO.NET API. The only aspect that is not obvious is that you can only have one DataReader open per connection: this is an ADO.NET restriction. If you have a single connection, and you open a DataReader with rdr=cmd.ExecuteReader(), then you must call rdr.Close() before you open another reader. (You can have several connections open but in that case you are not guaranteed that they will see exactly the same data as they have started at different times.)

3.4 The Java Library

The Pyrrho Java Connector OSPJC and the org.pyrrhodb.* package have been significantly modified as of April 2015. In earlier versions of Pyrrho there was an attempt to allow client applications to define the data model unilaterally using Java annotations, in the manner specified for javax.org. From around version 4.5 this has really been untenable, and annotations that differ from the database's implied data model will in future be reported as errors.

The library is contained in OSPJC\bin in the Open Source Distribution of Pyrrho. It is best to copy this folder to where your Java project is and compile and execute with

```
javac -cp . xxxx.java
```

```
java -cp . xxxx
```

Some features of JDBC 4.1 are completely incompatible with the architecture of PyrrhoDB (and the SQL2011 standard) and thus are unlikely to be incorporated at any stage. These include the DriverManager class, the SQLPermission class, PreparedStaments and their parameters, DataSources and Savepoints. The assumption is that clients open a Connection to a database, and use Statements and ResultSets to manipulate the database.

On the other hand, the intention is that entities specified as such in the database metadata should be retrievable using strongly-typed (generic) client-side methods with the help of reflection. Specifically, single-entity short cuts from Connection will lead to generic versions of first() and next() that automatically populate the public fields of specified entity classes.

```
import org.pyrrhodb.Connection;
import java.sql.Statement;
import java.sql.ResultSet;

public class JCTest
{
  static Connection conn;
  public static void main(String args[]) throws Exception
  {
      conn = Connection.getConnection ("localhost","def","guest","def");
```

```
      CreateTable();
      ShowTable();
  }

  static void CreateTable() throws Exception
  {
       try {
           conn.act("drop table a");
       } catch (Exception e) {}
        conn.act("create table a(b int,c char)");
        conn.act("insert into a values(1,'One'),(2,'Two')");
  }
  static void ShowTable()
  {
     try {
       Statement stmt = conn.createStatement();
       ResultSet rs = stmt.executeQuery("select * from a");
       for (boolean b = rs.first();b;b=rs.next())
       {
            System.out.println(""+rs.getInt("B")+"; "+rs.getString("C"));
        }
    }
    catch(Exception e)
    {
        System.out.println(e.getMessage());
    }
  }
}
```

3.5 SWI-Prolog

The Open Source Edition of Pyrrho also comes with some support for SWI-Prolog. This is contained in a module pyrrho.pl which is part of the distribution. The code is at an early stage, so comments are welcome. The following documentation uses the conventions of the SWI-Prolog project.

The interface with SWI-Prolog is implemented by providing SWI-Prolog support for the Pyrrho protocol (see technical details in the Pyrrho manual). The following publicly-visible functions are currently supported:

connect(*-Conn*, *+ConnectionString*)	Establish a connection to the Open Source Pyrrho server. Conn has the form **conn**(*InStream*,*InBuffer*,*OutStream*,*OutBuffer*). Codes in OutBuffer are held in reverse order.
sql_reader(*+Conn0*, *-Conn1*, *+SQLString*, *-Columns*)	Like ExecuteReader on the connection. Conn0. Conn1 is the updated connection. Columns is a list of entries of form **column**(*Name*,*Type*) .
read_row(*+Conn0,-Conn1,+Columns, -Row)*	Reads the next row (fails if there is no next row) from the connection Conn0. Conn1 is the updated connection. Columns is the column list as returned from sql_reader. Row is a list of corresponding values for the current row.
close_reader(*+Conn*)	Closes the reader on connection Conn.
field(*+Columns*,*+Row*,*+Name*,*-Value*)	Extracts a named value from a row. The atom null is used for null values.

3.6 LINQ

Language-Integrated Query was an innovation in C# 3.0. Linq allows queries of the sort

```
var query1 = from t in things where t.Cost > 300 select new {
t.Owner.Name, t.Cost };
```

to be written directly in C#.

The Pyrrho support for Linq is therefore inspired by the idea of supporting queries to simple small databases, and avoiding declarations and annotations wherever possible. The client-side objects can be modified using the methods in sec A9.6 but queries should always be to a new connection. The Linq support is only for single-component primary keys (they can be any scalar type and do not have be called “Id”).

The following complete program works with a database called home, which contains two tables with the following structure:

create table "Person" ("Id" int primary key, "Name" char, "City" char,"Age" int)

create table "Thing" ("Id" int primary key,"Owner" int references “Person”, "Cost" int, "Descr" char)

Then the Role$Class system table (see Appendix 8) provides text for the two class definitions as below.The PyrrhoConnect connects to the database as usual, and the database is opened. Two PyrrhoTable<> declarations form a link between client side data and data in the home database. Then the LINQ machinery is available. (For the program to produce output, there needs to be some data in the tables.)

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using Pyrrho;

namespace ConsoleApplication1
{
        /// <summary>
        /// Class Person from Database home, Role home
        /// </summary>
        public class Person {
          public System.Int64 Id;  // primary key
          public System.String Name;
          public System.String City;
          public System.Int64 Age;
        }

        /// <summary>
        /// Class Thing from Database home, Role home
        /// </summary>
        public class Thing {
          public System.Int64 Id;  // primary key
          public Person Owner;
          public System.Int64 Cost;
          public System.String Descr;
        }
    class Program
    {
        static void Main(string[] args)
        {
            //  Data source.
            PyrrhoConnect db = new PyrrhoConnect("Files=home");
            db.Open();
            // constructs an index for looking up t.Owner as a side effect
            var people = new PyrrhoTable<Person>(db);
            var things = new PyrrhoTable<Thing>(db);
            //  Query creation.
```

```
            var query1 = from t in things where t.Cost > 300 select new { t.Owner.Name, t.Cost
};

            //  Query execution.
            foreach (var t in query1)
                Console.WriteLine(t.ToString());

            var query2 = from p in people
                         select new { p.Name, Things=from t in things
                         where t.Owner.Id == p.Id select t};

            foreach (var t in query2)
            {
                Console.WriteLine(t.Name + ":");
                foreach (var u in t.Things)
                    Console.WriteLine("  " + u.Descr);
            }
             db.Close();
        }
    }
}
```

3.7 Documents

Databases outlast hardware and software platforms. Many “legacy” database systems still are in use today after 50 years. Databases need to be designed for interoperability, so that the data formats will still make sense years from now. In laboratories we have been looking at how databases can be accessed from a variety of languages and systems. In the labs, we have been using Windows systems, but as many of you will know, the computing industry has been very careful to ensure that systems can work together over the Internet.

TCP/IP is a good start and helps overcome many difficulties by enabling clients and servers to communicate. Java and PHP are available on all platforms, and even C# is available on Linux if the Mono runtimes are installed.

In particular, we have looked at how the very different worlds of .NET and PHP can communicate.
There are many examples today of non-relational and “NoSQL” database systems. All of these for various reasons depart from the standard SQL and relational database design. Some of these issues were discussed earlier in this course.

The point of view strongly expressed in this book is that relational DBMS offer a valuable general-purpose data management infrastructure, and that their most valuable benefits are the ACID properties, especially consistency and durability.

One of the more interesting NoSQL databases today is MongoDB. MongoDB provides schema-less data management for JSON-like “documents” identified by a special _id key, and there are some notes in the following based on the documentation available on https://www.mongodb.com/ .

To select a document from a MongoDB collection, a query consists of a Json object with a set of key-value pairs: the result set is the set of documents in the collection that match these properties. The properties are not limited to equality conditions. This is a very powerful and attractive way of selecting data from large distributed collections, and much to be preferred over standard SQL in many cases.

Mongo does not use SQL, does not support transactions (it does claim strict consistency) and does not have mechanisms for creating joins. I have begun to develop a MongoDB service offered by the Pyrrho server that when complete will offer full ACID guarantees on top of the full Mongo service. It will do this by running on the Pyrrho database engine, enhanced as necessary.

The enhancements turn out to be very exciting as extensions to SQL. SQL already allows columns in relational tables to contain structured types and XML data. It is exciting to allow integrity and

referential constraints to apply to fields within such structured objects. For example, in any document collection the _id key is the primary key: it is a field within the JSON object.

With Codd's principles in mind, Pyrrho allows extensions to SQL to support embedded JSON, so that anything that can be done using the Mongo service can also be done using the resulting extended SQL, including the construction of document sets.

First steps in Pyrrho

Pyrrho provides a MongoDB service, but the PyrrhoCmd client does not have the verbs such as find(), remove() etc. For simplicity we will allow PyrrhoCmd to be used by extending SQL a bit.

Let's allow SQL syntax that supports documents, beginning with DOCUMENT as a standard type:

create table people(doc document)

We won't specify primary key (doc._id) as this is the default. Taking the example from page 7:

insert into people values ({NAME: "sue", AGE: 26, STATUS: "A", GROUPS: ["news", "sports"]})

That is, we allow Json literals in value lists. Any document can be added to this people table. (Alas, Mongo is case sensitive so we need capitals here or else we need double quotes below). For the query example that follows on page 7, let's allow almost standard SQL

select doc from people where doc.age>18 order by doc.age

where we allow the standard dot notation in SQL to take us into the fields of documents. We will of course support MongoDB's large collection of special operators and constructs. With these we can rewrite the above query in an alternative form:

select * from people where doc={age: {$gt: 18}} order by doc.age

From this we can begin to see how complex search conditions can be pushed down to remote partitions. We can even allow MongoDB's explicit pipelines:

```
select {aggregate: people, pipeline: [{ $match: {age: {$gt: 18} },
                                        {$group: {_id: $age, count: {$sum: 1}}},
                                        {$sort: { age: 1 }}] } from static
```

In such expressions Mongo uses $ in value expressions to refer to other fields, e.g. { a: $x } would set field a to the value of field x. We also see here that we can get select expressions to construct new documents for us. In simple cases the resulting documents look like the one in the select statement, but with all these special operators in this case the resulting document looks like the following:

{ _id:…, v:1, ok: true, result: [{ age: 19, count: 4 },{age: 20, count: 3 },{age:24:, count:1}]}

Updates are actually quite complex in MongoDB, and the use of special operators is inescapable. For example the $set operator is used to add fields to a document. In Pyrrho we can allow

update people set doc = {$set: { friend: "Fred" }} where doc.name='sue'

Use these forms to explore the mappings given in the Mongo-DB documentation.

3.8 Pyrrho DBMS low level design

In this section we discuss some of the fundamental data structures used in the DBMS. The data structures in this section have been chosen because they are sufficiently complex or unusual to require such discussion. Obviously this section can be skipped at a first or even later reading.

B-Trees

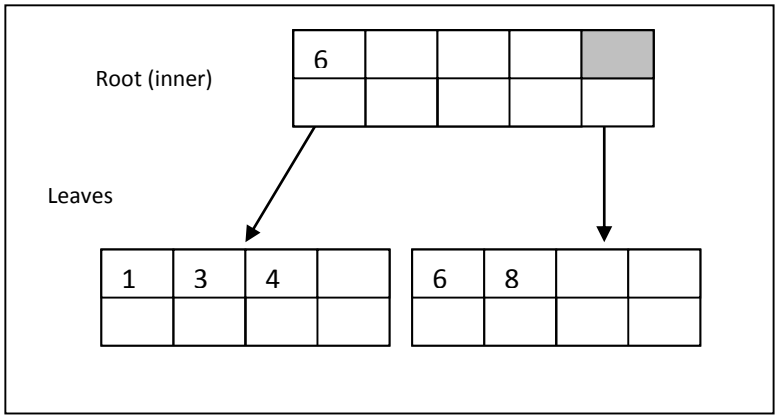
Almost all indexing and cataloguing tasks in the database are done by BTrees. These are basically sorted lists of pairs (key,value), where key is comparable. In addition, sets and partial orderings use a degenerate sort of catalogue in which the values are not used (and are all the single value **true**).

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 a type parameter, 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 value type. If the key is a class type, CTree is used instead. In both cases the Key type must implement IComparable.

The B-Tree is a standard, 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 pairs (called Slots in the code). An Inner Bucket contains Slots 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 Slots are kept in order of their key values, and the Slots 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 32: 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.

The BTree dynamically reorganizes its structure so that (apart from the root) all Buckets have at least N/2 Slots, 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.

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. Static methods are used for most operations because in almost all cases a new header structure is created if anything is modified (according to principle 2.2.3). So, for example to add a new entry to a list of tables, we have code such as

CTree<.string,DBObject>.Add(ref tables, name, tb);

The basic format here is ATree<K,V>.Add(ref Tree, Key, Value) . For a multilevel index, Key can be a Link (this is implemented in MTree and RTree, see section 3.2).

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
SlotEnumerator<K,V> GetRowEnumerator(..)	Enumerates the pairs in the B-tree

static Add(ref T, Key, Value)	For the given tree T, add entry Key,Value .
static Update(ref T, Key, Value)	For the given tree T, update entry Key to be Value
static Remove(ref T, Key)	For the given tree T, remove the association for Key.

Note that even where words like Update are used, any Tree is immutable: in particular the Update operation returns a new Tree sharing many of its immutable elements with the old one.

Immutable trees of this sort are shareable. Pyrrho has two mutable B-Tree types: these are Multiset and RTree. These are not shareable.

For multivalued tree types (see below) an additional parameter can be supplied to the last two methods, e.g.

Static ATree<K,V>.Update(ref T,Key,OldValue,Value)

This replaces the association (Key,OldValue) with (Key,Value) (there may be other values for the given Key).

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
SqlDataType kType	Defines the type of a compound key.
SqlDataType vType	The type of values indexed using the tree.
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.
int depth	A shortcut for spec.Length

SlotEnumerator<K,V>

Enumerating the entries of a tree is done using the SlotEnumerator class. Like any .NET IEnumerator implementation, this has the following basic operations:

Name	Description
bool MoveNext()	move to the next entry if any: return false if there is no next entry
object Current	this has the form Slot(CurrentKey,CurrentValue) here (but see below)
void Reset()	start the enumeration again

There are currently around 100 different SlotEnumerator implementations in the DBMS, including 26 special enumerators for system tables, and 32 for log tables, and 12 for joins of various sorts.

The ATree method GetRowEnumerator returns a SlotEnumerator that traverses the pairs of the tree in key order. There are two versions of this method, one of which supplies a Key for matching. This will enumerator all pairs where the key matches the given one. Now for a strongly-ordered tree (no key duplicates) the resulting enumeration will have 1 or zero entries (a TrivalEnumerator or an EmptyEnumerator) *provided the key supplied will be a constant*.

This is a very subtle and important point: we will see later that we can have expressions whose values changes as an enumerator advances. These are obviously not constant, and so if the Key value supplied to GetRowEnumerator was such a value, while it would still be true that in each case there is either one or zero matching pairs in the tree, we need to reset and re-enumerate the tree to find out which.

On the other hand, it is such an important optimisation to be able to replace an enumerator with a trivial or empty enumerator that it seems worth adding some machinery to the database engine to keep track of which expressions are constant. This is done using the extension method IsConstant, (the static class defining this is called Varies, in the Common.cs source file).

Note that even long values might not be constant: a long value might be a record number or defining address, which will advance during an enumeration.

ATree<K,V> Subclasses

The ATree class provides the basic tree implementation that is used by all the tree types in the DBMS. It also provides a standard mechanism for enumerating the Keys and Values of a tree, which allows the use of C#'s foreach statement for Slots, Keys and Values. 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 ATree<K,V> and Bucket<K,V> classes and their immediate subclasses.

There are just 5 ATree implementations:

Name	BaseClass	Description
BTree<K,V>	ATree<K,V>	The main implementation of B-Trees, for a one-level key that is IComparable
CTree<K,V>	ATree<K,V>	A similar class where the key is a TypedValue
SqlTree	CTree<TypedValue, TypedValue>	For one-level indexes where the keys and values have readonly strong types
MTree	CTree<TRow,long?>	For multilevel indexes where the value type is Nullable<long>
RTree	CTree<TRow,TRow>	For multilevel indexes where the value type is a TRow: Multisets are used for the final level in an RTree, and so the RTree is not shareable.

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 $2^{2039}-1$.

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.

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 2^{103}-1 .

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.

Documents

From v.5.1 Pyrrho includes an implementation of Documents as in MongoDB. Assignment of documents follows the MongoDB prescriptions, where $-operators determine how new data is combined into the existing document. The same mechanism is implemented for Update records in the database, so Document fields in Update records normally contain these operators, and Pyrrho computes and caches the updated document when the Update is installed in the database.

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.

Document matching recurses down to matching of fields, and then may involve comparisons of (say) 4 with {'$gt':3} , so care is taken in the coding that this is implemented as a comparison of {'$gt':3} with 4 rather than the other way around, so that Document comparison occurs.

Documents are always retained in memory as in MongoDB, and during updates the modifying Document is stored in the database, while the modified document is only in memory. The PhysBase keeps track of the documents by indexes for (colpos,recpos)->Document and (ObjectId)->Document.

Documents in memory contain no reserved $ keys apart from $id. A document containing $id is a DBRef, and when this is referenced the second index above is used to retrieve the referenced document.

SqlDataType

Strong types are used internally for all transaction-level processing. The main mechanism for this is the SqlDataType. It provides methods of input and output of data, parsing, coercing, checking assignability etc.

Domain constraints are applied at Level 2, i.e. at the point where a a Record or Update is being prepared for serialisation to the physical database, but they can use level 3 information (e.g. lookup tables implemented using table references). Such dependencies are tracked using the referers list, so that updates to the referenced tables may be restricted: for example where a column uses a domain, a table uses a column, a type uses a record structure (defined by a table). Changes to domain types therefore cascade through the in-memory data structures at level 2 when a schema change is read from the physical media or prepared for serialisation.

This means that the Level 2 PhysBase has a default standardTypes structure that contains the names standard types with domaindefpos marked as undefined. Obviously, this ATree structure gets updated as standard types are reified in the PhysBase.

The SqlDataType structure also controls the fields (columns) of a structured type, the supertypes (under) a data type has, and the order function that is used. It is possible to get hold of a SqlDataType for a record by using the DataTypeTracker information in the PhysBase. This enables types with custom orderings to be used for primary keys, since the indexes are constructed during database loading. However, the actual names of columns and types are not considered part of the SqlDataType (they are role-dependent, so are generated at the session level). For this reason, types with the same name are not necessarily compatible, and error messages try to give numeric references in addition to the names.

Because of custom orderings and role-based naming, at this level it is also possible to start parsing (e.g. a procedure body), using the owner role for the functions and structures concerned.

Changes installed at level 3 of the database affect the SqlDataTypes. The DataTypeTracker currently can be used to find the data type at a previous version of the database, as this is needed for reading any data in the data file.

All SqlDataTypes used for persistent data are located in the PhysBase. They should not be stored anywhere else. However, (a) during a transaction, each intermediate result has an SqlDataType (b) each database knows what standard data types are persisted in that database. For rapid type identification, SqlDataTypes can be looked up in two indexes: one for all types in use in the transaction (ToString()->bool), and one for persisted types for each PhysBase known to the server: each PhysBase has types (ToString()->defpos). (c) each role has an index of named domains defined in that role namedDomains (name->defpos). Note that the CompareTo function for SqlDataTypes is based on ToString() which does not include either pbname or defpos: thus SqlDataTypes can be considered equal for assignment etc but may need to be reified for a particular database if the value is made persistent.

The following well-known standard types are defined by the SqlDataType 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

Chapter 4: Database Servers

In this chapter, we look at the architecture of a database service from the viewpoint of the communication between client and server. We will consider some alternative architectures along the way.

4.1 Servers and services

The usual model of computing is that a great many processes (programs) are running on any computer at any time. Under Windows or Linux around 50 processes have started up by the time you log in. These are almost all services, some are part of the operating system and some are separate executables called servers (in Windows the boundary is often blurred since DLLs are called operating system extensions!).

Separate services are set up when something needs to be shared between processes (between users on a multi-user system, or between tasks where several are running at the same time). What is shared might be

- a resource, such as a printer
- a data file
- a communication gateway so that messages to or from different tasks on the computer don't get jumbled up

Some resources (such as the processor, memory, devices) are shared directly inside the operating system and tasks requiring them are kept in numerous queues for "system locks". For example, in C# a program needing a resource whose lock is called MyLock (say) will wrap a section of code with a declaration such as lock(MyLock) { … }, and then execution halts at the lock request until the resource is available, and the lock is released at the end of the critical section.

4.2 TCP/IP services

For other things that aren't at quite such a low level, a server process manages a request queue. A very popular way of doing this is to use TCP/IP. Each server is assigned a port on which it listens for requests for its service. When a client sends a message to this port, the TCP mechanism creates a two-way communication channel (using a new server port) for subsequent communication in that session. Messages on this 2-way channel will generally follow an application-defined protocol of request and response, maybe including callbacks and exception handling.

All operating systems have limits on the number of ports that can be open at any time, so it is important for the TCP channel to get closed as soon as possible. This will happen if either the client or server process terminates, but obviously it is important not to wait until then.

Many application protocols are designed to be very short-term. A Web service lasts only as long as it takes to respond to a single request from the client. An email service remains connected just for long enough to send a message. In these cases, the messages between client and server are simple and text-based. For email, there are headers such as To:, From: and Subject:, followed by the message body. For web servers, the first line of the request contains a verb and a URL, and the last line is blank; while the response begins with a status code, then headers, a blank line, and then the body of the response. (PUT and POST requests also have a body following the blank line.)

Services almost always listen on well-known port numbers, although there is always the option that servers and clients agree on the use of some other port. These port numbers are assigned by the Internet Assigned Numbers Authority (www.iana.org), so you can look up the one you want. Even Pyrrho has its own port number of 5433.

On a PC you can see what listeners are in operation by using netstat –a –b . If you see an IP address in square brackets with :s in it this is an IPv6 address, e.g. [::].

4.3 The application protocol

Once the application's 2-way channel is established, ordinary I/O operations for Steams can be used. The size of the first packet received is used in the end-to-end TCP packet negotiation. For many TCP/IP services (e.g. HTTP) there is only one message in each direction, so this is fine. But if there will be many messages, it is important to remember that the packet size negotiation is done again if the packet size changes. For best results always ensure that all packets used on a channel have the same size. This simple trick can affect communication speeds by a factor of 1000. Pyrrho always uses a packet size of 2048 octets.

For client-server communications it is often important to use asynchronous I/O calls. This is extremely important for interactive applications: you don't want the user's display to freeze while the process wits for a reply from a remote server. Many programming systems (such as Windows Forms) already ensure that the interactive events are done by a separate thread, but this brings its own complications, and the run-time system will insist on cross-thread method invocation (Invoke()) where required.

The messages on this two-way communication channel are called (application) protocol data units (PDU). For example, if your sporting club was not using SQL, you might have messages for enrolling a new member, for recording a match, for a score etc. The start of the message might have an identifier to say which message it is (using a small integer 1,2,3 for the different actions) and a set of strings for the different data involved. If you were using SQL, each request might just be a string consisting of an SQL statement (e.g. "insert into members ..."). This assumes that authentication of the user was already done during the connection step.

4.4 The client library

Since a service is designed to be used by a number of different applications, there is usually a client-side library whose methods manage the low-level communication with the server. Since low-level details will usually be platform-dependent, it is considered bad design for a client application to write directly to the communications stream. Instead, programming conventions have grown up for different sorts of service so that (for example) client libraries for database services all look very similar, as we have seen in Labs 1 and 2 in this course.

In the early days of programming distributed systems, a monolithic application would be simply broken into client and server by placing some of its components (functions etc) on the server side. Application code on the client side would be unaffected, because proxy functions were provided on the client side with the same names and parameters as before. The proxy would "marshal" its parameters for transmission to the server. This data would be disassembled on the server and used to cal the real server-side function, and so on. Nowadays we try to design in client-server design from the outset.

4.5 Sessions

As we have seen, the lifetime of the connection is an important consideration: the length of time connected to the server using PCT is called a TCP/IP session. For database services it often happens that very large amounts of data need to be transmitted between the client and the server, involving many steps and client-side decisions. As we will see, the whole notion of database transactions is very important. Assuming that the processing envisaged by the application involves zero or more transactions, we can imagine that a transaction involves one or more TCP/IP sessions. We will discuss this further later in this course.

At this stage, though, we will note that if the server needs to preserve information about the whole series of transactions ("session state") from one TCP/IP session to the next, this will require management on multi-server installations where subsequent sessions might be on another server. Either steps will be taken to ensure that subsequent requests from the same client are dealt with by the same server ("server affinity"), or servers will need to share session state somehow.

Another issue is that the TCP/IP setup time referred to earlier can become a significant cost. Some client server systems create pools of connections and threads to try to make this process as efficient as possible.

For both of these reasons, there is an argument for holding a connection open for the duration of a transaction, even though this might be quite a long time.

4.6 Database concurrency

In the meantime, the database server needs to be able to deal with other clients. With this design, it becomes inevitable that the database server will manage multiple clients concurrently (dealing with requests in different threads). Even requests from different clients for the same database may be handled at the same time.

How database servers manage this is crucial. In order to preserve consistency we cannot see a jumble of half-done transactions when we look at a database. Transactions (as we will see) need to be atomic. To achieve consistency and atomicity we could lock parts of the database in advance, delaying conflicting transactions until we are done (pessimistic), or we could simply allow all transactions to proceed in isolation, only identifying conflict when transactions commit (optimistic).

Either way, the database server programming will be complicated.

As mentioned above, on big installations there will be many servers. The scenario that a request might be handled by any of them is quite common, but there is an option to place different databases on different (clusters of) servers. Large databases might be partitioned so that data is spread over many servers. We will consider later in the course the different ways that servers can cooperate on managing a database.

Viewing this problem from the viewpoint of the application, we note that on the Internet, the traditional “pessimistic” solution of transactions locking the resources they are considering updating is widely considered unsuitable, and most vendors have settled for a concept of “eventual consistency” (e.g. see Elbushra and Lindström, 2014), relying on compensation methods for resolving conflicts (e.g Lessner et al 2012). Most application frameworks designed for the Web use a combination of optimistic concurrency (on the network) and pessimistic concurrency (in the DBMS). All such hybrid solutions really place the responsibility for verifying consistency on the application, where it does not really belong. We return to this problem in Chapter 5.

4.7 Databases and the file system

Changes to the database need to be made durable, so they need to get written to durable media, such as hard disks. The simplest possible sort of database file organisation would have a single (text?) file per database. These days computer memories are so large that many databases would fit in memory – we can almost imagine the whole thing simply being written to disk periodically. But in the interests of speed, we also have indexes to locate information very quickly, and these typically occupy similar amounts of memory to the data itself.

In the old days, computer memories were small, so that the data and indexes were kept on disk. Pages being modified would be in memory, and clever page replacement algorithms would ensure that the disk contents kept pace with changes to the data.

Pyrrho has a different approach: all the indexes are kept (only) in memory, and the disk file consists exactly of the transaction log. This makes the committing of a transaction very simple, typically a single disk write operation, appending the transaction data to the end of the database.

It is obviously good practice for the DBMS to have exclusive access to the database file while it is operating.

4.8 Alternative architectures

Needless to say, various alternatives to the above architectural description are possible. On a personal computer, sharing of data is less of an issue, so for example MS Access is a database product that supports no sharing at all. If such a database is on a shared folder, whole file-locking mechanisms (exclusive access above) are the best that can be managed.

Another no-sharing possibility is where an application has an embedded database. This is a persistent store in the application that is not accessible by any other application. If the database actually uses database technology such as SQL then the application will include a database engine in its executable code.

In other cases, the database technology is less important than the sharing, and people share “No-SQL” databases such a twitter feeds. Such arrangements involve rapid non-transacted publication of data, and nobody minds too much if a tweet gets overwritten. Since the data is not structured, there are no indexes to keep in synchronisation with data, and no database constraints.

Yet another sort of database is provided in “big data” warehousing, where huge read-only aggregations from data sources have been made accessible. Typically these systems avoid trouble by disallowing updates to the warehoused data.

Finally, at the ultra-fast end of the spectrum we have in-memory databases where writing to durable media does not matter.

In chapter 6 we will spend some time looking at information security issues. In client-server systems it must be assumed that authentication is dealt with at the time that connection to the server is established. Secure protocols such as HTTPS can help with this. Many databases are designed for use by people playing different roles: bank managers, bank tellers etc. These roles could be separated out completely by the client applications, but in this course we will study how good database design can help with maintaining a more secure system. Database objects can have permissions associated with them for access by people in different roles; and users can be authorised to exercise roles at different times.

Chapter 5 Locking vs Optimistic Transactions

In this chapter we return to the question of transaction control as a way of ensuring data consistency in multi-user databases. Although all commercial relational RDMS products use only pessimistic concurrency control, there is a long tradition of research that optimistic concurrency provides a better solution (e.g. Menascé and Nakamishi 1980, Haritsa et al 1990, Kaspi and Venkataraman 2014). The biggest conceptual hurdle in developing applications for Pyrrho is the use of optimistic transactions. It is very important for programmers to accept this approach as a fact of life, explained in the following paragraphs, and not try to imitate a locking model.

All good database architectures today support the ACID properties of transactions (atomicity, consistency, isolation and durability). Database products that use pessimistic locking (such as SQL Server or Oracle) acquire these locks on behalf of transactions by default, and it is not usually necessary for an application to deal with these issues directly. In a pessimistic locking product, transactions can be delayed (blocked) while waiting for the required locks to become available.

A transaction can fail because it conflicts with another transaction. For example, with pessimistic locking, the server may detect that two (or more) transactions have become deadlocked, that is, all of the transactions in the group is waiting for a lock that is held by another transaction in the group. In these circumstances, the server will abort one of the transactions, and reclaim its locks, so that other transactions in the group can proceed.

With pessimistic locking, if a transaction reaches its commit point, the commit will generally succeed. If it does not complete, it retains locks on database resources until it is rolled back. With SQL Server, for example, once a transaction T begins, it acquires locks on data that it accesses. If it updates any data, it acquires an exclusive lock on the data. Until T commits or is rolled back, no other transaction can access any data written by T or make any change to data read by T.

With optimistic locking, the first sign of failure may well be when the transaction tries to commit. A transaction will fail if it tries to make a change that conflicts with a change made by another transaction.

In both cases, it is important for database applications to be prepared to restart transactions. In the case of pessimistic transactions this would normally follow deadlock detection or timeout. With pessimistic locking an attempt could simply be made to re-acquire the same locks: this step could be performed automatically by the server. However, it is not good practice for the transaction's sequence of SQL statements to be simply replayed, since generally the state of the database will have changed (this is why the transaction failed), and the application should start again to see what to do in this new situation..

In the classic transaction example of withdrawing money from a bank account, a transaction for making a transfer might include an SQL statement of the form "update myaccount set balance=balance-100" or "update myaccount set balance=3456". Writing SQL statements in the first form makes them apparently easier to restart, but the point being made here is that it should be the client application's responsibility to decide if the statements should simply be replayed on restart. The server should not simply make assumptions about the business logic of the transaction. Pyrrho transaction checking includes checking that data read by the transaction has not been changed by another transaction.

5.1 A scenario of transaction conflict

To simplify the discussion, let us consider operations on a table Products.

Products: (id int primary key, description char, quantity int check(quantity>=0),price int)

In this system, some transactions will involve a purchase (failing in the absence of sufficient stock)

A(x): SELECT price FROM Products WHERE id=A.x; UPDATE Products SET quantity=quantity-1 WHERE id=A.x

Some transactions will request several items (failing if any item is unavailable)

B(x_1,x_2..,x_n): BEGIN TRANSACTION A(x_1); A(x_2);..;A(x_n); COMMIT

Now for normal levels of activity, these transactions execute very rapidly, and concurrency is not likely to be a problem. In order to have problems with transaction failures we need to assume huge transaction volumes, a huge size to the Products table, or that the Products table is geographically distributed over many servers, etc. So, assuming that we can imagine transaction conflict occurring at all, we note that transactions of type B(x_1,..x_n) will conflict with any concurrent A(x) where x=x_i some i.

Other transactions will involve adjustments to the stock levels or prices. For example, we might implement a policy of discounting plentiful items whose description matches a given pattern (e.g. '%BOLT%')

C(y): UPDATE Products SET price=price*0.9 WHERE quantity>40 AND description like C.y

This transaction will conflict with any A(x) such that description(x) is like y , even if quantity(x)≤40. Not all database experts consider that conflict arises here. With PCC we can imagine that all rows of Products would be locked for the duration of C(y) transaction. With OCC, some implementations might not report any conflict on the grounds that C(y) does not modify quantities. However, as transactions A and B also compute a required payment for the items purchased, the cost of the purchase might be debatable if transaction C was concurrently applying a discount. On these grounds we would say that C(y) will conflict with any A(x) such that quantity(x)>100.

Suppose Products contains an item (456,'500 3x5 BOLT',101,3.00), and A(456) followed by C('%BOLT'), the cost of A is 3.00 and the Products table reads (456,'500 3x5 BOLT',100,3.00) . If C is followed by A, the cost of A is 2.70 and the Products table contains (456,'500 3x5 BOLT',100,2.70) . The principle of serialisability of transactions should ensure that no other outcomes are possible. In the absence of proper concurrency control, both A and C might proceed on the basis of a snapshot of the Products table at the start of their transactions, so that A would cost 3.00 and the Products table would have (456,'500 3x5 BOLT',100,2.70). In this business scenario perhaps this uncertainty is unimportant, but in scenarios such as control of dangerous industrial processes, such uncertainties could be a matter of life and death.

To ensure serialisability, we must conclude that A(x) and C(y) will conflict if A(x) affects the value of a Boolean expression used by C, i.e. if quantity(x)=101 and description(x) like y. In this scenario a conflict will also be detected if C actually updates the price used by A.

As a result of these considerations, the conflict implementation rules require that changes made since the start of a transaction are checked for conflict with anything read by the transaction. Suppose that C starts before A starts, but A starts and commits before C attempts to commit. Then C will fail, because one of the quantities read by C has changed. If C commits first, then A will fail if x's price has changed.

5.2 Transactions and Locking Protocols

In chapter 2 we saw an introduction to the detailed operation of Pyrrho's optimistic transaction mechanism. The main commercial database systems use pessimistic (locking) protocols. The normal argument in favour of locking is that once locks are acquired, a correctly formed transaction can be guaranteed to complete, whereas an optimistic system might have to start over having done some work. However, in pessimistic system the process of acquiring locks can be lengthy and may require the application to release its locks and start again. Years ago there was a lot of debate in both directions, with many research papers claiming that optimistic methods result in higher throughput

(e.g. Kung and Robinson 1981). So in both cases, transaction failure can result from conflict: for pessimistic control, it is a conflict of intention, while for optimistic control it is a conflict of action.

Optimistic Concurrency Control (OCC) is not widely used in commercial DBMS products. Although it always produces serialisable transaction behaviour, there is no way of guaranteeing in advance that any given transaction will be able to commit. With pessimistic concurrency control (PCC), a transaction is allowed to delay starting until it has succeeded in locking the data it wishes to read or write, and these locks are maintained by the DBMS until the end of the transaction that owns them.

PCC is subject to denial-of-service attacks, since an attacker can repeatedly request locks on a large set of data items, thus delaying legitimate transactions. Such an attack might leave few traces, since the delay will occur even if the attacker's transaction makes no changes and simply times out.

In widely distributed information systems made possible by the Internet, the impossibility of maintaining database locking while a user organises their payment methods has led many to abandon the use of ACID databases altogether (Lessner et al 2012). Where locking processes have been combined with such distributed transactions it has been found necessary to introduce the idea of compensation processes, effectively to automate the cancelling of supposedly durable transaction commits.

Recent work from Microsoft, Google, and IBM supports optimistic transaction management by using versioning (e.g. Garus 2012, Guenther 2012, IBM 2011), and this represents a big change from always using locking protocols. In fact, optimistic transaction management is the default in Microsoft's Entity Framework, Google's Datastore, and IBMs EJB implementations.

At first sight the requirement at the Internet level for optimistic transactions seems fundamentally at odds with the requirement in the large commercial database systems to use locking protocols. Numerous papers (e.g. those cited above) provide complex workarounds but for many purposes the difficulties are not as severe as might be expected.

The first reason is that internet applications deal directly with databases on behalf of their multiple users: as far as the database is concerned there is only one client. Similarly, the databases at the heart of messaging systems have only one client, namely the enterprise server, and different enterprise servers (Exchange, BizTalk, WebSphere etc) use different databases.

The second is that concurrent access to the database is often limited by tuning arrangements. In many DBMS there may be parallel transactions, but the steps in these transactions are serialised by the TCP request socket mechanism: few DBMS use multi-threading at the step level. As we have seen Pyrrho's multithreading is at the connection level, and assumes that transactions for that connection are serialised by the client application so that any thread-specific data is disposed of at transaction boundaries.

Finally the granularity of locking can be adjusted. For normal row-based CRUD operations Pyrrho detects conflicts at the row level and detects conflicts at the level of database objects only when schema changes are being made. This level of granularity is slightly harder to achieve in pessimistic systems since a great deal of work may be required in advance to identify exactly which rows will be updated.

5.3 Snapshot isolation

Snapshot isolation is when transactions cannot see the activities of concurrent transactions, but proceeds with a view of how the database stood at the time the transaction started. Many DBMSs support snapshot isolation (SI) as an optional mode: Pyrrho enforces it.

In databases that provide so-called "serialisable snapshot isolation" (SSI) there is a check made before a transaction commits that no updates since the snapshot conflict with any updates the transaction is

about to commit. It used to be claimed that this results in serialisable transactions, but it does not. Transactions are only serialisable if all of their activities (reads and writes) have effect as if there is no concurrency, i.e. there is an ordering of the effective times of transactions such that the same results are achieved.

The commit time of a transaction is when its changes are written to durable media (not the time of the commit request): for example as in Pyrrho by flush-writes to the transaction log. To ensure this serialisability is valid we need to ensure that all of the records we have accessed, some of which we may be about to change, still have the values found in the snapshot taken at the start of the transaction.

Thus a first requirement at commit time of a transaction T is to ensure that none of this data has been modified by other commits since the start of T. The set of read records and proposed physical changes is checked against physical changes that other transactions have committed since the start of T. The first part (the read records) is handled by a list of read constraints maintained by the local transaction. For changes, the proposed physical records about to be written to disk are checked against those that have been committed to the database since the start of T. For example if we are updating a value we need to be sure that the table and record are still there, and the column still exists and has the right type. These checks guarantee consistency of the database.

There are three further checks that are needed to guarantee data integrity. The DBMS will already have checked for entity and referential integrity against the values it has in the snapshot, but at commit time checks are needed against any relevant changes committed by other transactions. These are (a) for primary and unique keys to check that a duplicate key has not been added since the start of T, (b) to check that a key referenced by an inserted record has not been deleted since the start of T and (c) to check that a key we are deleting is not referenced by a record that has been inserted since the start of T.

Needless to say, as soon as we start to check the effects of other transactions, isolation is over, so such checks can only be made during T's commit, and all the steps described in the last two paragraphs must be done before any other transaction can start to commit. Pyrrho goes to a lot of trouble to reduce the amount of processing needed to carry out these checks, but inevitably the cost of performing the checks is linearly dependent on the number C of changes by T and also on the number D of physical changes by other transactions since the start of T. The cost R of read constraints in T is a bit better than linear in the number of records read: R increases by 1 for each table all of whose records are read, and for each specific record read. The total cost of guaranteeing serialisability is $O(CD+D log R)$.

In some ways, given the commitment to transaction safety, Pyrrho's design is near-optimal, and even works well for distributed databases and transactions. It is not excessive, as the benchmarks in Lecture 1 show, but people are not used to paying for this level of serialisability.

There are alternative approaches. If the transaction contains only updates, SSI does guarantee serialisability. If the correctness of reads is not an issue, they should be taken out of the transaction, e.g. handled in a parallel connection. If a transaction dos require correct reads, and SSI is the best available in a DBMS, true serialisability can be gained by upgrading reads to updates of the form "set x=x". If the DBMS supports row versioning, the application can check these at commit time. But it seems wrong to leave transaction safety to the client.

5.4 Transaction masters

The enforcement of full ACID requires that for each resource there should be a single transaction master that enforces serialisability of transactions that access its data, and any process that needs to know an up-to-date value in the resource, or commit a change to this value, needs to be able to communicate with that transaction master.

Many designers of large systems dislike the notion of a single server playing such an important role. There are two objections (a) it acts as a bottleneck at times of heavy traffic, (b) it represents a single point of failure.

If the network is partitioned so that the transaction master is unreachable, then no updates should occur. If the transaction master is permanently out of action, then the remaining network can elect a new one, but it is not reasonable for two disconnected parts of the network to continue separately.

Partitioning a database "horizontally" (for example on a geographical basis) can spread the load between transaction masters. This can enable higher throughput, provided transactions that use data from more than one partition are very rare, as even a small number of distributed transactions can cause serious delays. Transaction profiling can help to identify useful choices of partitions (e.g. see Curino et al 2011). We return to consider distributed databases in Chapter 8.

Despite all the theory, and despite some very well-publicised disasters, few business people accept the need for a single transaction master for each database fragment, or the need to stop all transactions if the network becomes partitioned.

5.5 ADO.NET and transactions

It is rather important to understand that ADO.NET 2.0 introduced two parallel mechanisms of operation, with different concurrency mechanisms.

- The DataSet and DataAdapter types used a disconnected data model based on optimistic concurrency
- The DbCommand and DataReader types used pessimistic concurrency.

Because only one DataReader can be open for a given database connection this all works in a fairly natural way: the duration of locking is the length of time that the data reader is open. We can make local changes to a DataSet, and when we try to commit them to the database, ADO.NET makes a new transaction for us, and checks that the affected records are still the same as when we read them.

5.6 Versioning

From April 2015, Pyrrho has a type of row versioning which this section compares with corresponding features in IBM's SolidDB and Microsoft's SQL Server.

Pyrrho always supplies a pseudocolumn in all base tables called CHECK. The value is a string that includes the transaction log name, defining position and current offset of the row version. When retrieved it refers to the version valid at the start of the transaction, but it can be used at any time subsequently (inside or outside the transaction) to see if the row has been updated by this or any other transaction (this is the only violation of transaction isolation in Pyrrho).

There is a method in the PyrrhoConnect subclass of IDbConnection for verifying a check string:

bool Check(string ch)	Check to see if a given CHECK pseudocolumn value is still current, i.e. the row has not been modified by a later transaction.

Unlike other DBMS, the check cookie is just a note of a transaction log position and so is persistent.

In IBM's solidDB, the concurrency control mode can be set per table using the ALTER TABLE t SET OPTIMISTIC/PESSEMISTIC statement, or for all tables using the General.Pessimistic setting in solid.ini. With the default optimistic setting:

1. Each time that the server reads a record to try to update it, the server makes a copy of the version number of the record and stores that copy for later reference.
2. When it is time to commit the transaction, the server compares the original version number that it read against the version number of the currently committed data.

- If the version numbers are the same, then no one else changed the record and the system can write the updated value.
- If the originally read value and the current value on the disk are not the same, then someone has changed the data since it was read, and the current operation is probably out-of-date. Thus the system discards the version of the data, aborts the transaction, and returns an error message.
- The step of checking the version numbers is called validation. The validation can be performed at the commit time (normal validation) or at the time of writing each statement (early validation). In solidDB, early validation is the default method (General.TransactionEarlyValidate=yes).

Each time a record is updated, the version number is updated as well.

Each user's transaction sees the database as it was at the time that the transaction started. This way the data that each user sees is consistent throughout the transaction, and users are able to concurrently access the database. Even though the optimistic concurrency control mechanism is sometimes called optimistic locking, it is not a true locking scheme—the system does not place any locks when optimistic concurrency control is used. The term locking is used because optimistic concurrency control serves the same purpose as pessimistic locking by preventing overlapping updates. When you use optimistic locking, you do not find out that there is a conflict until just before you write the updated data. In pessimistic locking, you find out there is a conflict as soon as you try to read the data.

To use an analogy with banks, pessimistic locking is like having a guard at the bank door who checks your account number when you try to enter; if someone else (a spouse, or a merchant to whom you wrote a check) is already in the bank accessing your account, then you cannot enter until that other person finishes her transaction and leaves. Optimistic locking, on the other hand, allows you to walk into the bank at any time and try to do your business, but at the risk that as you are walking out the door the bank guard will tell you that your transaction conflicted with someone else's and you will have to go back and do the transaction again.

With pessimistic locking, the first user to request a lock, gets it. Once you have the lock, no other user or connection can override your lock.

SQL Server’s optimistic concurrency uses versioning: they call it “snapshot isolation”. When a record in a table or index is updated, the new record is stamped with the transaction sequence_number of the transaction that is doing the update. The previous version of the record is stored in the version store, and the new record contains a pointer to the old record in the version store. Old records in the version store may contain pointers to even older versions. All the old versions of a particular record are chained in a linked list, and SQL Server may need to follow several pointers in a list to reach the right version. Version records need to be kept in the version store only as long as there are there are operations that might require them.

5.7 Transaction Profiling

In the current literature, transaction profiling is usually associated with detection of security breaches: a transaction that does not fit any known business process deserves investigation. This paper presents a new model for lightweight transaction profiling that also focuses on traffic optimisation, by considering failed transactions also. Where transactions repeatedly fail because of lock-timeout or transaction conflict, there are two options: redesign of the task, or scheduling it to take place during maintenance periods. In experiments the mechanisms proposed here added less than 10% to DBMS memory usage and had no appreciable effect on transaction timings. These mechanisms can bring immediate benefits in database security and can assist in improvements to access control and role management for a live system.

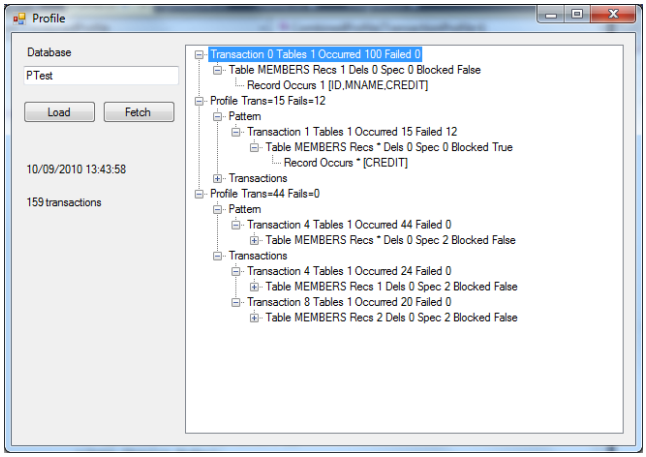
The creation of transaction profiles is very important for proactive security monitoring, and for database traffic management. A poorly designed database, or careless application design, can lead to transactions that lock more data than they need to, and thus degrade performance of the whole system. Where transactions repeatedly fail because of lock-timeout or transaction conflict, there are two options: redesign of the task, or scheduling it to take place during maintenance periods.

Pyrrho includes a mechanism for diagnosing incidents where database transactions fail. Generally, a transaction *T* has a read a set R_T of data items and is committing changes to a set W_T of data items, and typically these sets overlap. With optimistic concurrency control, transactions are unaware of concurrent transactions but a transaction commit will fail if another transaction has committed a change to any data item in $R_T \cup W_T$. To analyse such failures, Pyrrho assists with aggregating failures of this type, using a supplemental log that records the read and write details for each transaction along with the success or failure of the transaction.

5.8 Profiling implementation

If profiling is turned on for a database, Pyrrho maintains a transaction profile, which is persisted not in the database itself, but in an XML file: this is because it is a record not of the entire database activity, but just the periods for which profiling is enabled. Profiles can be deleted without harming the database in any way.

There is a convenience utility called ProfileViewer which displays the profile in a readable tree-view format. The profile can either be "fetched" from the server (assuming profiling is enabled), or "loaded" from the XML file (in which case ProfileViewer expects to find the xml file in its working folder).



Profiling has a negligible effect on performance and memory use. Profiling can be enabled for all databases, or in the configuration of individual databases.

The purpose of gathering or storing profile information is to understand and monitor the causes of transaction conflicts. Performance tuning and database design should seek to minimise failed transactions during normal operation. It is inevitable that an unusual operation, such as changing the schema or making an update affecting all rows of a table, will be hard to commit during heavy traffic, because a conflicting transaction will probably occur in the meantime.

When profiling is turned off or on for a database called *name* profiling information is destructively saved as or if available loaded from an XML document with name *name*.xml. Thus a database administrator can carefully take a database offline by throttling, and then turning off profiling to record a snapshot before shutting down a server, and in this way a full profile of normal operations

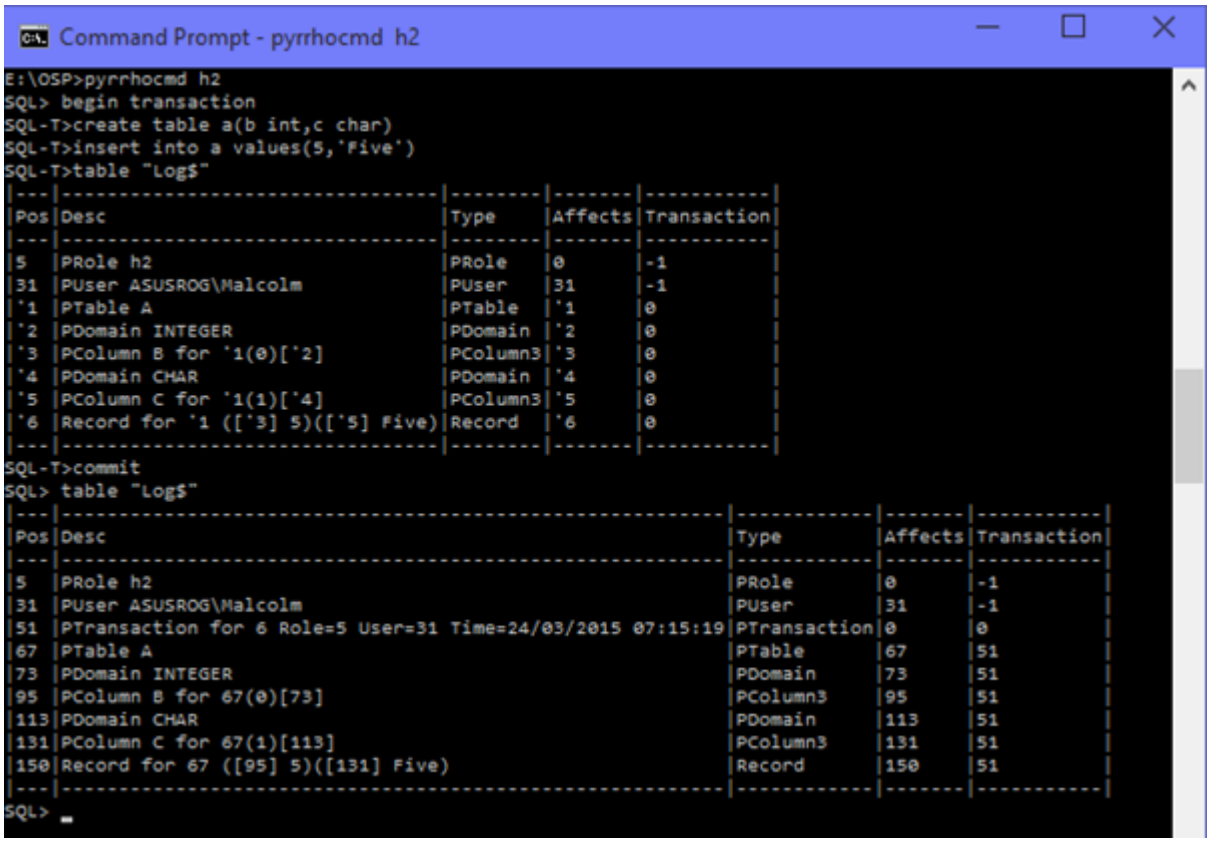
can be maintained. This level of completeness for profile information will not be achieved if the database server is simply killed.

If profiling is enabled, any failed transaction will report its profile. The system profile table will contain the number of successful and failed transactions recorded for this profile: the number of successful transactions will be based on the entire history of the database, while the number of failed transactions recorded will be based on the available information from recorded periods of full profiling (or since the time profiling was enabled for the server).

If profiling is turned on, a set of system tables (Profile$, Profile$ReadConstraint, Profile$Record, Profile$RecordColumn, and Profile$Table) enable inspection of the real-time state of the profile information, always excluding any information about transactions in progress. As with other system tables these tables are not persisted but instrument the running server by exposing in-memory data structures as if they were database tables. The profile viewer described in section 5.8 obtains profile information from these tables or from the XML document, and also groups profiles with similar pattern (for example where everything is the same apart from the number of affected rows).

5.9 PyrrhoDBMS: safe optimistic transactions

The Distributed Database and Partitioned tutorial in Appendices 4 and 5 demonstrate how Pyrrho uses three phase commit for distributed transactions. At this point in this book it seems a good point to state once again that while Pyrrho uses optimistic concurrency control, it is totally transaction-safe. If you are using explicit transactions you can use the system "Log$" table to view the proposed changes for the current transaction. Each connection will have its own, and it is easy to see the they are isolated: the only entries with known positions are the ones that predated the start of the transaction.



Accordingly the transaction commit protocol is in 4 or 5 phases controlled by locks on the transaction log file (which in Pyrrho is the durable version of the database): 1. Verify the transaction does not

conflict with anything written since the start of the transaction. 1.5 Lock the database and repeat this test. 2. Prepare the binary package to be written. 3. Write it to the disk file and unlock the database. 4. Now discard the local transaction and allow the client to see the database as it now is. If multiple servers or databases are active then step 3 here requires three-phase commit during which time the proposed changes are written to temporary files. If all is well, these temporary files do not need to be read, and can be removed once all participants have acknowledged the commit request.

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: $P=p_0p_1…p_n$ etc.

The verification step performed by Pyrrho 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 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 LocalTransaction.check(Physical p) which is called from Commit1.

Entity Integrity

The main entity integrity mechanism is contained in LocalTransaction. 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 a linked list of values
- A pointer to the next IndexConstraint.

During LocalTransaction.AddRecord and LocalTransaction.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 and discussed next, this list is tested for conflict.

Referential Integrity

The main referential integrity mechanism is contained in LocalTransaction. 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 a linked list of values
- A pointer to the next ReferenceDeletionConstraint.

Concurrency control for referential constraints for insertions 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 a linked list of values
- A pointer to the next ReferenceInsertionConstraint.

For distributed databases all the above checking information needs to be sent to the transaction master for verification.

Chapter 6: Role Based Security

In any organisation, the allocation of responsibilities to individuals varies over time, and so it makes sense to assign permissions not to individual users, but to roles. Roles are associated with business processes, not job descriptions: any one individual might be assigned a number of roles in different business processes such as validate travel expenses, assign salesman to region, publish telephone directory. It is a good idea to have a number of roles: if there are none than there is no traceability and no security: anyone can do anything and nobody will ever know why. It is also a good idea that every operation on a database declares the role being exercised, so that the action can be checked for validity. The principles of transparency and accountability mean that people need to explain what they are doing – it is not enough simply to say I am doing this because I can.

Security analysis begins with an account of who is allowed to enter or modify data and on what basis, and who is allowed to read that data. Permissions can be granted to applications as well as to users, but in that case the application takes on the responsibility for allowing different individuals to carry out different operations, and for best results it is these that should be recorded in the transaction record. For a particular database and application, it will be clear at any stage what role is being exercised. The same considerations apply to stored procedures and to methods of structured types.

From this discussion we see that database operations should be granted to roles, and roles should be granted to users. In SQL there is also the possibility of allowing users to administer a role, and allowing a role to grant privileges to other roles.

For an example, suppose we have a warehouse containing products, being ordered by customers. We can imagine that the list of products is maintained by a Manager role, that a Clerk can add a new customer or take a new order, that a Storeman can manually alter stock levels, that a Deliveryman can record that a delivery has been done, etc. We expect none of this information is confidential, except that customer address information is only visible to the Clerk and Deliveryman. Individuals might be allowed to adopt more than one role, but it should always be clear what role they are currently in. So if John the Clerk is temporarily allowed to do something in the Manager's absence, we should be able to look back to see what he did in that role.

Example

For example, suppose a small sporting club (such as squash or tennis) wishes to allow members to record their matches for ranking purposes:

```
Members: (id int primary key, firstname char)
```

```
Played: (id int primary key, winner int references members, loser int
references members, agreed boolean)
```

For simplicity we give everyone select access to both these tables.

```
Grant select on members to public
```

```
Grant select on played to public
```

Although Pyrrho records which user makes changes, it will save time if users are not allowed to make arbitrary changes to the Played table. Instead we will have procedure Claim(won,beat) and Agree(id), so that the Agree procedure is effective only when executed by the loser. With some simple assumptions on user names, the two procedures could be as simple as:

```
Create procedure claim(won int,beat int)
      insert into played(winner,loser) values(claim.won,claim.beat)
```

```
Create procedure agree(p int)
  update played set agreed=true
     where winner=agree.p and
      loser in (select m.id from members m where current_user like
('%'||firstname))
```

We want all members of the club to be able to execute these procedures. We could simply grant execute on these procedures to public. However, it is better practice to grant these permissions instead to a role (say, `membergames`) and allow any member to use this role:

```
Create role membergames 'Matches between members for ranking purposes'
Grant execute on procedure claim(int,int) to role membergames
Grant execute on procedure agree(int) to role membergames
Grant membergames to public
```

This example could be extended by considering the actual use made of the Played table in calculating the current rankings, etc.

6.1 Application or DBMS based security

In many commercial environments, DBMS security is a neglected topic. This is partially excusable if the only way to use a database is through a set of applications whose use is subject to strong authentication and authorisation mechanisms, but it should be recognised that a good security structure in the databases can lead to greatly enhanced forensic opportunities. These will be lost if the tables in a database are all public, or (worse) if the tables all belong to the database administrator and the database administrator identity is used by all applications.

In many commercial DBMS, it is very hard to discover who made a particular change to the database, or when, or what value was there before the change occurred. Although transaction logs can be maintained, they are often discarded after a time. It is better practice to retain the logs, or to adopt a DBMS design such as Pyrrho's where the transaction log is inseparable from the database.

On the other hand, the user of DBMS-based security makes a database much less portable. It is no longer a simple matter of copying the database tables to another machine or domain, since the authorisation identifiers will be different. For example, if a student develops a database at home, there is an extra step required to ensure that the database is usable in the workplace environment, namely to grant all privileges on the base tables to the student's user identity in the workplace:

grant all privileges on players to "DOMAIN\user"

or to PUBLIC of course.

6.2 Forensic investigation of a database

Pyrrho supports two kinds of investigation of a database.

First, full log tables are maintained. These are accessible to the current owner of the database, or to an investigator specified in the server configuration file. The log files allow tracing back to discover the full history of any object: when it was created, what changes to it were made, and when it was dropped. In each case, full transaction details are recorded: user, role and timestamp. Since objects can be renamed, logs use numeric identifiers to refer to objects in the database. Full details of the log tables are given in chapter 8. Using these tables it is always possible to obtain details of when and by whom entries were made in the database.

Secondly, Pyrrho supports a sort of time travel, in which a Stop time can be specified in the connection string (see chapter 6). The connection then allows the database to be seen exactly as it was at that time, and provided the operating system can restore the right user identities and application versions, these can be used to inspect the database, which is generally easier than working with the log files. In complex cases, a detailed investigation of the database as it was at a former time may be necessary to discover just how a particular user and role could have made a particular change to the database (since the change might have been made indirectly, for example by a trigger or a stored procedure).

One extension to SQL2011 syntax which assists with forensic investigation is the pseudo-table ROWS(n) where n is the “Pos” attribute of the table concerned in “Sys$Table” (see Appendix 8). For example, suppose we want a complete history of all insert, update and delete operations on table BOOK. Then lookup BOOK in Sys$Table:

```
select "Pos" from "Sys$Table" where "Name"='BOOK'
```

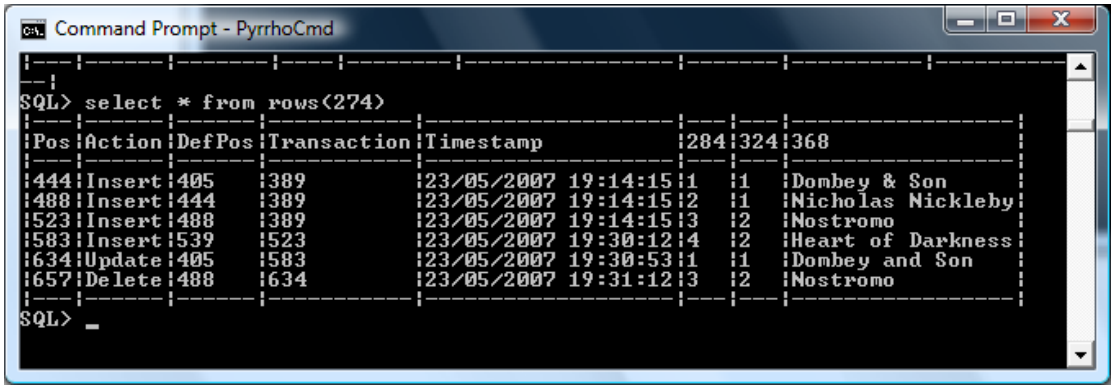
If this yields 274, then the required history is

```
select * from rows(274)
```

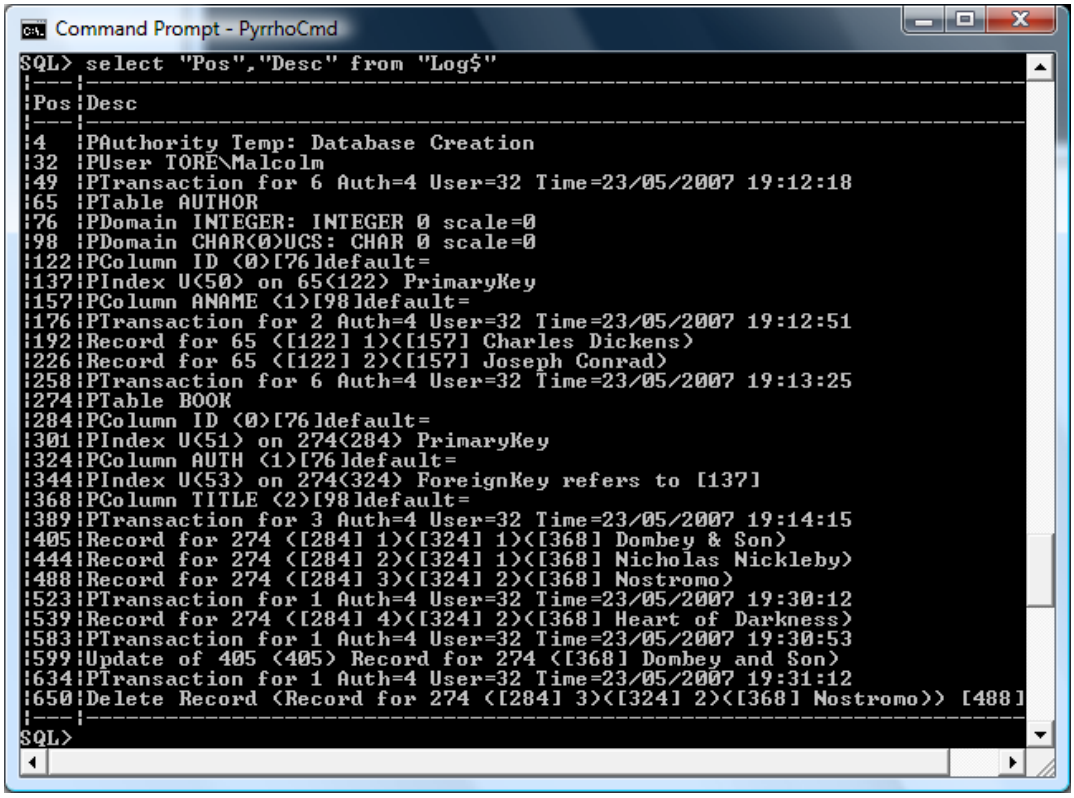
These can of course be combined:

```
select * from rows((select "Pos" from "Sys$Table" where "Name"='BOOK'))
```

The second set of parentheses is needed in SQL2011 here to force a scalar subquery.



The Log$ table gives a semi-readable account of all transactions:



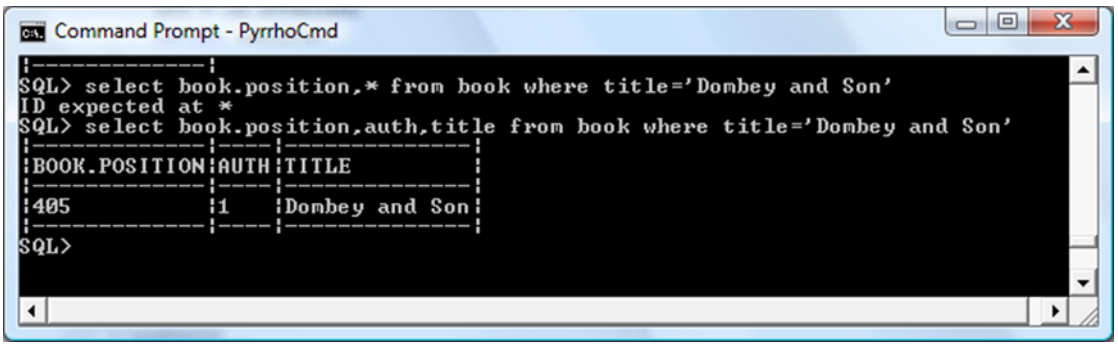
The system log refers to columns and tables by their uniquely identifying number rather than by name. Note also that the Update record shows which field(s) have been modified.

Most of the System and log tables have a column called “Pos” which gives the defining position of the relevant entry.

There is a pseudo-column in every table called POSITION which allows the defining position of current records in the database to be retrieved using ordinary queries, e.g. in the above example

select book.position from book where title='Dombey and Son'

would give 405. This value is in fact the defining position of the first record with the same primary key as ‘Dombey and Son’, rather than the place where the current title was set, and so it can be used to find other relevant log entries for this record.



An authorisation identifier is like a user. Users are defined in SQL by granting them privileges. It is assumed that there is some implementation defined way of associating a particular session with an authorisation identifier. For example in SQL server, users are defined within SQL server or by means of Windows integrated authentication. In Pyrrho the user identity is taken from Windows in form “domain\user” (or in Linux from the connection string), and cannot be changed in a session..

SQL recognises a predefined authorization identifier _SYSTEM . Apart from _SYSTEM, any authorisation identifier can be a granted privileges or roles.

6.3 Privileges

The SQL standard says that a **privilege** authorises a given category of action to be performed by a specified authorisation identifier on a specified object, such as a table, a column, a domain, a user-defined type, or a routine. The actions that can be specified are insert, update, delete, select, references, usage, under, trigger and execute. Insert, update, select and references can be for whole tables or views, or can be limited to a specified set of columns. Usage privileges apply to domains or user-defined types. Under privileges apply to structured types, and execute privileges apply to routines.

The security model in the SQL standard is based on the GRANT and REVOKE statement. There are two versions of each, for granting or revoking privileges to grantees and for granting or revoking roles to grantees.

A grantable privilege is a privilege that may be granted by a grant privilege statement: it can specify WITH GRANT OPTION in which case the grantee can grant it to others.

Every database object has an owner. This is initially set to the creator of the object, and _SYSTEM is considered to have granted the owner all privileges when the object is created. On creation a database has a default role with the same name as the database, and the owner of the database can use this role to create the starting set of objects for the database.

The normal way for ownership of a Pyrrho database to be changed is for the database owner to invoke the Pyrrho-specific GRANT OWNER statement. This is implemented as part of the normal database service, and it is good practice to ensure that owners of database objects are user identities that are still available in the operating system.

6.4 Roles

A role can be created by the CREATE ROLE statement: initially the owner has administrative rights on the role (granted by _SYSTEM). The grant role statement is used to allow this role to authorisation idnetifiers, and if WITH ADMIN OPTION the grantee may grant it to others.

Each role is an authorisation identifier. SQL recognises a special role called PUBLIC which is associated with any user and is the owner of standard domains.

In the SQL standard an authorisation identifier is permitted any action granted to it directly or through a role. An authorisation identifier is enabled if it is the current user identifier, the current role name, or the name of a role that is applicable for the current role. A privilege is **current** if it is applicable for an enabled authorisation identifier.

In Pyrrho DBMS only one role is current at any point in a session. A user (authorisation identifier) must choose a single role as the session role, and can modify this within the session using the SET ROLE statement to another role they have been granted. Thus in Pyrrho, the only enabled authorisation identifiers are the current user name and the current role.

6.7 The role stack

During query execution, any invoked operation is checked to see that the current role has been authorised to carry out the operation: at the start of the analysis the current role is set to the session role. When the operation involves transferring control to a routine, and the current role is permitted to execute the routine, the current role becomes the role of the routine (the “definer’s role”), and is restored on exit from the routine.

When the transaction is committed, all of the modifications will be recorded against the original user’s id and the session role. When reviewing such a record, it is important to remember that the changes may have been made by a routine operating with different permissions.

In Pyrrho, these permissions affect the metadata that can be viewed in a session, e.g. default values, view definitions and routine definitions. If these are examined by the current user (using the system tables) the SQL text may contain identifiers that have a different name or are not available to the current user and role. Pyrrho displays the identifiers that are appropriate to the current user and role or <hidden> if this data is not viewable from the current user and role.

6.8 Revoking privileges

In the SQL standard it is often a complex matter to discover by what route a particular user is entitled to take a particular action. There are many parts of the SQL standard where a schema change results in a cascade of grants of permissions. Unfortunately, it then becomes very unclear what effect revoking a privilege from a user or role will have, as a simple statement of the form

revoke all privileges on T from “System\Fred”

may allow Fred to retain privileges that he has acquired through some complex chain of grants.

Some DBMS regard this position as unsatisfactory, and in Pyrrho the semantics of grant and revoke operate somewhat differently from the standard. The effect is that a revoke statement of the above form will actually leave Fred with no privileges on the specified object (and any consequential privileges are also removed, in a cascade). The derogation from the SQL standard in this respect is extensively documented in the Pyrrho manual.

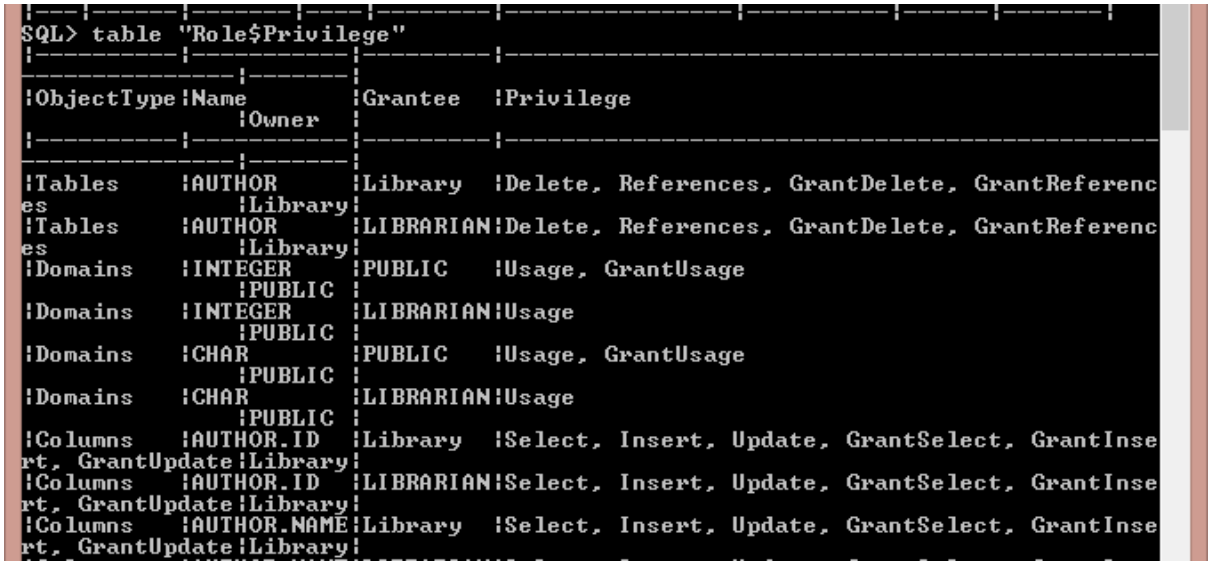
Apart from the owner privilege (which can be held by just one user), granting privileges directly to users is deprecated. It is recommended to grant roles to users instead. Similarly, attempting to create a hierarchy of roles is also deprecated, and in Pyrrho the grant of role A to role B has the effect only of granting role A to all users authorised to use role B at the time of the grant: it does not create a permanent relationship between the roles; revoking a role from a role does nothing, and all roles are in the root namespace. This behaviour appears to be a departure from SQL2011.

Similarly, a grant of privileges does not create any permanent relationship between roles. For example, granting Select on a Table implies granting select on all of the current columns. The grant can be repeated later if new columns are added, or the new columns can be granted. Similarly in Pyrrho, access to a column can be revoked even though the role was previously granted access to the whole table.

Granting a role to a user is different: it means that the user is entitled to exercise the role, and any privileges that the role has at the time of use.

6.9 Verifying privileges

The DBMS should provide one or more system tables to verify the current permissions on an object. In Pyrrho, this is done by the “Role$Privilege” table. Here is an example:



As can be seen in the illustration, the fields in this system table are ObjectType, Name, Grantee, Privilege and Owner. Note the different privileges associated with database objects (e.g. tables and columns).

Chapter 7: Role-based modelling and legacy data

In the last chapter we examined roles and security. The roles assigned to a user, and the permissions assigned to the roles, control what a user is able to do. For the reasons outlined in the last chapter, Pyrrho requires the user to exercise one role at a time. In this chapter we explore a major advantage of this approach, in that schema changes made by a user in Pyrrho are local to the role, so that each role may have a different data model. We will see that this allows data analytics to operate conveniently, and in real time, on the physical database.

On Windows systems, the user identity is obtained from Windows, and the default role has the same name as the database. The user can specify another role in the connection string, or specified by the SET ROLE statement, provided this role has been assigned to them. Pyrrho allows database objects to be renamed or altered by holders of the appropriate permissions: but such renaming and alteration applies to the current role, so that a database object can have different names in different roles.

By default all roles in a Pyrrho database have a default data model based on the base tables, their columns, and using foreign keys as navigable properties. Composite keys use the list notation for values e.g. (3,4) and the name is the reserved word key, which can be suffixed by the property name of the key component. The default data model can be modified on a per-role basis to provide more user-friendly entity and column names, and user-friendly descriptions of these entities and properties. Tables and columns can be flagged as entities and attributes as desired.

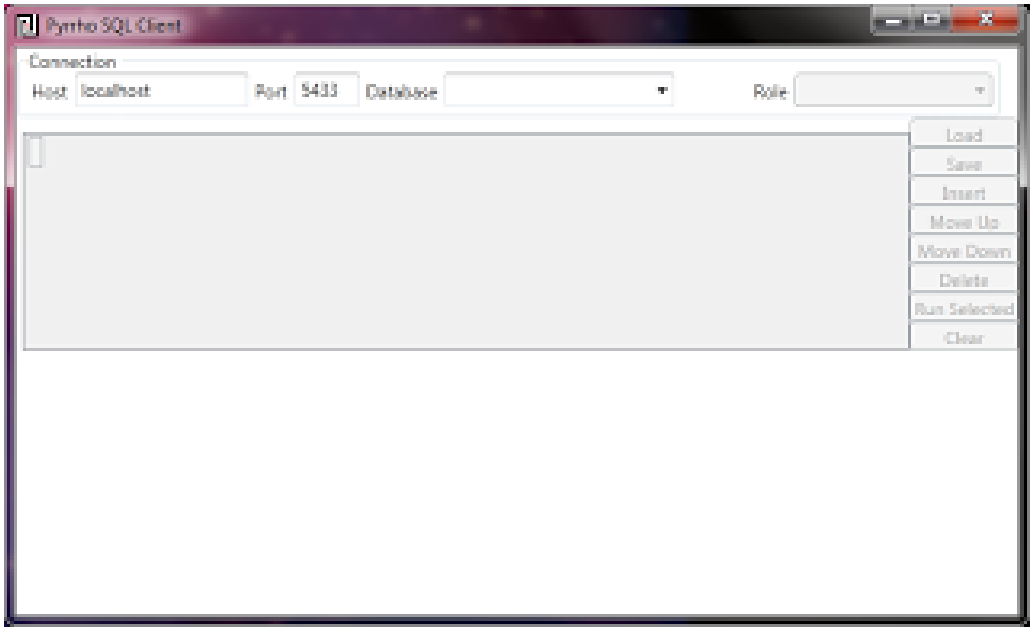
For example, roles could be defined for users in different countries, using entity names, property names and descriptions appropriate to the language of the country, giving access to localised columns or views. The localisation of columns is facilitated by the Pyrrho-specific UPDATE clause for generated columns which can perform lookups or casts behind the scenes. These defined views or generated columns could even have specific data types targeting specific roles, since they impose no overhead unless they are explicitly used.

Roles that are granted usage of an object will not see any subsequent name changes applied in the parent role, but the role administrator can define new names. Stored procedures, view definitions, generation rules etc use the definer's permissions for execution. If the code is examined in the different roles that use them objects will be referred to using the viewing role's names. If such embedded code refers to objects inaccessible to the viewer, the code will be reported as "(definer's code)".

Apart from object names, only the owner of an object can modify objects (ALTER). This includes changes to object constraints and triggers, and inevitably such modifications can disrupt the use of the object by other roles, procedures etc. References in code in other roles can introduce restrictions on dropping of objects, but as usual, cascades override restrictions, and in Pyrrho, revoking privileges always causes a cascade. Granting select on a table must include at least one notnull column. Granting insert privileges for a role must include any notnull columns that do not have default values, and cannot include generated columns.

An example

We walk through a simple database example, about a library database. Either start up the PyrrhoSQL client as shown,



If you are using the PyrrhoSQL client shown, give the Database name as Library and click Connect. If you are using an ordinary command prompt give the command

pyrrhocmd Library

We begin by controlling access to the database, and then start to build a simple database of books and authors.

revoke “Library” from public

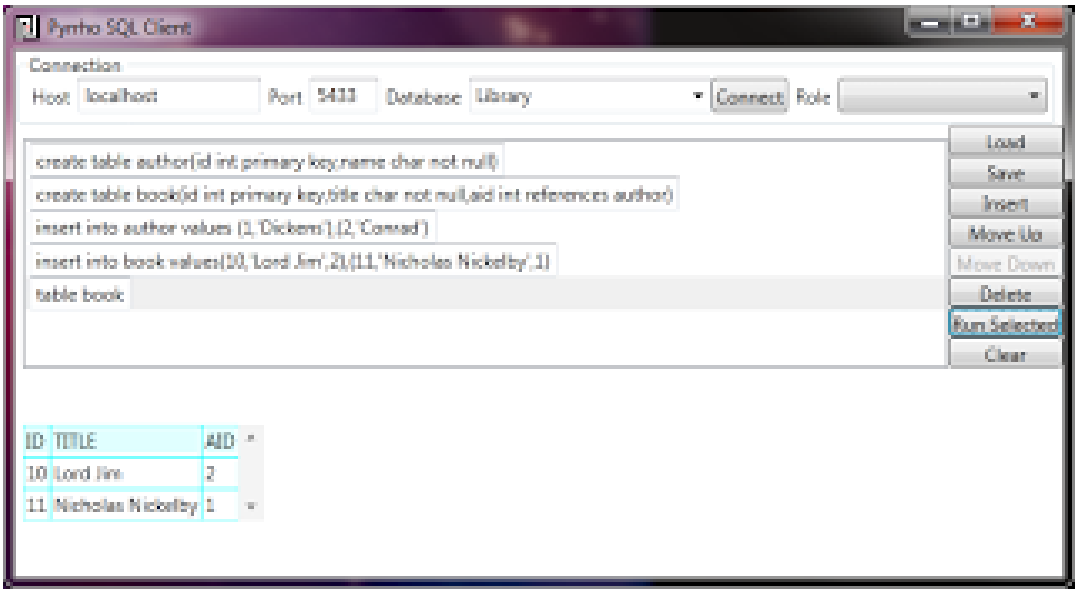
create table author(id int primary key,name char not null)

create table book(id int primary key, title char not null, aid int references author)

insert into author values(1,'Dickens'),(2,'Conrad')

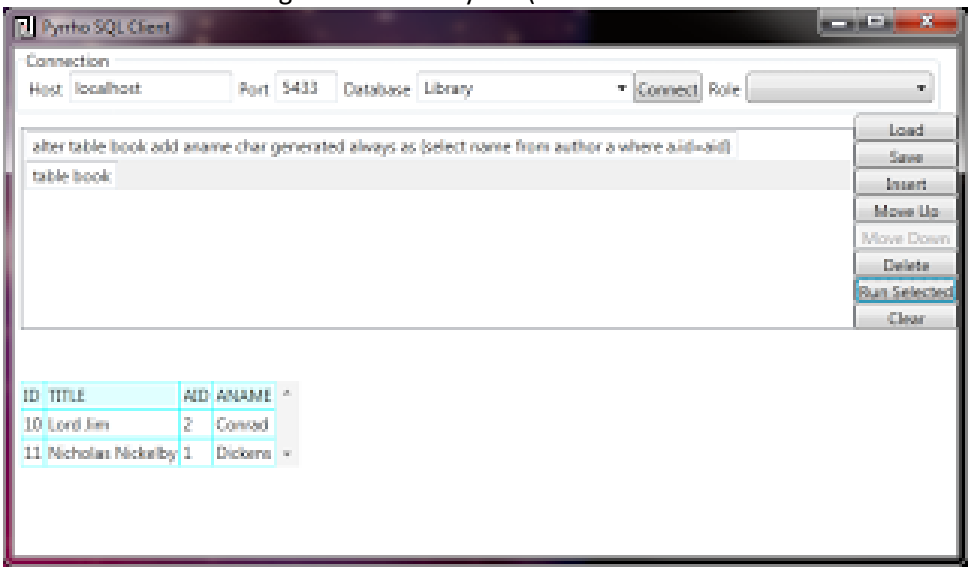
insert into book values(10,'Lord Jim',2),(11,'Nicholas Nickleby',1)

table book



This looks okay to a database specialist but the Librarian is not impressed. He wants the author's name in the book table: after feebly trying to explain about joins, I provide a special generated column in this table using the standard SQL2008 syntax:

alter table book add aname char generated always as (select name from author a where a.id=aid)



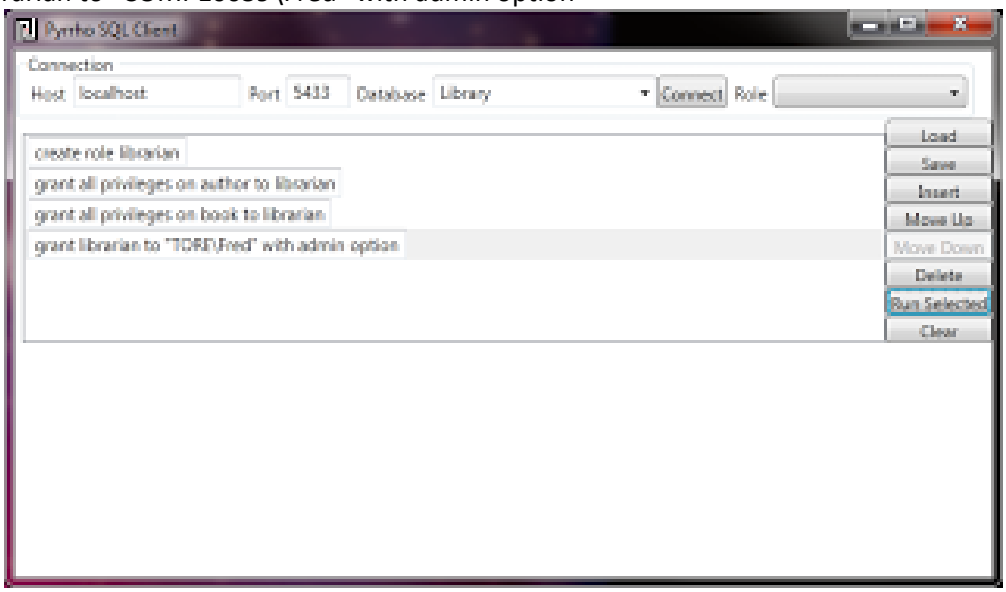
This pleases him a bit but he wants more reader-friendly names and to hide these numeric columns. So I add a new role for the Librarian, and allow Fred the admin option so he can define his preferred column headings:

create role librarian

grant all privileges on author to librarian

grant all privileges on book to librarian

grant librarian to "COMP10059\Fred" with admin option



(A generation rule in SQL2011 is not allowed to contain a query expression. Otherwise there are no Pyrrho extensions here.)

Fred can now log in to the system with his Librarian role. With the PyrrhoSQL client shown below, we make sure Fred login with the LIBRARIAN role selected from the drop-down. If he uses the command line, then after starting with pyrrhocmd Library, he needs

set role librarian

or he won't see much. He decides to rename some columns (this is a Pyrrho extension), define a new column called Availability, and to create a role for his readers with a simpler table structure:

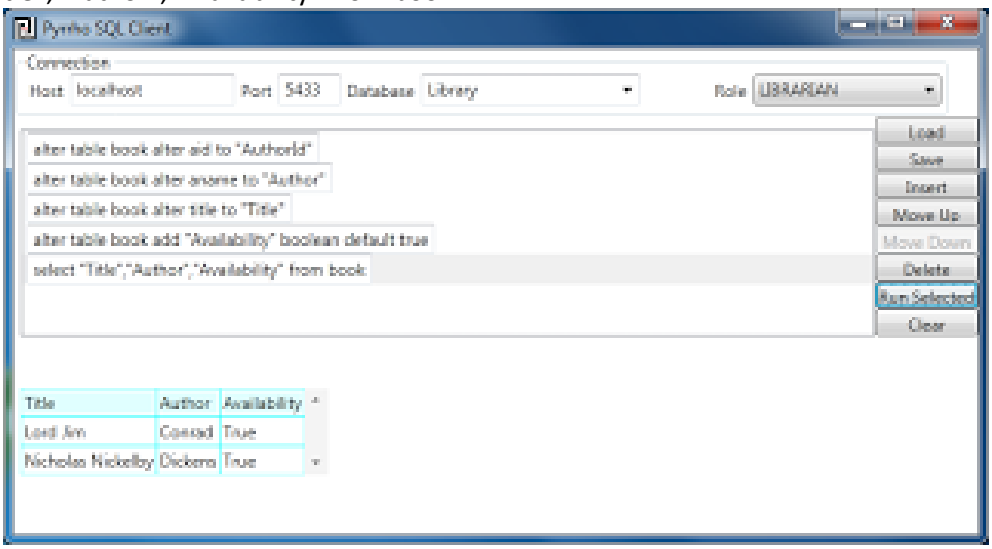
alter table book alter aid to "AuthorId"

alter table book alter aname to "Author"

alter table book alter title to "Title"

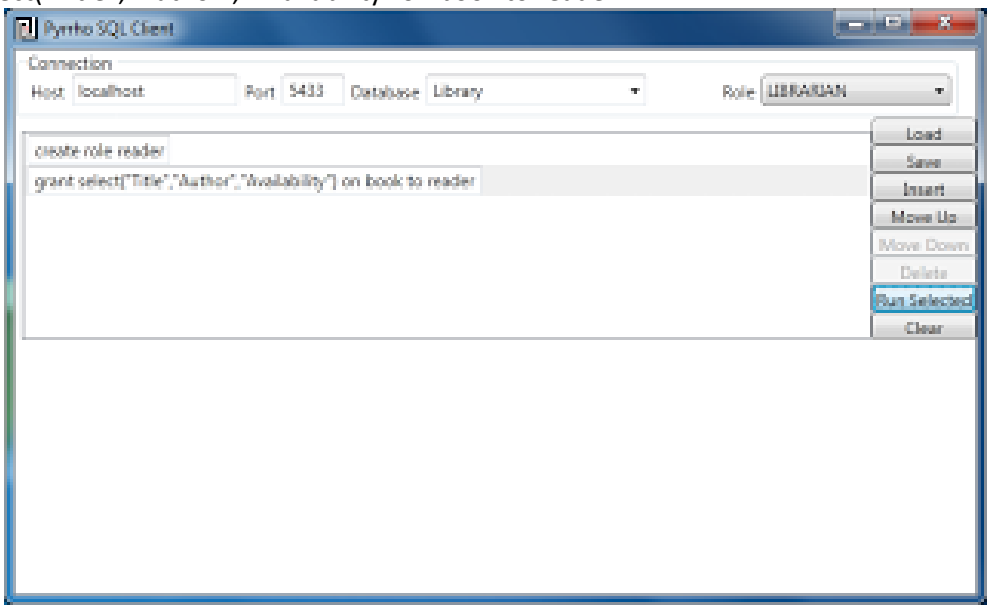
alter table book add "Availability" boolean default true

select "Title","Author","Availability" from book

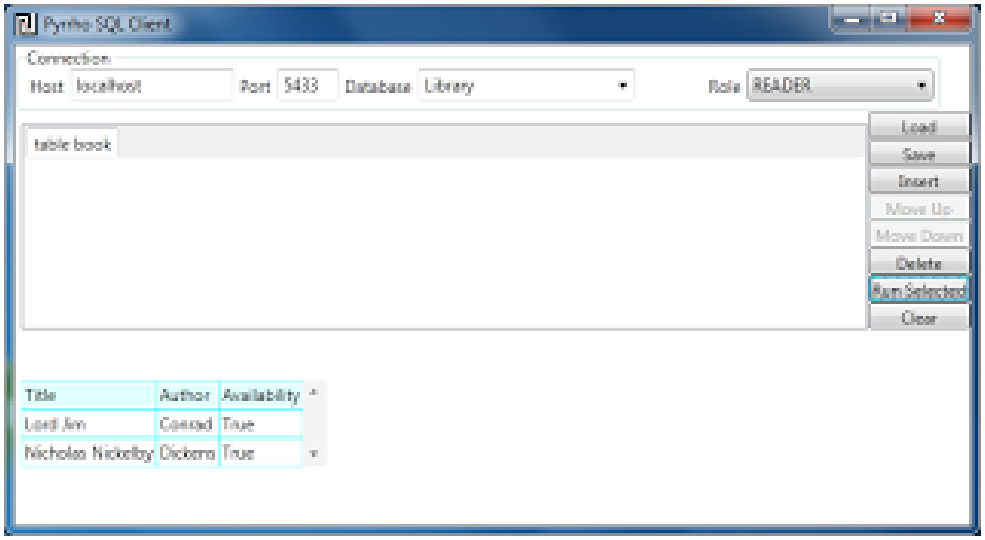


create role reader

grant select("Title","Author","Availability" on book to reader

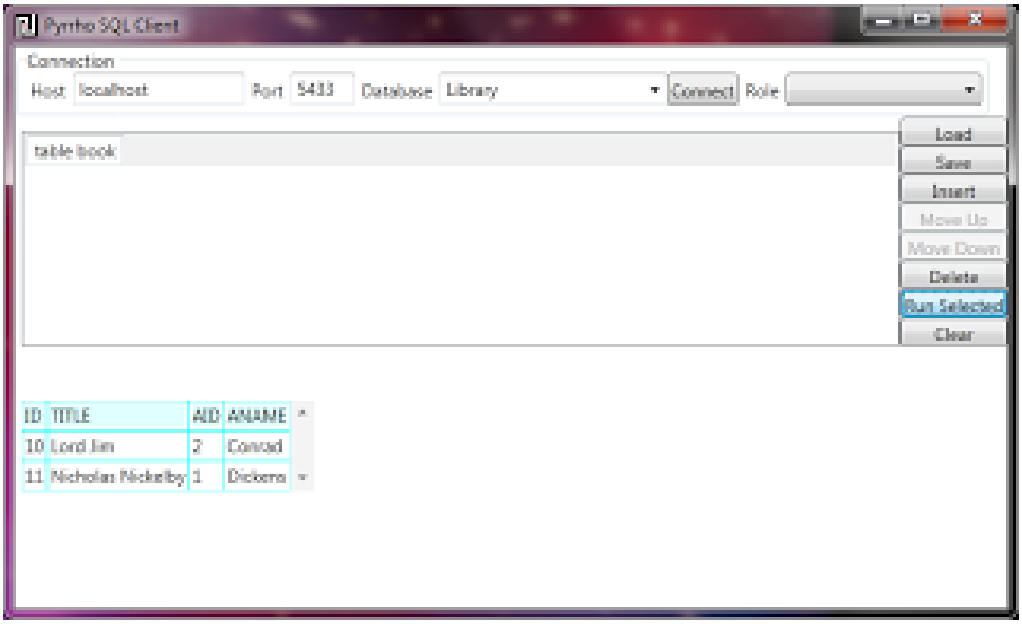


The only columns the Reader can see are the ones granted, so Reader can say simply "table book" to see these:

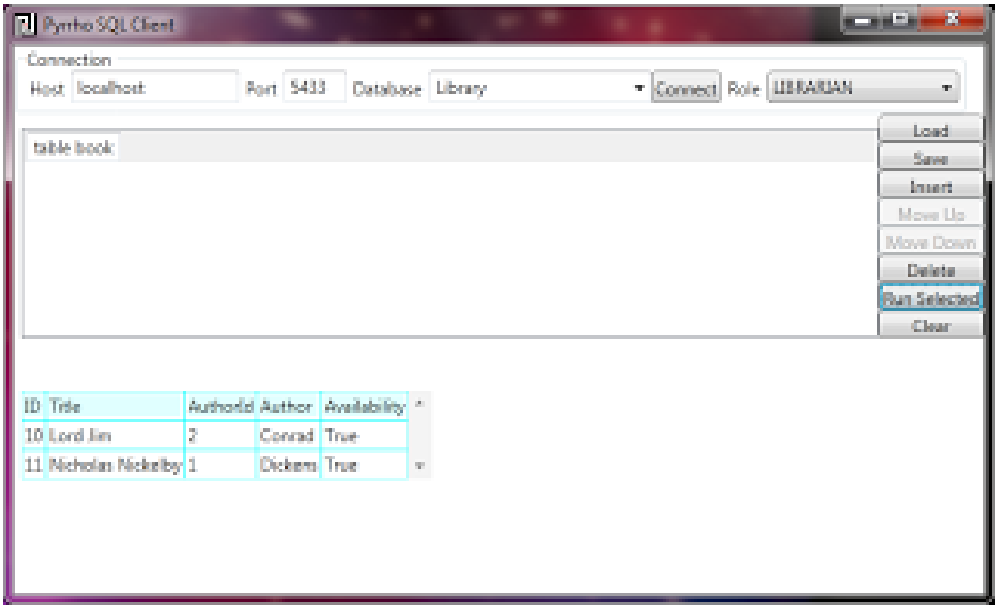


Note that the Author data comes from a table that is otherwise inaccessible to the Reader, because the generation rule uses “definer’s rights”.

Now this is how things stand. The database objects as viewed from the default “Library” role have not changed:



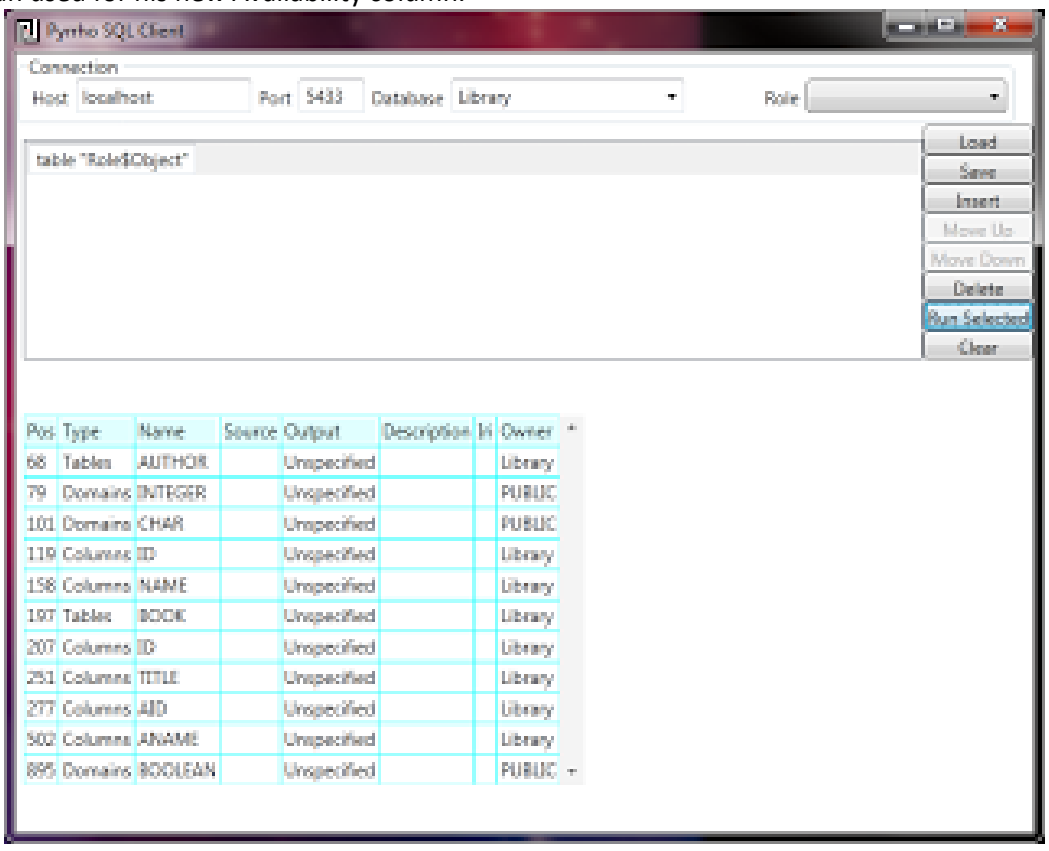
From the Librarian role we have:



and as we have seen the Reader does not see the numeric fields.

7.1 How the mechanism works

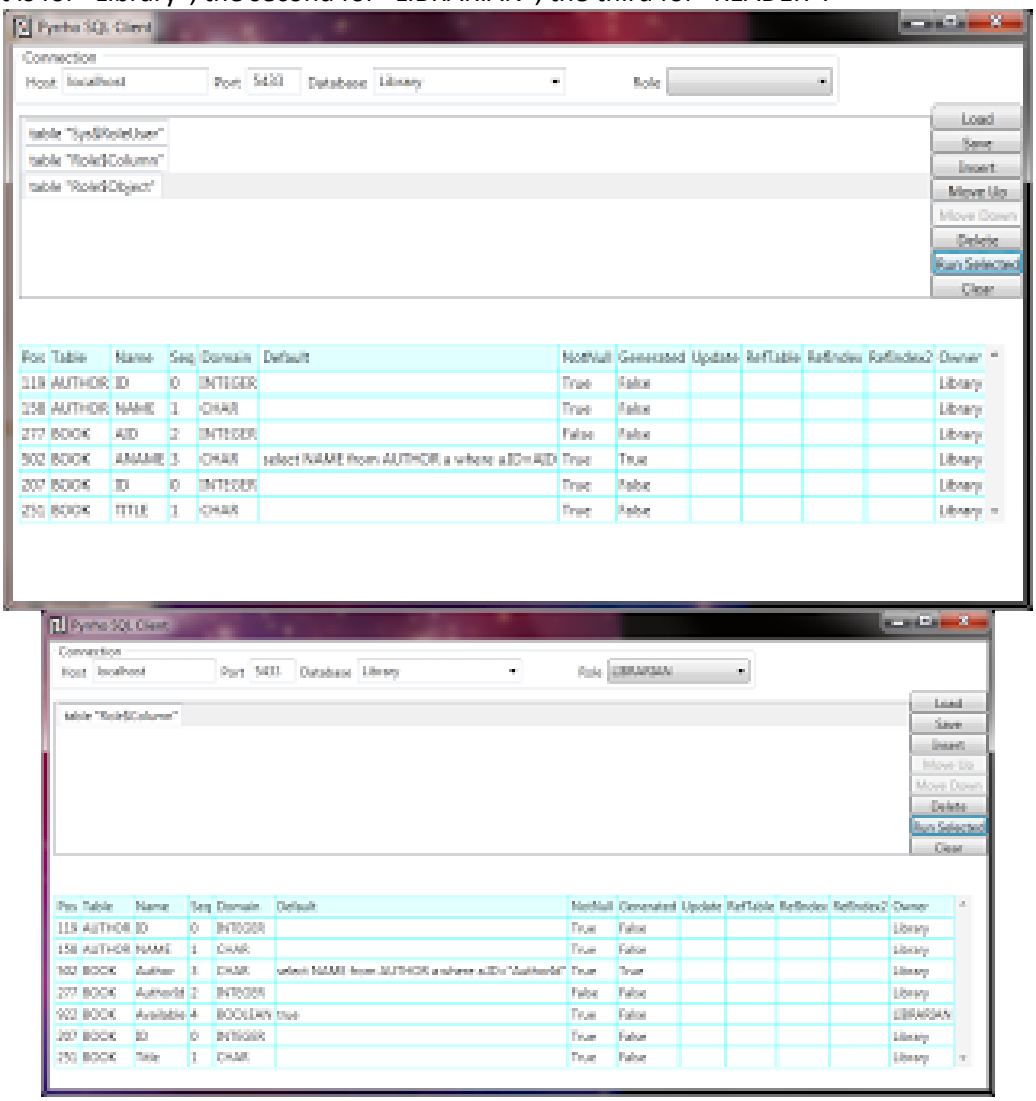
The database creator has set up the following objects in the Library database: tables AUTHOR(ID,NAME) and BOOK(ID,TITLE,AID,ANAME). In the "Role$Object" system table we can see these objects as owned by the default database role, and the PUBLIC standard types that have been used: INTEGER and CHAR as required for these tables, and the BOOLEAN standard type that the librarian used for his new Availability column.

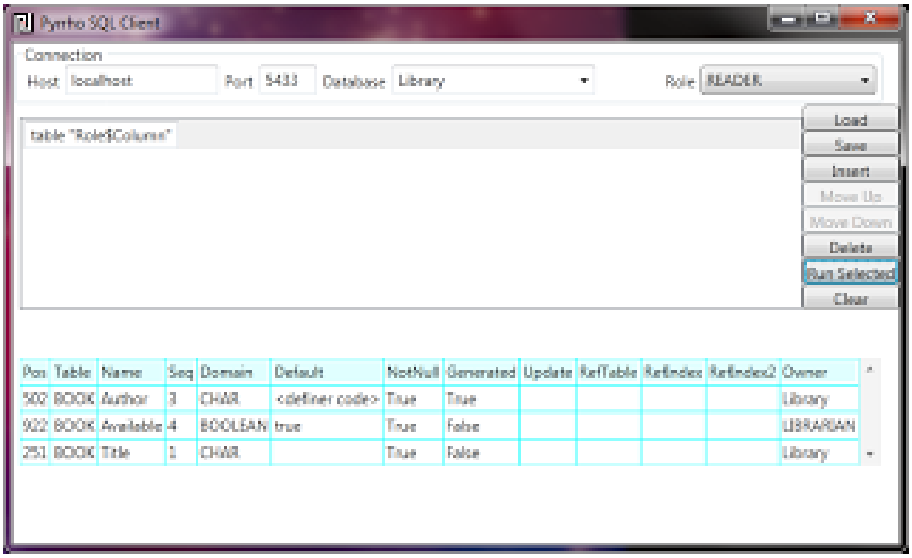


In this table we can also see that database objects can have other role-based metadata such as an output flag (this can be Entity or Attribute as we will see later), a human-readable Description, and an Iri for Web metadata.

In the corresponding tables for the other roles, we see different metadata for different sets of objects. The LIBRARIAN role renamed three of these objects, and defined the Availability column, and the READER role contains just a few entries. As at the end of the last blog posting, the database owner cannot use this role: it was created by the LIBRARIAN and had not yet been made public. Fred can get us the entries, and also make the role PUBLIC so anyone can use it.

Instead of looking at the Role$Object table for each role, let's instead look at the Role$Column table: the first is for "Library", the second for "LIBRARIAN", the third for "READER":

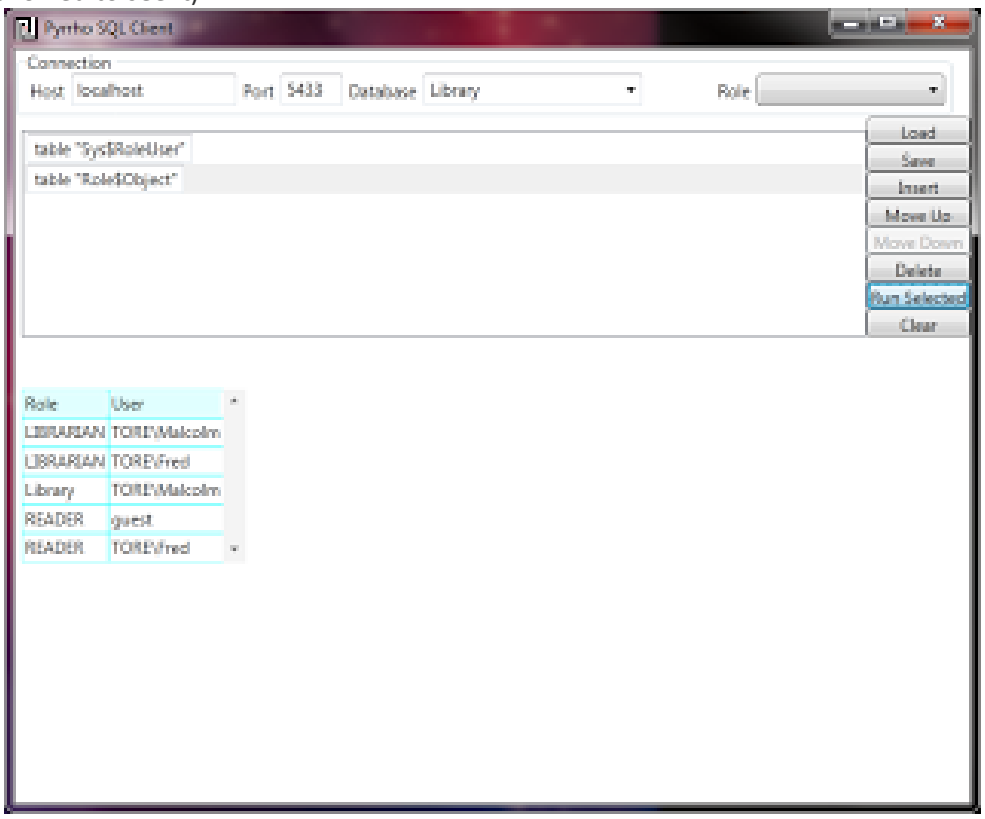




As expected, we see the librarian's column names in the second two tables. But the biggest difference is the way that the Default value for the ANAME or Author column is shown. None of these exactly matches the actual definition used (select name from author a where a.id=aid). The first screenshot shows the identifiers capitalised, the second uses the LIBRARIAN's name Authorid for the AID column, and in the third the code cannot be displayed, since the READER role does not know about the AUTHOR table. In fact, Pyrrho uses numeric identifiers internally (select "158" from "68" a where a."119"="277"), and, if possible, displays the code appropriately for the viewing role.

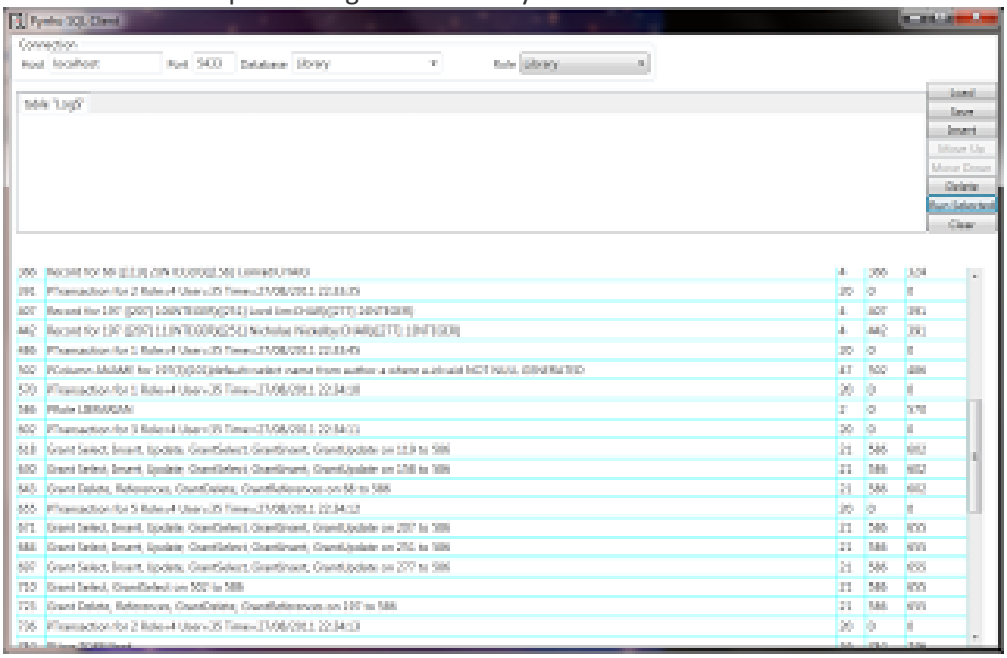
There are four blank columns in these tables Update can specify a set of actual assignments to be carried out if a generated column is assigned to. The next three columns are used for reverse relationship navigation and are specified using Pyrrho's new REFLECTS syntax.

Let's examine the list of users allowed to login to roles (this Sys$RoleUser table looks the same from any role allowed to see it):



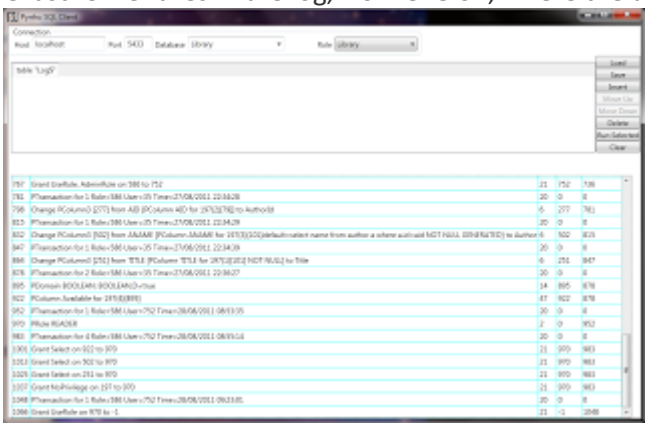
"guest" appears in this list because Fred has ordered "grant reader to public". Finally in this section I'd like to show some entries from what the database file actually contains. These are from the Log$ table.

The first shows where I create the LIBRARIAN role and grant all privileges on table AUTHOR with grant option. I'd have liked to crop this image to show only the lines from 570 to 643:



We can see that both these transactions are by Role=4, which is the default role for the database (always the first database object to be created). User=35 is TORE\Malcolm, the database creator. So role Library is defining the librarian role. Granting all privileges on the AUTHOR table, unless it is restricted to a particular set of columns, implies granting all privileges on all the columns too. And "all privileges" means all the privileges held by the grantor, in this case also all of the grant options. So the single SQL statement has been expanded into three Grant records in the database. 586, as we can see, refers to the Librarian. Generally, log entries refer to database objects by number rather than by name. Pyrrho has always done this because objects can be renamed. The mechanism now works really well for role-based naming, so that the new version is backwards compatible with existing Pyrrho databases.

The second extract is the last few entries in the log, from 878 on, where the user is Fred:



Here the user is Fred, and the role is LIBRARIAN. The transactions correspond to the four SQL statements:

```
alter table book add “Available” boolean default true
create role reader
grant select(“Title”,”Author”,”Available”) on book to reader
grant reader to public
```

The Grant NoPrivilege entry is probably not required, but at present it ensures that table BOOK (197) is entered in the namespace for READER (970). One other oddity in this list is where the “Avaialble” column is defined. The figures 197(4)[895] are for the table BOOK, the table’s owner, and the new column’s domain, which is a slightly odd collection of data to display in the Log entry (the table’s owner is not actually mentioned in the log entry).

7.2 Legacy Data

When importing tables from an existing database, it is good to take the opportunity for some minor redesign. For example, additional integrity constraints can be added, or data types can be simplified, for example by relaxing field size constraints. Keywords that imply such sizes, e.g. DOUBLE PRECISION, BIGINT etc are not supported in Pyrrho, which provides maximum precision by default. National character sets are deprecated since they make data locale-specific: universal character sets are used by default.

A more important area for attention is Pyrrho’s security model. This offers an opportunity for improving the security of the business process. Pyrrho’s default settings are that the database creator’s default role is the schema role, and this will generally allow all desired operations to be performed. But database administrators should take advantage of Pyrrho’s facilities here. Full details are given in Chapter 5, but the following notes provide an executive-level overview of the approach.

The first thing to note is that Pyrrho expects the operating system to handle user authentication so that there is no way for a user to pretend to be someone else: a custom encryption of the connection string is used to ensure this. There is an implicit business requirement to know which staff took the responsibility for data changes (corresponding to initials in former paper-based systems), and Pyrrho’s approach is that it is undesirable for the database management system to force anonymity on such operations by disguising the staff responsible behind a faked-up application identity.

This means that users of the database must be identified and granted permissions. Where the number of authorised staff is large, mechanisms for authorising new users can be automated. Generally it is useful to use the role mechanism to simplify the granting of groups of permissions to the users. Generally a role should be created with the same rights as each application in the legacy system.

Existing users and roles can be imported from the existing database: assuming users are identified in the existing database by their login identities. Where applications have been given user identities in the legacy system, this should generally be replaced by roles. Ideally each business process should have a role to enable associated database changes to be tracked. Each connection to Pyrrho is for a role, and this can enable a good record of the reasons for changes to data.

7.3 The REST service

By default Pyrrho will try to set up a REST service on ports http 8180 and https 8133, using Windows authentication. (You can supply your own server certificate for transport layer security and/or specify different ports.) Users who have not been granted roles in the database will be able to access public data.

From the viewpoint of this book the importance of considering these features here is that the results are delivered by the standard database engine, so that any updates will be subject to the same access control, constraint checking, triggers etc.

*proto***://***host*:*port*/d*atabase*/*role*{/Selector}{/Processing}

Selector matches[8]:

[table]*Table*_id

[**procedure**]*Procedure*_id [‘(‘ Parameters ‘)’]

[where]*Column*_id=string

[**select**]*Column*_id{,*Column*_id}

[**key**]string

of *Table*_id[‘(‘*Column*_id{,*Column*_id}’)’]

of *Table*_id[’(‘*Table*_id’)’]

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. The **of** keyword is used for reverse navigation of foreign key relationships, and for navigating many-many relationships: the column list if present is for choosing a foreign key or secondary table. See examples below.

Processing matches:

distinct [*Column*_id{, *Column*_id}]

ascending *Column*_id{, *Column*_id}

descending *Column*_id{, *Column*_id}

skip *Int*_string

count *Int*_string

The Http/https Accept and Content-Type headers control the formatting used. At present the supported formats are XML (text/xml), HTML (text/html, only for responses) and SQL (text/plain). The Pyrrho distribution includes a REST client which makes it easier to use PUT, POST and DELETE. A URL can be used to GET a single item, a list of rows or single items, PUT an update to a list of items, POST one or more new rows for a table, or DELETE a list of rows. Thus GET and POST are very different operations: for example, POST does not even return data. All tables referenced by selectors must have primary keys.

For example with an obvious data model, GET http://Sales/Sales/Orders/1234 returns a single row from the Orders table, GET http://Sales/Sales/Orders/Total>50.0/OrderDate/distinct returns a list of dates when large orders were placed, GET http://Sales/Sales/Orders/OrderDate,Total returns just the dates and totals, GET http://Sales/Sales/Orders/1234/of OrderItem returns a list of rows from the OrderItem table, and GET http://Sales/Sales/Orders/1234/CUST/Customer/NAME returns the name of the customer who placed order 1234. The response will contain a list of rows: if HTML has been requested it will display as a table (or a chart if specified by the Metadata flags, sec 7.2). Using HTML will also localise the output for dates etc for the client. Metadata can also specify XSL transforms so that simple business objects can be generated directly by Pyrrho.

PUT http://Sales/Sales/Orders/1234/DeliveryDate with text/plain content of ((date’2011-07-20’)) will update the DeliveryDate cell in a row of the Orders table. PUT content consists of an array of rows,

[8] The optional keywords here are less restrictive than might appear: In this syntax views and tables can be used interchangeably, so that the keyword **table** if present may be followed by a view. Similarly, the keyword **procedure** if present may be followed by a function call.

whose type must match the rowset returned by the URL. If the array has more than one row, commas can be used as separators. XML format can also be used, which should match the data format returned by the URL.

POST http://Sales/Sales/Orders will create one or more new rows in the Orders table. In Pyrrho an integer primary key can be left unspecified. In SQL (text/plain) format, column names can be included in the row format, e.g. (NAME:'Fred',"DoB":date'2007-10-22'): if no names are provided, all columns are expected. Remember that the REST service is case-sensitive for database object names. XML format can also be used, in which case column values for the new row can be supplied either as attributes or child nodes irrespective of the data model. A mime type of text/csv has been added to facilitate import from Excel spreadsheets.

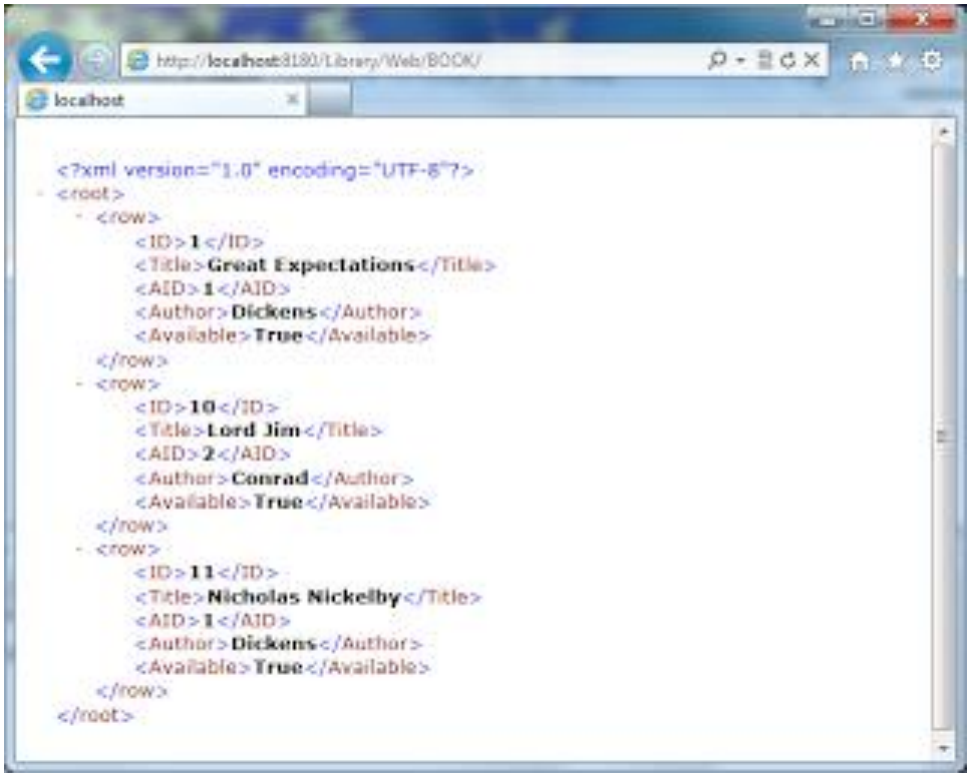
If no Selector or Processing components are provided, the target is the Role itself. For this target GET returns a set of C# class definitions for POCO use, as described in section 3.6.

There are some extra columns in the Log$ table: the record type, a related previous log entry if any, and the start of the transaction.

For simplicity we will continue to use the example database from the last two postings, with the following additional steps. These create a new role "Web" with read-only access to the tables, and some metadata for XML formatting of the output. The details are given at the end of this section. For now let's just consider GET actions. (As we will see in the next posting, one simple way of handling moderate security for PUT, DELETE and POST is to grant Insert, Update and Delete to a role with a hard-to-guess name.)

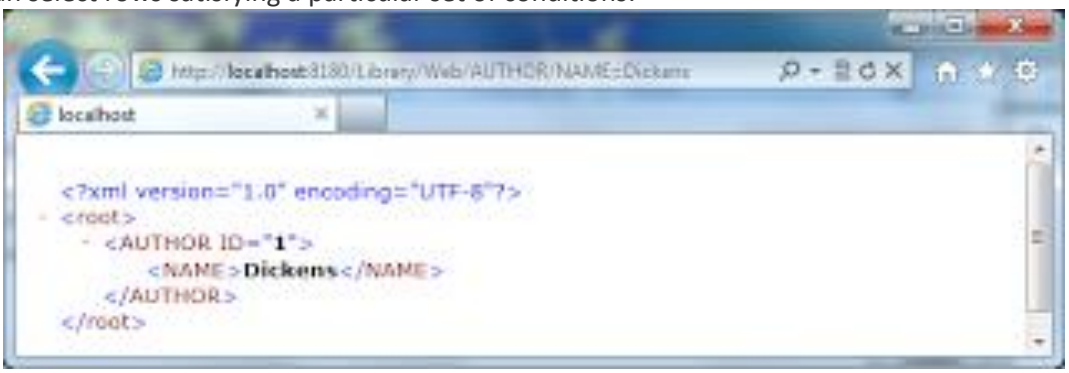
We can use REST to explore the Web role of the database:

For the Author table, AUTHOR has been declared as an entity, and ID has been declared as an attribute, so the output has a different form:



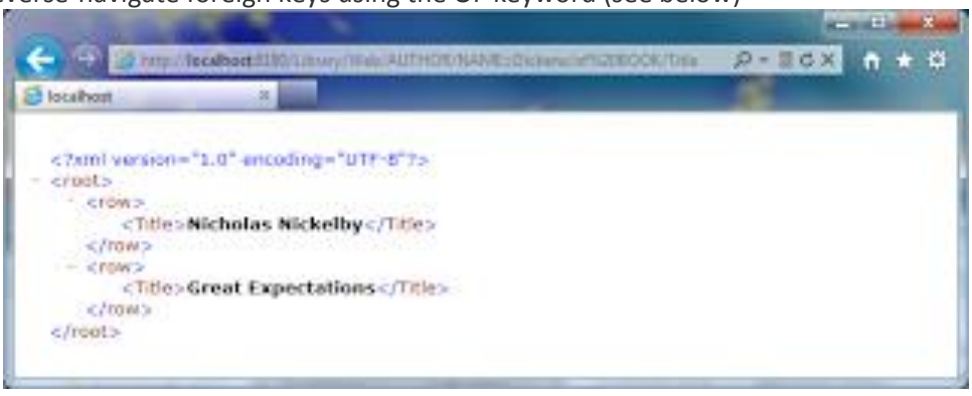
We can limit the output to particular columns:

We can select rows satisfying a particular set of conditions:



We can navigate foreign keys:

We can reverse-navigate foreign keys using the OF keyword (see below)



The relationship of this Library database to the one in the section 7.1 is (approximately) as follows:

In role Library:

```
Create role "Web"
Grant select on author to "Web"
Grant select on book to "Web"
Insert into book(title,aid) values('Great Expectations',1)
```

In role "Web":

```
Alter table author entity
Alter table author alter id attribute
```

7.4 Data Visualisation and CSS

The system table Role$Object shows the metadata defined for database objects. Some of these are for control of Pyrrho's Web services.

In particular, Pyrrho offers some simple charts that can be obtained via the Web services.

The Metadata flags and the string "constraint" are Pyrrho extensions., Attribute and Entity affect XML output in the role, Histogram, Legend, Line, Points, Pie (for table, view or function metadata), Caption, X and Y (for column or subobject metadata) affect HTML output in the role. HTML responses will have JavaScript added to draw the data visualisations specified. The string is for a description, and for X and Y columns is used to label the axes of charts. If the table's description string begins with a < it will be included in the HTML so that it can supply CSS style or script. If the table's string metadata begins with <? it should be an XSL transform, and Pyrrho will generate and then transform the return data as XML.

Chapter 8 – Web semantics and OWL

According to W3C, "In addition to the classic 'Web of documents' W3C is helping to build a technology stack to support a 'Web of data,' the sort of data you find in databases… The term 'Semantic Web' refers to W3C's vision of the Web of linked data. Semantic Web technologies enable people to create data stores on the Web, build vocabularies, and write rules for handling data. Linked data are empowered by technologies such as RDF, SPARQL, OWL, and SKOS."

A new version of the SPARQL standards was published in 2013, and also RIF RDF and OWL compatibility. I was one of the early implementers of SPARQL 1.0 and quickly found the non-intuitive rules for value equality a real turn-off, and made querying an RDF database a total nightmare. As far as I can see, the same problems remain, and there are so many reasons for values not to be equal that ad-hoc queries are always unlikely to yield expected results.

That said, the ambitions of the semantic Web remain exciting:

- Precise, unique URIs can be associated with content items: the associations may be direct (assigned by someone) or inferred. For example, a web site that hosts a URI might also host a starting set of associations using that URI.
- The same content may be associated with multiple URIs by different people or to highlight different aspects of the content. For example, a web site that hosts a URI might also host a starting set of related URIs which in turn can be associated with it through other URIs.

Using these two observations we can see how semantic relationships can lead to knowledge discovery in the parts of the web where such associations have been recorded. However, only a small proportion of the World Wide Web uses these semantic notations.

Try http://www.cambridgesemantics.com/en_GB/semantic-university/semantic-web-design-patterns .

The closest analogue to such semantic associations in DBMS comes from the notion of data type, as the next few sections indicate.

8.1 URIs: first steps

A URI may look like a URL, so that many URIs are constructed for uniqueness by starting with an organisation's domain name. However, the disadvantage of having a widely used URI is that the domain name may be accessed rather often, and a way to avoid your web server being overloaded is to use a domain name for uniqueness, but change the protocols part to something other than http: (e.g. urn:). The term IRI is also used for an international URI: IRIs allow a wider character set, but the distinction between URI and IRI is gradually being lost now that all UNICODE characters are allowed in URLs.

A common notation to indicate a URI is to enclose it in pointy brackets, e.g. <http://abc.com/a#unit> . This is called an absolute URI . URIs with common initial segments form XML namespaces. For example, we could have a namespace all of whose URIs begin with http://abc.com/a . We might define a shorthand to save us repeating this part. In XML we can add an attribute of form xlmns:a="http://abc.com/a#" and then an element with name a:thing would be defined in the namespace at <http://abc.com/a#thing> . Prefixes introduced in this way in XML take effect from the start of the element that contains such an attribute (so the xlms attribute in this case might be in an element named a:thing). xmlns= can be used to define or redefine the blank or default namespace.

There are similar facilities for defining namespaces in SQL.

8.2 OWL Types

SQL2011 (like SQL2003) differed from older DBMS's by having a stronger system of data types. For example, user defined types have methods and constructors, and ordering functions can be declared.

Pyrrho has built on this system by including support for OWL types. For convenience and best results, IRIs identifying OWL types can be added to domain and type definitions e.g.: the following is accepted as SQL by Pyrrho:

```
create domain watts as real^^units:"watt"
```

provided that "units" has been previously defined (for example, with Pyrrho's create xmlnamespaces statement). Adding an IRI in this way creates a subtype or subdomain (of real in this case), and informs Pyrrho how to deal with values of the new domain. The OWL namespace prefixes and standard types are predefined in Pyrrho. Pyrrho does not use semantic reasoning, so, for example, will not know of the relationship between kilowatts and watts (or of watts and amps).

Pyrrho supports OWL literal syntax, e.g. "2.37"^^watts (or "2.37"^^units:"watt") is a valid literal of the above domain. Note the use of double quotes for such literals: double quotes normally create identifiers, but the ^^ syntax gives a literal. The type following the ^^ can be a domain name as here or take the OWL forms units:"watt" or <http://sweet.jpl.nasa.gov/1.1/units.owl#watt> . Note that @ is a special character in OWL string literals, which Pyrrho interprets as introducing a collation.

However, it is much more convenient to allow abbreviations for units so that '2.37 W' would also be allowed. The formal syntax for the representation part here is StandardType [UriType] where UriType is defined as [*Abbrev*_id]^^(*Prefix*_id:id|uri). A uri in this syntax is delimited with <>. The namespace prefix must be one of the standard namespaces given above (see XmlOption syntax), have been previously defined in the database using the CREATE XMLNAMESPACES statement, or declared in a preceding XmlOption.

The provision of an abbreviation is enough to specify a default parser for a new Domain. The parser will use the underlying type and the supplied abbreviation, and the abbreviation is allowed either before or after the value. For example, if the above domain definition was modified to

```
create domain watts as real "W"^^units:"watt"
```

where units stands for http://sweet.jpl.nasa.gov/1.1/units.owl# , then allowable literals would include both "2.37"^^units:"watt" and '2.37 W' . Note the different use of respectively double and single quotes here, and the optional white space in the string (single-quoted) version.

When adding rows or assigning values involving such types, values of the correct subtype should be provided, or expressions with compatible base types explicitly coerced to match the declared type of the column or variable (so that in the above example the real literal 2.37 could not be used to give a value for a column declared as type watts). In cases where a value is already a subtype of the required type, the subtype information is retained and even persisted in the database. For value expressions the TREAT function can be used to coerce a value to a subtype, and in Pyrrho, the ^^ notation can be used as a shorthand for this (e.g. (a+b)^^watts).

Otherwise Pyrrho's type system is as in SQL2011 with the following changes (a) char and char(0) indicate unbounded strings; int, int(0), integer and integer(0) indicate 2048-bit integers (see example in the section above); and real has a mantissa of 2048 bits by default; (b) size-specific standard types

such as bigint or double are not supported; (c) persisted data is not changed by subsequent changes to column datatypes as long as it is coercible to the new type.

To explain the last point, suppose a table has a column of type numeric, and contains values with (say) up to 5 signifanct digits. Suppose now the table is altered so that the column is numeric(3). At this point all new values will be truncated on insertion, and all existing values will be truncated on retrieval, so that the table appears to contain values with a maximum of 3 significant digits. Now suppose the data type is changed back to numeric. Now the old data with 5 significant digits is visible once more, but of course the data inserted when the data type was numeric(3) will only have 3 significant digits. A case could be made that this behaviour is incorrect. But it helps to avoid accidental loss of data.

8.3 IRI references and subtypes

Semantic information (from provenance or some other source) can be used to define a subtype, for example, a Pyrrho extension to SQL2011 allows declarations such as:

CREATE DOMAIN ukregno AS CHAR^^<uri://carregs.org/uk>

Subtype information can be examined using the standard SQL2011 type predicate, for example

SELECT * FROM cars WHERE reg IS OF (ukregno)

Pyrrho allows the ^^ notation from OWL/RDF as a way of assigning an OWL type, so that a value of type ukregno can be inserted in cars by writing

INSERT INTO cars VALUES (1,”TEA 123”^^ukregno)

Note the use of double quotes, as in OWL, instead of single-quotes as in SQL. The type information following the ^^ can be an iri, or an iri expression using a namespace (e.g. dvla:”reg”, or a domain identifier as here.

Namespaces can be managed in the database using the CREATE XMLNAMESPACES syntax, e.g. CREATE XMLNAMESPACES ('http://dvla.gov.uk/types.owl#' AS dvla, DEFAULT 'http://abc.com/t.owl#') . Note the use of single quotes to match the standard SQL2011 syntax for WITH XMLNAMESPACES. The default namespace is referenced by using a blank prefix, e.g. ^^:m .

The same notation can be used in expressions as a shorthand for a TREAT expression:

UPDATE cars SET reg=reg^^ukregno WHERE country=’UK’

8.4 Row and table subtypes

In an INSERT operation, whole rows or tables can be assigned a subtype using the TREAT function. A structured type can be declared with additional uri information, such as

CREATE TYPE t AS (c CHAR, b INT)^^<http://a.com>

Then supposing table A had been created with a compatible row type, such as CREATE TABLE(c CHAR,b INT), we could write either of the following equivalent forms:

INSERT INTO A TREAT (VALUES (‘Ex’,1)) AS t

INSERT INTO A VALUES (‘Ex’, 1)^^t

The type of a row can be tested using the ROW keyword, e.g. ROW IS OF(*type*) .

8.5 Provenance

In Pyrrho, provenance information can be associated with transactions and INSERT operations:

BEGIN TRANSACTION WITH PROVENANCE iri

INSERT WITH PROVENANCE iri INTO t VALUES(data)

Potentially, therefore, each record in a database could have two items of provenance information: one specific to the record, and one specific to the import transaction. If both are specified, the record iri should have the form of a relative iri.

A pseduocolumn PROVENANCE was also added so that queries can retrieve or select on the provenance information, and the value in this pseudocolumn is the result of concatenation of the transaction and record provenances if any, or the uri associated with a row subtype. These features are preserved for backwards compatibility and convenience.

8.6 Interationalisation

In SQL, for the convenience of users, time values without specified time zones are assumed to be local. This approach is easy to criticise: after all, the client and server are frequently in different time zones. Accordingly, in Pyrrho any time value without a specified timezone is assumed to be coordinated universal time (UTC) and this is how it is stored in the database.

DateTime

SQL specifies its own special syntax for dates and times, but on output from the database, Pyrrho uses the operating system's regional settings, and/or the conventions of the target language (such as C#) to represent the datetime.

Keyword	**Meaning**
YEAR	Year
MONTH	Month within year
DAY	Day within month
HOUR	Hour within day
MINUTE	Minute within hour
SECOND	Second and possibly fraction of a second within minute
TIMEZONE_HOUR	Hour value of time zone displacement
TIMEZONE_MINUTE	Minute value of time zone displacement

There is an ordering of the significance of <primary datetime field>s. This is, from most significant to least significant: YEAR, MONTH, DAY, HOUR, MINUTE, and SECOND.

The <primary datetime field>s other than SECOND contain non-negative integer values, constrained by the natural rules for dates using the Gregorian calendar. SECOND, however, can be defined to have a <time fractional seconds precision> that indicates the number of decimal digits maintained following the decimal point in the seconds value, a non-negative exact numeric value.

There are three classes of datetime data types defined within this part of ISO/IEC 9075:

- DATE — contains the <primary datetime field>s YEAR, MONTH, and DAY.
- TIME — contains the <primary datetime field>s HOUR, MINUTE, and SECOND
- TIMESTAMP — contains the <primary datetime field>s YEAR, MONTH, DAY, HOUR, MINUTE, and SECOND.

Items of type datetime are comparable only if they have the same <primary datetime field>s.

Intervals

There are two classes of intervals. One class, called *year-month* intervals, has an express or implied datetime precision that includes no fields other than YEAR and MONTH, though not both are required. The other class, called *day-time* intervals, has an express or implied interval precision that can include any fields other than YEAR or MONTH.
A year-month interval is made up of a contiguous subset of those fields.

Keyword	Meaning
YEAR	Years
MONTH	Months

A daytime interval is made up of a contiguous subset of those fields.

Keyword	Meaning
DAY	Days
HOUR	Hours
MINUTE	Minutes
SECOND	Seconds and possibly fractions of a second

The actual subset of fields that comprise a value of either type of interval is defined by an <interval qualifier> and this subset is known as the precision of the value.

Within a value of type interval, the first field is constrained only by the <interval leading field precision> of the associated <interval qualifier>.

Keyword	Valid values of INTERVAL fields
YEAR	Unconstrained except by <interval leading field precision>
MONTH	Months (within years) (0-11)
DAY	Unconstrained except by <interval leading field precision>
HOUR	Hours (within days) (0-23)
MINUTE	Minutes (within hours) (0-59)
SECOND	Seconds (within minutes) (0-59.999...)

Localisation and collations

Pyrrho uses the character set names as specified in SQL2011. Specifying a character set restricts the values that can be used, not the format of those values. By default, the UCS character set is used.

By default, the UNICODE collation is used, and all collation names supported by the .NET framework are supported by Pyrrho. CHAR uses standard culture-independent Unicode. NCHAR is no longer supported and is silently converted to CHAR. UCS_BINARY is supported.

The SQL2011 standard specifies a locale-neutral interface language to the server, for example using a locale-independent format for dates in SQL statements.

Pyrrho maintains this, with locale-neutral database files. From this viewpoint, localisation is a matter for client configuration, since once dates, currency amounts etc are being displayed in the client, the client application will use the UI properties set in the client's operating system.

Some areas of localisation are notorious: no two people in Scotland will agree on how to sort the names Mabon, Mackay, MacKay, McKay, Macdonald, McDonald, MacDonald, M'Donald, Martin, and the placement of names starting with de, or the treatment of double surnames in Spain, present well-known problems.

The Unicode reports (http://www.unicode.org/reports/tr10/) give examples including conventions for orderings based on accents, whether case is considered, or punctuation, or combination characters.

Fortunately, the makers of operating systems have solved these problems for us, with satisfactory libraries to associate acceptable behaviours with a given locale. While the result will not please everyone, at least it will be consistent across a large number of applications written for that operating system.

Thus, ordering of strings on the server side (for example with the SQL ORDER BY clause), will need to be informed about the locale context for the strings being sorted. The SQL standard assumes that the collation to use is defined for each table, or within a given SQL statement or expression. In designing localised applications, programmers need to select the right combination of server side settings to give an entirely satisfactory localised experience.

At the server side, views and updatable generated columns provide opportunities for localisation, which can be targeted by defining roles for specific locales. With the help of the role-based models in Chapter 7, a role with the Chinese locale (for example) could see Chinese names for tables and columns, and there could be role-specific “generated always” columns that defined Chinese versions of informative messages for a user application. The localised version of the application would then attach to the appropriate role and use the appropriate column to get the localised resources for the application. This could be a very powerful tool to add to the localisation mechanisms available in ASP.NET for example.

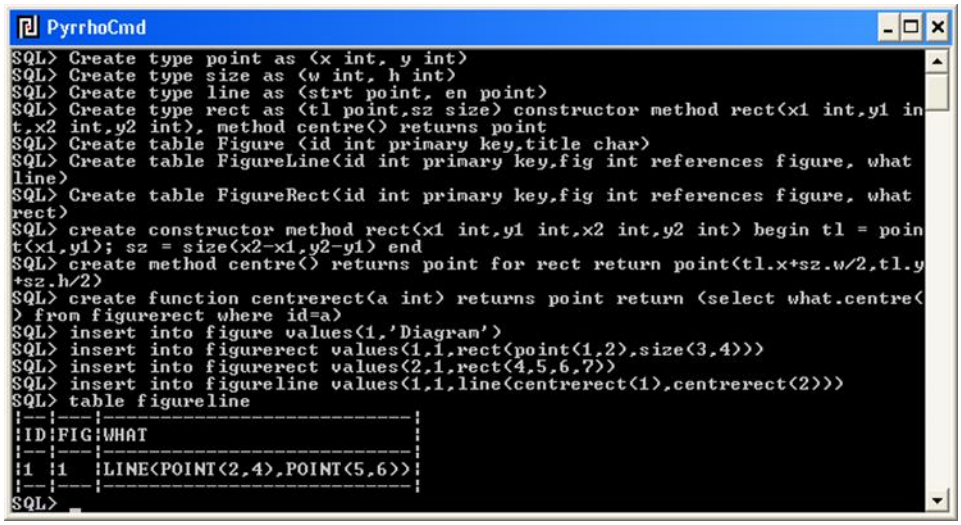
There are evident gaps in this provision. For example, it could be a property of a role to set the locale, so that the collations used for ordering string data are set by default to match the role’s locale.

8.7 Using structured types

Structured types, multisets and arrays can be stored in tables. There is a difference between (say) a table with certain columns, a multiset of rows with similarly named fields and a multiset of a structured type with similarly named attributes, even though in an element of each of these the value of a column, field or attribute respectively is referenced by syntax of the form a.b . Some constructs within SQL2011 overcome these differences: for example the INSERT statement uses a set of values of a compatible row type to insert data into a table, and TABLE v constructs a table out of a multiset v. The type model in Pyrrho allows user-defined types to be simple or structured, they can define XML data types (e.g. for RDF/OWL use) have an associated URI and constraints.

To use structured types, it is necessary to CREATE TYPE for the structured type: this indicates the attributes and methods that instances of the type will have. Then a table (for example) can be defined that has a column whose vales belong to this type. At this stage the table could even be populated since (there is an implicit constructor for any structured type); but before any methods can be invoked they need to be given bodies using the CREATE METHOD construct. Note that you cannot have a type with the same name as a table or a domain (since a type has features of both).

Values of a structured type can be created (using a constructor function), assigned to variables, used as parameters to suitably declared routines, used as the source of methods, and placed in suitably declared fields or columns.



(Note that the coordinates have been declared as int, so the first point here is not (2.5, 4)).

Arrays and multisets of known types do not need explicit type declaration. Their use can be specified by the use of the keyword ARRAY or MULTISET following the type definition of a column or domain.

You can define ordering functions for any user-defined type. Ordering functions can simply specify equality, or allow < and > comparison (FULL). The ordering function can specify a relative ordering, in which case the corresponding routine takes two parameters of the udt, and returns -1, 0 or 1. A mapping ordering function defines a numeric value for each value of the udt which can then be compared. The other option you can specify (STATE) merely tests for componentwise equality.

8.8 Stored Procedures and Methods

In SQL2011 the syntax :v is not supported for variable references, and instead variables are identified by qualified identifier chains of form a.b.v . The syntax ? for parameters is not supported either.

In SQL2011-2-11.50 we see that procedures never have a returns clause (functions should be used if a value is to be returned), and procedure parameters can be declared IN, OUT or INOUT and can be RESULT parameters. Variables can be ROW types and collection types. For functions, TABLE is a valid RETURNS type (it is strictly speaking a “multiset” in SQL2011 terminology). From SQL2011-2-6.39 we see that RETURN TABLE (queryexpression) is a valid return statement.

Here are some outlines of procedure statements specified in SQL2011-4 and supported in Pyrrho. Complete syntax summaries for Pyrrho are given in Appendix 6.

The operation of the security model for routines is rather subtle. All routines operate with definer’s rights by default, but access to them is controlled according to the current role.

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

create table book(id int primary key, authid int, title char)

...

create function booksby(auth char) returns table(title char)
    return table(select title from author a inner join book b on a.id =
    b.authid where aname = booksby.auth )
```

This example also shows that a routine body is a single procedure statement (possibly a compound BEGIN..END statement). If you use the command line utility PyrrhoCmd, very long SQL statements

such as the last one above can be enclosed in square brackets and supplied on several lines as described in section 1.7.

The above function can be referenced by statements such as

```
select * from table(booksby('Charles Dickens'))
```

The keyword `table` in this example is required by SQL2011-2(7.6).

However, methods of a structured type van have a returns clause.

8.9 Condition handling statements

The following condition handling apparatus (as specified in SQL2011) is also supported. The predefined conditions are SQLSTATE string, SQLEXCEPTION, SQLWARNING and NOT FOUND, but any identifier can be used . All of the following can appear where statements are expected, and handlers apply anywhere in the scope where they are declared.

DECLARE CONTINUE HANDLER FOR conditions statement

DECLARE EXIT HANDLER FOR conditions statement

DECLARE UNDO HANDLER FOR conditions statement

UNDO is defined in the SQL standard (04-4.8): it offers more fine-grained behaviour than rollback, as it merely removes any changes made in the scope of the handler.

SIGNAL condition setlist

Here the options for condition are SQLSTATE string or any identifier. The setlist allows a set of keywords defined n the SQL standard, corresponding to items in the diagnostics area. For example, you can pass a reason in the diagnostic area using the MESSAGE_TEXT keyword.

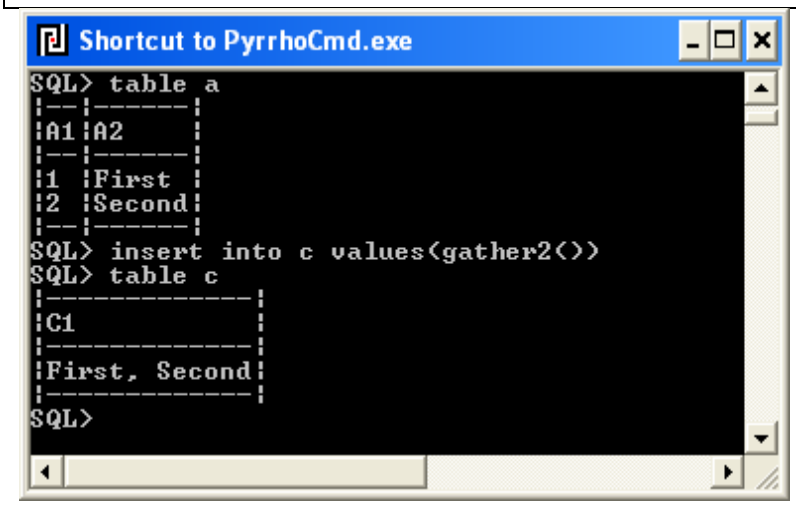
Examples

The following functions perform the same task. The first uses a handler, while the second uses a for statement.

```
create function gather1() returns char
begin
  declare c cursor for select a2 from a;
  declare done Boolean default false;
  declare continue handler for sqlstate '02000' set done=true;
  declare a char default '';
  declare p char;
  open c;
  repeat
    fetch c into p;
    if not done then
      if a = '' then
        set a = p
      else
        set a = a || ', ' || p
      end if
    end if
  until done end repeat;
  close c;
  return a
```

```
end
```

```
create function gather2() returns char
begin
  declare b char default '';
  for select a2 from a do
      if b='' then
            set b = a2
      else
            set b = b || ', ' || a2
      end if
  end for;
  return b
end
```



Chapter 9: Distributed Databases

For reasons of availability, security, governance and purpose it is often useful to consider distributed databases, that is, situations where several physical databases act as a single one. The database servers should handle all of the details, so a database client should simply contact any of them with a query that can naively ignore the distribution issues.

The different physical databases might hold different tables, or some tables might be partitioned vertically (by columns) or horizontally (with some rows being held in different fragments), or both. For vertical partitioning, the columns making up the primary key are usually common to all partitions. For horizontal partitioning, the fragments are usually based on elements of the primary key (for example, data from different countries might be in different partitions).

Data may also be replicated on multiple servers for increased availability.

Needless to say, all such arrangements require significant management overhead by the DBMS, so that a lot of care is needed to ensure that the benefits gained outweigh the costs.

It must be assumed that authentication is handled in some coordinated way, so that all of the database servers can agree on who is allowed to access the data, and what they are allowed to do. Secondly, the roles of the different servers must be established. Some servers may simply act as agents, forwarding requests to other servers and/or combining the results from other servers, some may process SQL queries against database tables held locally or on other servers, some may provide read-only copies of tables, some may control transactions of some data held locally, etc.

9.1 Distributed transactions

Pyrrho, like other DBMSs, supports many aspects of such distributed database configuration, and naturally is extremely strict about preserving ACID properties even for distributed databases. Provided clients always access the same database server, all the guarantees from Chapter 3 and the associated analysis hold good.

Unlike most other DBMSs, Pyrrho has many fewer issues over database locking. Transactions that change data managed by more than one transaction master will take longer, as a version of three-phase commit is required, but the database remains accessible (snapshot isolation) while this is going on. Unfortunately, however, the durability of the changes now depends on the survival of more than one durable storage installation. If a disaster occurs, then any copy of a physical database file can be used to restore the service as of the date the copy was made, but it is possible for copies of different parts of a distributed database not to be fully in synch if this happens. For this reason, Pyrrho records all distributed transactions in a special way in the log, so that if a database is cold-started (a rare occurrence in production environments) it checks every participant in distributed transactions to ensure that all the records agree.

If a fully ACID database is widely copied and distributed we will easily find consistent but possibly slightly out-of-date copies. This might be totally satisfactory for our purposes. We need to ensure only that we consistently use the same copy. Accessing the transaction master might make a marginal improvement in the currency of the data, but there may be a gigantic transaction about to be committed in the transaction master, and isolation means you don't see the impending changes.

If we want to be sure our data is correct, we can check with the transaction master by committing a read only transaction. However the person who wants to do this should be warned that there is no guarantee that the data won't be changed immediately thereafter and before he can do what he plans to do next. So it's better only to worry about such matters when actually making a change: we read, and then commit a change. If the change works, then the data on which it was based is still valid.

With distributed transactions, several transaction masters will be involved. Since there is no locking, the fact that the commit takes longer does not affect other readers, but does delay the writer. The transaction commit will only succeed when all the participants commit, but then it is guaranteed durable. The write is held up a bit but is then safe.

9.2 Dynamic Configuration

Each server has its own folder for holding databases (although full pathnames can be specified for databases). The configuration database (if any) is found in this folder and is called _ ,. It contains tables with names starting with _. The basic schema of _ is hardwired in the server engine so that _ is created the first time the server owner alters a configuration table.

By default the configuration tables are empty: databases that are not mentioned in the configuration tables are local databases, and we know about no other servers. In this way we already have an API for configuration (namely SQL/ADO.NET) and we conform to Codd's rule that SQL should be the DDL for the DBMS.

Configuration tables holding server data are automatically partitioned so that each _ database only holds information for data managed by that server instance, and is the transaction master for its own data. Thus any change to properties of remote servers is handled as a remote update – the Pyrrho protocol already supports this. It turns out that the provision for verification of distributed transactions is exactly what is required to guarantee consistency of the information held by different servers.

When the server starts up it should load the _ database if present. What will be new is a more elegant handling of the situations where servers are unavailable: obviously this should mean that their databases and partitions are unavailable. Code exists in the server already for deferring distributed transaction verification and this is exactly what is needed for if and when the remote server comes online later. See also "Database dependency" below.

As of v 5.0, we will use the following schema for _:

_Client: (Server, Client, User, Password).

We locally store entries for which Server=us. This table is maintained automatically: don't update it. Passwords use Pyrrho's password type so are not readable. The user and password information enables access to the configuration database on the client.

_Database: (Name, Server, Password, ServerRole, Remote, RemoteUser, RemotePassword). (Remote, Server) references _Client. We locally store entries for which Server=us. Passwords use Pyrrho's password type so are not readable, but they must be supplied when this table is updated to enable server-server communication. The remoteuser and remotepassword information enable server-server access to the named database on the remote server. The password information enables access to the configuration database on the server.

_Partition: (Base, BaseServer, BasePassword, Table, PartitionName, PartitionServer PartitionServerConfigUser, PartitionServerConfigPassword, SegmentName, Column, MinValue, MaxValue, IncludeMin, IncludeMax).

Table and Column are positions in the base database: we understand that the partition database has appropriate entries in its schema and a mapping from the base positions. We locally store entries where BaseServer=us. If you create such an entry, Pyrrho automatically defines the table in the partition database, and makes a Partition1 record in the partition database that gives the server details. If the PartitionServer field is null, the partition is marked as dropped. The partition user and password are for server-server access from the base database: the base server password is a security precaution: it must match the base server's account. The PartName field enables a number of tableparts to be specified as being in the partition: each part can specify a number of column conditions.

Remember that _ is for distributed configuration information, and is not affected by connection-specific things such as creating or accessing non-configured databases. The current server's serverRole for non-configured databases will be 7 (local) and 0 (remote), but they are not entered in the configuration tables. No server is obliged to have complete information.

In the _Database table, Remote is null if ServerRole has bit 1 (Master), and otherwise references cause distributed transactions: e.g. a server providing query and/or storage only will usually list the master server as remote. If no master server is configured the database is read-only (this is not an error). However, at most one server can have the master role.

To change configuration information, the owner of the server account simply connects to the local _ database and modifies it. The information about other servers is read-only, although selects, joins etc show the overall information to the extent required for server-server communication (server roles and partitions). When changes are committed, affected databases are unloaded and a background process is started to reload them. Pyrrho does try to notify affected servers, using the same mechanism as for any update to a distributed database: this will be an area for continuing improvements.

Note, however, that the server passwords in the configuration tables are for enabling access from one server to another, using standard operating system security, for the accounts under which the servers have been configured to run. The partition base credentials enable access to the base database of the partition being configured. On a single server or in a single domain, it is quite likely that a single account and password will be used in all or most of the tables.

As a special case, the entry in the _Database table for a partition will have all 3 server roles and the remote information will be for the base server.

9.3 Auto-partition algorithm for _

Maintain a list D of servers mentioned in our part of the _ database. This list is called directServers in the code.

Maintain a list L of all servers mentioned in the distributed _ database. This list is initially constructed as follows: Add us to L, then for each server in L, add its D list, and containue until the list stops growing.

L is marked for resfresh after an update to _ . If any servers are offline, a background process retries the refresh L every 20 seconds.

Then to select from _ we merge the results of the query on each server in L. That is, From(x) is replaced by Union(From(x),Union(….).,From(x))..), similarly to other partitioned tables.

9.4 Connection Management

At the moment, the connection string names a "Pyrrho server" (default localhost), a Pyrrho port (by default 5433), and one or more databases, and assumes that its Windows user credentials will be understood by that server. That server, however, might have no local data and act merely as a client to other servers that can locate the data connections it really requires.

For now let's consider the linked notions of configuration, connections and transactions.

1. The server has a list of configured local and remote databases/masters/stores that it knows about, and it also allows local (unconfigured) databases to be accessed and created. At this stage (and for any newly defined database) initial loading occurs. For a full database this includes recreation of database objects such as indexes, for a master it includes verification of distributed transactions, for storage it includes syncing with the master if remote, and for a remote database it involves none of these things.
2. If any of these configured servers are offline, the server will retry in 10 seconds, and will continue to retry but the interval doubles on every retry.

3. When a client connects to (one or more) databases it supplies some extra information for that connection (user, role, and maybe other per-database stuff), and the server spawns a new thread for the connection, so that the connection is local to the thread. If streams are opened to remote servers then these will access a new connection thread on each remote server connected to. Thus the connection has a thread-local list of databases, tailored to the connection details. Complete isolation is maintained between threads (and therefore transactions). No changes are made to the global database list until commit (see below). Although all of the versions of the database share the same local or remote datafile changes are merely cached until commit, at which time only the transaction master actually writes new data to the datafile (other storage files are updated during sync).
4. If a database is partitioned there are two situations: (a) the connection is to the base database, and the partitions are silently added to the connection; (b) the connection is to a partition, and the base database is silently added to the connection.
5. Within the connection, there will be transactions: for each connected database there will be a corresponding localtransaction with its own evolving database schema and set of proposed changes. Distributed transactions affect all levels of the DBMS so even storage needs to be transacted.
6. Local transactions allow SQL queries in all cases too, such as examination of system tables, processing of new data (for databases and partitions), and new DDL (for databases only). For master and storage databases the set of objects may be limited – for example, for a storage database the system tables will be mostly empty although the log tables will be available. (This is useful for forensic examination of data files, crash analyses etc. since log data can still be filtered, joined between databases etc).
7. When a transaction finally commits both the connecteddatabase and global database lists are updated with the new versions of the databases involved, and the changes are loaded.
8. A localtransaction for the configuration database is rather special: when the transaction is about to commit the proposed changes are examined to see which ones affect other servers. If there are any such, the other server configuration databases are added to the transaction with the consequential, changes for them. If the changes involve configuring partitions, any data moves are added to the distributed transaction.
9. When the transaction finally commits, all databases where the server role has changed must be reloaded.

9.5 Database Dependency

If we need multi-database transactions, for example between a local database and a remote one, then we will create dependencies between them. Just because a database is remote doesn't mean we don't own it! So we should generally check that the relationship between them makes sense, and that one of the participants to a distributed transaction has not been restored to an earlier time.

On the other hand, in a world of distributed transactions there might be historical dependencies that no longer matter. Suppose originally database A was constructed on the basis of data in B, to the extent that updates to a table T were part of a distributed transaction that involved B. Does this mean that A cannot survive the destruction of B? Would it matter if T is dropped from A? The fact that A no longer cares about database B needs to be configured in the local information about A.

Certainly it makes for an unpractical situation if we cannot draw a line and say "take the contents of this table as given and don't enquire where it came from". After all, if a table is built by an application that has several connections open then the DBMS will have no knowledge about the transactional dependency. Just because we used a multi-database connection and SQL to create T need not create a database dependency.

9.6 Cooperating Servers

In this new design, obviously there is no central point of control (we regard domain user names and authentication as someone else's problem), and Pyrrho servers work co-operatively to provide support for distributed data of various kinds.

By default, a Pyrrho server will start by trusting the account that started it up and the machine it is running on. It will load the configuration database if present that tells it what its role is: if this database is not present, it assumes it is an isolated server, that is, it has Master, Storage and Query roles for any database that is opened. If the database is present then it can specify the roles that this server has for each of a number of databases. If the role is not the default Master+Storage+Query, then the local configuration database should also specify another server that will be trusted to help with that database, and optionally a set of credentials to use for that database.

If a database is partitioned, then the base server may be specified. If we are the base server, then a set of partitions we know about should be specified. For partitions on other servers we need connection information in the form host/port but not credentials as the current user credentials should work.

A server may have different roles for different partitions of the database. It will trust any host or domain mentioned in the configuration database. More than one server may be opened on a single machine or by a single user (on different machines).

If the server loads a database, and the checksum checks out, then users mentioned (in form domain/user or host/user) in the database will have their assigned permissions on this database. The user who requests a connection to the database if mentioned in the database, will have the assigned permissions; otherwise will have the permissions assigned to PUBLIC. This will also apply when the database is opened by a remote server. The request will be honoured if it comes from a trusted server and the named user account matches the one in the database (fragment). Trusted servers are trusted to pass user identities that are the result of a windows login (on the Web a STS): connection strings and other connection management information is always encrypted. As of v4.x Pyrrho does not encrypt normal database traffic: I think in v5 we should allow for SSL connections for this, and make use of the SecureString class internally when appropriate.

Now if the database is opened remotely or is partitioned, the assumption is that the user identities in the database make sense somehow to any access of the database, i.e. the connection string potentially mentions users who are mentioned in the database. So for example, any user connecting to the database should be entitled to some access to all fragments. At least, the server they connect to should be able to validate their access: thus any Query role server must be able to authorise users. If a Pyrrho server succeeds in loading a database for the Query role, this means that it has succeeded in gaining access to all the fragments needed, and that there is an agreed list of trusted servers.

Any request is trusted only if the effective user identity is in the relevant database and has the relevant permissions.

This analysis already leads to some new ideas: that establishing the Query role for a database will be checked when the database is loaded or reloaded.

If someone accesses a partitioned table in the base database, we should assume that they intend to access all of the partitions: so we should extend the connection to all of the partitions.

9.7 Transaction implementation

Pyrrho's transaction design is actually very well suited to sharing cloud storage between database engines, because its transaction serialisation handling is performed at the level of the binary records ("Physical"s) that are written to the durable storage when a transaction commits. Pyrrho uses

optimistic locking, which is also very well suited to use with cloud storage, since it would be a bad idea to have an exclusive lock on the Cloud service.

For a proper understanding of the mechanism, it is necessary first to mention that the tree and queue data structures managed in the Logical Database layer have the property that all their elements are immutable: any change results in a new head structure, and following links through new components of the data structure usually leads to components of the original structure.

So, at the start of a transaction, new headers for the database(s) involved are created, which initially lead to the current committed state: if a few transactions are in progress, there will be several versions of the database(s), mostly coinciding (on unchanged portions). The changes associated with the transaction each have a Physical which will be written to durable storage along with a descriptor of the transaction itself.

Whether such ongoing transactions conflict can be determined by examining just these Physicals. For example, two updates to the same row of a table will conflict, an insert in a table will conflict with dropping the table, etc. This means that transaction serialisation can be determined at the Physical Records level of the database.

There are two subtleties to the resulting design, which apply equally to local and remote storage. The first relates to relocation of Physicals, the second to transaction conflicts where reads conflict with changes.

The relocation issue arises because Pyrrho uses the (immutable) defining addresses of data in Physical records: so that for example a Column will refer to its parent Table by giving its defining address rather than its (mutable) name. For this reason a group of Physicals in a transaction are very likely to refer to each other using their positions in the data file. While transactions are in progress, nobody can tell which transaction will commit first, so the positions of Physicals in the data file are generally not known until the Commit succeeds. The physical layer of the DBMS therefore relocates the transaction to its final place in the data file.

The read-conflict issue is rather pedantic. Pyrrho uses a very strict concept of transaction isolation, and notes all data that a transaction reads. If any of this data changes before the transaction commits, Pyrrho will roll back the transaction. For example, if a transaction computes a value to insert in the database, it should be invalidated by changes to any values used in the computation. Pyrrho calls these ReadConstraints.

Similarly, referential constraints (called IndexConstraints in the code) must also be checked again at Commit time, in case another transaction has inserted a record with a conflicting unique key, or deleted a record that our transaction intends to refer to.

For this reason, the data used in the Commit process consists of the list of proposed Physicals together with sets of ReadConstraints and IndexConstraints. For a remote database. It is this collection of data, and not the final binary data, that must be sent to the remote master server for processing.

Unfortunately, we are left with the situation that serialisation must ultimately be decided by a single transaction master server. The most we can use the cloud for in transaction management is as an enterprise system bus, routing transaction streams to the transaction master. To ensure that we have read the most up-to-date version, we simply call commit: if it is not up to date, our transaction will fail, and re-running the query will get its new value.

Chapter 10: Partitioned Databases

Classically there are two sort of partitioning for relational databases, so-called vertical partitioning where a relational table has some columns provided by another database, and horizontal partitioning where the rows of a table are divided among different databases, usually on different servers.

In this chapter we deal with horizontal partitioning, and we will drop the word horizontal for now. Partitioned databases are actually a very special case of a connection is to several databases, as we will see.

10.1 Multiple database connections

There are three circumstances in which it is common for a database connection to reference more than one database file. These are for partitioned databases, master-slave database architectures, and access to remote data from mobile devices with their own database engine.

A feature of Pyrrho is the availability of the complete history of the database. This means that unless the steps taken in this section are adopted, ad-hoc tables constructed for data analysis and for other purposes will be persisted in the historical record. This is less of a nuisance than might appear: for example, dropping a table called Fred means that the table name Fred can be used subsequently for a new table – names of database objects only need to be currently unique, not historically unique. Nevertheless, if the historical record of the database becomes a source of pride, there can be some irritation that users are polluting this history with their ad-hoc tables.

Accordingly, Pyrrho has a facility to connect to several databases at once. New database objects such as tables created during such a session will be added to the first-named database, while objects in the other databases remain accessible subject to the permissions that have been granted to the user. Connections can be opened and closed for very little cost, since the database file is only fully processed the first time the server accesses it.

For example, a connection list is of form “Files=A,B,C,D”, would be appropriate for a connection for performing some sort of data analysis on database D, using tools stored in database C, where database B contains partially-completed analyses, and database A is being used for temporary results that will be deleted at the end of a session. Database B can be archived and a fresh analysis database constructed for the next period of analysis, while the tools in C are kept under revision for future use, separate from the live database D. By default only the first file in a connection can be modified using the connection (see section 2.8.3).

With this scenario, connections of form “Files=D” would be used for normal business operations on D, connections of form “Files=C,D” would be used for adding new tool objects such as stored procedures or views useful for data analysis, and connections of form “Files=B,C,D” would be used to create the analysis tables. B and C would probably not be usable on their own. The ordering of files is the search order when resolving names of database objects. In the absence of name conflicts, “Files=A,C,D,B” would be no different to “Files=A,B,C,D”.

With the use of operating system integrated user identities, the user identity can be expected to be valid in all databases involved in the connection. Roles are a different matter. Generally at most one of the databases will be modified in any transaction, and the Role string chosen for the connection should be the correct one for such a modification. It is not expected or required that role identifiers in different databases should match in any way.

There are some limitations on usage in such multi-database connections:

- All data definition, drop, and access control statements affect only the local database.
- Object integrity cannot create dependencies on other databases: generally, schemas must not contain references to other databases. This means, for example, that new referential constraints can only be specified where the referenced table is in the local database. On the other hand, subtypes (including uri-based subtypes) are constructed in the receiving database as needed when data from another database is inserted in the local database.

Data manipulation can affect all databases in the connection provided the connection string specifies this. It is relatively unusual for a single transaction in a multi-database connection to result in changes in more than one database (for example in the above scenario with four databases, at most one would be modified in any transaction). The occurrence of a transaction that modifies more than one database makes a permanent link between the databases since for example the transaction cannot be verified unless all the participating databases are online. By default Pyrrho verifies such transactions for consistency each time any of the participating databases is loaded, so that all participating databases must be available to the server (they may of course be remote). A database can be made known to the server through use of configuration files, or using a connection string that refers to all of the databases.

The use of multifile connections is particularly interesting for the embedded editions of Pyrrho, since it becomes possible to access dtabases on servers as well as on the local machine using a syntax of form file@host[:port[:user[:role]]] (e.g. main@myhost.com:5433:admin) to name the database file. From the above limitations, we recall that changes to remote data sources are disallowed, and in addition, data from different hosts must be obtained in different subqueries.

10.2 Partitioning a database

If a database becomes too large or too busy for the server(s) on which it is provided, an option is to partition it to create a “distributed database” (Ceri and Pelagatti, 1984). When the partitioning is done horizontally by selecting ranges of values of fields in the primary key (typically a multi-column primary key is used), the result is nowadays called “shared-nothing replication”. From October 2010, Pyrrho supports this architecture. Configuration files are used to specify the relationship between databases, partition files, and the partitioning mechanism (see section 10.3).

Since Pyrrho retains a historical record of the database, creation of a new partition is an event in this history. Each partition has its own database file. The complete database consists of a collection of database files, one of which (the “root”) has the same name as the database. All of the files agree on the initial part of the file, and effectively the collection of files form a branching tree-like structure. Each new partition starts out as a copy of a database file in the set, and a configuration file entry is added to specify its file name, the name of the (“base”) file it branches from, and the new partition key data for the table(s) it contains. Pyrrho servers only maintain indexes for the partition they have loaded, and so a cold start is required for the base file server(s). No data is shared between partitions (e.g. lookup tables will generally remain in the root file), apart from information contained in the logs.

When supplying the connection string for a partitioned database, the client must specify all of the database file partitions it wishes to connect to. A client can obtain this set dynamically from the root database (see section 8.1.8).

A connection that needs to refer only to the data in a single partition only need connect to that partition, but generally a multi-file connection will be required. For example, alteration to a table which references the base partition will require a connection that includes the base partition. Note that many cross-partition operations in the logs will be treated as cross-database transactions, and the server will try to verify coherence of the participating databases.

Schema information should be in the root database, so tables should be initially created there. A new partition can be configured to contain existing data: this data will then no longer be available in the base database. It is possible to add a new empty partitioned table to an existing partitioned database. Pyrrho servers can be configured to do this automatically in response to increases in database traffic.

10.3 Database Partitioning

Suppose that one of the tables on a database has so much traffic that it is worth while placing a part of it on a different server, and then this part should be chosen to minimise the number of transactions that access both parts of the table. Then single-partition transactions can be dealt with by the partition server, which is the transaction master for its data. It needs only to check with the base server only that the schema has not changed. Cross-server transactions will be slower. Schema changes need to be done in the base database so they can be notified to partitions: this includes ownership and permissions.

Database partitioning is configured using a single table ("_Partition") in the _ configuration database on the base database's server, and operates transparently to SQL clients. Thus some databases hosted on a server may be partitions; a partitioned table contains non-overlapping segments allocated to partitions, while the rest of its data remains in the base database.

Partition definition is independent of the definition of constraints such as primary and foreign keys, checks and triggers, but obviously the database designer needs to consider whether their operation will result in cross-partition traffic. In particular, traversing an indexed partitioned table will in general involve an n-way merge, and the checking of constraints that do not involve partitioning columns will result in broadcasts to all partitions.

This design allows dynamic reconfiguration of live databases. Each partitioned table contains a number of segments defined by 1 or more ValueBounds structures for particular columns. The columns used for partitioning should be indexed in the table. Currently the _Partition table has the following form:

```
_Partition: (PartitionName, PartitionServer, PartitionServerConfigUser,
PartitionServerConfigPassword, Base, BaseServer, Table, SegmentName, Column,
MinValue, MaxValue, IncludeMin, IncludeMax)
```

The table is indexed by (Base, PartitionName, Table, SegmentName, Column). It includes the credentials needed to create the partition(s) on the remote server but of course does not display these. The Column field can be a selector (dot-separated names) for accessing data within a document or user-defined structured type.

Each partition holds all rows in the configured partitioned tables that match the value bounds specified. For each table, the segments thus defined must be non-overlapping, and this property is checked at the end of a reconfiguration transaction. Accordingly, if several partitioning records in the configuration database are being changed, it is important to wrap the steps into an explicit transaction. The following reconfiguration transactions are supported: New Segment, Split Segment, Move Segment, and Delete Segment, so the sequence of steps must allow the group to be classified as one of these operations. Automatically, the process of commiting the resulting transaction will move records out of and/or into partitions as required.

The changes to the configuration database must be made on the base server by the owner of the base database (who must therefore have at lreast temporary permission to modify the base server's configuration database).

If a transaction changes data in more than one partition, a link between the two partitions is formed so that both partitions must be available for verification when the database is loaded. It is possible to place an entry in the configutaion database to mark a database as no longer relevant: this amounts to a guarantee that all related information has been deleted from all remaining databases, and prevents the verification of distributed transaction histories for this data.

10.4 Partition sequences

In some applications, such as messaging, records can be safely discarded once they have been processed. Pyrrho is not immediately suitable for such data, because transaction logs maintain a permanent record. However, the database partitioning concept can be used to achieve the same effect, as follows.

Let a base database partition define the table(s) used for messaging, and let these tables include a non-null date field. Then let ranges of dates define a new partition for these tables. The configuration file needs to specify the partitions currently in use: these can extend into the past and the future as may be convenient. An application adding a message only needs to connect to the current partition. An application accessing a message simply accesses the partition the message is in. Messages can be deleted once they have been processed. It is an optimised query to determine if a partition no longer contains any messages: this partition file can be deleted and the corresponding entry marked as no longer relevant in the configuration.

10.5 Managing Partitions

Database partition management is a transacted process. When the partition information changes this probably involves multiple rows in the _Partition table of the base server, so these should occur in explicitly transacted groups (each group preceded by Begin Transaction, and finished by Commit), so that Pyrrho can enforce validation (non-overlapping) at the end of each group, when it is also determined what records need to transfer between partitions or to/from the base database. Table segments should move in their entirety. Four situations are supported (for at most one base database at a time):

a. A new partition (or new table or segment for an existing partition) has been added without any changes to other partitions, and some records may transfer from the base database to the new partition.

b. One or more configuration rows for a partition P has been deleted. No updates to other rows: records affected will move to the base database.

c. Changes to other partitions that may now receive tables or segments from P.

d. Split of a single TableSegment: no records need to move between partitions.

It should be possible to design any change in partitioning as a sequence of these four steps. Note that movement of records happens after each validation step, so the transacted group only has to match one of the above.

References

Ceri, S.; Pelagatti, G. (1984): Distributed Database Design: Principles and Systems (McGraw-Hill)

Cheung, A., Arden, O. (2012): Automatic Partitioning of Database Applications, Proceedings of the VLDB Endowment, 5, p. 1471-1482

Codd, E. F. (1985) Does your DBMS run by the rules? *ComputerWorld* Oct 21, 1985.

Crowe, M. K. (2005): Transactions in the Pyrrho Database Engine, in Hamza M.H. (ed) Proceedings of the IASTED International Conference on Databases and Applications *DBA 2005*, Innsbruck, February 2005 (IASTED, Anaheim) ISBN 0-88986-460-8 ISSN 1027-2666, p.71-76, https://www.researchgate.net/publication/220984896_Transactions_in_the_Pyrrho_Database_Engine

Crowe, M. K. (2007): An introduction to the source code of the Pyrrho DBMS. *Computing and Information Systems Technical Reports*, **40**, University of Paisley. An updated version is included in the Pyrrho distribution as SourceIntro.docx.

Curino, C.; Jones, E. P. C.; Popa, R. A.; Malviya, N.; Wu, E.; Madden, S.; Balakrishnan, H.; Zeldovich, N. (2011): "Relational Cloud: A Database-as-a-Service for the Cloud." 5th Biennial Conference on Innovative Data Systems Research, CIDR 2011, January 9-12, 2011 Asilomar, California.

Elbushra, M. M., Lindström, J., (2014): Eventual Consistent Databases: State of the Art, *Open Journal of Databases* **1**, p.26-41, ISSN 2199-3459 http://www.ronpub.com/publications/OJDB-v1i1n03_Elbushra.pdf

Fernandez, E.B., Washizaki, H., Yoshioka, N., VanHilst, M. (2011): An Approach to Model-based Development of Secure and Reliable Systems, Availability, Reliability and Security (ARES), 2011 Sixth International Conference on , vol., no., pp.260-265, 22-26 Aug. 2011, doi: 10.1109/ARES.2011.45

Floridi, Luciano: Sextus Empiricus: The transmission and recovery of Pyrrhonism (American Philological Association, 2002) ISBN 0195146719

Fonseca, J; Vieira M,; Madeira H.: (2008) Online Detection of Malicious Data Access using DBMS Auditing, Proceedings of the 2008 ACM symposium on Applied Computing, Fortaleza, Brazil, p. 1013-1020

Frank, L. (2011); , Architecture for Integrating Heterogeneous Distributed Databases Using Supplier Integrated E-Commerce Systems as an Example, *Computer and Management (CAMAN), 2011 International Conference on* , pp.1-4, 19-21 May 2011, doi: 10.1109/CAMAN.2011.5778783

Garus, K. (2012): Version-Based Optimistic Concurrency Control in JPA/Hibernate, http://squirrel.pl/blog/2012/11/02/version-based-optimistic-concurrency-control-in-jpahibernate/

Guenther, J. (2012): Optimistic Concurrency in Entity Framework, http://it.toolbox.com/blogs/aspnet-development/optimistic-concurrency-in-entity-framework-50651

Haritsa, J. R., Carey, M. J., & Livny, M. (1990, December). Dynamic real-time optimistic concurrency control. In *Real-Time Systems Symposium, 1990. Proceedings., 11th* (pp. 94-103). IEEE.

IBM (2011) SolidDB v7.0 announcement, http://www-01.ibm.com/common/ssi/rep_ca/1/897/ENUS211-491/ENUS211-491.PDF

Iyer, S. (2009): New approaches to securing the database, *Network Security*, Volume 2009, Issue 11, November 2009, Pages 4-8, ISSN 1353-4858, 10.1016/S1353-4858(09)70120-5.

Kaspi, S., Venkataraman, S. (2014): Performance Analysis of Concurrency Control Mechamisms for OLTP Databases, *International Joiurnal of Information and Education Technology,* **4**, p. 313-318.

Kung, H.T., Robinson, J.T. (1981): On optimistic methods of concurrency control, *ACM Transactions of Database Stystems*, **6**, p. 213-226.

Laertius, Diogenes (3rd cent): The Lives and Opinions of Eminent Philosophers, trans. C. D. Yonge (London 1895)

Lessner, T., Laux, F., Connolly, T., Crowe, M. (2012): Transactional Composition and Concurrency Control in Disconnected Computing, *International Journal of Advances in Software*, **4**, p.442-460.

Mensacé, D. A., Nakamishi, T.: Optimistic versus Pessimistic ConcurrencyControl Mechanisms in Database Management Systems, *Information Systems* **7**, p.13-27

Moorthy, M. K., Seetharaman, A., Mohamed, Z., Gopalan, M., & San, L. H. (2011). The impact of information technology on internal auditing. *African Journal of Business Management*, *5*(9), 3523-3539.

Moreau, L. (2010): *The foundations for provenance on the Web*, (Now Publishers Inc)

Oh, S., Park, S (2003): Task-role-based access control model, *Information Systems* **28**, p.533-562.

Ouyang, X., Nellans, D., Wipfel, R., Flynn, D., Panda, D.K. (2011), Beyond block I/O: Rethinking traditional storage primitives, *High Performance Computer Architecture (HPCA), 2011 IEEE 17th International Symposium on* , pp.301-311, IEEE, doi: 10.1109/HPCA.2011.5749738

Raab, F., Kohler, W., Shah, A. (2001): Overview of the TPC-C benchmark: The Order-Entry Benchmark, Transaction Processing Performance Council. www.tpc.org.

SQL2011: ISO/IEC 9075-2:2008 Information Technology – Database Languages – SQL – Part 2: Foundation (SQL/Foundation); ISO/IEC 9075-4:2008: Information Technology – Database Languages – SQL – Part 4: Persistent Stored Modules; ISO/IEC 9075-14:2008: Information technology — Database languages — SQL — Part 14::XML-Related Specifications (SQL/XML) (International Standards Organisation, 2011)

SWI-Prolog, www.swi-prolog.org.

Thomson, A., Diamond, T., Weng, S. C., Ren, K., Shao, P., & Abadi, D. J. (2012, May). Calvin: fast distributed transactions for partitioned database systems. In *Proceedings of the 2012 ACM SIGMOD International Conference on Management of Data* (pp. 1-12). ACM.

Tozun, P., Porobic, D., Branco M. (2012): Transaction Processing, http://dias.epfl.ch/OLTP

Wust, J., Boese, J. H., Renkes, F., Blessing, S., Krueger, J., & Plattner, H. (2012, October). Efficient logging for enterprise workloads on column-oriented in-memory databases. In *Proceedings of the 21st ACM international conference on Information and knowledge management* (pp. 2085-2089). ACM.

Appendix 1: Using ADO.NET for various databases

In this lab we review simple database application development using C# and ADO.NET.

In each case we will use a simple sporting club as a model. For simplicity we will work with an individual sport such as table tennis or squash.

Member: (id int primary key, firstname char, surname char) .

Played: (id int primary key, playedon date, winner int references member, loser int references member, agreed Boolean) .

If all of the players are able to modify this database they may well be problems with people putting in incorrect details in the played table.. For now we simply focus on writing simple programs that access and modify this data.

The details of the above description will change a bit as we work with different DBMS. You will need to install Visual Studio C# or Professional, which you can get from DreamSpark. These notes assume Visual Studio 2012 but really they are all very similar.

A1.1 MySQL

We begin with MySQL. I downloaded the web community installer from http://www.mysql.com/downloads. Choose the options for development. There is no need to download Connector/NET separately.

Start up the MySQL Command Line Client. On the VM provided on our Hyper-V server, the password is MySQL_123.

```
mysql> create database mydatabase;
mysql> use mydatabase;
mysql> create table member (id int primary key, firstname varchar(20), surname varchar(20));
mysql> insert into member values(56,'Fred','Bloggs');
mysql> insert into member values(78,'Mary','Black');
mysql> select * from member;
mysql> create table played  (id int primary key, playedon date, winner int references member, loser
int references member, agreed boolean);
mysql> insert into played values(32,'2014/1/9',56,78,false);
```

Now that we have a database and some tables, let's construct a database application that accesses it. I made sure I had a folder called C:\Temp, and then created a Visual C# Windows Forms Application in this folder called club.

1. I added a reference to Extensions>MySQL.Data and used the Toolbox to place a Data>DataGridView in the Form1 window. Ignore the prompt to Choose Data Source.

In Solution Explorer, right-click Form1.cs and choose View Code. Add

```
using MySql.Data.MySqlClient;
```

near the top, and inside the public partial class, add

```
MySqlConnection conn = null;
MySqlDataAdapter ad = null;
```

2. After InitializeComponent(); add (using your user name and password)

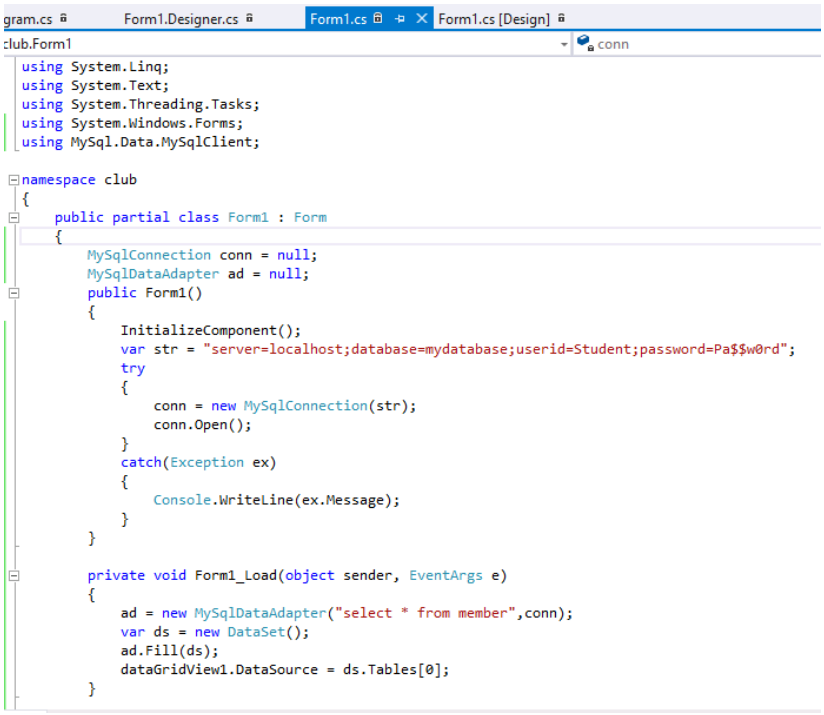
```
var str = "server=localhost;database=mydatabase;userid=root;password=MySQL_123";{
```

```
        try {
        conn = new
MySqlConnection(str);
        conn.Open();
        } catch(Exception ex) {
        Console.WriteLine(ex.Message);
        }
```

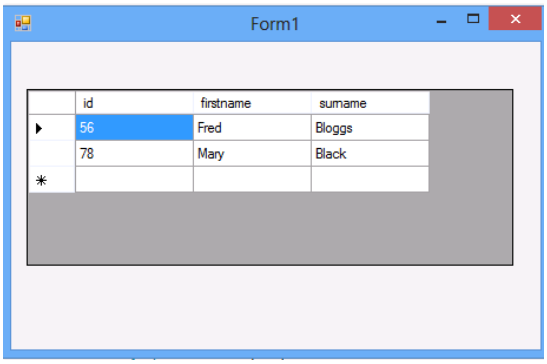
Now, we need to add two events to the program.

3. With the design view of Form1.cs, left-click the form, then select the events tab in the Properties window, and double-click Load. In the code window, place the following code inside the Form1_Load method:

```
ad=new MySqlDataAdapter(“select *
from member”,conn);
var ds = new DataSet();
ad.Fill(ds);
dataGridView1.DataSource = ds.Tables[0];
```



4. Try out the program: you will see the data in the Members table, though you may want to fix the sizes of the data grid and window and try again.



You will be able to change the data on screen, but in order to update the database, you need a second event handler.

5. Close the program and go back to the design view. Click the datagridview and find the RowValidated event in the Properties window. Double-click it and add the following code in the handler:

```
var dt = dataGridView1.DataSource as DataTable;
var ch = dt.GetChanges();
if (ch!=null)
{
        var cb = new MySqlCommandBuilder(ad);
        ad.UpdateCommand =
cb.GetUpdateCommand();
        ad.Update(ch);
        dt.AcceptChanges();
}
```

```
private void dataGridView1_RowValidated(object sender, DataGridViewCellEventArgs e)
{
    var dt = dataGridView1.DataSource as DataTable;
    var ch = dt.GetChanges();
    if (ch != null)
    {
        var cb = new MySqlCommandBuilder(ad);
        ad.UpdateCommand = cb.GetUpdateCommand();
        ad.Update(ch);
        dt.AcceptChanges();
    }
}
```

6. Let’s demonstrate some other coding things you can do. Add a textbox and a ComboBox to the form. Populate the combobox from the database table (you can do this any time, e.g. after you change the database):

```
comboBox.Items.Clear();
var cmd = new MySqlCommand(“select * from member”, conn);
var rdr = cmd.ExecuteReader();
while (rdr.Read())
```

```
        comboBox1.Items.Add(rdr[1]);
```

7. Click the datagradview1 and double-click the SelectionChanged event. In the event handler add the following code

```
if (dataGridView.SelectedCells.Count>0)
        textBox1.Text = dataGridView1.SelectedCells[0].Value.ToString();
```

8. Declare a class

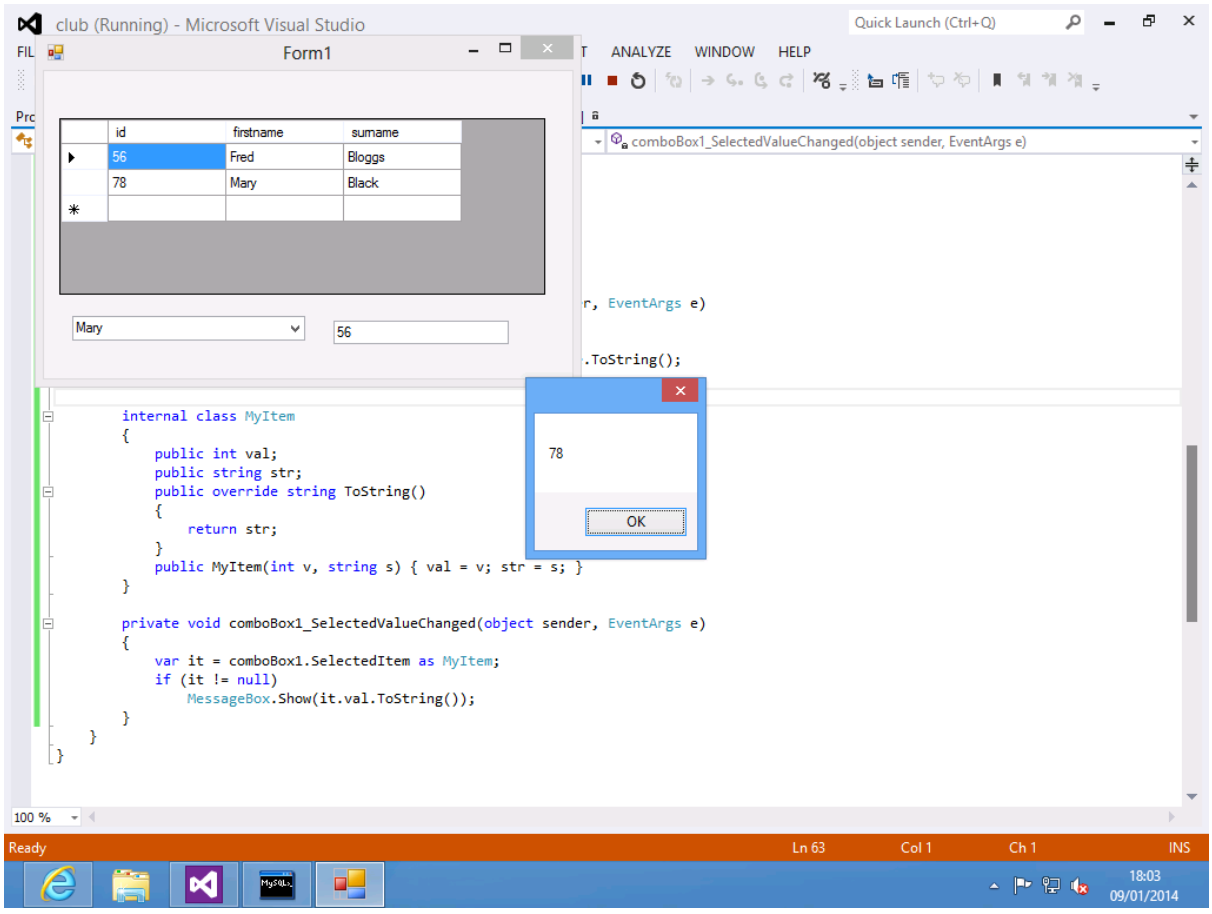
```
internal class MyItem
{
        public int val;
public string str;
public MyItem(int v,string s) { val=v; str=s; }
public override string ToString() { return str; }
}
```

9. Change the comboBox1.Items.Add line above to

```
comboBox1.Items.Add(new MyItem((int)rdr[0],(string)rdr[1]));
```

10. In the designer, click the combo box and double-click the SelectedValueChanged event. In the handler give the code

```
var it = comboBox1.SelectedItem as MyItem;
if (it!=null)
        MessageBox.Show(it.val.ToString());
```



A1.2 Using SQL Server Compact Edition

1. You can use the local database bundled with Visual Studio as a kind of SQL Server lite. Create a new Windows Forms application with Visual Studio. Right-click the Project in Solution Explorer and then Add>New Item.., click Data, select Local database, DataSet and then confirm opening of the empty database.
2. View Server Explorer, and expand the connection to the new database, right-click Tables and select Create Table. In the New Table dialogue, give the table name as Member, add the columns we want and set the Primary Key. Similarly create the Played table (for the Boolean field use bit).
3. Create the foreign key references by opening the Table Properties and selecting Add Relations, Give WinnerFK as the relation name, and select winner as the Foreign Key Table column. Add Columns, then Add Relation and confirm. Repeat for loserFK, and click OK to close the dialogue. (Note the default action is NO ACTION, which is ridiculous.)
4. To place data in the tables, right-click the tables and select Show Table Data. When you enter the date in the playedon field, the date format is dd/mm/yyyy (the other way round from MySQL).
5. Now double-click the Database1DataSet and drag the Members table onto it.
6. This time, when you add the DataGridView, click Choose Data Source, and browse down to get Database1DataSet>Member.

If you now view code you will see that a member table adapter already has been configured to load the data into the DataGridView.

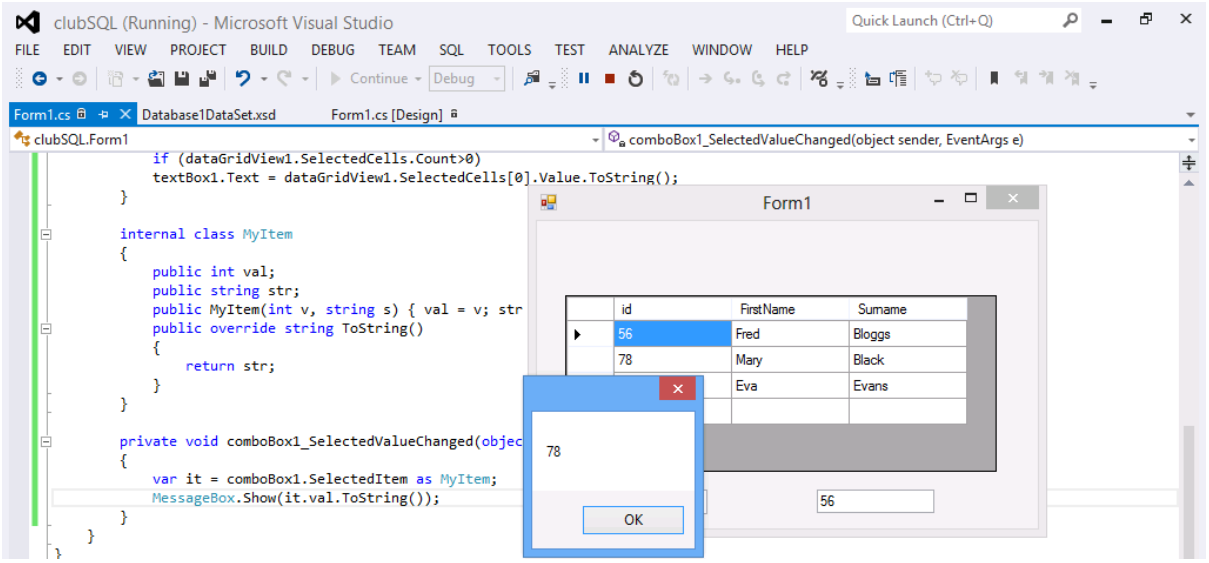
7. As before, we need to implement a way of updating the database. This time, the code we want in RowValidated is

```
memberTableAdapter.Update(database1DataSet.Member);
```

8. Once again I add the two gadgets we had in the last tutorial: a textbox and a combobox. The code of the textbox is identical to the previous time.
9. For the comboBox, we can set up the Items as follows:

```
comboBox1.Items.Clear();
var rdr = database1DataSet.CreateDataReader();
while (rdr.Read())
        comboBox1.Items.Add(rdr[1].ToString());
```

10. We can modify this as before to get the key values for an item.



A1.3 Using SqlServerCe with basic ADO.NET

The above example used fancy classes such as data adapters (and so did the MySQL example). These classes have been added to the frameworks to assist with DataGridView, a rather complex beast. With Windows Presentation Framework, ASP.NET, and mobile platforms, we tend to use simpler classes, as in this example. For fun, let's use WPF, which does not have DataGridView.

Create a WPF project and add a local database to it as before. If you right-click the database in the server explorer and select Properties, you will see that the Connection String is something like Data Source=C:\Temp\clubWPF\Database1.sdf.

In the Toolbox you will see a DataGrid, but just for fun let's work with Grid instead. There is a Grid on the design surface. Click in the top edge of the Grid to make some columns. Select the Events tab in the properties window and double-click Loaded.

Look to see what has happened to the XAML. Find the Grid, and set its Name="members".

Add using System.Data; and using System.Data.SqkServerCe; at the top of the code file, and declare fields for the connection string and connection inside the class as we did for MySQL.

```
string str;
SqlCeConnection conn;
```

In the MainWindow() method give the value of the connection string you found above (the @ tells C# not to interpret \ as an escape character), and open the connection:

```
str  =@" Data Source=C:\Temp\clubWPF\Database1.sdf";
conn = new SqlCeConnection(str);
conn.Open();
```

In the Grid_Loaded_1 method, give the following code:

```
var cmd = conn.CreateCommand();
cmd.CommandText = "select * from Member";
var rdr = cmd.ExecuteReader();
members.Children.Clear();
var nr = 0;
while (rdr.Read())
{
        var rd = new RowDefinition();
        rd.Height = new GridLength(1,GridUnitType.Auto);
```

```
            members.RowDefinitions.Add(rd);
            for (int j=0;j<3;j++)
                  AddBox(rdr,nr,j);
            nr++;
}
```

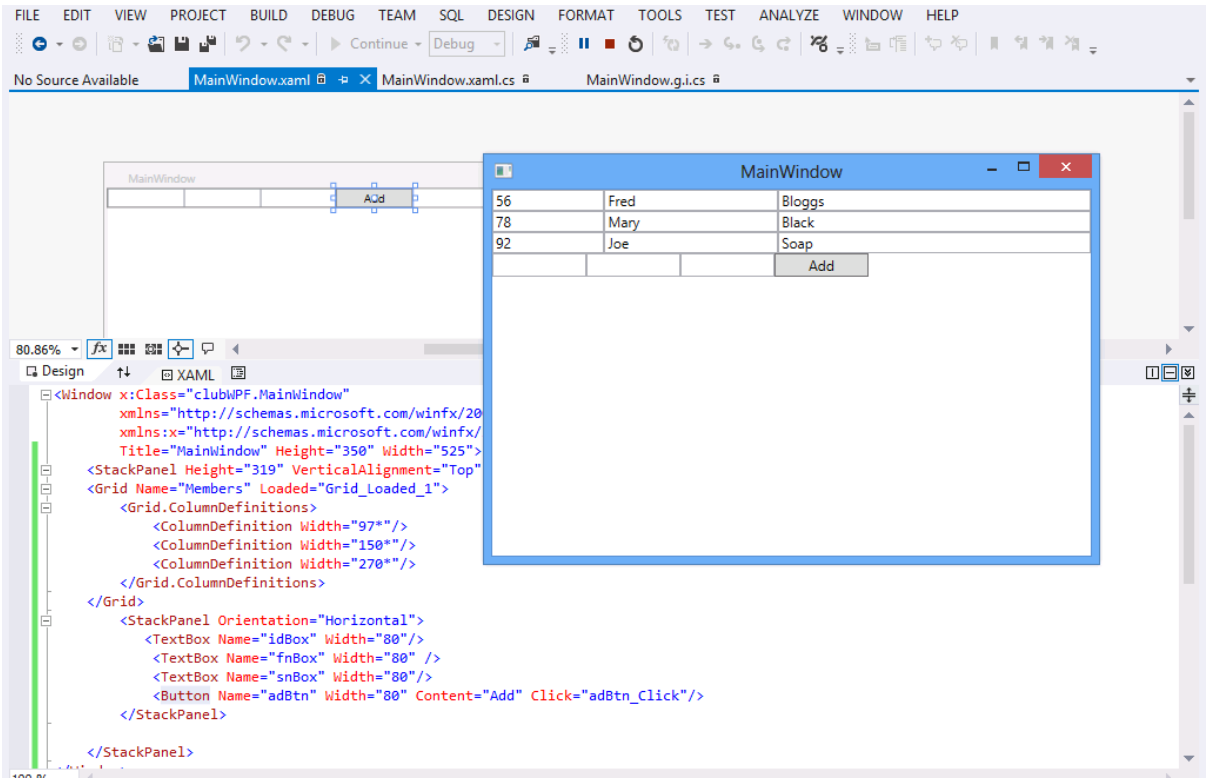
and add a new method to the class:

```
void AddBox(IDataReader r, int nr, int nc)
{
            var tx=new TextBox();
            tx.Text = r[nc].ToString();
            members.Children.Add(tx);
            Grid.SetRow(tx,nr);
            Grid.SetColumn(tx,nc);
}
```

WPF allows you very tight control over appearance of everything, and is very fast. To make changes to the database with ADO.NET you can do something like

```
cmd.CommandText=”insert into member values(92,’Joe’,’Soap’)”;
cmd.ExecuteNonQuery();
```

So modify the xaml to provide some extra textboxes and buttons, wrapping these and the Grid with a StackPanel, something like:



A1.4 Using SQL Server Express

Using SQL Server Ce resembles using SQL Server in many ways: much of the interface in Visual Studio and for programming is the same. But the two systems differ much more than their name suggests. Either of the two previous exercises can be carried out with SQL Server, and the instructions for creating the database with Visual Studio contain many of the same steps.

1. First create the database we want on the server. In Server Explorer, right-click Data Connectons, and select Add Connection.. If prompted, select Microsoft SQL Server. Give the Server name as .\SQLEXPRESS, and the database name as Club. Confirm that you want to create the database.
2. View Server Explorer, and expand the connection to the new database, right-click Tables and select Create Table. Add the columns we want and set the Primary Key. Click Save and In the New Table dialogue, give the table name as Member. Similarly create the Played table.
3. Create the foreign key references by right-clicking the Winner column and selecting Relationships.. In the Foreign Key Relationships dialogue, click Add. Click on Tables and Columns Specific and click the ellipsis … button. Change the Primary Key table to Member, and select Id, and select winner as the Foreign Key Table column. Click OK and click Add again for Loser. Click Close, and Save the tables.
4. To place data in the tables, right-click the tables and select Show Table Data. When you enter the date in the playedon field, the date format is dd/mm/yyyy (the other way round from MySQL).
5. Add a DataSet to the project and drag the Members table onto it.
6. This time, when you add the DataGridView, click Choose Data Source, and browse down to get DataSet1>Member. Adjust the size so you can see all three columns.

If you now view code you will see that a member table adapter already has been configured to load the data into the DataGridView.

7. As before, we need to implement a way of updating the database. This time, the code we want in RowValidated is

```
memberTableAdapter.Update(dataSet1.Member);
```

8. Once again I add the two gadgets we had in the last tutorial: a textbox and a combobox. The code of the textbox is identical to the previous time.
9. For the comboBox, we can set up the Items as follows:

```
comboBox1.Items.Clear();

var rdr = database1DataSet.CreateDataReader();

while (rdr.Read())

        comboBox1.Items.Add(rdr[1].ToString();
```

Note that the connection string to the dataset is "DataSource=\SQLEXPRESS;Initial Catalog=Club;Integrated Security=True".

A1.5 Using PyrrhoDB

At one time Pyrrho also had DataAdapters, but now it stays with the simple ADO.NET approach so as to be more compatible with Linux. So for the final exercise in this lab, let us go back to Windows Forms, but avoid DataAdapters.

I am making a version of Pyrrho 5.1 available for the course, and this should be available on the D drive of the virtual machines. Copy the OSP folder to the C drive.

I downloaded Open Source Pyrrho version 4.8 from www.pyrrhodb.com, and extracted the files to C:\Temp. I created shortcuts on the desktop for the OSP application in C:\Temp\OSP48\OSP, and started up the server by right-clicking the OSP shortcut and selecting Run as Administrator. If prompted, download .NET 3.5 and reboot. Leave the OSP window running.

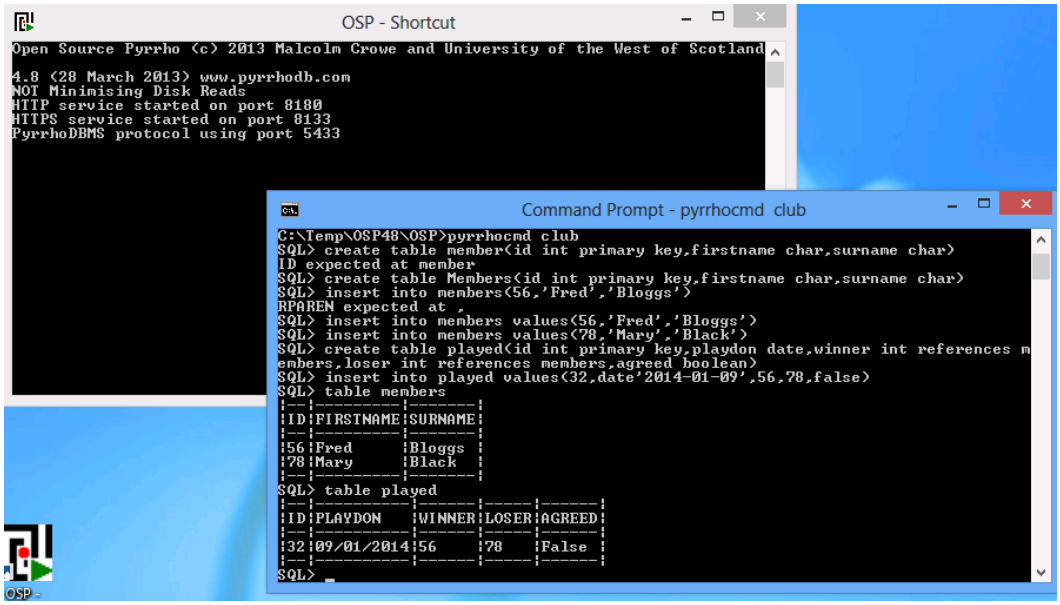
To create the database use the command line tool PyrrhoCmd in C:\Temp\OSP48\OSP. Start a new ordinary Command Prompt window and change directory to

```
cd \Temp\OSP48\OSP

PyrrhoCmd club
```

At the SQL> prompt issue the following commands:

```
create table members(id int primary key,firstame char, surname char)
insert into members values(56,'Fred','Bloggs')
insert into members values(78,'Mary','Black')
create table played(id int primary key,playedon date,winner int references members,loser int references members,agreed boolean)
insert into played values(32,date'2014-01-09',56,78,false)
```

You can verify this has worked in the usual way (select * from members) etc.



Now start up Visual studio and make a new Windows Forms project. Change the target framework to .NET 3.5.

This time add Reference and browse to C:\Temp\OSP48\OSP\OSPLink.dll . Remove the reference Microsoft.CSharp.

In the two cs files in the project delete the using lines for System.Threading.Tasks, and add using Pyrrho;

As before, place a DataGridView in the design surface. Double-click the design surface (outside of the DataGridView).

In the class, declare PyrrhoConnect conn;

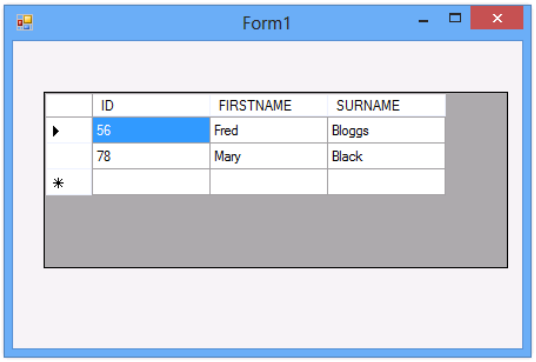
In the Form1() constructor method, add the lines

```
conn = new PyrrhoConnect("Files=club");
conn.Open();
```

In the Form1_Load method, give the code as follows:

```
var cmd = conn.CreateCommand();
cmd.CommandText = "select * from members";
var rdr = cmd.ExecuteReader();
dataGridView1.ColumnCount = rdr.FieldCount;
dataGridView1.ColumnHeadersVisible = true;
for (int j=0;j<rdr.FieldCount;j++)
        dataGridView1.Columns[j].Name = rdr.GetName(j);
while (rdr.Read())
{
        var row = new string[rdr.FieldCount];
        for (int j=0;j<rdr.FieldCount;j++)
                row[j] = rdr[j].ToString();
        dataGridView1.Rows.Add(row);
}
```

```
clubOSP.Form1                                   dataGridView1_RowValidated(object sender, DataGridViewCellEventArgs e)
using System.Linq;
using System.Text;
using System.Windows.Forms;
using Pyrrho;

namespace clubOSP
{
    public partial class Form1 : Form
    {
        PyrrhoConnect conn;
        public Form1()
        {
            conn = new PyrrhoConnect("Files=club");
            conn.Open();
            InitializeComponent();
        }

        private void Form1_Load(object sender, EventArgs e)
        {;
            var cmd = conn.CreateCommand();
            cmd.CommandText="select * from members";
            var rdr = cmd.ExecuteReader();
            dataGridView1.ColumnCount = rdr.FieldCount;
            dataGridView1.ColumnHeadersVisible = true;
            for (int j = 0; j < rdr.FieldCount; j++)
                dataGridView1.Columns[j].Name = rdr.GetName(j);
            while (rdr.Read())
            {
                var row = new string[rdr.FieldCount];
                for (int j = 0; j < rdr.FieldCount; j++)
                    row[j] = rdr[j].ToString();
                dataGridView1.Rows.Add(row);
            }
        }
```



Stop the program. As before, we need to implement updates. In the designer, left-click the DataGridView, select the Events tab in the properties window, and double-click RowValidated, repeat for CellValidated and RowEnter. Add declarations in the Form1 class for bool newRow=false; int id; bool[] cellChanged = new bool[3];
Enter the following code in the event handlers:

```
    private void dataGridView1_RowValidated(object sender, DataGridViewCellEventArgs e)
    {
        var r = dataGridView1.Rows[e.RowIndex];
        var cm = "";
        if (newRow)
        {
            cm = "insert into members values(" + r.Cells[0].Value.ToString() +
                ",'" + r.Cells[1].Value.ToString() + "','" + r.Cells[2].Value.ToString() + "')";
            newRow = false;
        }
        else
        {
            var s = "";
            var c = "";
            if (cellChanged[0])
            {
                s += c+"id=" + r.Cells[0].Value.ToString();
                c = ",";
            }
            if (cellChanged[1])
            {
                s += c+"firstname='" + r.Cells[1].Value.ToString()+"'";
                c = ",";
            }
            if (cellChanged[2])
            {
                s += c+"surname='" + r.Cells[2].Value.ToString()+"'";
                c = ",";
            }
            if (s != "")
                cm = "update members set " + s + " where id=" + id;
        }
        if (cm!="")
            try { conn.Act(cm); }
            catch { }
    }

    private void dataGridView1_RowEnter(object sender, DataGridViewCellEventArgs e)
    {
        var r = dataGridView1.Rows[e.RowIndex];
        if (r!=null && !newRow && r.Cells[0].Value!=null)
```

```
            int.TryParse(r.Cells[0].Value.ToString(), out id);
        for (int j = 0; j < 3; j++)
            cellChanged[j] = false;
    }

    private void dataGridView1_CellValidated(object sender, DataGridViewCellEventArgs e)
    {
        cellChanged[e.ColumnIndex] = true;
        if (!newRow)
        {
            var r = dataGridView1.Rows[e.RowIndex];
            int.TryParse(r.Cells[0].Value.ToString(), out id);
        }
    }
```

A1.6 Using Java with Pyrrho

There are several analogues to Windows Forms in Java, such as Swing. But just for fun let's do a very simple console application that retrieves data from a database.

You will need the Java Development Kit (JDK) installed on your computer. The Pyrrho distribution includes a library called OSPJC.

First set up the Path and CLASSPATH environment variables. (Start with Computer>Properties>Advanced System Settings>Environment Variables, and use Edit and New respectively).

Add the following to Path:

;C:\Program Files (x86)\Java\jdk1.7.0_09\bin

Set CLASSPATH to

```
.;C:\Program Files (x86)\Java\jdk1.7.0_09\lib;C:\PyrrhoDB\OSP\OSPJC\bin
```

Alternatively, copy the org folder in OSPC\bin to the current directory and use –cp . with the javac and java commands below.

The following program assumes that database Temp has a table called A with columns B int and C char.

Use Notepad or something to make a test program JCTest.java (and remember to use All files when saving):

```
import org.pyrrhodb.Connection;
import java.sql.Statement;
import java.sql.ResultSet;
public class JCTest {
    public static void main(String args[]) throws Exception
    {
        Connection conn =
Connection.getConnection("localhost","Temp","COMP10059\\Student","Temp");
        Statement stmt = conn.createStatement();
        ResultSet rs = stmt.executeQuery("select * from a");
        for (boolean b = rs.first();b;b=rs.next())
        {
            System.out.println(""+rs.getInt("B")+"; "+rs.getString("C"));
        }
    }
}
```

Note that the public class has the same name as the file. You need to remember that Java is case sensitive while SQL isn't, so use e.g. B and C even if you declared your table with lower-case names, e.g. create table a(b int, c char). Note that both pyrrhodb and java.sql define a Connection class, so you can't use * above.

Now compile it with

```
javac JCTest.java
```

and run it with

```
java JCTest
```

As an exercise try out your own database. Note the column names in getInt() etc are case sensitive. You should be able to do update, delete etc using stmt.ExecuteNonQuery().

A1.7 Using PHP with Pyrrho

Rename the C:\Program Files (x86)\PHP folder to PHP1. Copy the PHP folder in Pyrrho51.iso to \Program Files (x86).

Not in an Administrator command prompt, change direct to \OSP .

Install the OSPLink.dll in the gacutil:

```
“C:\Program Files (x86)\Microsoft SDKs\Windows\v8.0A\bin\NETFX 4.0
Tools”\gacutil –i OSPLink.dll
```

Register the assembly:

```
C:\Windows\Microsoft.NET\Framework\v4.0.30319\regasm /tlb OSPLink.dll
```

Now try the PHP version of the above program. Get Notepad to put the following in try.php:

```
<?php
$conn = new COM("OSPLink") or die("Cannot connect");
$conn->ConnectionString="Files=Temp";
$conn->Open();
$rdr=$conn->Execute("table a");
$row=$rdr->Read();
while(!is_int($row))
{
        print($row[0].': '.$row[1]."\r\n");
        $row = $rdr->Read();
}
?>
```

Now at a command prompt try

```
php try.php
```

Relational Database Implementation

Appendix 2: The Transactions mystery tour

I've included this as an appendix because I found it a genuinely astonishing experience to work with Martti Laiho on this DBTech tutorial (see www.DBTEchNet.org). We never really finished it but it led me to make a number of changes.

I've included the complete text of the tutorial as published. Don't enter the text in blue though as it's either comments or specific to the Linux version they were using.

```
DBTechNet / DBTech VET
Martti Laiho 2012-12-19

SQL Transactions
----------------

Appendix 1 / Pyrrho

Welcome to the "Transaction Mystery Tour" using Pyrrho DBMS.
Following experiments with the Pyrrho transactions can be tested
using the free DebianDB database laboratory of DBTechNet or on Windows.

---------------------- on Linux ------------------------
For the first steps on using Pyrrho in DebianDB see
the "Quick Start Guide" at
http://www.dbtechnet.org/download/QuickStartToDebianDBv05.pdf

Downloading OSP.zip from
http://pyrrhodb.uws.ac.uk/OSP.zip
and unzipping it as
root@debianDB:/home/student/Downloads# unzip -Z OSP.zip -d /opt


Login as student/Student1

To start the Pyrrho server enter following commands in a Gnome Terminal
window

# Pyrrho Server
cd /opt/OSP
mono OSP.exe


For client sessions in following experiments open 2 parallel Gnome Terminal
windows
starting the client using following commands

# Pyrrho Client
cd /opt/OSP
mono PyrrhoCmd.exe TestDB

---------------------- on Windows ----------------------
REM Pyrrho Server on Windows
Unzip Pyrrho.zip to C: \Temp\Pyrrho
CD \Temp\Pyrrho
PyrrhoSvr

REM Pyrrho Client on Windows
CD \Temp\Pyrrho
```

Start osp in one window and start pyrrhocmd in another.

```
PyrrhoCmd testdb
```

Here's an example of the sort of thing that went wrong. Note that in the comments above, on Linux the instructions say to call the database TestDB. Whoever wrote the instructions clearly reasoned that Windows file names are not case sensitive. This is not actually true. If the database is really called TestDB, then the above command will result in lots of error messages! To check this, try creating a database in one case and then get the case wrong, as in:

```
C:\OSP>pyrrhocmd MixedCase
SQL> create table a(b int)
SQL> ^C
C:\OSP>pyrrhocmd mixedcase
SQL> table a
Could not use database mixedcase.osp (database not found or damaged)
SQL> _
```

Actually this used to cause all sorts of internal errors.

```
-------------------------------------------------------------

Notes: As DEFAULT Pyrrho uses AUTOCOMMIT mode.
       Pyrrho does not accept the word "WORK" after COMMIT.
       SMALLINT is not a supported data type.

-------------------------------------------------------------
-- A1.1   Experimenting with single explicit transactions
-------------------------------------------------------------

--  Autocommit mode ?
CREATE TABLE T (id INT NOT NULL PRIMARY KEY, s VARCHAR(30), si INTEGER);
INSERT INTO T (id, s) VALUES (1, 'first');
SELECT * FROM T;
ROLLBACK; -- what happens?
```

Here's another example, which I've left for your amusement. It you type exactly what is above, Pyrrho does nothing at all:

```
SQL> ROLLBACK; -- what happens?
SQL> _
```

because there is no transaction active, and the PyrrhoCmd program was confused by the strange text. If you just say rollback, PyrrhoCmd actually tries to say something useful:

```
SQL> ROLLBACK; -- what happens?
SQL> ROLLBACK
There is no current transaction
SQL>
```

I actually added the warnings such as "There is no current transaction" because of this tutorial. Even worse was the way that Martti and his students kept pasting in things like `Let's try` *and because this is not correct SQL the transaction would roll back.*

```
SELECT * FROM T;

-------------------------------------------------------------
-- Transactional mode
-- testing also use of a DDL command in a transaction!
BEGIN TRANSACTION;
CREATE TABLE T2 (id INT NOT NULL PRIMARY KEY, s VARCHAR(30));
INSERT INTO T (id, s) VALUES (2, 'second');
INSERT INTO T2 (id, s) VALUES (2, 'second');
SELECT * FROM T ;
ROLLBACK;
SELECT * FROM T;
SELECT * FROM T2; -- What has happened to T2 ?
```

```
COMMIT;

-----------------------------------------------------------------
-- Testing if an error would lead to automatic rollback in Pyrrho?
-----------------------------------------------------------------
--  Let's first implement the DUAL table like in Oracle
--  for single line info queries
```
I've since included the `from static` *trick in Pyrrho.*
```
BEGIN TRANSACTION;
CREATE TABLE DUAL (c  INT NOT NULL PRIMARY KEY, CHECK (c = 1));
INSERT INTO DUAL VALUES (1);
SELECT CURRENT_DATE FROM DUAL;
COMMIT;
--
BEGIN TRANSACTION;
INSERT INTO T (id, s) VALUES (2, 'Error test starts here');
-- division by zero should fail
SELECT (1/0) AS dummy FROM DUAL;
COMMIT;
BEGIN TRANSACTION;
-- updating an non-existing row
UPDATE T SET s = 'foo' WHERE id = 9999;
```
I've since included the `0 records` *message only very recently. I didn't regard this as an error at all. Very reluctantly I implemented the NOT_FOUND handler in stored procedures for this situation.*
```
-- deleting an non-existing row
DELETE FROM T WHERE ida = 7777 ;
--
BEGIN TRANSACTION;
INSERT INTO T (id, s) VALUES (2, 'Error test starts here');
INSERT INTO T (id, s) VALUES (2, 'Hi, I am a duplicate');
--
BEGIN TRANSACTION;
INSERT INTO T (id, s) VALUES (3, 'how about inserting too long string
value?');
INSERT INTO T (id, s, si) VALUES (4, 'Integer overflow?',
9223372036854775808);
INSERT INTO T (id, s) VALUES (5, 'Testing an INSERT after errors');
SELECT * FROM T;
COMMIT;
BEGIN TRANSACTION;
DELETE FROM T WHERE id > 1;
COMMIT;
-------------------------------------------------------------
-- So, what have we found out of automatic rollback in Pyrrho ?
-------------------------------------------------------------

-- Testing the database Recovery
BEGIN TRANSACTION;
INSERT INTO T (id, s) VALUES (9, 'Let''s see what happens if ..');
SELECT * FROM T;
-- <close the client!!!>


#-----------------------------------------------------------------
#-- Starting a new terminal window and connecting to our TestDB
#-- we can study what happened to our latest uncommitted transaction
#-- just by listing the contents of table T

# Pyrrho Client
cd /opt/OSP
mono PyrrhoCmd.exe TestDB
```

```
SELECT * FROM T;
COMMIT;
```
I don't regard closing the client and restarting it as database Recovery – what do you think?

```
-------------------------------------------------------------
-- A1.2   Experimenting with Transaction Logic
-------------------------------------------------------------
-- Experiment 1: COMMIT and ROLLBACK
-- in session of client A:

# Pyrrho Client
cd /opt/OSP
mono PyrrhoCmd.exe TestDB

BEGIN TRANSACTION;
[CREATE TABLE Accounts (
acctID  INTEGER NOT NULL PRIMARY KEY,
balance INTEGER NOT NULL
 CONSTRAINT uncreditable_account  CHECK (balance >= 0)
)]
INSERT INTO Accounts (acctID,balance) VALUES (101,1000);
INSERT INTO Accounts (acctID,balance) VALUES (202,2000);
SELECT * FROM Accounts;
COMMIT;

-- let''s try the bank transfer
BEGIN TRANSACTION;
UPDATE Accounts SET balance = balance - 100 WHERE acctID = 101;
UPDATE Accounts SET balance = balance + 100 WHERE acctID = 202;
SELECT * FROM Accounts;
ROLLBACK;

-------------------------------------------------------------
-- Experiment 2:  Transaction logic
-- following commands are "sensitive" to previous balance values
BEGIN TRANSACTION;
UPDATE Accounts SET balance = balance - 2000 WHERE acctID = 101;
```

I think you should do something else just here…

```
UPDATE Accounts SET balance = balance + 2000 WHERE acctID = 202;
COMMIT;
SELECT * FROM Accounts;
-- Do we have a problem ?

-- Experiment 2b  Transaction logic
-- restoring the original contents
BEGIN TRANSACTION;
DELETE FROM Accounts;
INSERT INTO Accounts (acctID,balance) VALUES (101,1000);
INSERT INTO Accounts (acctID,balance) VALUES (202,2000);
SELECT * FROM Accounts;
COMMIT;

#------------------- Advanced topic -----------------------
# Experiment with IF structure
# See the Stored Procedure at the end of this file ?

#------------------- end of the Advanced topic ------------------------
```

```
-------------------------------------------------------------------------
-- A1.3   Experimenting with Concurrent Transactions
--        For concurrency experiments we will open two parallel
--        sessions

-- Note:  SERIALIZABLE is the default and only supported
--        isolation level in Pyrrho! So some of our test cases are
--        not relevalnt in Pyrrho.

-- To start with fresh contents we enter following commands on a session
-- restoring the original contents
BEGIN TRANSACTION;
DELETE FROM Accounts;
INSERT INTO Accounts (acctID,balance) VALUES (101,1000);
INSERT INTO Accounts (acctID,balance) VALUES (202,2000);
SELECT * FROM Accounts;
COMMIT;

-- Experiment 3  Simulating "Lost update problem"
-- 1. client A starts
BEGIN TRANSACTION;
SELECT acctID, balance FROM Accounts WHERE acctID = 101;

-- 2. client B starts
BEGIN TRANSACTION;
SELECT acctID, balance FROM Accounts WHERE acctID = 101;

-- 3. client A continues
UPDATE Accounts SET balance = 1000 - 200 WHERE acctID = 101;

-- 4. client B continues
UPDATE Accounts SET balance = 1000 - 500 WHERE acctID = 101;

-- 5. client A continues
SELECT acctID, balance FROM Accounts WHERE acctID = 101;
COMMIT;

-- 6. client B continues
SELECT acctID, balance FROM Accounts WHERE acctID = 101;
COMMIT;
-- Note: In this experiment we did not have the real "Lost Update Problem",
-- but after A commits its transaction B usually can proceed and overwrite
-- the update made by A.  We call this reliability problem as
-- "Blind Overwriting" or "Dirty Write".
-- The optimistic concurrency control of Pyrrho solves the Dirty Write
Problem!!!

-------------------------------------------------------------------------
-

-- Experiment 4  "Lost Update Problem" fixed by locks
--              (competition on a single resource)
--
--  Note:  this experiment is not relevant with Pyrrho!
--
-- First restoring the original contents by client A
BEGIN TRANSACTION;
DELETE FROM Accounts;
INSERT INTO Accounts (acctID,balance) VALUES (101,1000);
INSERT INTO Accounts (acctID,balance) VALUES (202,2000);
SELECT * FROM Accounts;
```

```
COMMIT;

-- client A starts
SELECT acctID, balance FROM Accounts WHERE acctID = 101;

-- client B starts
SELECT acctID, balance FROM Accounts WHERE acctID = 101;

-- client A continues
UPDATE Accounts SET balance = balance - 200 WHERE acctID = 101;

-- client B continues
UPDATE Accounts SET balance = balance - 500 WHERE acctID = 101;

-- the client which survived will commit
SELECT acctID, balance FROM Accounts WHERE acctID = 101;
COMMIT;


------------------------------------------------------------
-- Experiment 5
---
-- Competition on two resources in different order
-- First restoring the original contents by client A
BEGIN TRANSACTION;
DELETE FROM Accounts;
INSERT INTO Accounts (acctID,balance) VALUES (101,1000);
INSERT INTO Accounts (acctID,balance) VALUES (202,2000);
SELECT * FROM Accounts;
COMMIT;

-- 1. Client A starts
BEGIN TRANSACTION;
UPDATE Accounts SET balance = balance - 100 WHERE acctID = 101;

-- 2. Client B starts
BEGIN TRANSACTION;
UPDATE Accounts SET balance = balance - 200 WHERE acctID = 202;

-- 3. Client A continues
UPDATE Accounts SET balance = balance + 100 WHERE acctID = 202;

-- 4. Client B continues
UPDATE Accounts SET balance = balance + 200 WHERE acctID = 101;

-- 5. Client A continues
COMMIT;

-- 6. Client B continues
COMMIT;

--************************************************************
-- In the following we will experiment concurrency anomalies i.e.
-- data reliability risks known by ISO SQL standard
--   can we identify those?
--   how can we fix the experiments?
--************************************************************

-- Experiment 6     Dirty Read ?

-- First restoring the original contents by client A
```

```
BEGIN TRANSACTION;
DELETE FROM Accounts;
INSERT INTO Accounts (acctID,balance) VALUES (101,1000);
INSERT INTO Accounts (acctID,balance) VALUES (202,2000);
SELECT * FROM Accounts;
COMMIT;

-- 1. client A starts
BEGIN TRANSACTION;
UPDATE Accounts SET balance = balance - 100 WHERE acctID = 101;
UPDATE Accounts SET balance = balance + 100 WHERE acctID = 202;
SELECT * FROM Accounts;

-- 2. Client B starts - will this be a Dirty Read ?
BEGIN TRANSACTION;
SELECT * FROM Accounts;
COMMIT;

-- 3. Client A continues
ROLLBACK;
SELECT * FROM Accounts;

------------------------------------------------------------
-- Experiment 7     Unrepeatable Read ?

-- First restoring the original contents by client A
BEGIN TRANSACTION;
DELETE FROM Accounts;
INSERT INTO Accounts (acctID,balance) VALUES (101,1000);
INSERT INTO Accounts (acctID,balance) VALUES (202,2000);
SELECT * FROM Accounts;
COMMIT;

-- 1. client A starts
BEGIN TRANSACTION;
-- Accounts having balance > 500 euros
SELECT * FROM Accounts WHERE balance > 500;

-- 2. Client B starts
BEGIN TRANSACTION;
UPDATE Accounts SET balance = balance - 400 WHERE acctID = 101;
UPDATE Accounts SET balance = balance + 400 WHERE acctID = 202;
SELECT * FROM Accounts;
COMMIT;

-- 3. Client A continues
-- Let's see the results after client B's transaction:
SELECT * FROM Accounts WHERE balance > 500;
COMMIT;

------------------------------------------------------------
-- Experiment 8     Insert Phantom ?

-- First restoring the original contents by client A
BEGIN TRANSACTION;
DELETE FROM Accounts;
INSERT INTO Accounts (acctID,balance) VALUES (101,1000);
INSERT INTO Accounts (acctID,balance) VALUES (202,2000);
SELECT * FROM Accounts;
COMMIT;
```

```
-- 1. client A starts
BEGIN TRANSACTION;
-- Accounts having balance > 1000 euros:
SELECT * FROM Accounts WHERE balance > 1000;

-- 2. Client B starts
BEGIN TRANSACTION;
INSERT INTO Accounts (acctID,balance) VALUES (303,3000);
SELECT * FROM Accounts;
COMMIT;

-- 3. Client A continues
-- Let's see the results:
SELECT * FROM Accounts WHERE balance > 1000;
COMMIT;

------------------------------------------------------------
-- Experiment 9     Update Phantom ?

-- First restoring the original contents by client A
BEGIN TRANSACTION;
DELETE FROM Accounts;
INSERT INTO Accounts (acctID,balance) VALUES (101,1000);
INSERT INTO Accounts (acctID,balance) VALUES (202,2000);
SELECT * FROM Accounts;
COMMIT;

-- 1. client A starts
BEGIN TRANSACTION;
-- Accounts having balance > 1000 euros:
SELECT * FROM Accounts WHERE balance > 1000

-- 2. Client B starts
BEGIN TRANSACTION;
UPDATE Accounts SET balance = balance + 2000 WHERE acctID = 101;
SELECT * FROM Accounts;
COMMIT;

-- 3. Client A continues
-- Let's see the results:
SELECT * FROM Accounts WHERE balance > 1000;
COMMIT;


============================================================

Note1: Multi-line commands need to be enclosed in [ ] brackets
Note2: COMMIT is not allowed in a procedure/function


-- The following test is copied from the Pyrrho manual and works fine
CREATE TABLE A (A2 CHAR(1));

[CREATE FUNCTION GATHER1() RETURNS CHAR
BEGIN
        DECLARE C CURSOR FOR SELECT A2 FROM A;
        DECLARE DONE BOOLEAN DEFAULT FALSE;
        DECLARE CONTINUE HANDLER FOR SQLSTATE '02000' SET DONE=TRUE;
        DECLARE A CHAR DEFAULT '';
        DECLARE P CHAR;
        OPEN C;
```

```
        REPEAT
                FETCH C INTO P;
                IF NOT DONE THEN
                        IF A = '' THEN
                                SET A = P
                        ELSE
                                SET A = A || ', ' || P
                        END IF
                END IF
        UNTIL DONE END REPEAT;
        CLOSE C;
        RETURN A;
END;]
--------------------------------
BEGIN TRANSACTION;
drop function BankTransfer (int,int,int);

[CREATE FUNCTION BankTransfer
   (IN fromAcct INT,
    IN toAcct   INT,
    IN amount   INT)
    RETURNS VARCHAR(100)
BEGIN
    DECLARE msg VARCHAR(100) ;
    DECLARE NOT_FOUND BOOLEAN DEFAULT FALSE;
    DECLARE CONTINUE HANDLER FOR SQLSTATE '02000' SET NOT_FOUND=TRUE;
    SET msg = 'ok';
    UPDATE Accounts SET balance = balance - amount WHERE acctID = fromAcct;
    IF (NOT_FOUND) THEN
        SET msg = '* Unknown from account ' || CAST(fromAcct AS
VARCHAR(10))
    ELSE
    BEGIN
        UPDATE Accounts SET balance = balance + amount WHERE acctID =
toAcct;
        IF (NOT_FOUND) THEN
            SET msg = '* Unknown from account ' || CAST(toAcct AS
VARCHAR(10))
        ELSE
            SET msg = 'OK'
        END IF
        END
    END IF;
    RETURN msg
        || ' toAcct: ' || CAST(toAcct AS VARCHAR(10))
        || ' amount: ' || CAST(amount AS VARCHAR(10)) ;
END;]
COMMIT;

BEGIN TRANSACTION;
DELETE FROM Accounts;
INSERT INTO Accounts (acctID,balance) VALUES (101,1000);
INSERT INTO Accounts (acctID,balance) VALUES (202,2000);
SELECT * FROM Accounts;
COMMIT;

BEGIN TRANSACTION;
SELECT BankTransfer (101, 202, 100) FROM DUAL;
SELECT * FROM Accounts;
ROLLBACK;
```

```
BEGIN TRANSACTION;
SELECT BankTransfer (100, 202, 100) FROM DUAL;
SELECT * FROM Accounts;
ROLLBACK;

BEGIN TRANSACTION;
SELECT BankTransfer (101, 200, 100) FROM DUAL;
SELECT * FROM Accounts;
ROLLBACK;

BEGIN TRANSACTION;
SELECT BankTransfer (101, 202, 2000) FROM DUAL;
SELECT * FROM Accounts;
ROLLBACK;

SQL> BEGIN TRANSACTION;
SQL-T>DELETE FROM Accounts;
SQL-T>INSERT INTO Accounts (acctID,balance) VALUES (101,1000);
SQL-T>INSERT INTO Accounts (acctID,balance) VALUES (202,2000);
SQL-T>SELECT * FROM Accounts;
|------|-------|
|ACCTID|BALANCE|
|------|-------|
|101   |1000   |
|202   |2000   |
|------|-------|
SQL-T>COMMIT;
SQL> BEGIN TRANSACTION;
SQL-T>SELECT BankTransfer (101, 202, 100) FROM DUAL;
|-----|
|Col$1|
|-----|
|OK   |
|-----|
SQL-T>SELECT * FROM Accounts;
Internal error: Object reference not set to an instance of an object.
The transaction has been rolled back
SQL> ROLLBACK;
There is no current transaction
SQL>
SQL> SELECT * FROM Accounts;
|------|-------|
|ACCTID|BALANCE|
|------|-------|
|101   |1000   |
|202   |2000   |
|------|-------|
SQL> BEGIN TRANSACTION;
SQL-T>SELECT BankTransfer (101, 202, 100) FROM DUAL;
|-----|
|Col$1|
|-----|
|OK   |
|-----|
SQL-T>SELECT * FROM Accounts;
Internal error: Object reference not set to an instance of an object.
The transaction has been rolled back
SQL> BEGIN TRANSACTION;
SQL-T>SELECT BankTransfer (100, 202, 100) FROM DUAL;
|-------------------------|
|Col$1                    |
```

```
|-------------------------|
|* Unknown from account 100|
|-------------------------|
SQL-T>SELECT * FROM Accounts;
Internal error: Object reference not set to an instance of an object.
The transaction has been rolled back
SQL> SELECT * FROM Accounts;
|------|-------|
|ACCTID|BALANCE|
|------|-------|
|101   |1000   |
|202   |2000   |
|------|-------|
SQL> BEGIN TRANSACTION;
SQL-T>SELECT BankTransfer (101, 200, 100) FROM DUAL;
|-----|
|Col$1|
|-----|
|OK   |
|-----|
SQL-T>SELECT * FROM Accounts;
Internal error: Object reference not set to an instance of an object.
The transaction has been rolled back
SQL> SELECT * FROM Accounts;
|------|-------|
|ACCTID|BALANCE|
|------|-------|
|101   |1000   |
|202   |2000   |
|------|-------|
SQL> BEGIN TRANSACTION;
SQL-T>SELECT BankTransfer (101, 202, 2000) FROM DUAL;
|-----|
|Col$1|
|-----|
|OK   |
|-----|
SQL-T>SELECT * FROM Accounts;
Internal error: Object reference not set to an instance of an object.
The transaction has been rolled back
SQL> SELECT * FROM Accounts;
|------|-------|
|ACCTID|BALANCE|
|------|-------|
|101   |1000   |
|202   |2000   |
|------|-------|
SQL>


-- Unsolved problems:

-- Why the function return an empty string ?

[CREATE PROCEDURE TransferTest
   (fromAcct INT,
    toAcct   INT,
    amount   INT)
IF BankTransfer (101, 202, 100) = 'OK' THEN
   COMMIT
ELSE
```

```
   ROLLBACK
END IF;]

BEGIN TRANSACTION;
SELECT BankTransfer (101, 202, 100) FROM DUAL;
```

Appendix 3: Roles and Security

A3.1: The sporting club

1. Recall that in Lab 1 we set up the following tables in a database called club:

```
Members: (id int primary key, firstname char)
```

```
Played: (id int primary key, winner int references members, loser int
references members, agreed boolean)
```

with the following commands

create table members(id int primary key,firstame char, surname char)
insert into members values(56,'Fred','Bloggs')
insert into members values(78,'Mary','Black')
[create table played(id int primary key,playedon date,winner int references members,loser int references members,agreed boolean)]
insert into played values(32,date'2014-01-09',56,78,false)

2. For simplicity we give everyone select access to both these tables.

```
Grant select on members to public
```

```
Grant select on played to public
```

3. Although Pyrrho records which user makes changes, it will save time if users are not allowed to make arbitrary changes to the Played table. Instead we will have procedure Claim(won,beat) and Agree(id), so that the Agree procedure is effective only when executed by the loser. With some simple assumptions on user names, the two procedures could be as simple as:

```
[Create procedure claim(won int,beat int)
insert into played(winner,loser) values(claim.won,claim.beat)]
[Create procedure agree(p int)
  update played set agreed=true
     where winner=agree.p and not agreed and
loser in (select m.id from members m
where current_user like ('%'||firstname))]
```

4. We want all members of the club to be able to execute these procedures. We could simply grant execute on these procedures to public. However, it is better practice to grant these permissions instead to a role (say, `membergames`) and allow any member to use this role:

```
Create role membergames 'Matches between members for ranking purposes'
Grant execute on procedure claim(int,int) to role membergames
Grant execute on procedure agree(int) to role membergames
Grant membergames to public
```

5. Check the above procedures work using some sample data, for example `call claim(56,78)` . Alter the Claim procedure to record the current_date as the date of the match. (`Alter procedure claim`…)
6. Now create users Fred and Mary (say) in Windows using the Control Panel.
7. Log in as Fred and check that Fred select * from the tables but not make changes directly. Get Fred to claim a win.
8. Log in as Mary and accept.

This example could be extended by considering the actual use made of the Played table in calculating the current rankings, etc.

A3.2: A forensic investigation

Examine the log of the club database as described in the lecture. Look at the last few transactions. What are the user and role? Try writing select statements in the manner described in the lecture to find the previous values of things that have been changed.

Also look at the (current) "Role$Privilege" table.

A3.3: Some more PyrrhoDB stuff

I will be updating the OSPnn.iso files every so often, so always use the most recent (highest numbered). Use this to *overwrite* the folder you have previously installed on your virtual machine (and then you will be able to use the new binaries while retaining any databases you have developed). When Pyrrho starts up it gives the date of the server.

There is a manual in the distribution on your virtual machine and from the PyrrhoDB website http://pyrrhodb.com . A lot of the same material is available in the Sample code section of the website, including full reference details for the SQL that Pyrrho uses. There is also the blog, which is accessible from the website. Here are a few pointers that you might find useful in your coursework:

1. You can use the pyrrhodb command line to import data from a text file. You first need to create a table with suitable columns to receive the data. The latest version of the manual says (sec 4.3.6)

> A textfile containing rows for a table can similarly be added using a command such as
>
> **`insert into directors values ~rowsfile`**
>
> Simple data can be provided in a csv or similar file. The first line containing column headings and exposed spaces in the file are ignored. Data items in the given file are separated by exposed commas or tabs. Rows are parenthesized groups (optionally separated by commas), or provided without parentheses but separated by exposed semicolons or newlines. Characters such as commas etc are not considered to be separators if they are within a quoted string or a structure enclosed in braces, parentheses, brackets, or pointy brackets.

   Of course if the file is really called rowsfile.txt you need to say so: ~rowsfile.txt .
2. You can also use the REST service (there is a RESTclient in the distribution) to POST csv data to a table. However, this only works for tables that have a primary key. For this service, don't post the first line of a csv file since this contains column headers. (Don't forget to run the OSP server as administrator: if you get the Access denied message on start-up, the REST service will not be available.)
3. You can copy data from one table to another by using the INSERT..SELECT combination as in `[insert into mytable select somecolumn,anothercolumn from anothertable]`
4. You can get PyrrhoDB to draw charts if you want. You can add metadata to tables and columns. There is a blog post about this but we don't use the SERIES keyword any more. Things like HISTOGRAM, PIE, X, Y are keywords. For example (assuming table mytable has suitable data columns mycaptions and mycolumn)

```
alter table mytable histogram
alter table mytable alter column mycaptions x
alter table mytable alter column mycolumn y
```

Use the HTTP/REST service to view the histogram in a browser: the URL you want is of form http://localhost:8180/mydb/myrole/mytable. If your database has no roles defined yet, the default role has the same name as the database.

5. The rules for case-sensitivity come separately from Windows and SQL, and are a little confusing.

   In the command line and the URL, the database file name (and thus the name of Pyrrho's default Role) are case sensitive. By default, lower case letters remain in lower case. So if you create a database called mydb, the actual file name on the server will be mydb.osp. If you need to use these lower case identifiers in SQL, you need to enclose them in double quotes. (The default role for example will be "mydb".)

   In SQL, the names of database objects that you create are not case sensitive unless they are enclosed in double quotes. In the absence of double quotes, lower case letters will be turned into upper case. If you create a table called mytable in SQL, the actual name will be MYTABLE, and so if it is mentioned in a URL, you will need to use capitals.

   Se we end up with URL's like http://localhost:8180/mydb/mydb/MYTABLE .

6. You can view the metadata such as PIE, HISTOGRAM etc for database objects such as tables, views, procedures and table columns by using the Role$Object sytem table (on the command line you would say table "Role$Object"). For columns of views or stored functions there is another system table called "Role$Subobject" which does not seem to be in the manual just now ☹.

   You should be able to modify metadata for objects and subobjects by using the keywords ADD and DROP (you don't really need ADD as it is the default behaviour) e.g.

   ```
   alter table mytable drop histogram
   alter view myview alter someviewcolumn drop x
   alter function myfunc(int) alter someresultcolumn y
   ```

   etc.

7. There are ways of supplying style sheets hidden in the Description metadata string. The manual's notes on Metadata read (sec 7.2):

Metadata = ATTRIBUTE | CAPTION | ENTITY | HISTOGRAM | LEGEND | LINE | POINTS | PIE | X | Y | CAPPED | USEPOWEROF2SIZES | BACKGROUND | DROPDUPS | SPARSE | MAX'('int')' | SIZE'('int')' | string | iri .
The Metadata flags and the string "constraint" are Pyrrho extensions., Attribute and Entity affect XML output in the role, Caption, Histogram, Legend, Line, Points, Pie, X and Y affect HTML output in the role. Other metadata keywords are for MongoDB. The string is for a description, but if it begins with a < it will be included in the HTML so that it can supply CSS style or script. If the string begins with <? it should be an XSL transform, and Pyrrho will generate and then transform the return data as XML. HTML responses will have JavaScript added to draw the data visualisations specified.

Appendix 4: The Distributed Database Tutorial for Windows

The exercise follows the blog at http://pyrrhodb.blogspot.com, just with more detailed instructions.

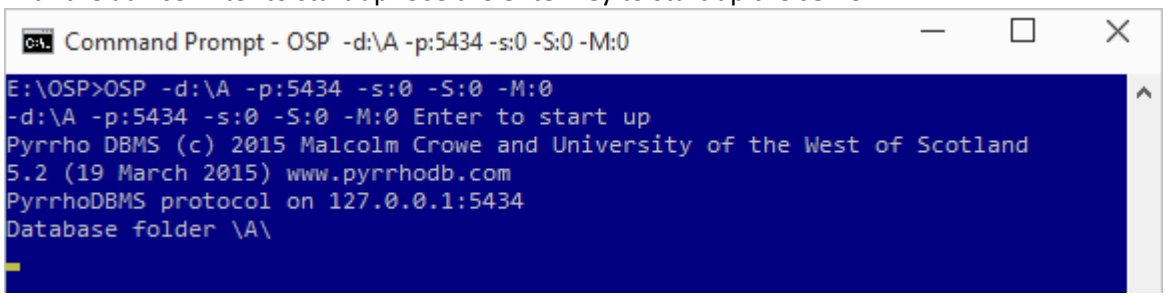
This version of the tutorial uses Open Source Pyrrho v5.2 19 March 2015 on Windows 10. If you can get a later version use it. Pyrrho has been installed in E:\OSP (You will probably use C:.)

A4.1 Start up the servers

For this exercise we will use 3 servers, all on the local machine (127.0.0.1), but in separate database folders. Create empty folders \A, \B and \C . To keep security aspects simple, everything is owned by the user Student, and student's password is password. In the following screenshots, these folders are in E:. We will use 3 file manager windows so we can see the contents of these foldersFor the 3 servers, we will use 3 command windows, and a fourth for the command line processor. All will use the same folder \OSP. On the first we issue the following commands:

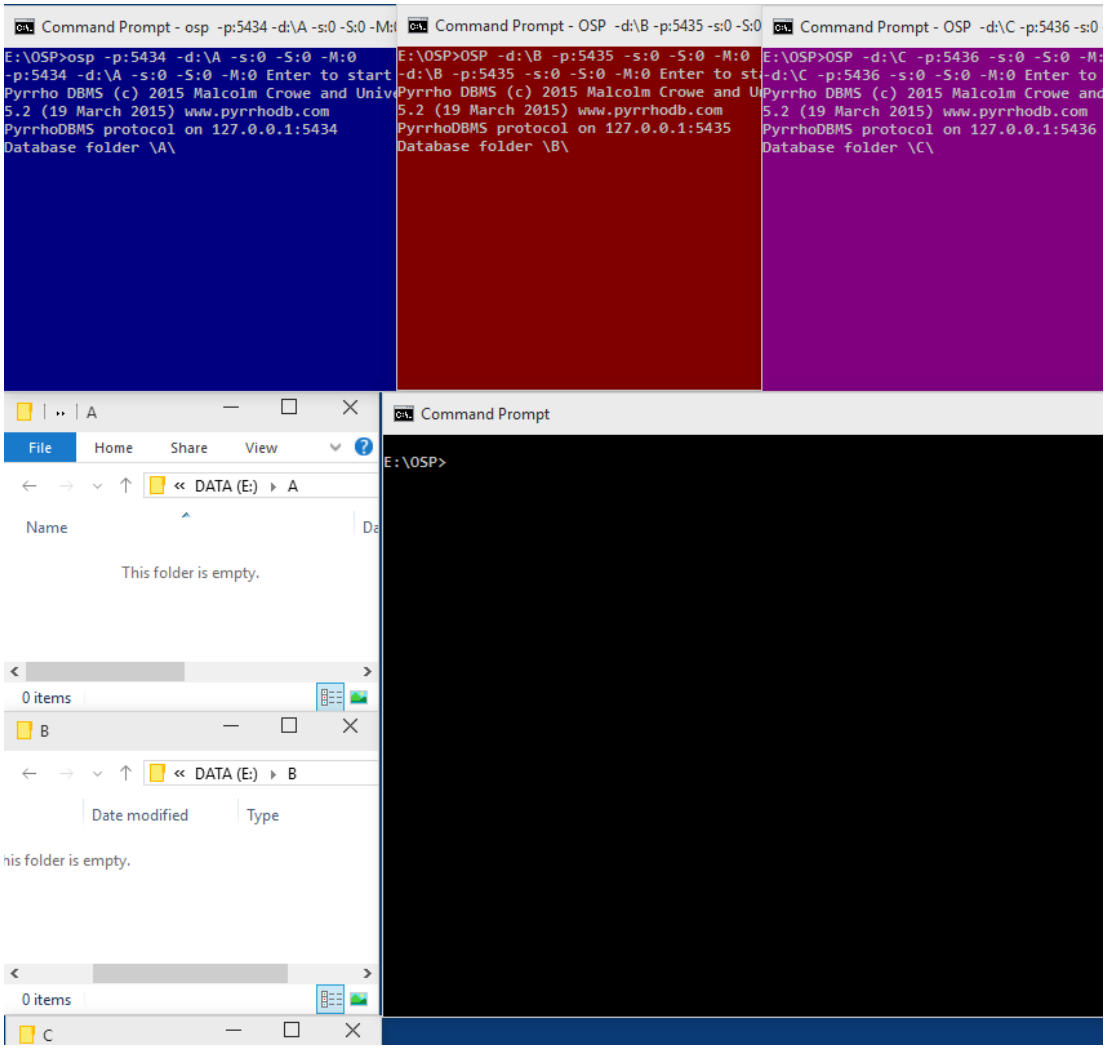
cd \OSP
OSP -d:\A -p:5434 -s:0 -S:0 -M:0

The –s, –S and -M flags prevent the server starting the http, https and Mongo services, as we would need to allocate non-conflicting ports for these. The arguments are echoed to the terminal window with the advice Enter to start up. Use the enter key to start up the server.



We should see output from the OSP server announcing that it is using port 5434 and directory \A\ , as shown here.

Similarly (in different command windows) start up servers on ports 5435 and 5436 and folders \B and \C. Leave these open also. (These windows will occasionally show diagnostic output, as in the distributed system under development it is sometimes useful to know where a problem is first reported.)

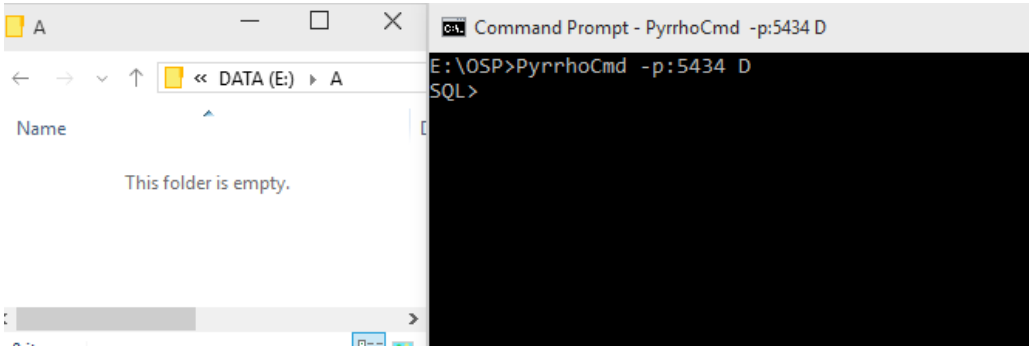


In these screenshots I have overlapped these windows, and I have adjusted the properties so it is easier to see which window is which when I show just one. It is still possible to see if extra lines have been output to these windows. Now open a file browser, and change directory to the A folder. We will use this window to check folder contents as we go along. In the screenshots I show all three folders A, B and C. All should be empty at this stage (C is out of sight in the above screenshot.)

A4.2 Create a sample database

In the command window, create a new database called D, by giving the command
PyrrhoCmd -p:5434 D

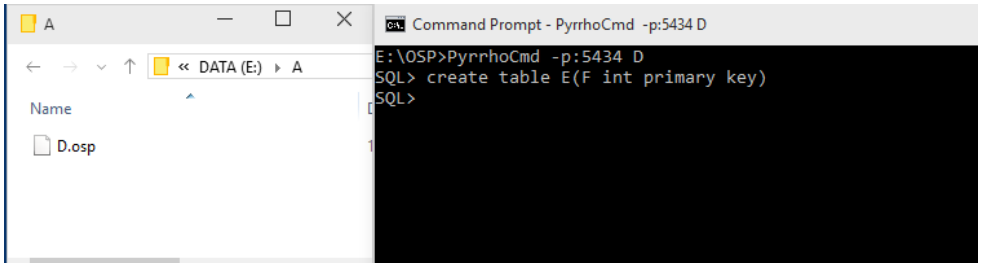
Notice the SQL> prompt in the terminal window. Although this command implies that a new database D.osp will be created, nothing is actually written to disk until the first change is committed.



At the SQL> prompt give the command

create table E(F int primary key)

Notice the creation of D.osp in the folder browser.

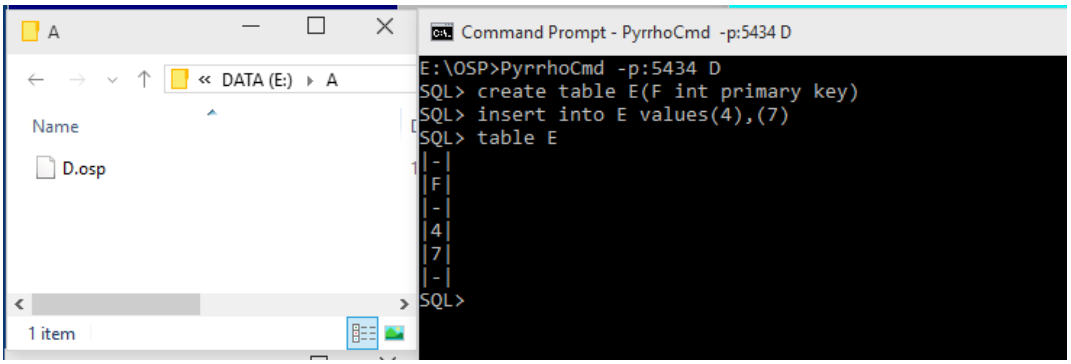


At the SQL> prompt give the commands

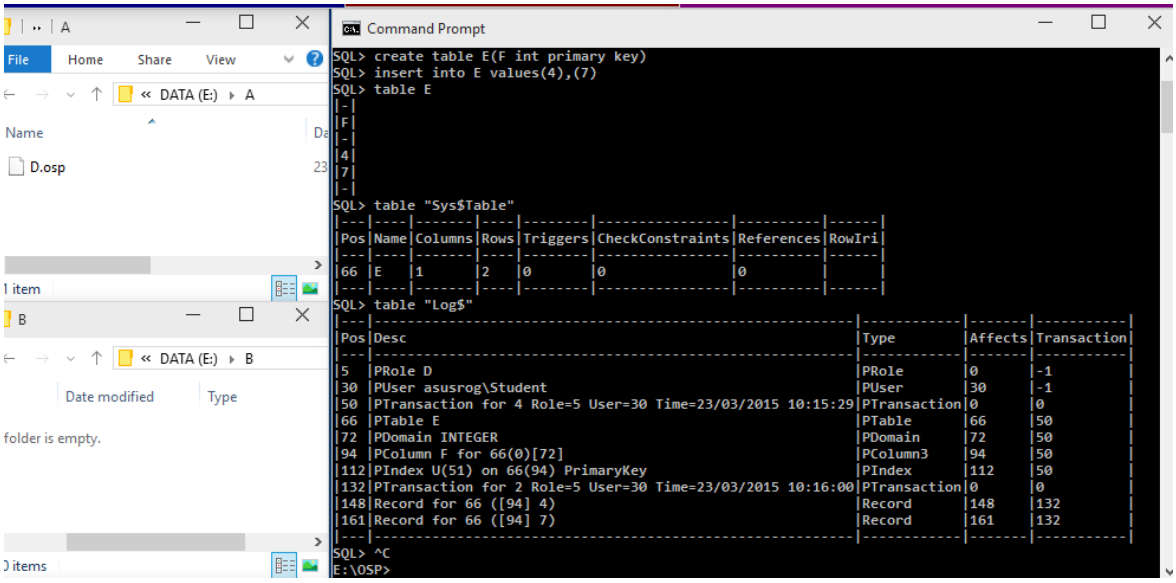
insert into E values(4),(7)

table E

Verify that we have two rows in table E.



The command **table "Sys$Table"** also gives a way of reporting on tables in the local database. Here it reports that E has one column and two rows. Also look at **table "Log$"** and close the session with ^C. You can leave the command window open.

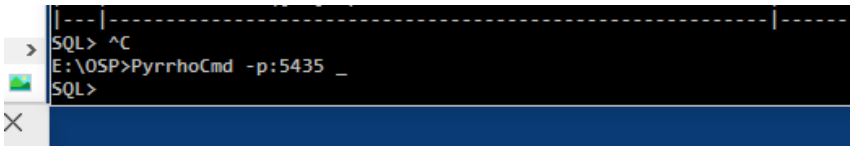


Before we go on, we note that this is exactly how normal databases work: if we insert 2 rows, we see 2 rows. If we create no tables we see no tables, etc. In the very next step we will see some very different (but still correct) behaviour.

A4.3 Configure a storage replica of the sample database

In the command window create a configuration database (whose name is _) for server B

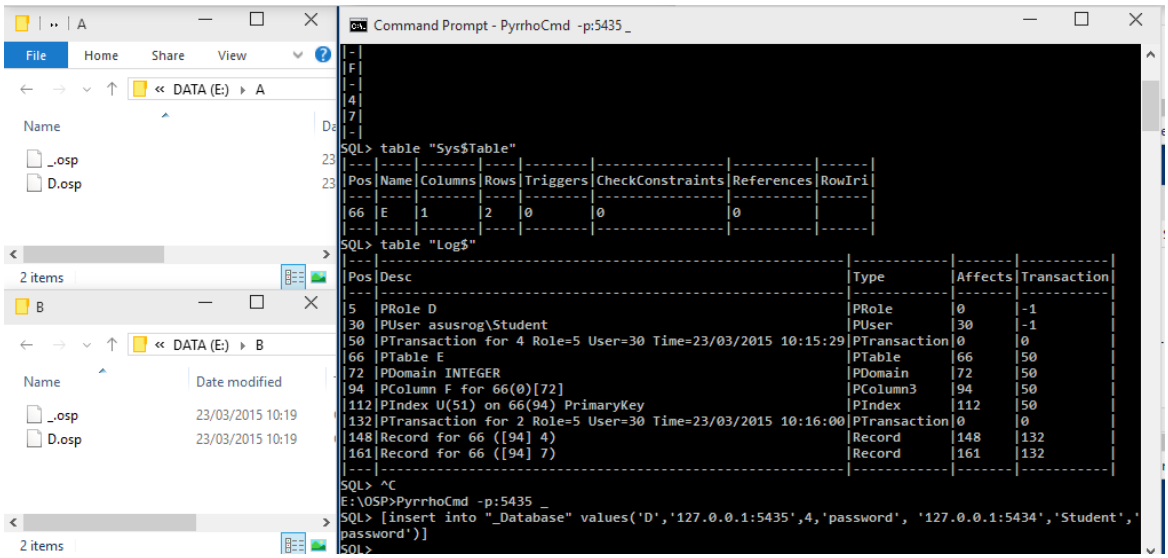
PyrrhoCmd -p:5435 _



At the SQL> prompt, give the command (on a single line, or enclosed in [ ]):

[insert into "_Database" values('D','127.0.0.1:5435',4,'password',
'127.0.0.1:5434','Student','password')]

This looks as if it shouldn't work, since we have not created a table called _Database. But Pyrrho treats the configuration database in lots of special ways. In the file browser we can see that we now have a database called _.osp in the B folder. This is as expected. However, we see that Pyrrho has also created D.osp in B, and _.osp in A.



Moreover, Pyrrho automatically creates three tables called _Client, _Database and _Partition inside any new configuration database. The first two will feature in this tutorial: as the name implies, the _Partition table is for configuring partitioned databases. Anyway, the command succeeds and we get another SQL> prompt.

The D.osp in B is a binary copy of the D database from A, as this is the effect of the mumbo-jumbo in the above insert command. But the two configuration databases are different, as we will now see.

A4.4 Examining the configuration file

At the SQL> prompt, examine the _ database with the commands (to the B server)

table "_Database"

We inserted one record in the _Database table, but we see two.

```
SQL> table "_Database"
|----|--------------|----------|--------|--------------|----------|--------------|
|Name|Server        |ServerRole|Password|Remote        |RemoteUser|RemotePassword|
|----|--------------|----------|--------|--------------|----------|--------------|
|D   |127.0.0.1:5435|4         |********|127.0.0.1:5434|Student   |********      |
|D   |127.0.0.1:5434|7         |********|              |          |              |
|----|--------------|----------|--------|--------------|----------|--------------|
SQL> table "_Client"
```

table "_Client"

```
|----|--------------|----------|--------|--------------|----------|--------------|
SQL> table "_Client"
|--------------|--------------|---------------|--------|
|Server        |Client        |User           |Password|
|--------------|--------------|---------------|--------|
|127.0.0.1:5434|127.0.0.1:5435|asusrog\Student|********|
|--------------|--------------|---------------|--------|
SQL> table "Sys$Table"
```

We did not add anything to the _Client table, but we see a record. It is clear that a lot has been happening behind the scenes. The details are quite technical and involve distributed transactions (there are some explanations given in section 6 of this document). (You will see a different machine name from “asusrog”.)

table "Sys$Table"

```
|--------------|--------------|---------------|--------|
SQL> table "Sys$Table"
|---|----------|-------|----|--------|----------------|----------|------|
|Pos|Name      |Columns|Rows|Triggers|CheckConstraints|References|RowIri|
|---|----------|-------|----|--------|----------------|----------|------|
|50 |_Client   |4      |0   |0       |0               |0         |      |
|221|_Database |7      |1   |0       |0               |0         |      |
|475|_Partition|14     |0   |0       |0               |0         |      |
|---|----------|-------|----|--------|----------------|----------|------|
SQL>
```

Reassuringly though, the Sys$Table table shows that the _ database on B really does have just one record (the one we inserted). The record we inserted called for the creation of binary storage on B or a database from A, so the configuration database on A was created to ensure the copy is kept updated by A, which of course continues to be the transaction master for the D database.

And the _Client database is empty.

The extra entries in the table “_Database” and table “_Client” listings actually show us also the important configuration entries that have been automatically added in the configuration database on A. As you can see, the server address in each case is that of A.

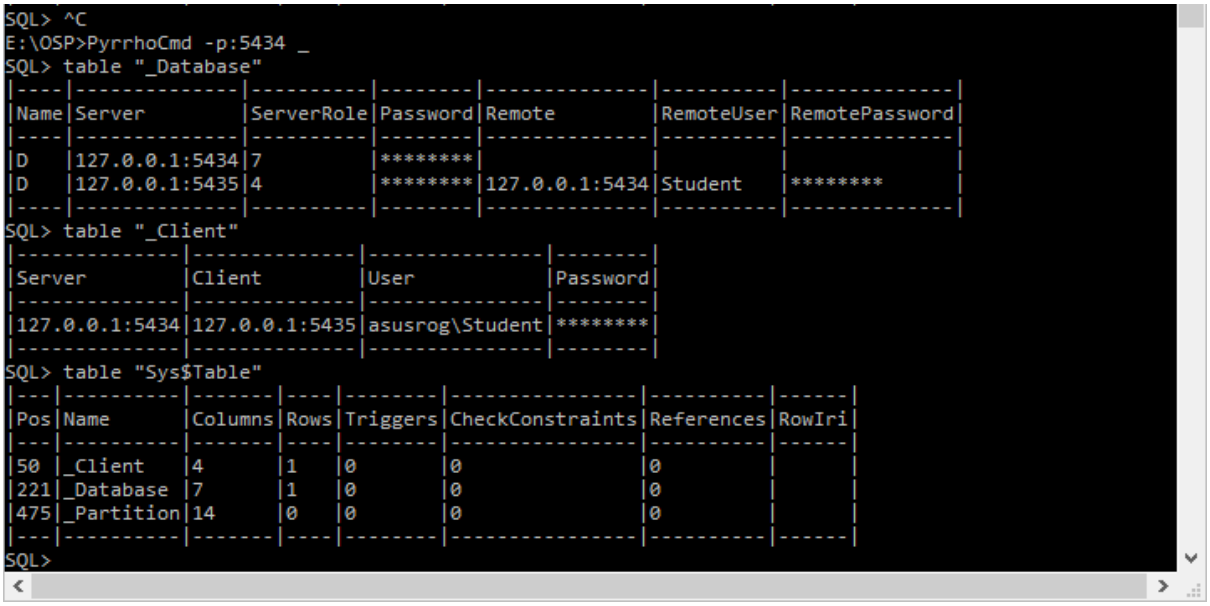
Close the session to B with ^C, and let’s verify the contents of the configuration database on A:

PyrrhoCmd -p:5434 _

At the SQL> prompt give the same three commands:

table "_Database"
table "_Client"
table "Sys$Table"

We see the same contents in table "_Database" and table "_Client", but the "Sys$Table" shows that A has one record in _Client and one in _Database.



Thus, while the servers agree on the configuration, they locally store only their own data: the entries for Server=127.0.0.1:5434 are on A, and those for 127.0.0.1:5435 are on B.

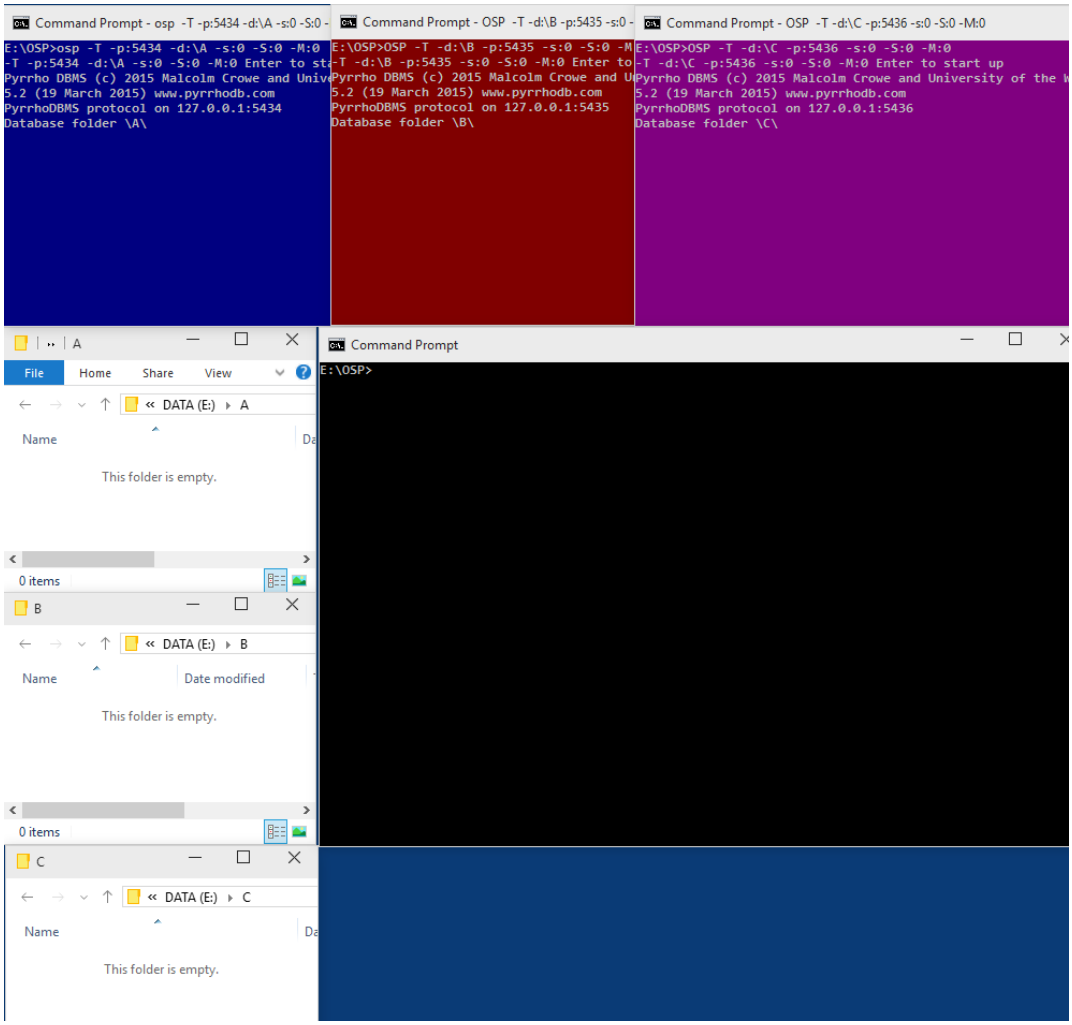
You can use Visual Studio to open D.osp with the Binary Editor to check that the D.osp files match. But you can't use the Pyrrho server on B to examine the contents, because we have configured it for the Storage role only.

Close the terminal session with ^C, leaving the terminal window open.

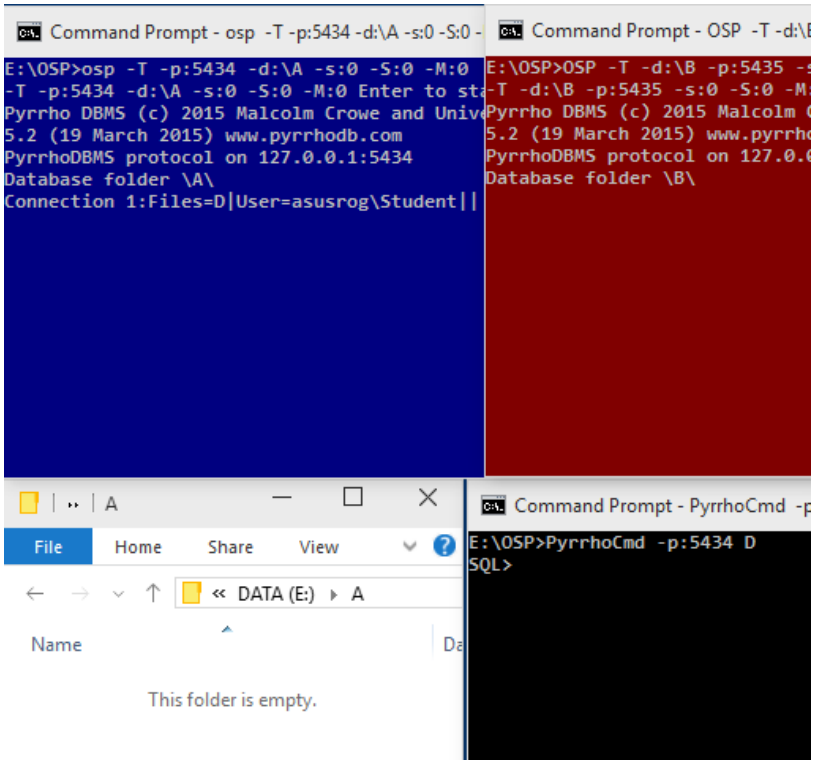
A4.5 What happened in step 3

In this section we use the special -T (Tutorial) mode of OSP.exe to illustrate the steps involved when we created the configuration entry on B with its side effects.

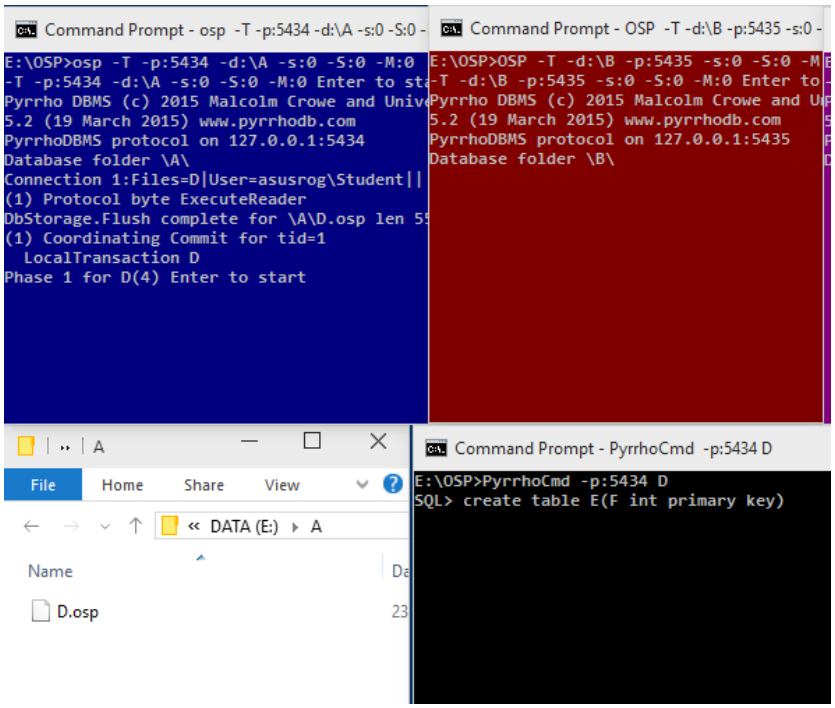
To get the screenshots in this section, I stoped the 3 servers, emptied all 3 folders I have started the servers again with the –T flag:



When we start to create the database D on the server A we get a message from server A acknowledging the connection (1) to the database D:



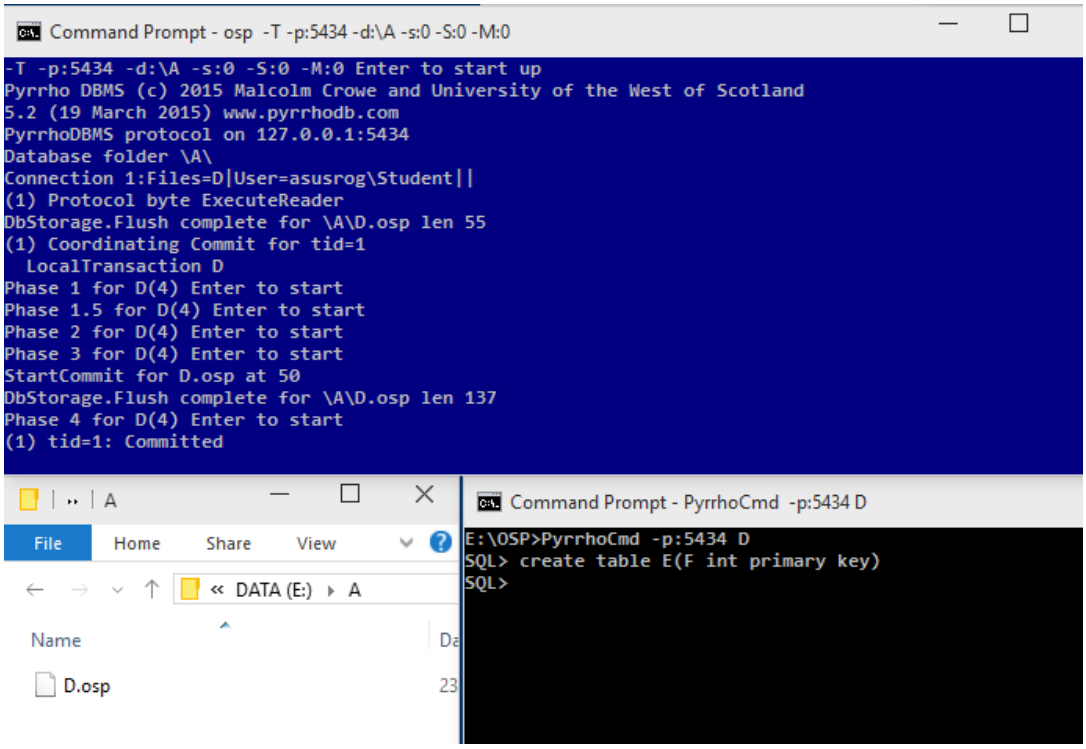
In this mode, you need to confirm each step of each transaction with the Enter key, so for example in the next step (create table E..) we get this:



We see that PyrrhoCmd used ExecuteReader even though it is not a SELECT or TABLE command.

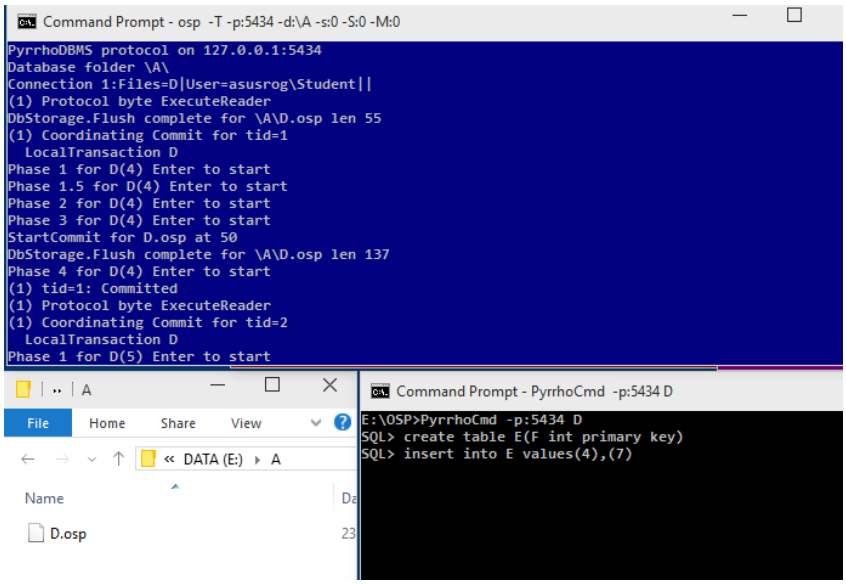
We are in auto-commit mode, so the commit of this transaction is already underway. The server is telling us it first creatied an empty database D.osp in folder A, has started a LocalTransaction to check the proposed changes, and is waiting for us to confirm Phase 1 (transaction validation). We press Enter in the server window several times until the Committed message appears.

At this point we also see the SQL> prompt in the PyrrhoCmd window. We see that the changes were written to disk in Phase 3.

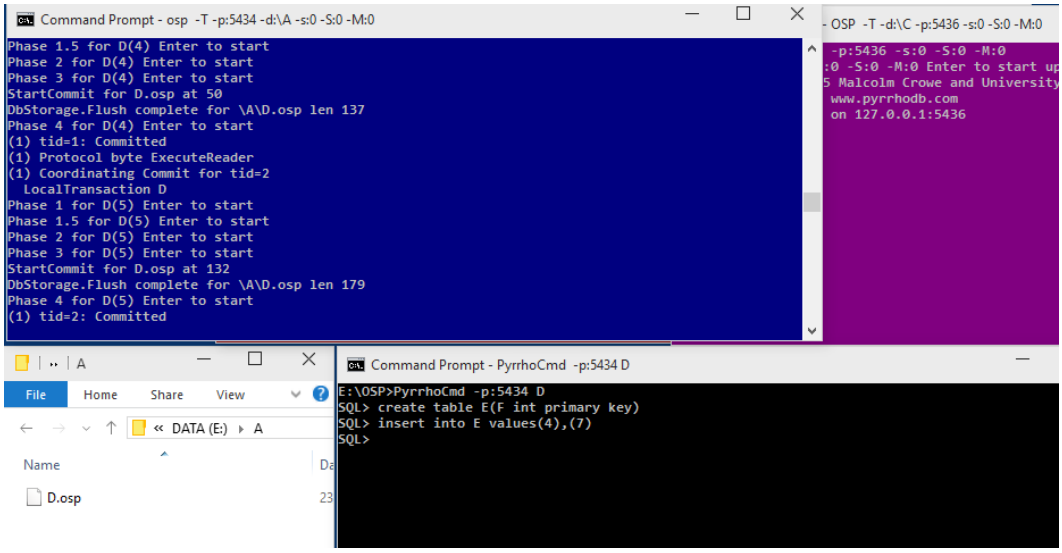


Now in the PyrrhoCmd window,

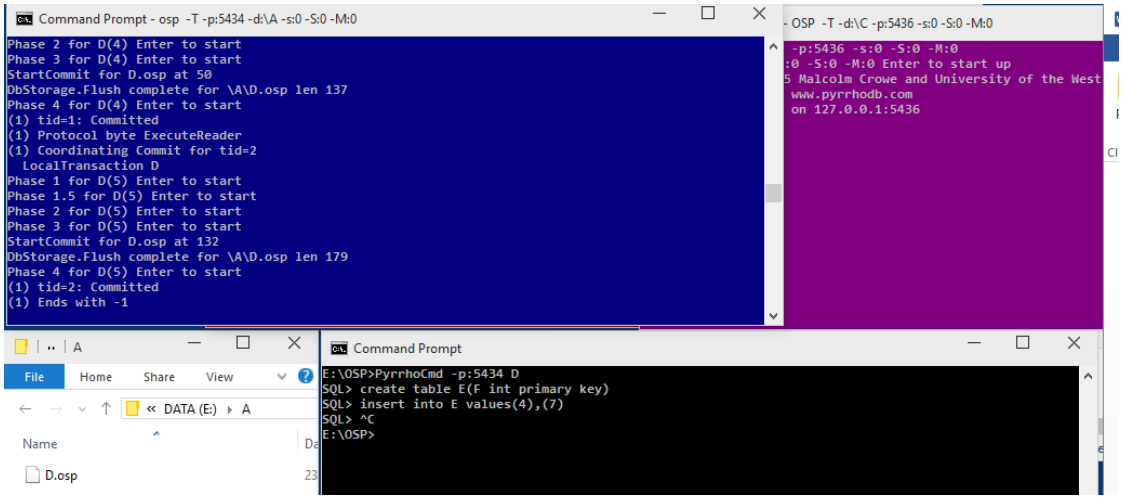
insert into E values(4),(7)



In the A server window, press Enter five times:

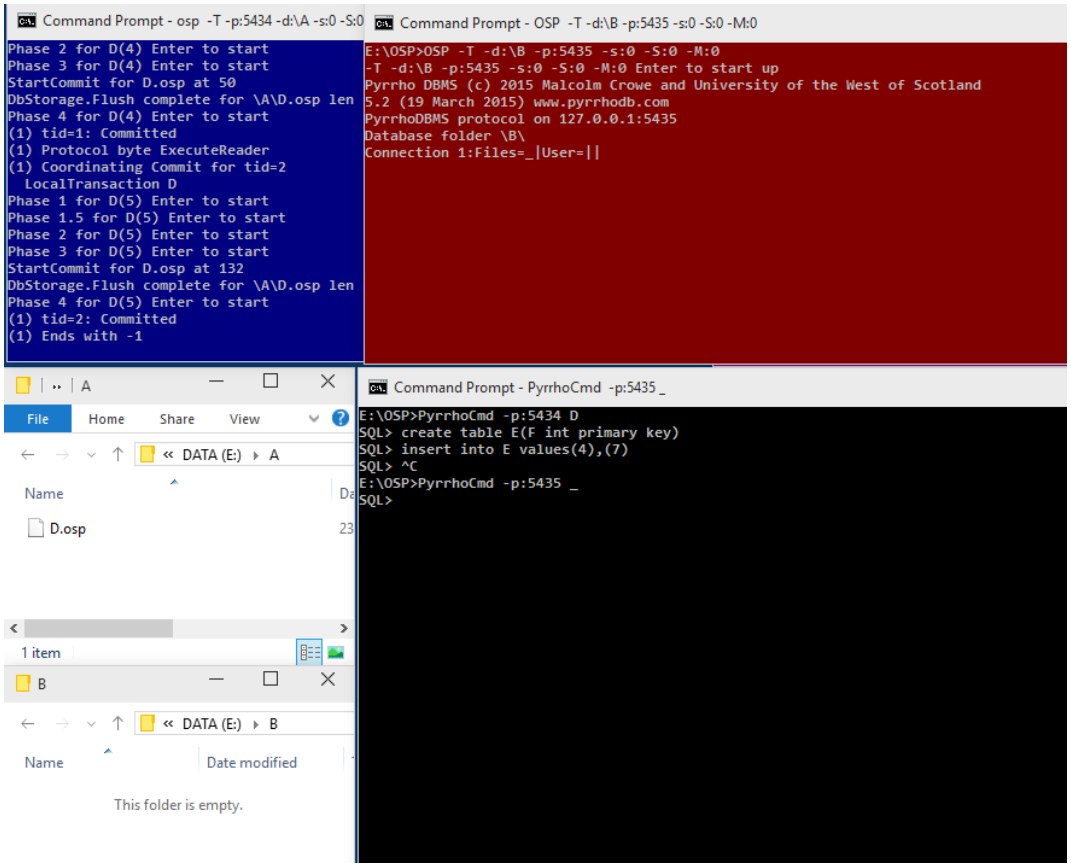


In the PyrrhoCmd window we close the session with ^C, and the server acknowledges the end of the Connection (1).



The next step is to create the configuration file on server B (which had many side effects).

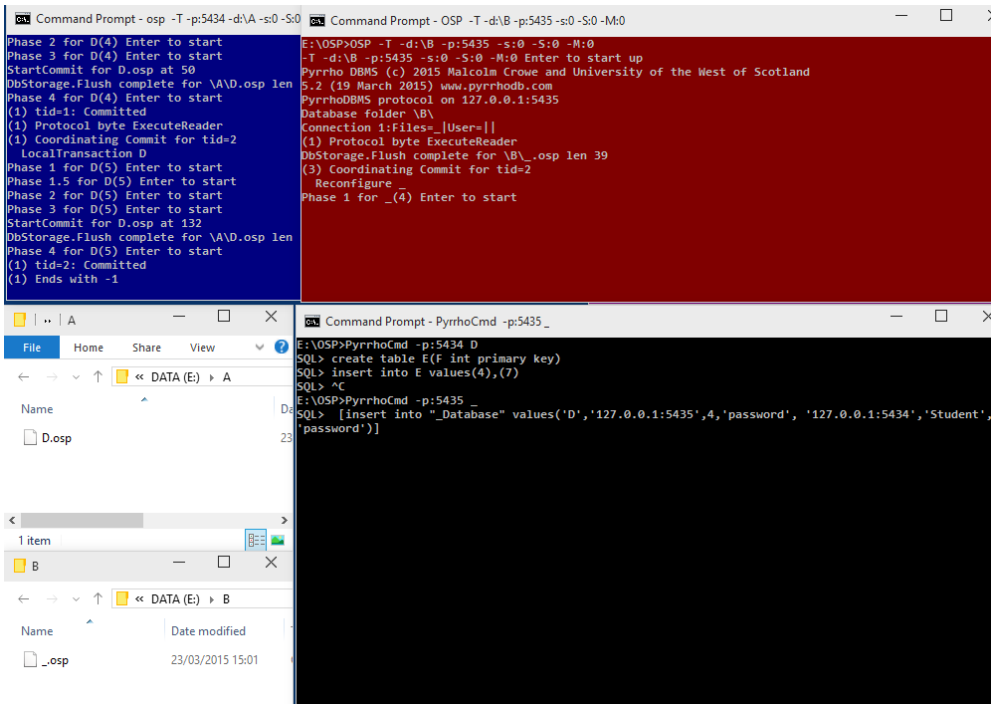
PyrrhoCmd -p:5435 _



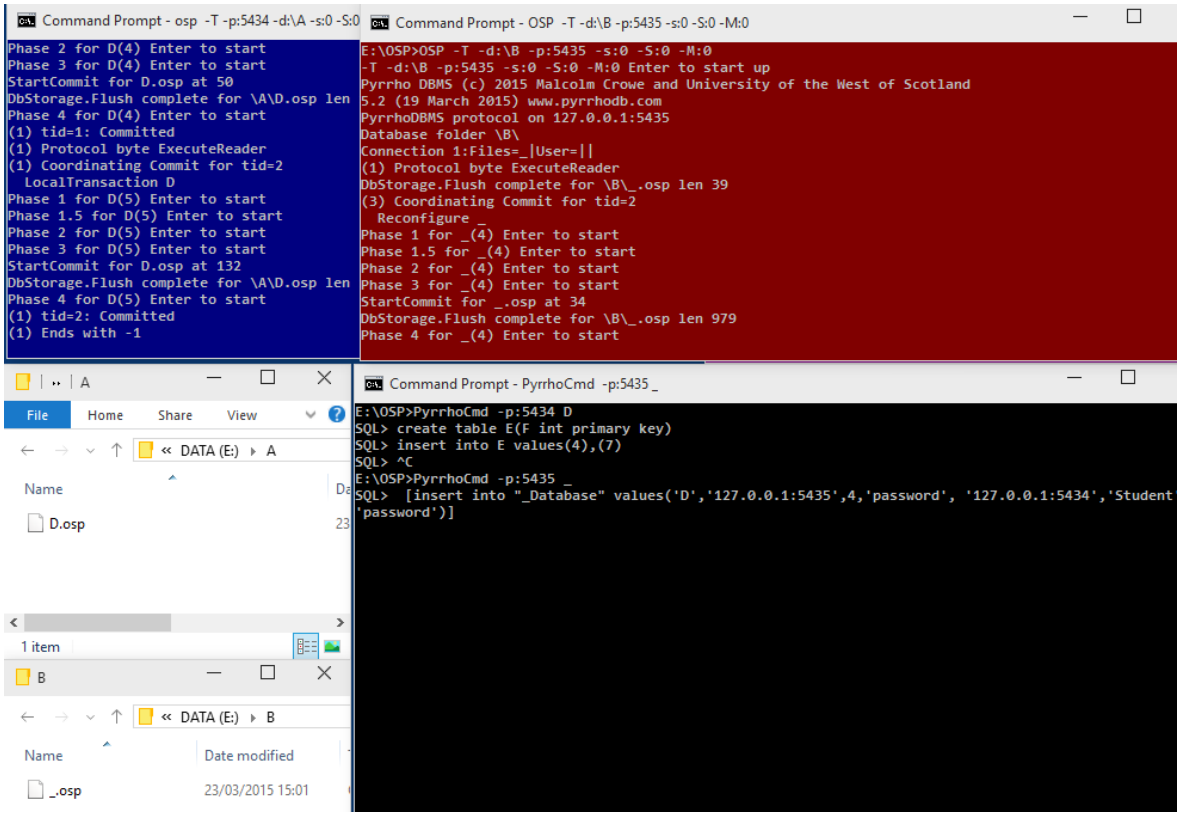
The screenshot shows server B has received the connection information: connection 1 on server B to database _.

However the database is not actually opened until a transaction begins. This happens when the user requests the insertion of a record into the _Database table, or when an explicit transaction starts:

[insert into "_Database" values('D','127.0.0.1:5435',4,'password', '127.0.0.1:5434','Student','password')]

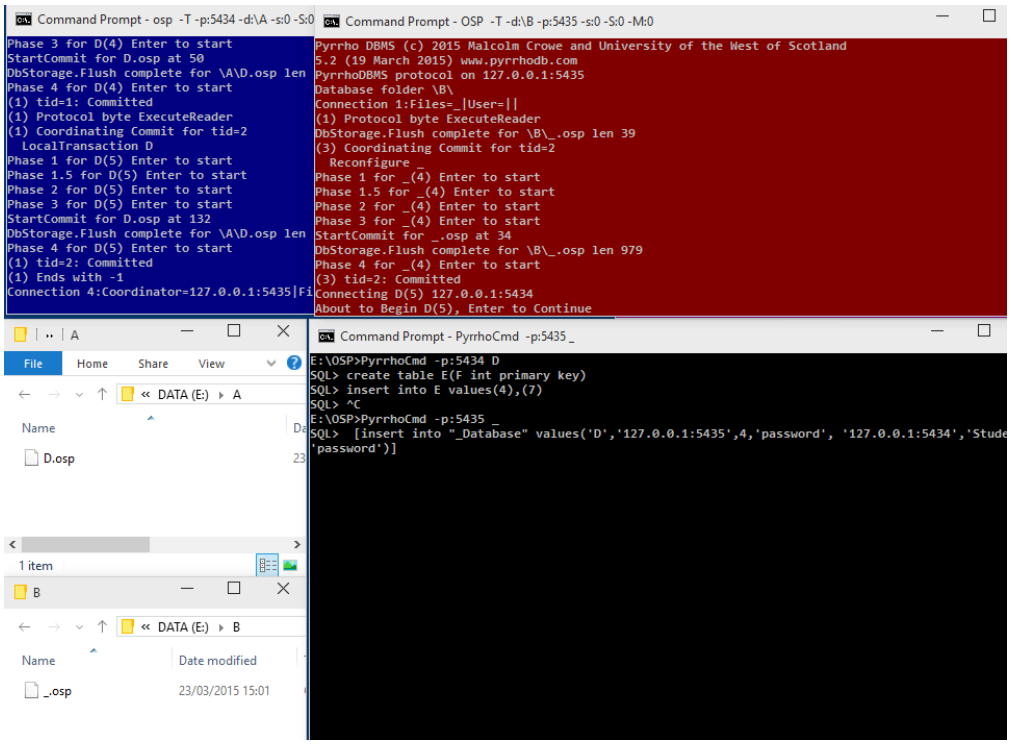


We see that the new configuration file \B_.osp has been created. But instead of an ordinary LocalTransaction, the server has started a special Reconfigure transaction. In the B server window, use the Enter key four times:



We see that the configuration database has grown to 979 bytes to accommodate the three empty tables _Database, _Client and _Partition.

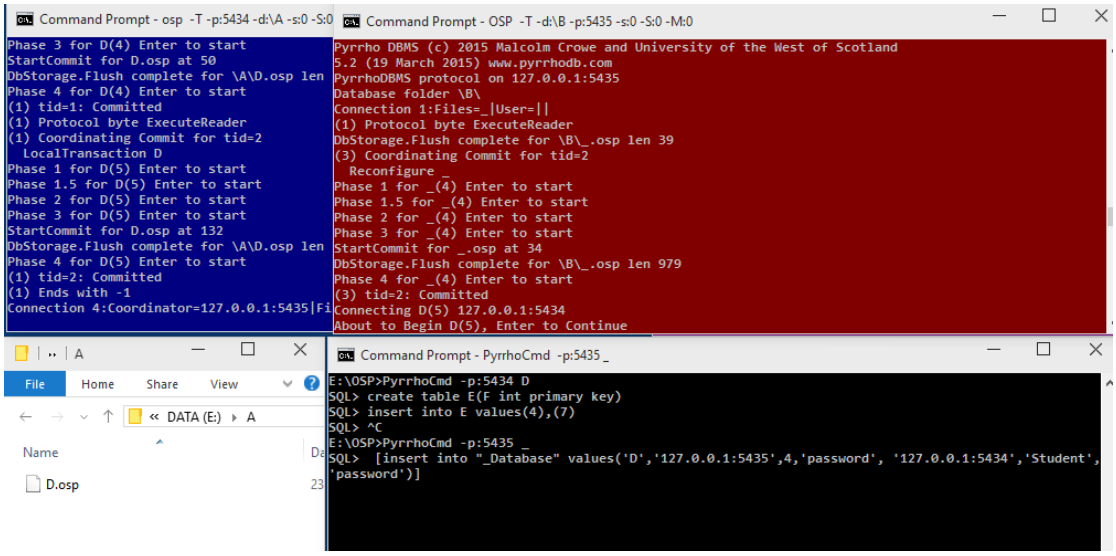
Now press the Enter key to start phase 4.



A4.6 A distributed transaction begins

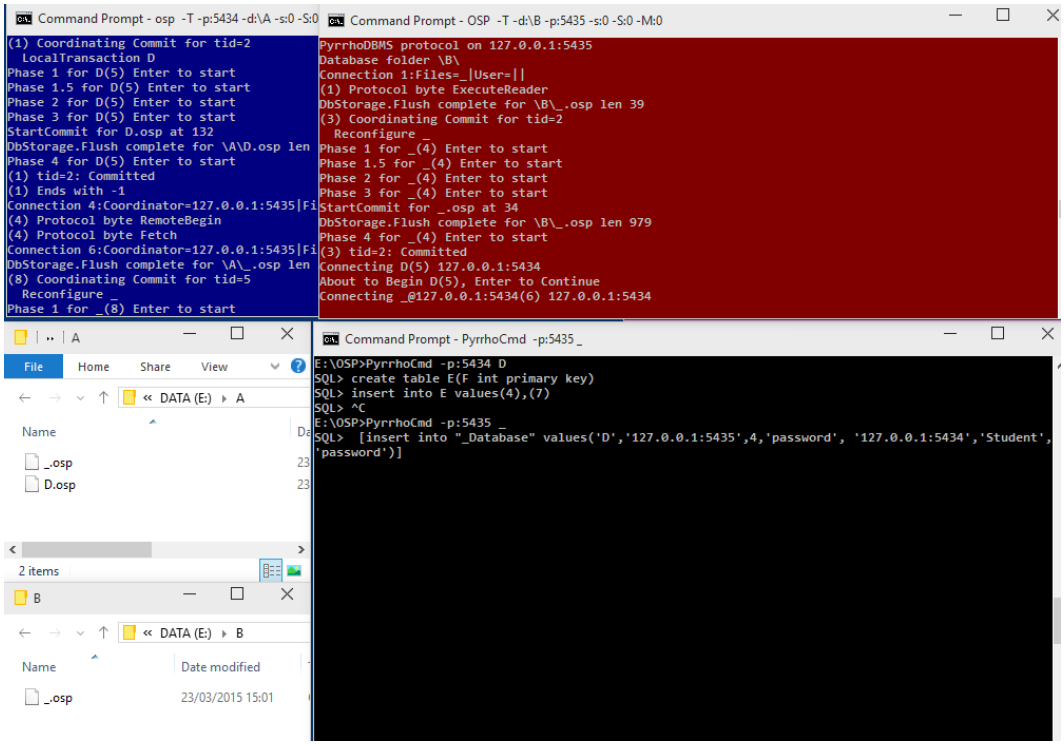
The user has requested that a new record is added to the configuration database. The Reconfigure class overrides the AddRecord method to watch out for references to remote databases (D on A in this case), as these will need entries in the configuration database on the remote server. At the point shown in the screenshot, we have identified a reference to a new local D connected to a remote D on A.

At the start of phase 4, server B begins to coordinate a distributed transaction, and contacts server A. In the above screenshot we see server A has acknowledged a connection for database D from server B, and server B is about begin to create database D. This connection is no 3 on server A, and no 5 on server B. Press Enter:

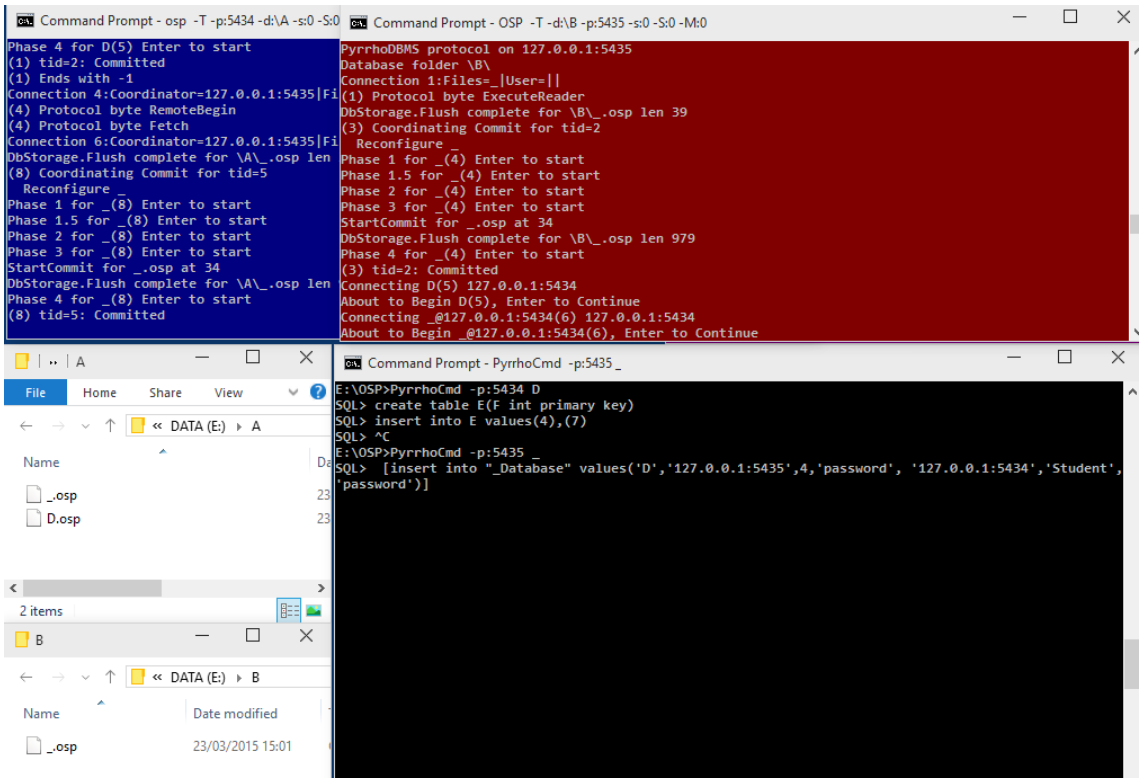


The Begin for D involves getting the contents of database D from A, which we see in the Fetch message in A's window. B can now write these contants in its LocalSlave database D, and will do so when it closes D below.

B creates a second connection to server A to A's configuration file (_@127.0.0.1:5434), as connection 6. A acknowldeges this new connection (as 5) and creates an empty coniguration database. A initialises the configuration file in a transaction that it is coordinating (connection 7), and at this point we need to use the Enter key five times in A's window to move things along:



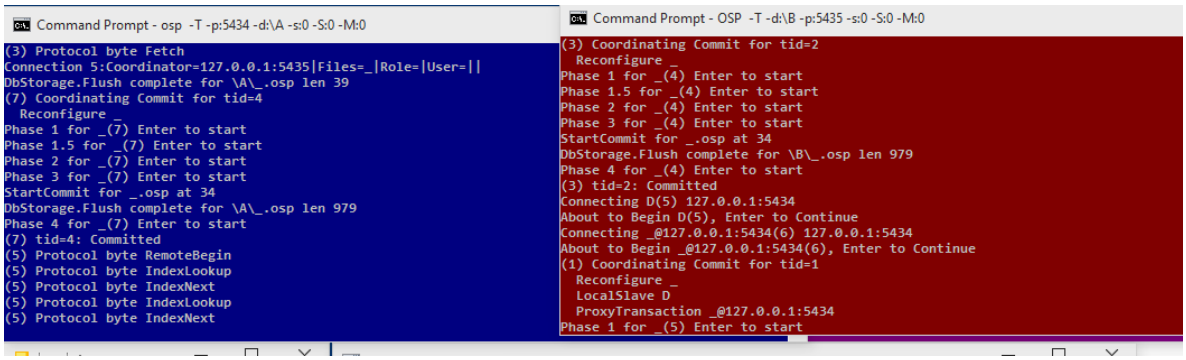
As before, and the end of phase of the configuration initialisation transaction on connection 7 we see the empty configuration database has 979 bytes.



The distributed transaction is coordinated by server B, and so the current transaction needs to have references to the remote database that will be created and modified. The name of the database on A will of course be _.osp, but this remote database is referred to in server B as _@127.0.0.1:5434. The name of both databases is _, so inside the server, databases are catalogued by transName instead of name to keep such entries separate. The current transaction on B configures information about a remote database called _@127.0.0.1:5434 , and adds it to the transaction.

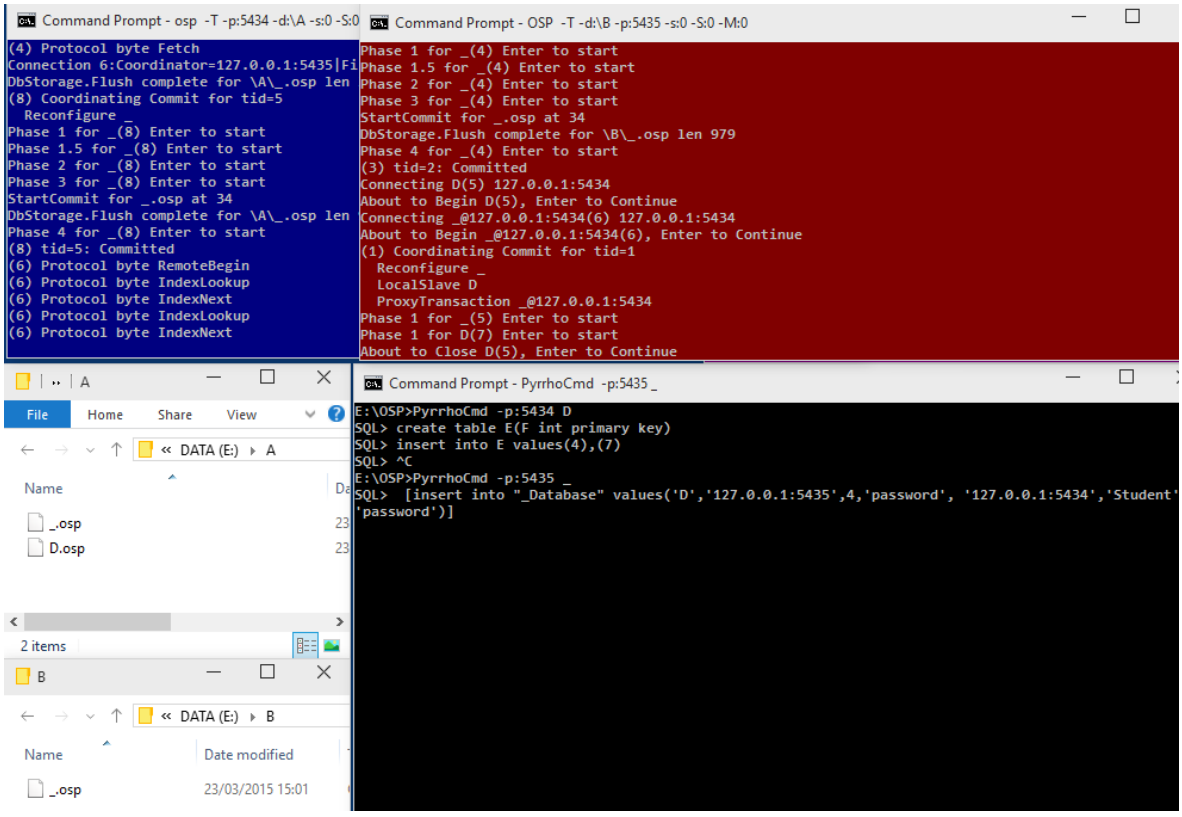
To this ProxyTransaction (referring to _ on A) it then adds the counterpart of the new record in _ on B. Unfortunately this is not a simple matter, as we will first need to check what information the configuration file on A currently contains about D.

Server B is now ready to make the requested entries in the (distributed) configuration database. In B's window, press Enter:

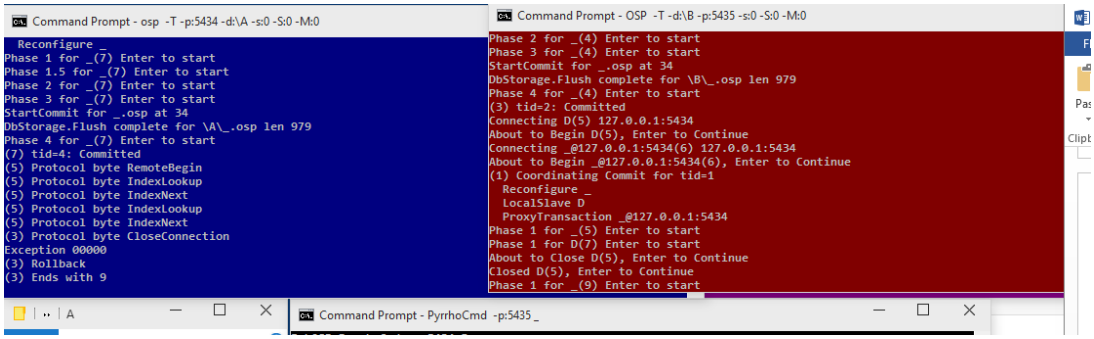


B tells us that there are 3 parts to the transaction it is coordinating. Reconfigure, the LocalSlave for D, and a ProxyTransaction to make the configuration changes on A. In A's server window we can see that B has already used the ProxyTransaction to check the contents of A's configuration database (and finds it contains nothing conflicting with what is proposed).

In B's window, press Enter twice:

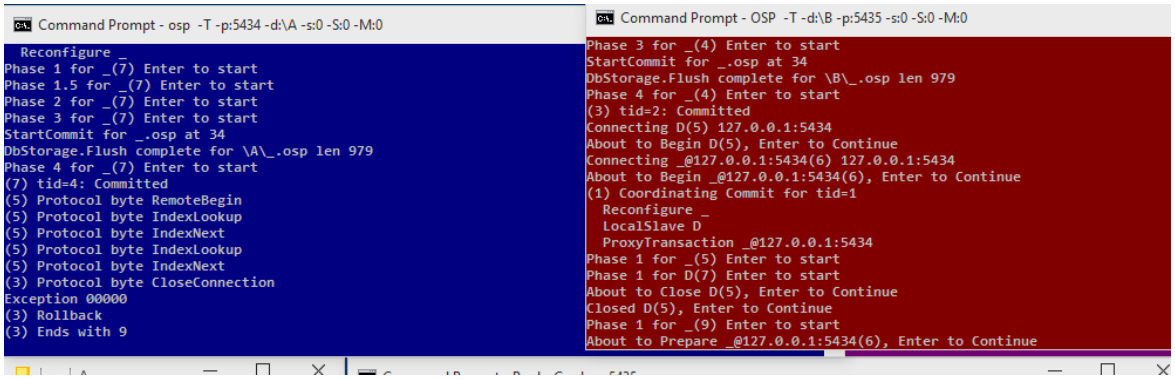


B has no changes to make to database D, so it is closed. Press Enter twice:

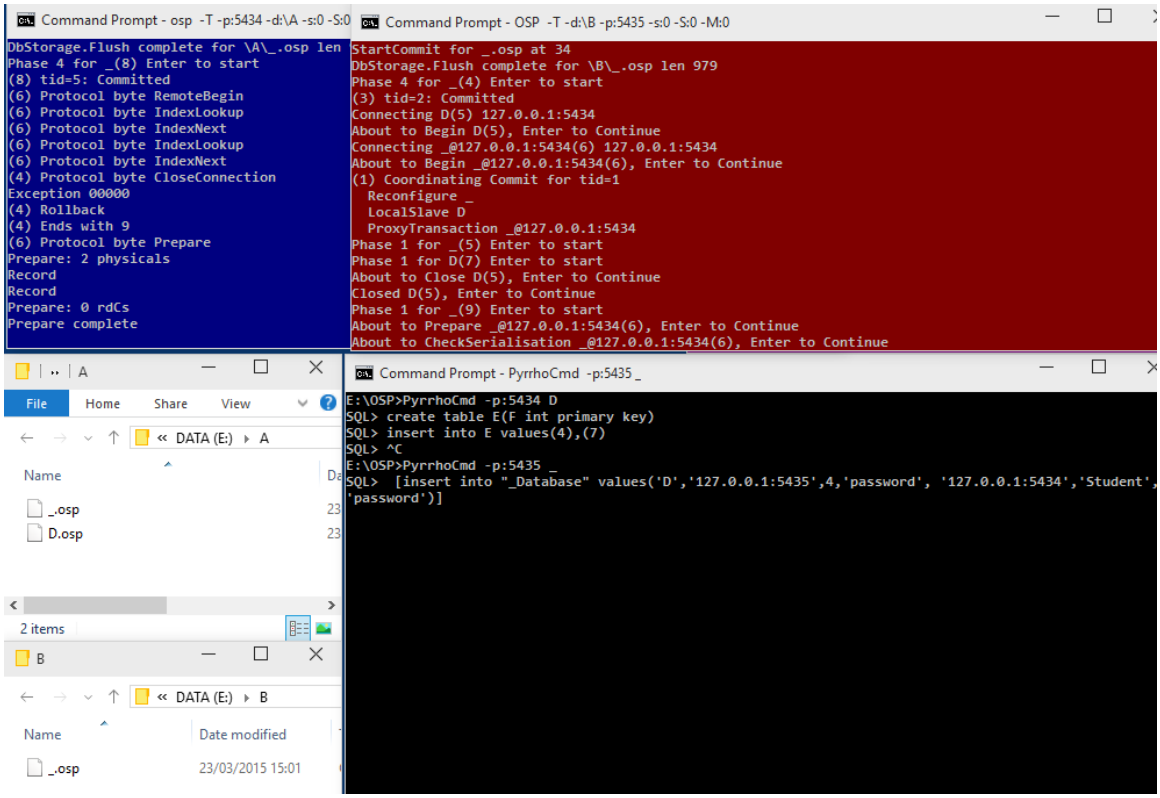


The closing of the connection for D on both servers is acknowldged byserver A (Exception 0000, Rollback is the normal ending for a transaction that makes no changes).

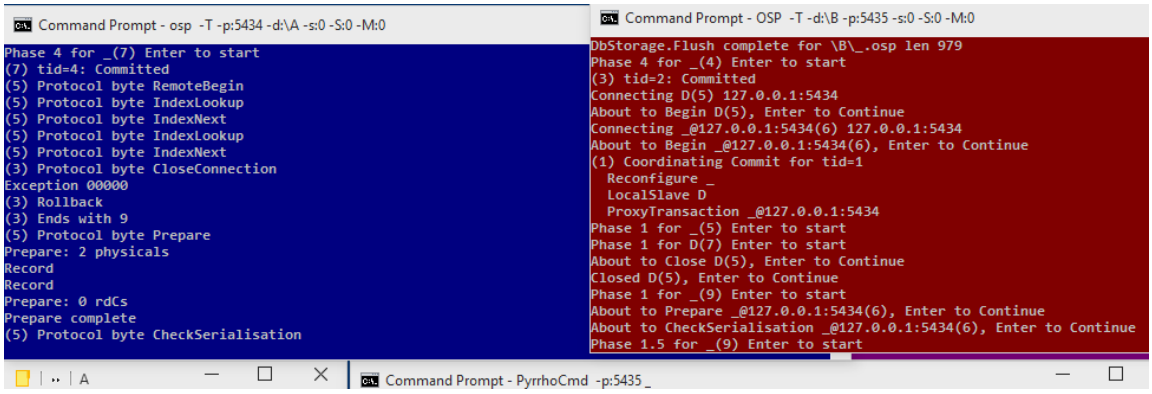
B now wants to make the configuration changes to _ . Press Enter:



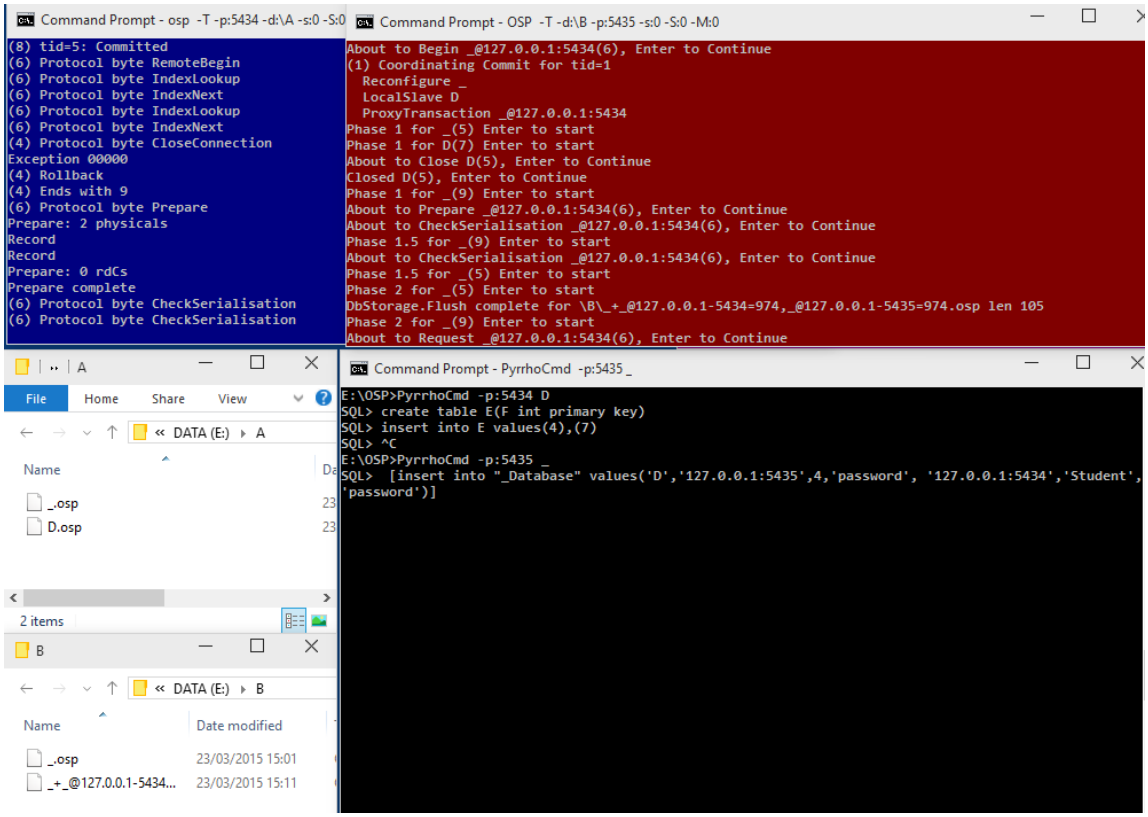
Validation of this transaction requires starting a two-phase commit protocol with server A. We begin with a Prepare which sends all of the proposed changes to server A. Press Enter:



A receives the Prepare request containing two Records for _ . From the above discussion we know that one of these is for _Database and the other for _Client. On B, press Enter to perform the CheckSerialisation step (this confirms no conflicting changes in A's configuration):



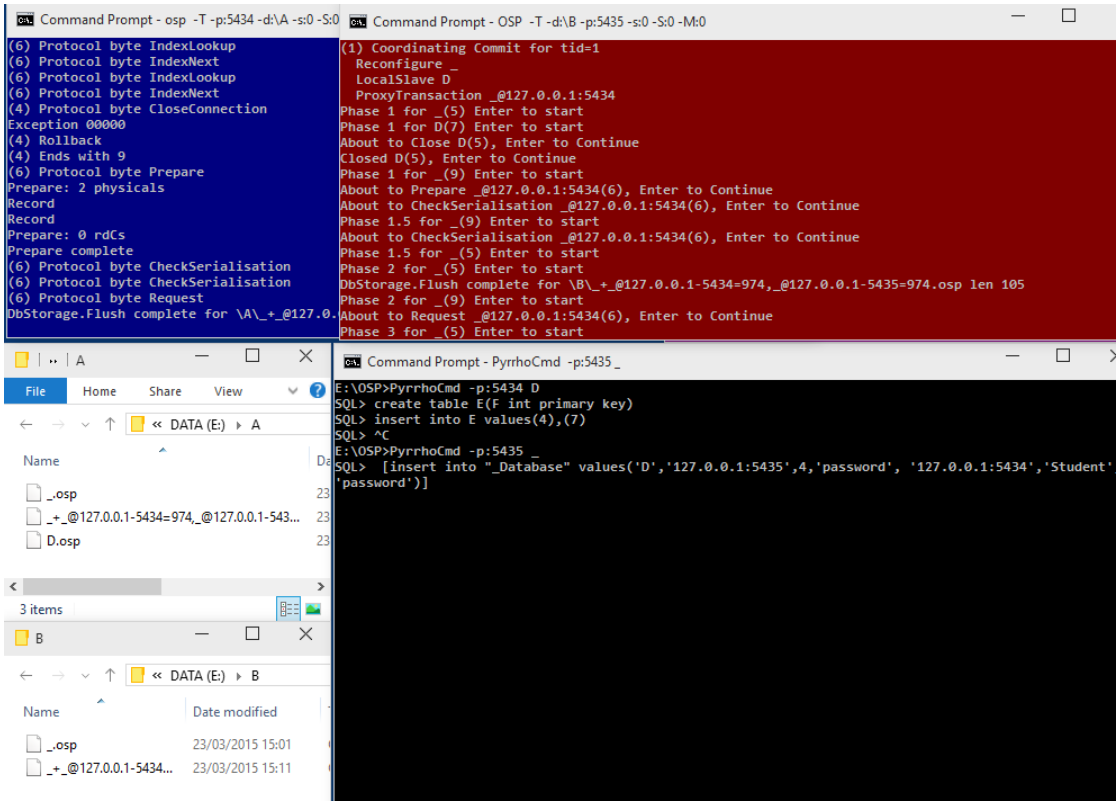
Press Enter again four more times:



What has happened here is that B locked the database and checked serialisation again: finding all is fine, it has written all of the transaction details to disk in a specially named file. This filename records the sizes of the transaction logs for the participating databases, and the contents of the file contain binary details of the changes being made.

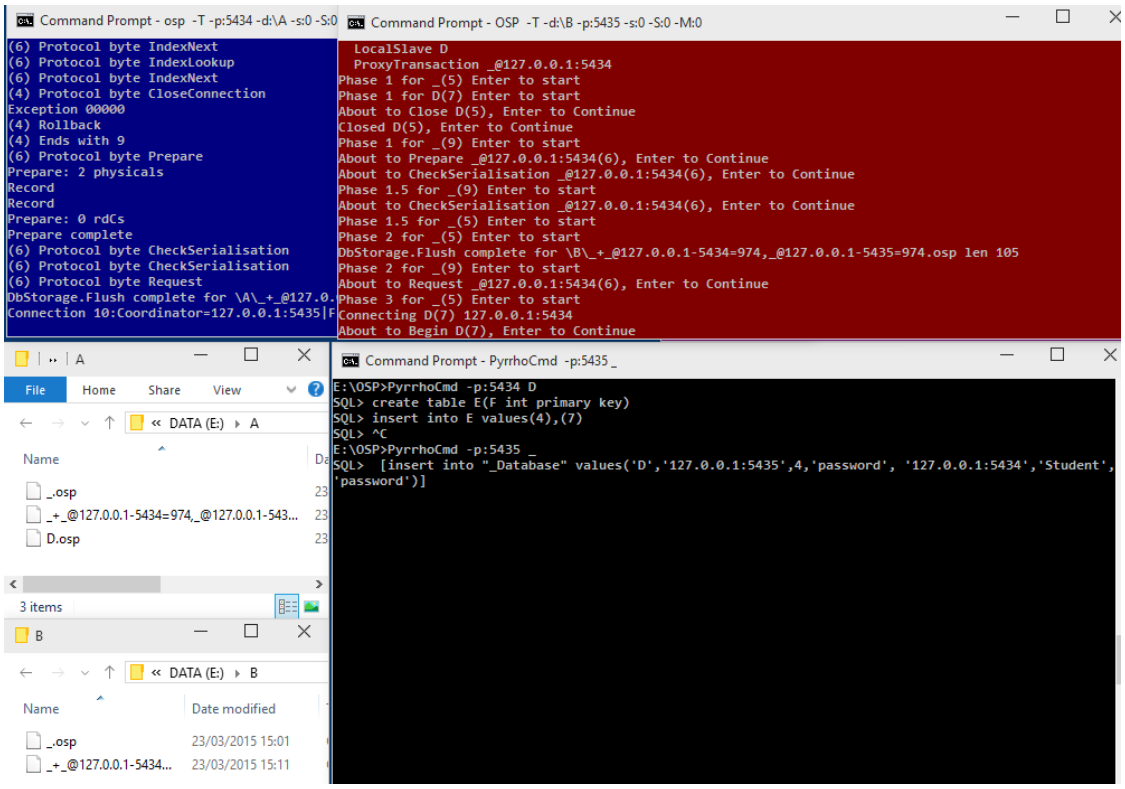
In this case the filename is _+_@127.0.0.1-5434=974,_@127.0.0.1-5435=974.osp, which merely shows that both configuration databases are still in their initialised state (the file size of 979 bytes includes an end-of-file marker).

Press Enter again twice, to make a Request to server A:

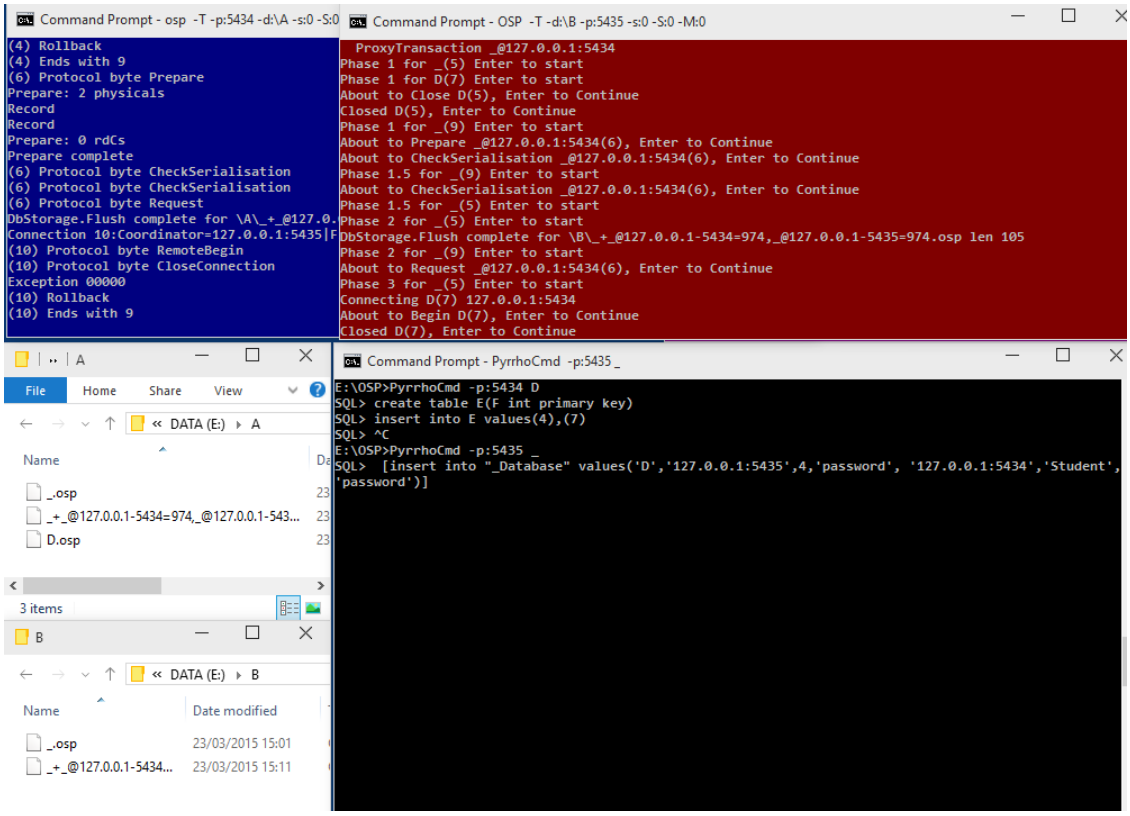


A has now also recorded the transaction details, with its own, similarly named file. If you look at this stage, you will see that the two temporary transaction files have different sizes.

Still in B's window, press Enter again to start phase 3:

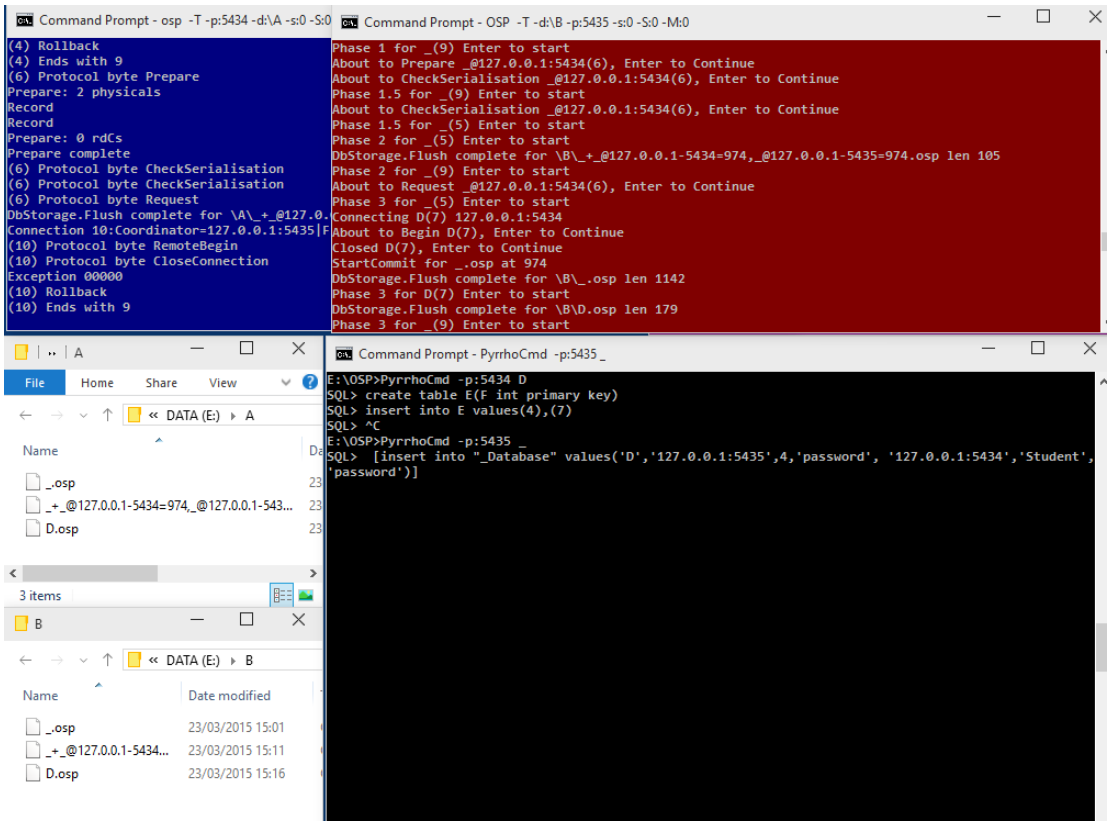


Press Enter:

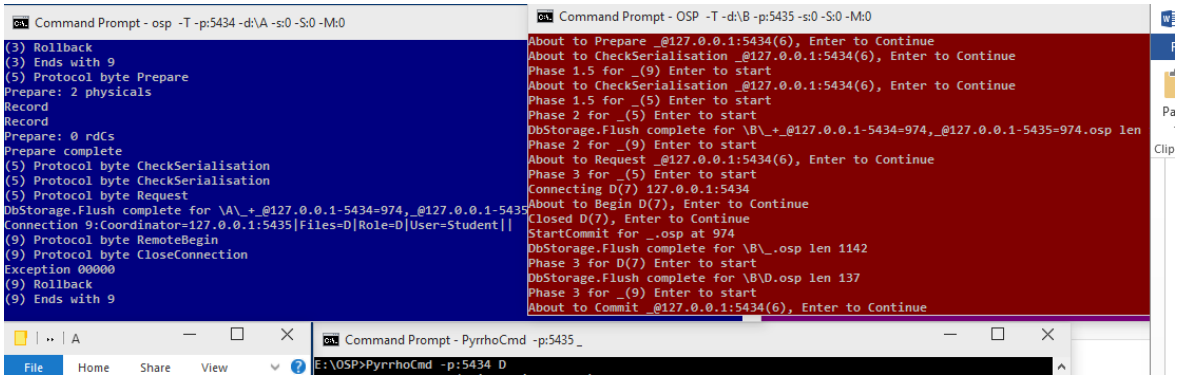


B once again checks D in a new connection. (This is just possibly theoretically redundant).

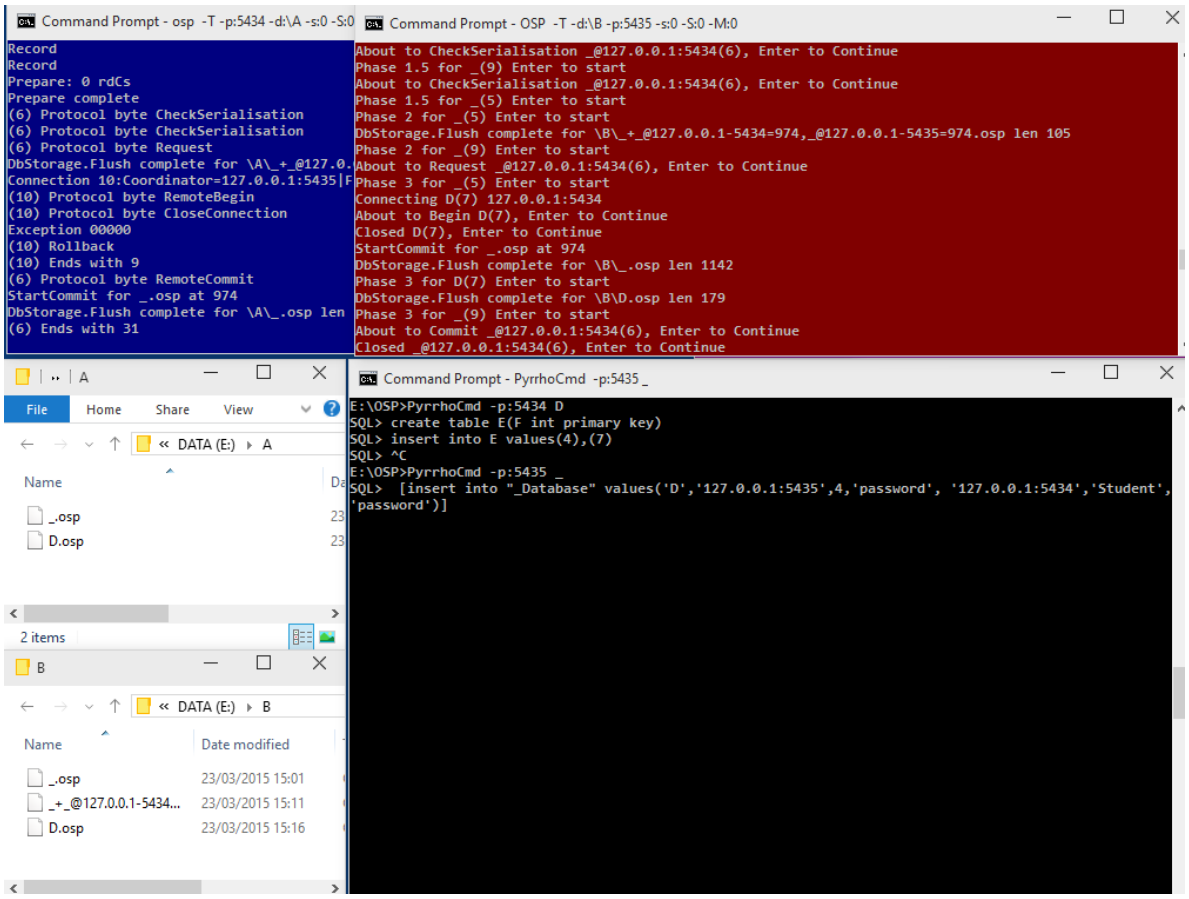
Press Enter again twice:



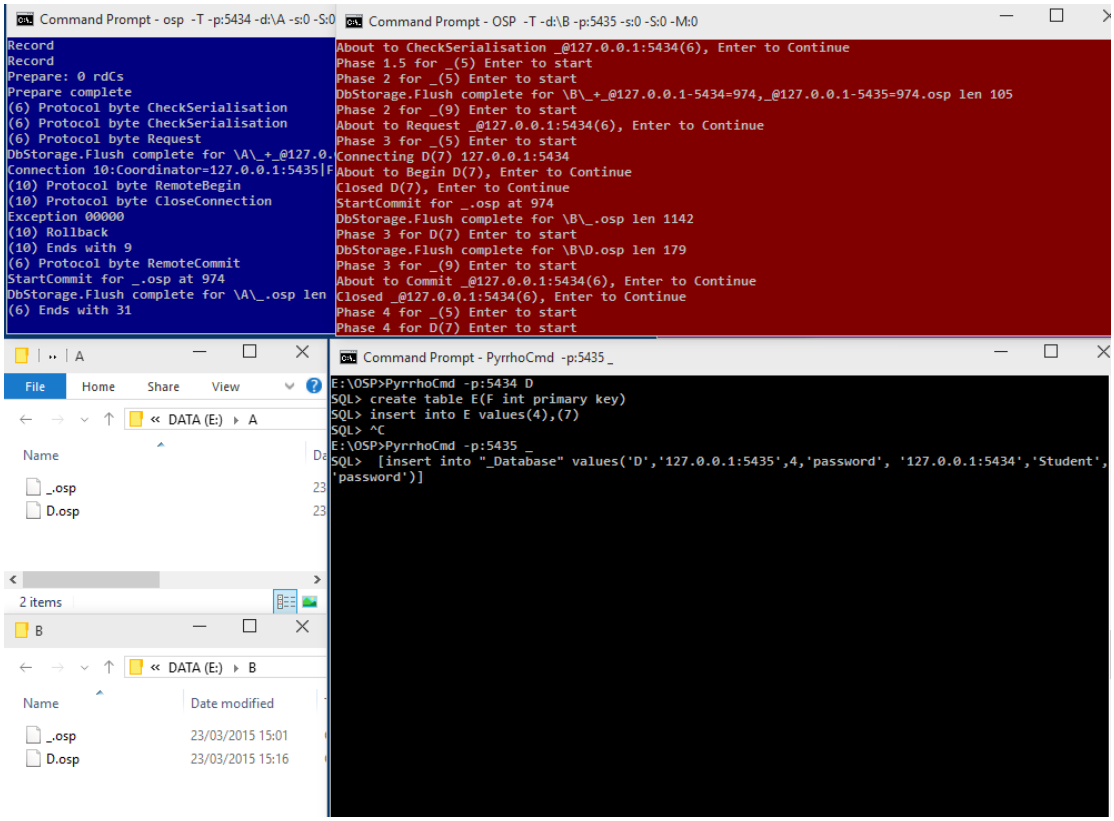
We now have the binary replica of D in B's folder. Press Enter:



We see we are about to commit the changes to _ on A. Press Enter:

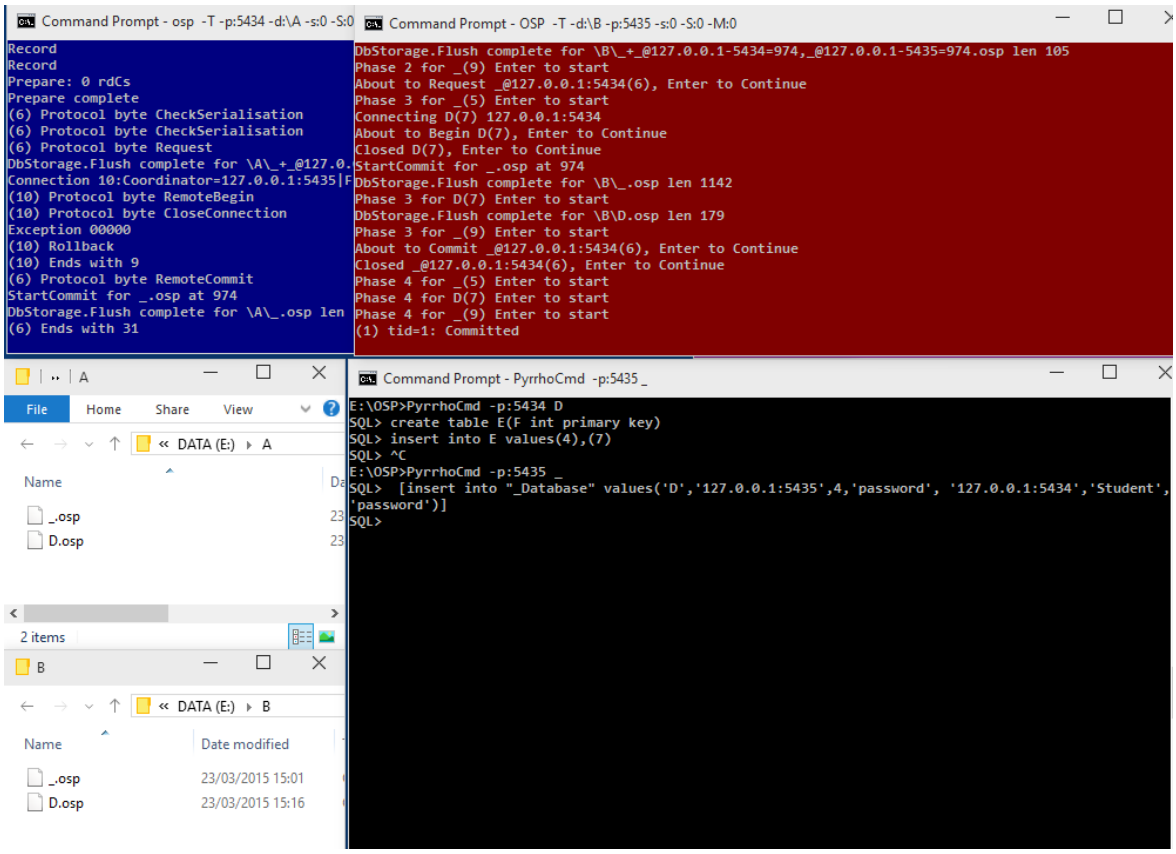


A commits its changes (note A's _ is now 1175 bytes) and deletes the temporary transaction record. Press Enter twice:



We see that on completing Phase 4 for _, B has removed the temporary transaction file in folder B.

Press Enter twice more to complete the transaction and get the SQL> prompt in the PyrrhoCmd window:



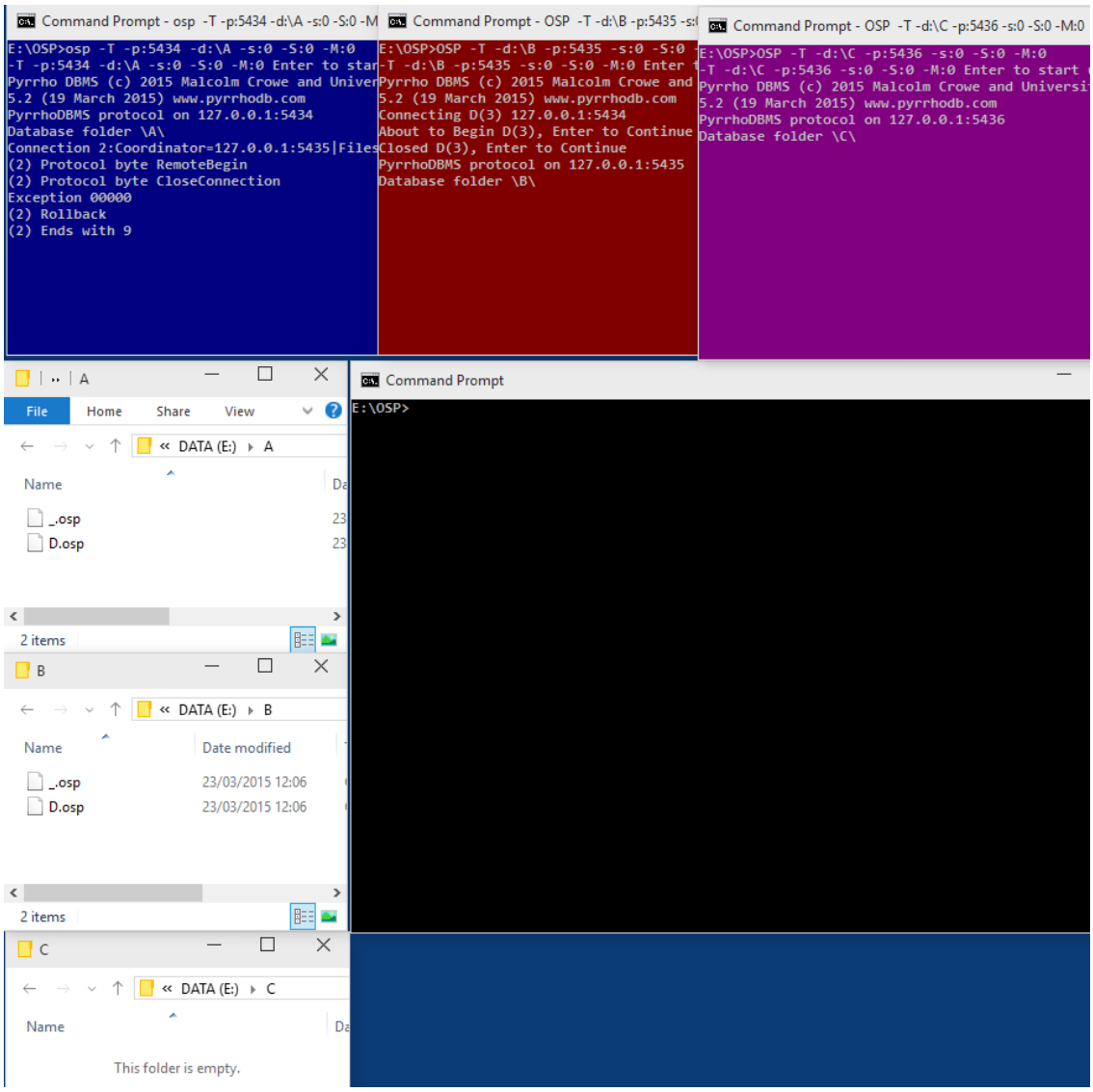
In the final screenshot we can see in the file browser for folder A that the configuration database has been created on A. Records will be added to both (currently empty) configuration databases when the distributed transaction commits.

The distributed transaction mechanism is quite an old part of the Pyrrho DBMS, and for example is used when an application sets up a transaction using multiple databases (so-called multi-database connections) even on the same server. It uses three-phase commit, which has been improved in version 5.0 to reach high standards of transaction safety.

As an exercise, repeat all of the above steps in an explicit transaction, and examine the distribute databas tables _Database and _Client *before* committing the transaction. You will find although nothing has yet been written to disk, we see that the "_Database" table contains the expected contents.

A4.7 What happened in step 6

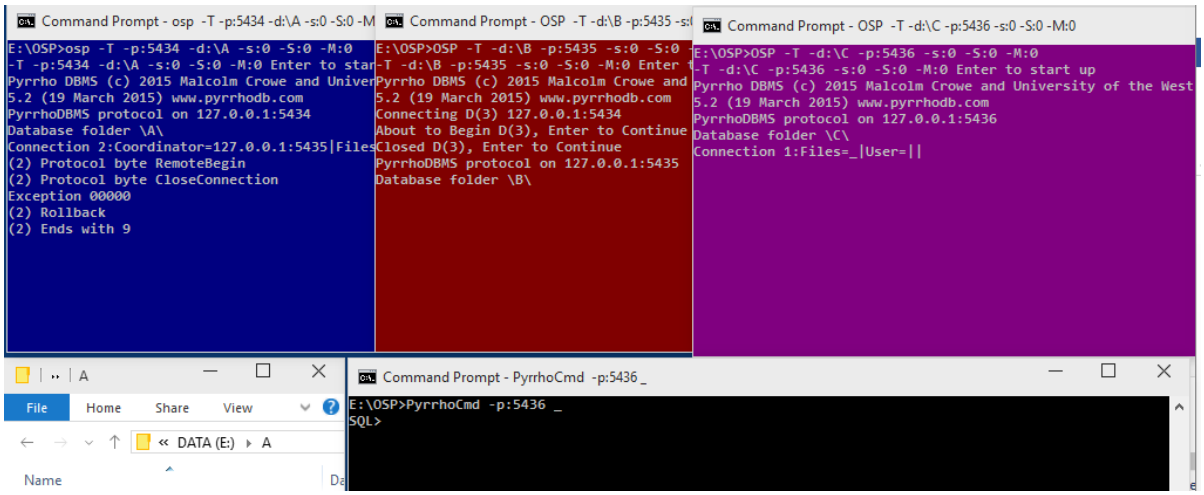
At this point we have effectively reached the end of step 3. To get nearly the same screenshots as me, restart the three servers (still with the –T flag) with the Enter key used twice during B's startup sequence:



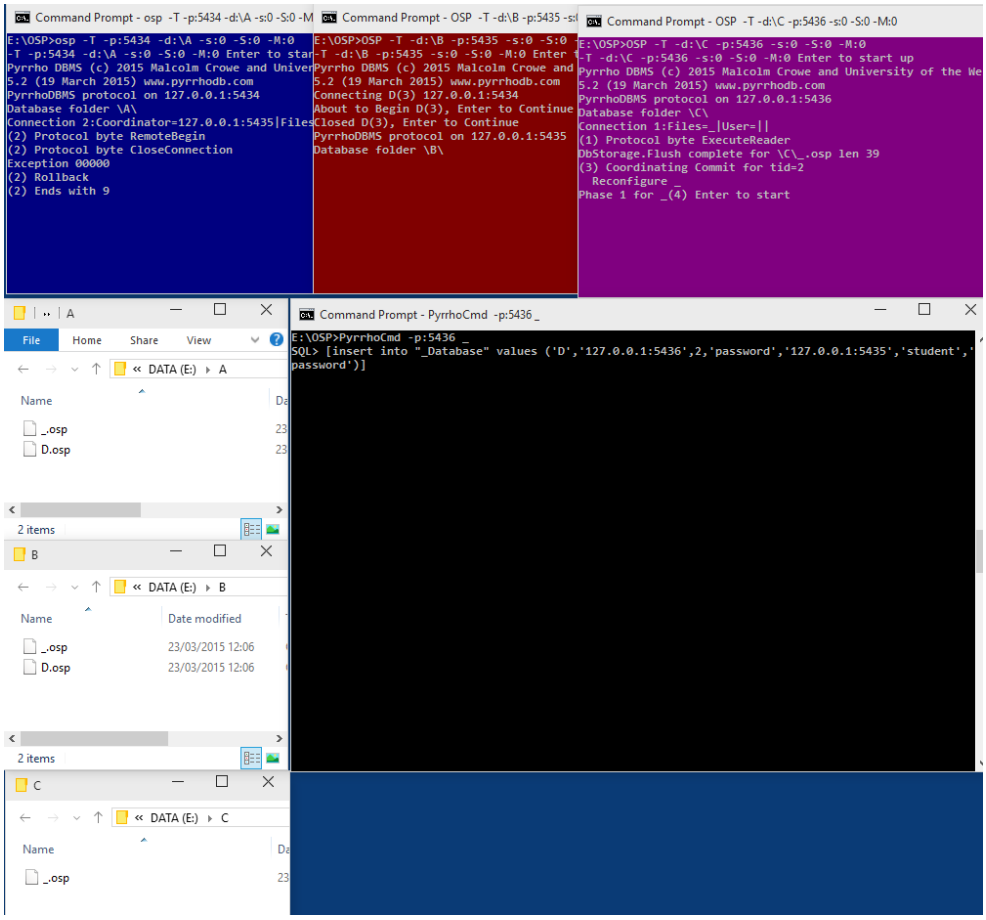
A4.8 Creating the query service for D on C

In the PyrrhoCmd window

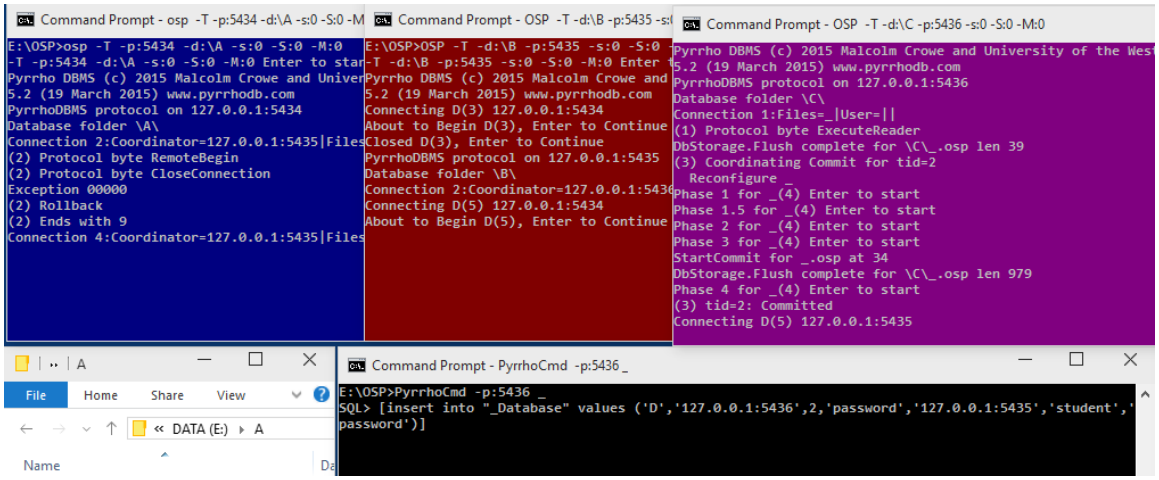
PyrrhoCmd –p:5436 _



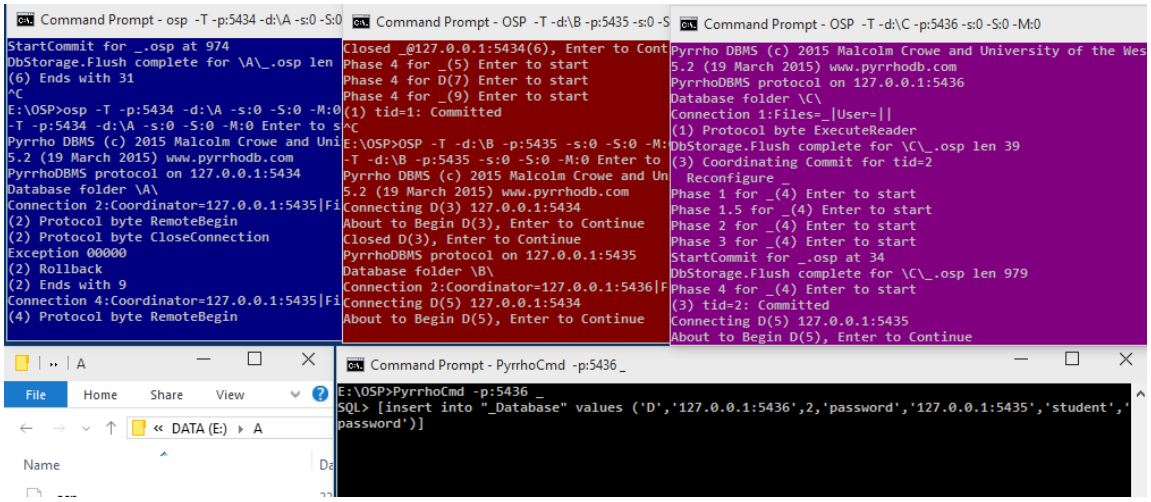
SQL> **[insert into "_Database" values ('D','127.0.0.1:5436',2,'password','127.0.0.1:5435','student','password')]**



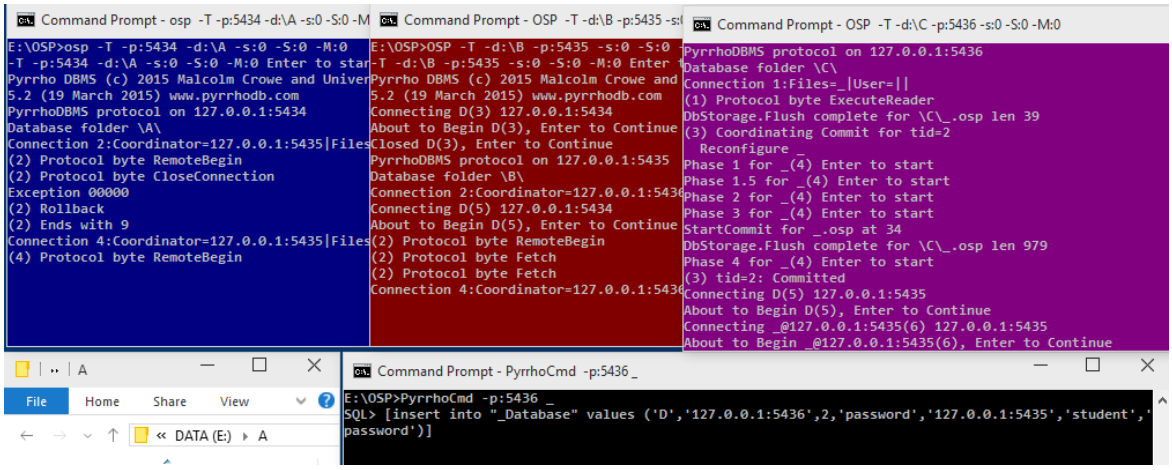
We see the new configuration database in folder C. C now initialises this empty database by creating the three tables _Database, _Client and _Partition. In C's server window, press Enter five times:



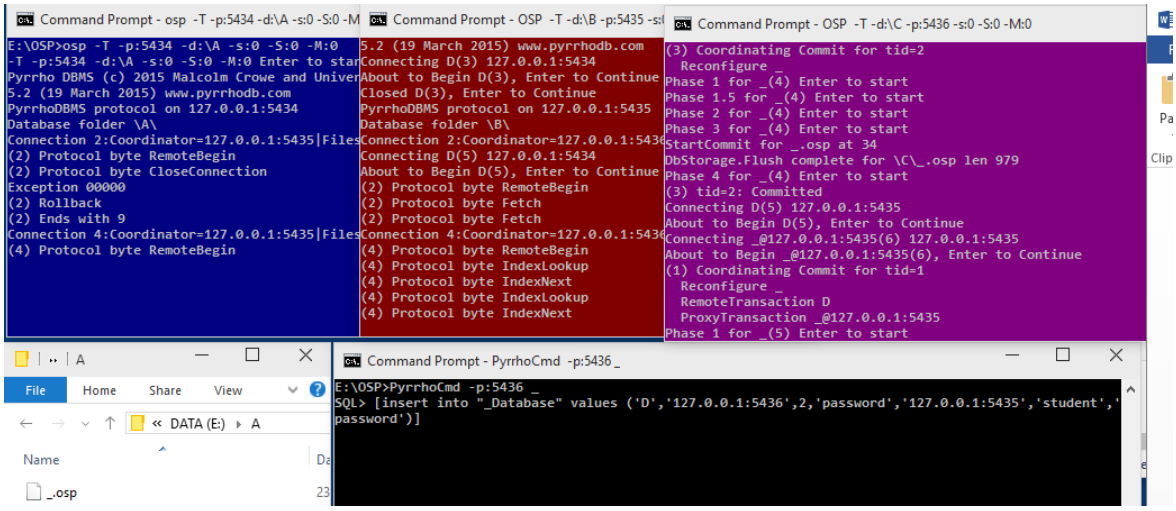
We recall that the insert statement has configured a query service for D on C, to obtain its data from server B. We see that server C has just connected to D on B, and B has synchronised with D's master server A. To move things along we need to press Enter in the B server window:



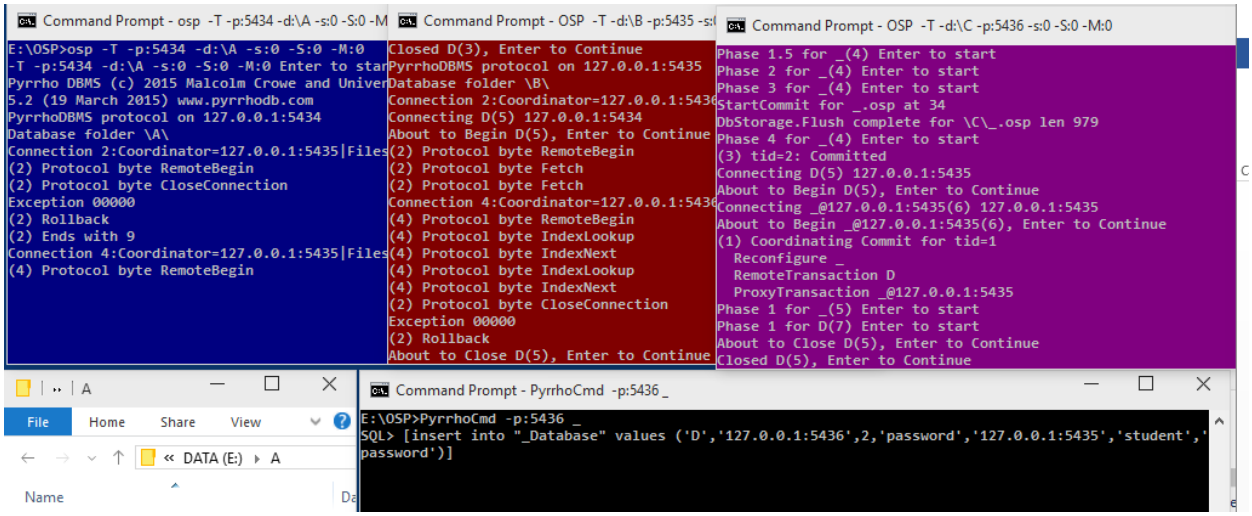
This simply checks the synchronisation with A. Now press Enter in the C server window:



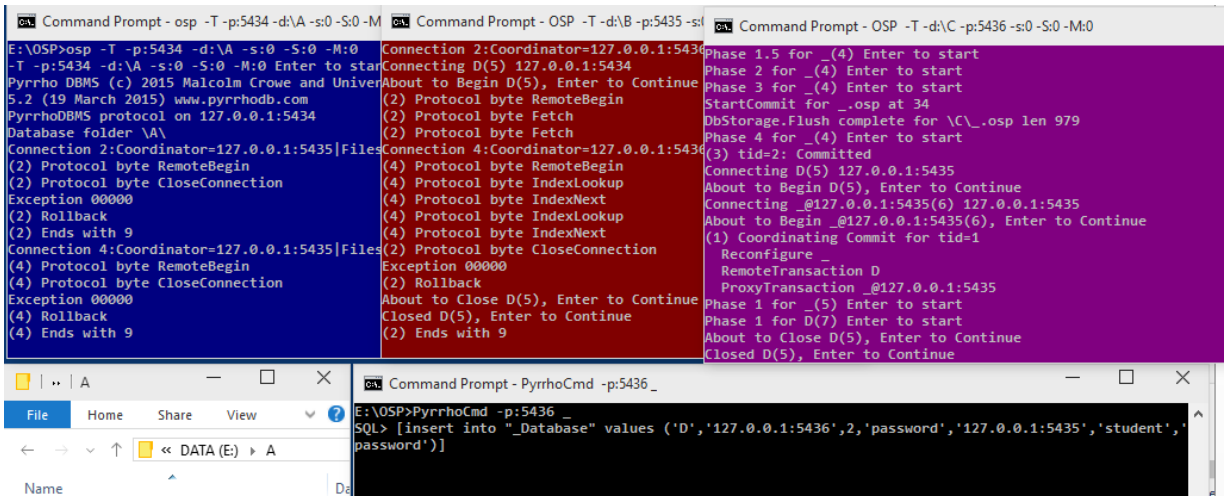
Since D will be a new database for C, C needs to read all of the data coming from B and construct all of the indexes required to provide a query service. We can see it has fetched data from B. Press Enter on C:



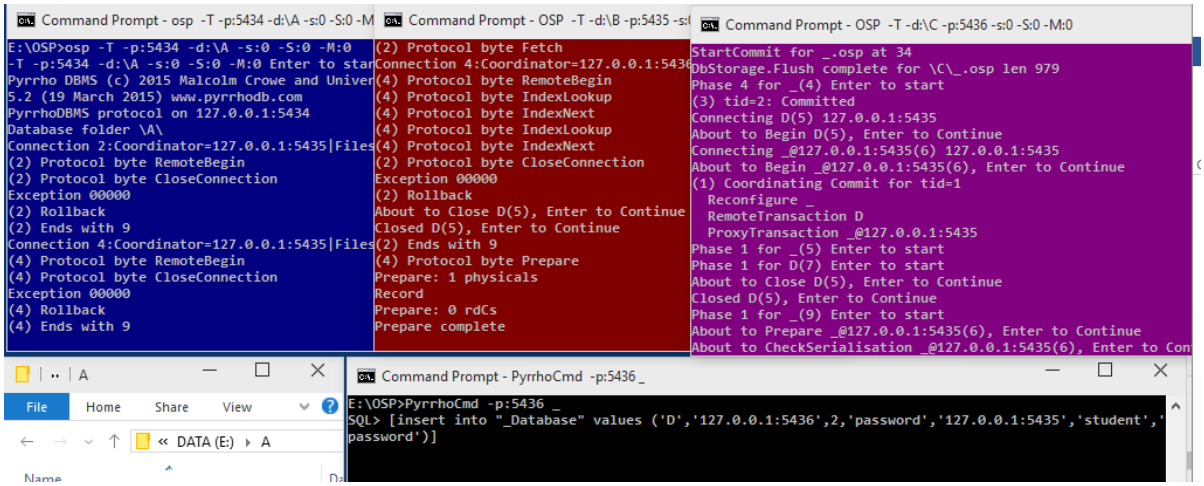
Now we see that C is coordinating a distributed reconfiguration transaction, checking the configuration database on B (like B did to A in the previous section). Press Enter 3 times:



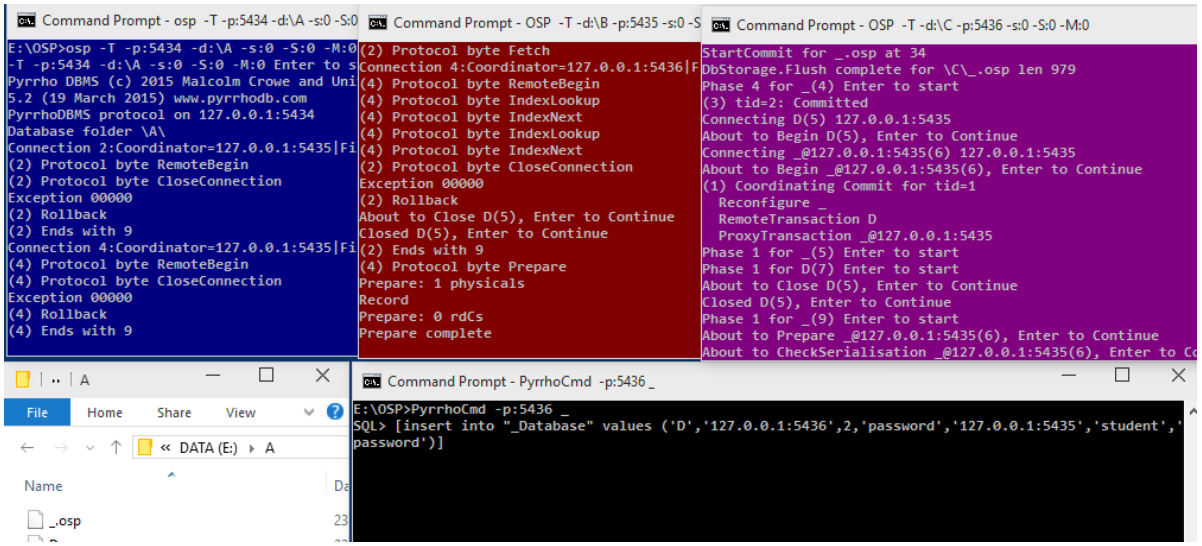
During Phase 1 validation for the D participant, we find we are not changing D, so D can be closed. Press Enter on B twice:



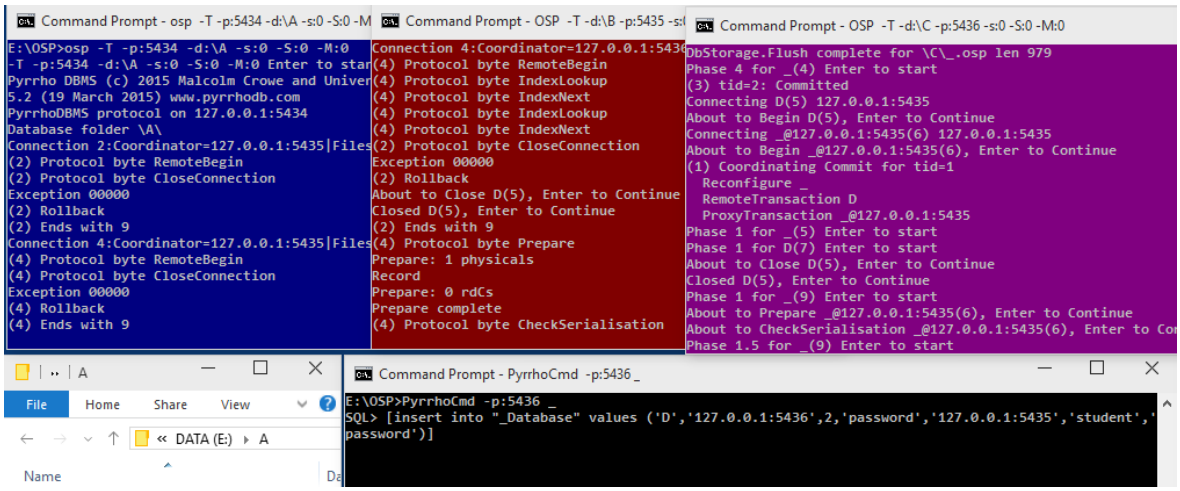
Now press Enter on C three times:



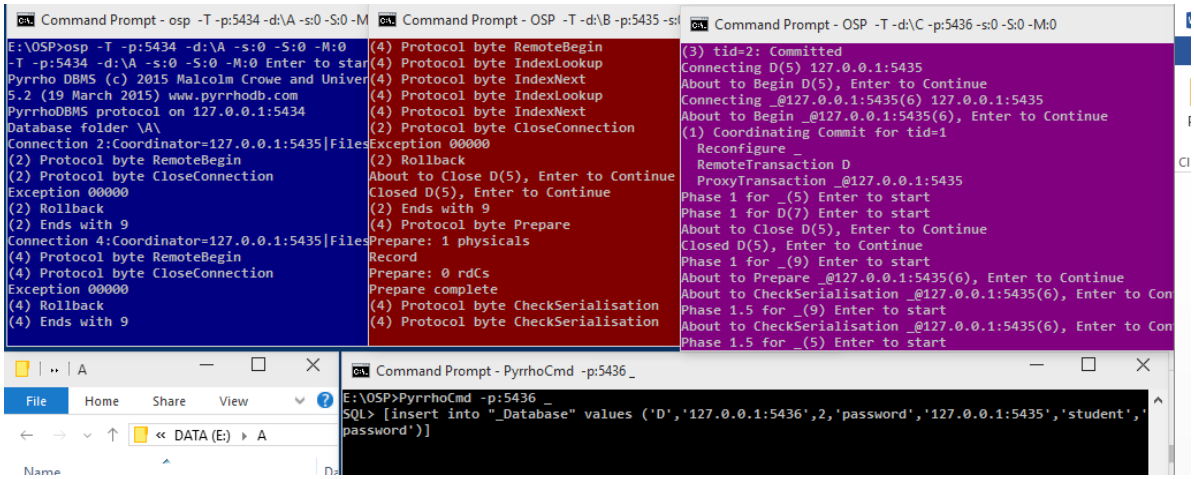
We are now in the Prepare phase for the distributed reconfiguration involving changes to the configuration files on B and C. Press Enter:



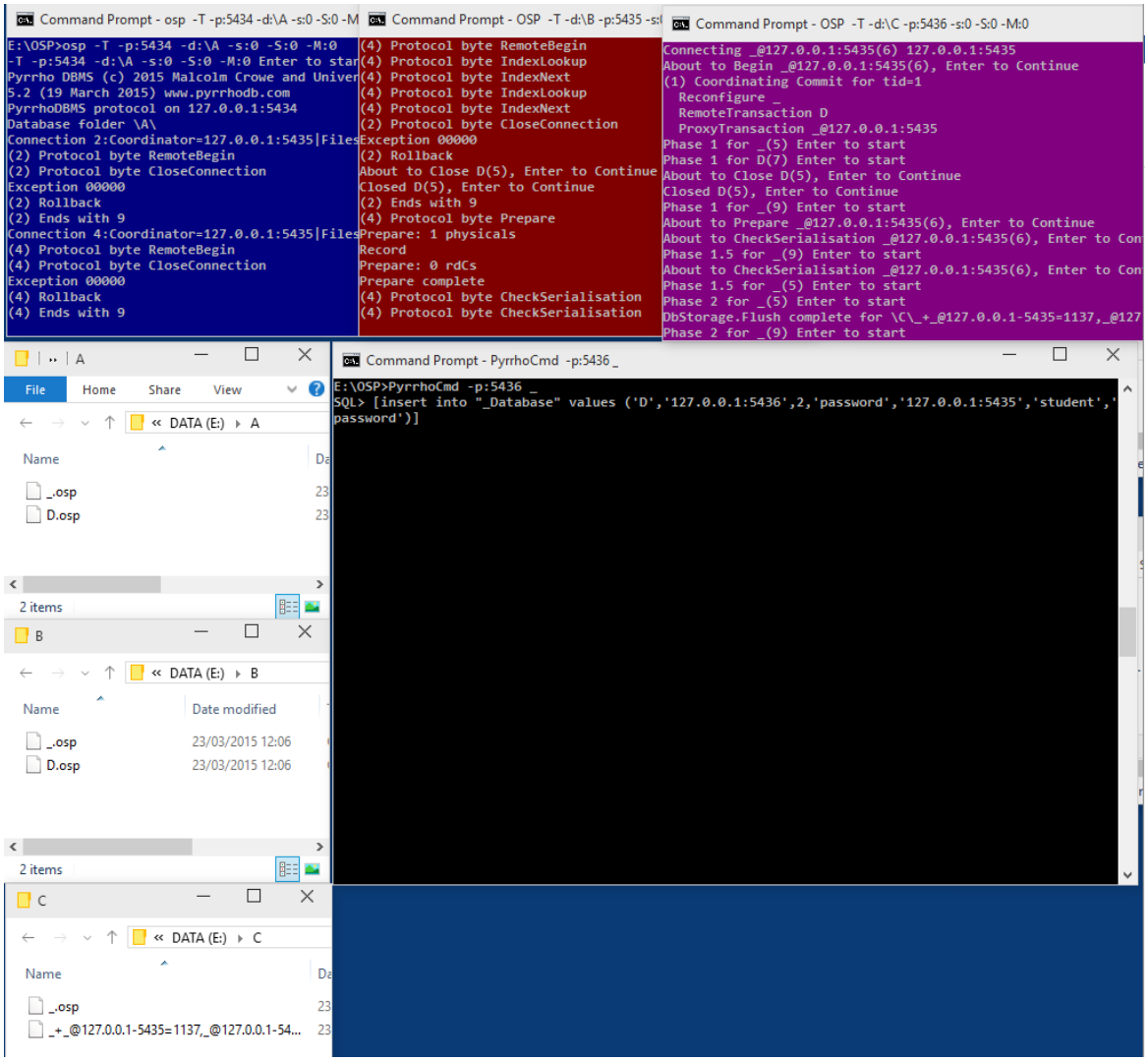
Press Enter:



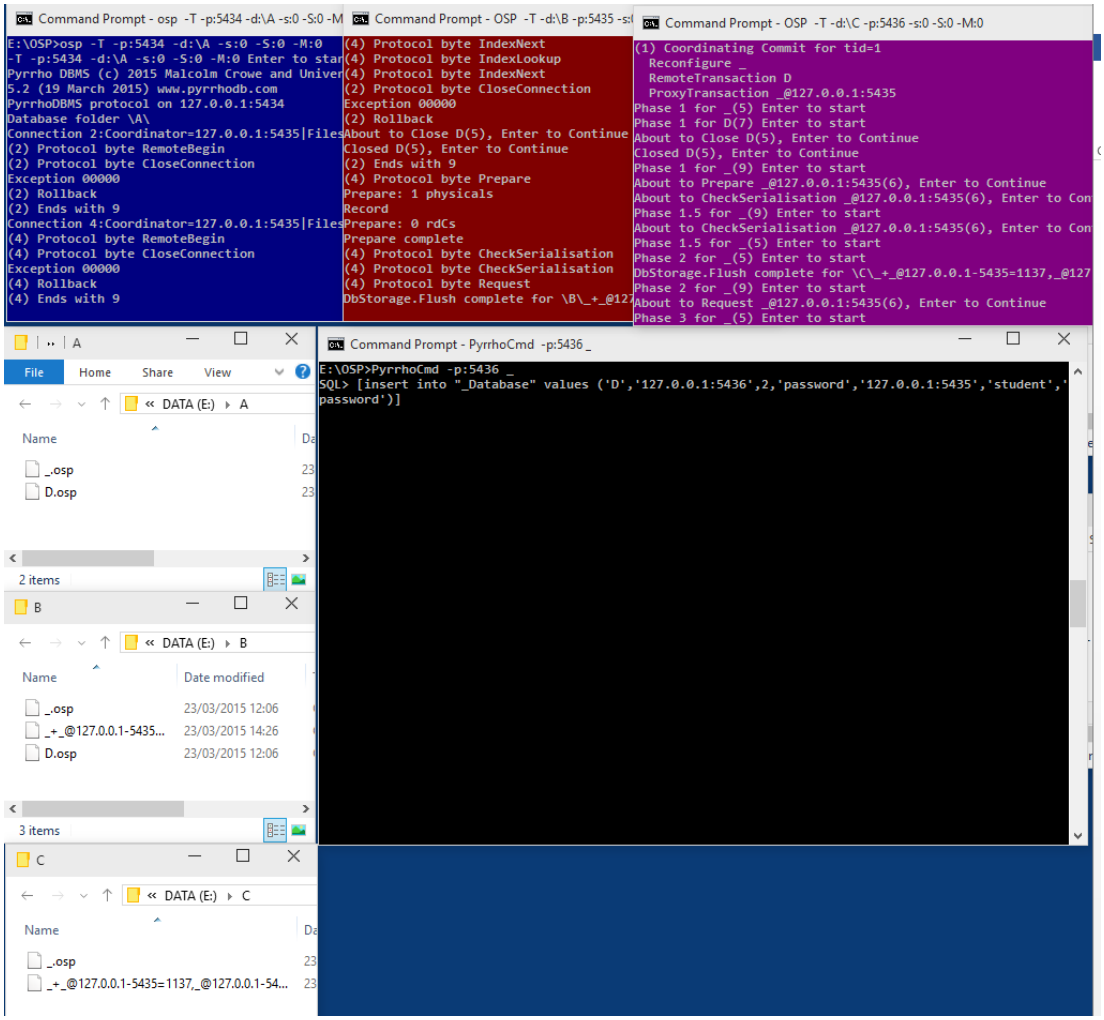
We see that C is organising a distributed commit with B: Press Enter again twice:



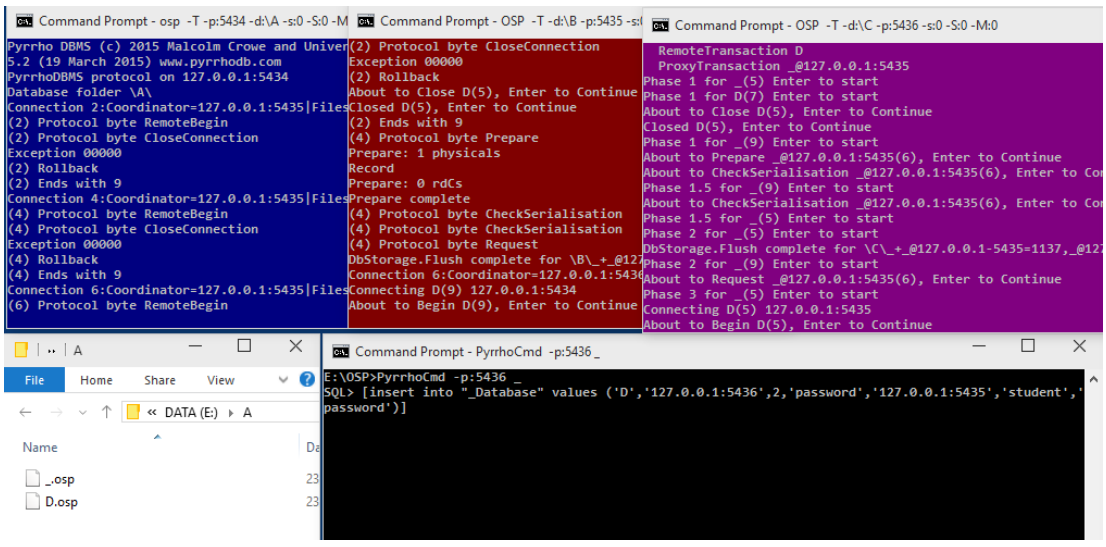
In Phase 1.5 we repeat the check serialisation with the databases locked. Press Enter again twice:



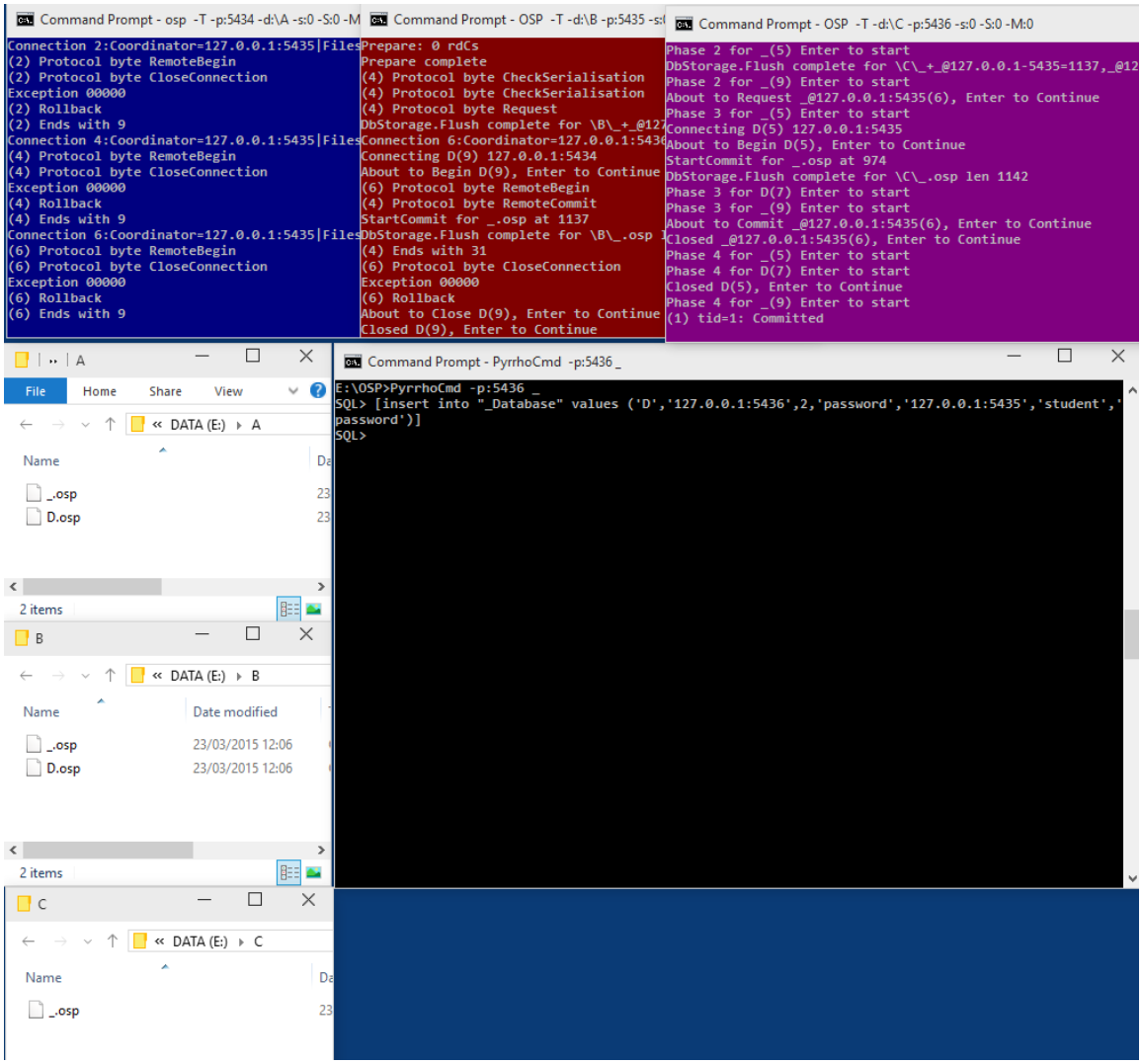
We see that C server has written a temporary transaction data file to the C folder. Press Enter again twice:



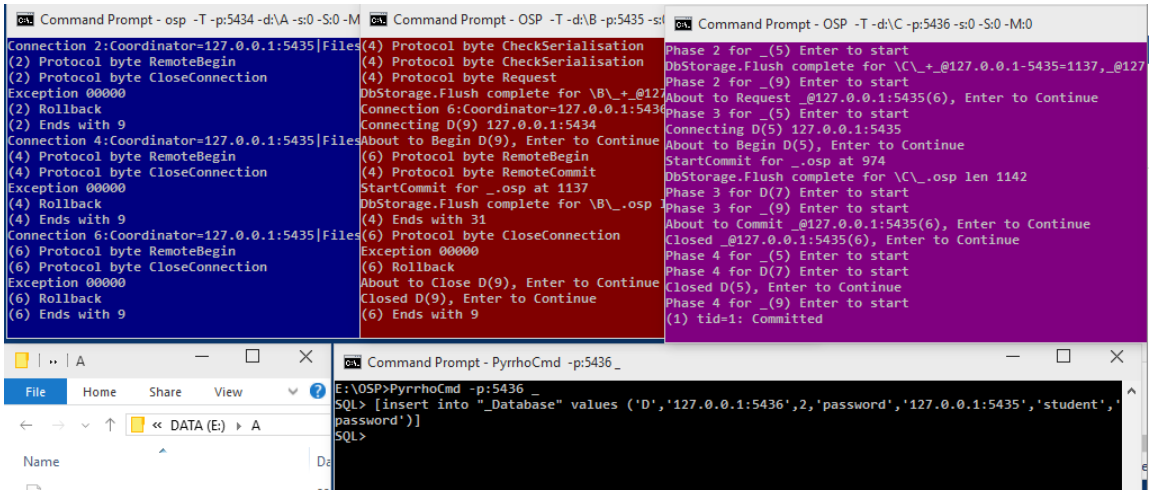
And we see that B has done the same. On C server, press Enter once:



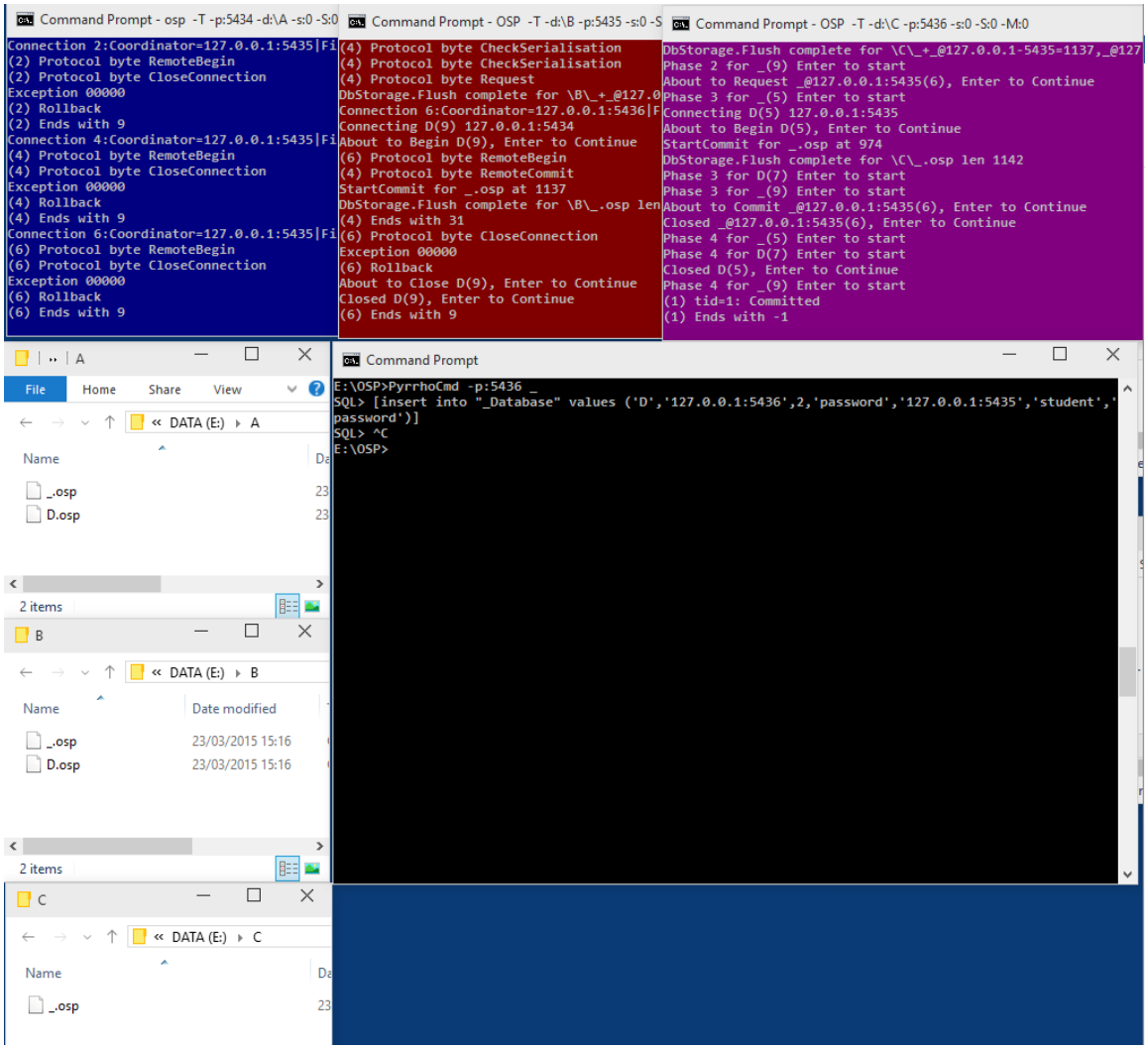
Now B is synchronising D with A again. On B, press Enter, and on C press Enter several times until the transaction is committed:



We now have the SQL> prompt in the PyrrhoCmd window, the temporary files have been removed, and the B server needs to finish its read-only transaction: press Enter twice in the B server window:



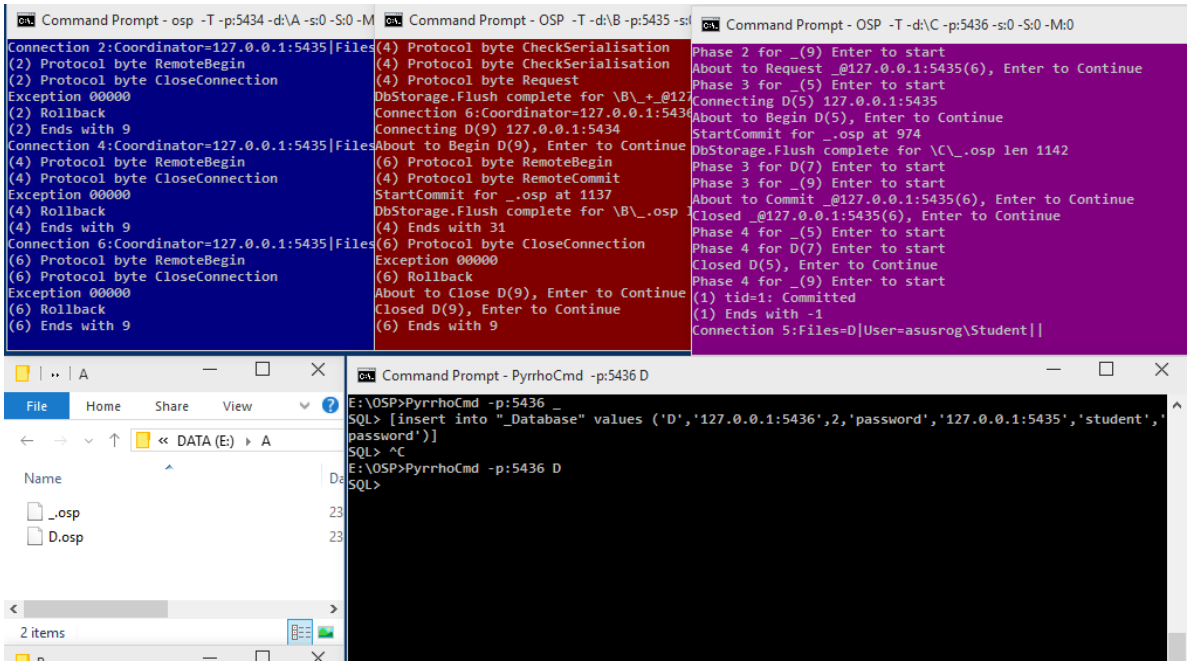
Close the session in the PyrrhCmd window with ^C.



A4.9 What happened in Step 7.

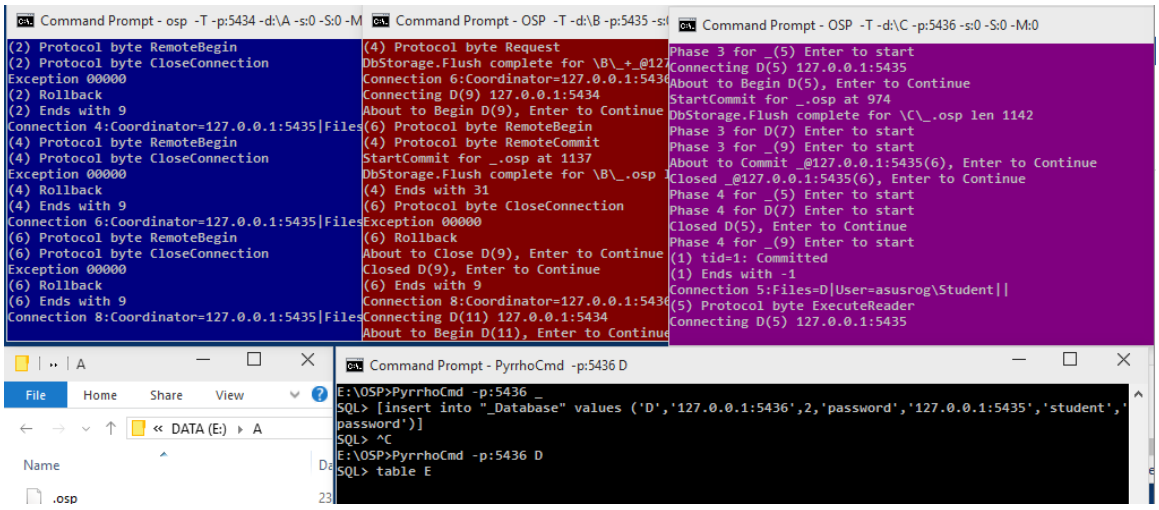
At this stage, server C is running and has set up all its data structures and indexes to provide a query service for D. In the PyrrhoCmd window let us connect to this service:

PyrrhoCmd -p:5436 D

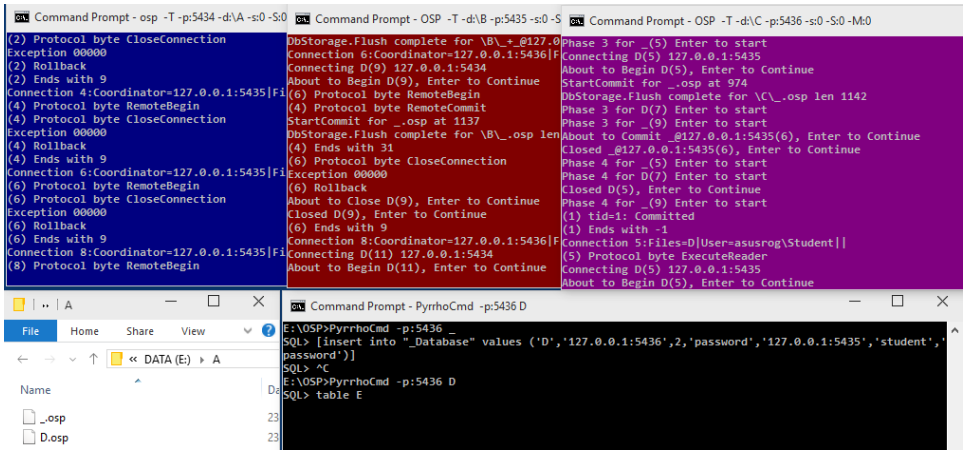


We see the connection to server C.

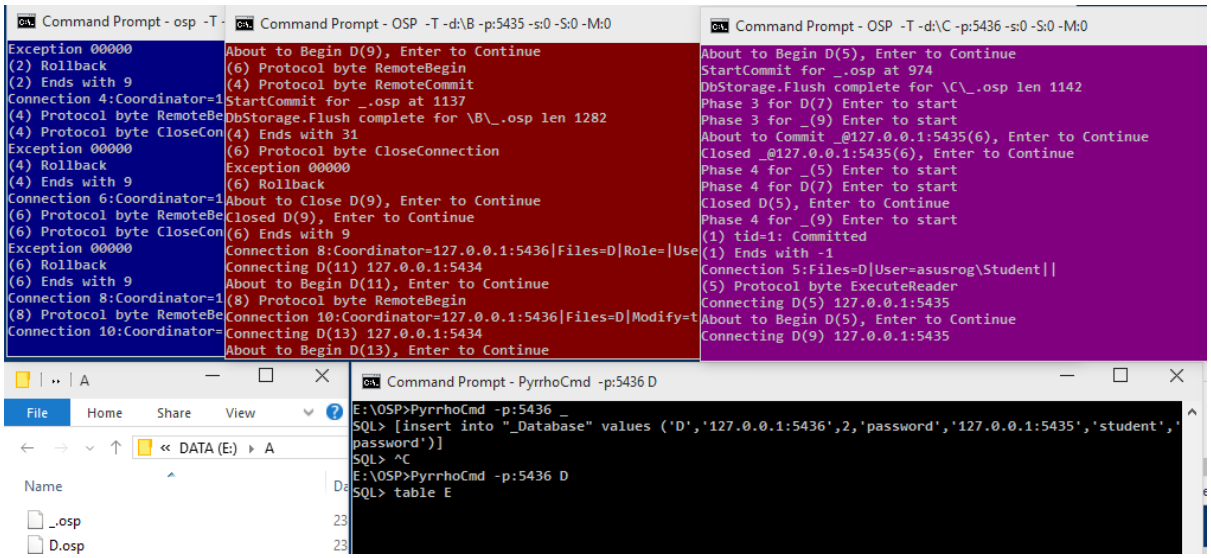
SQL> **table E**



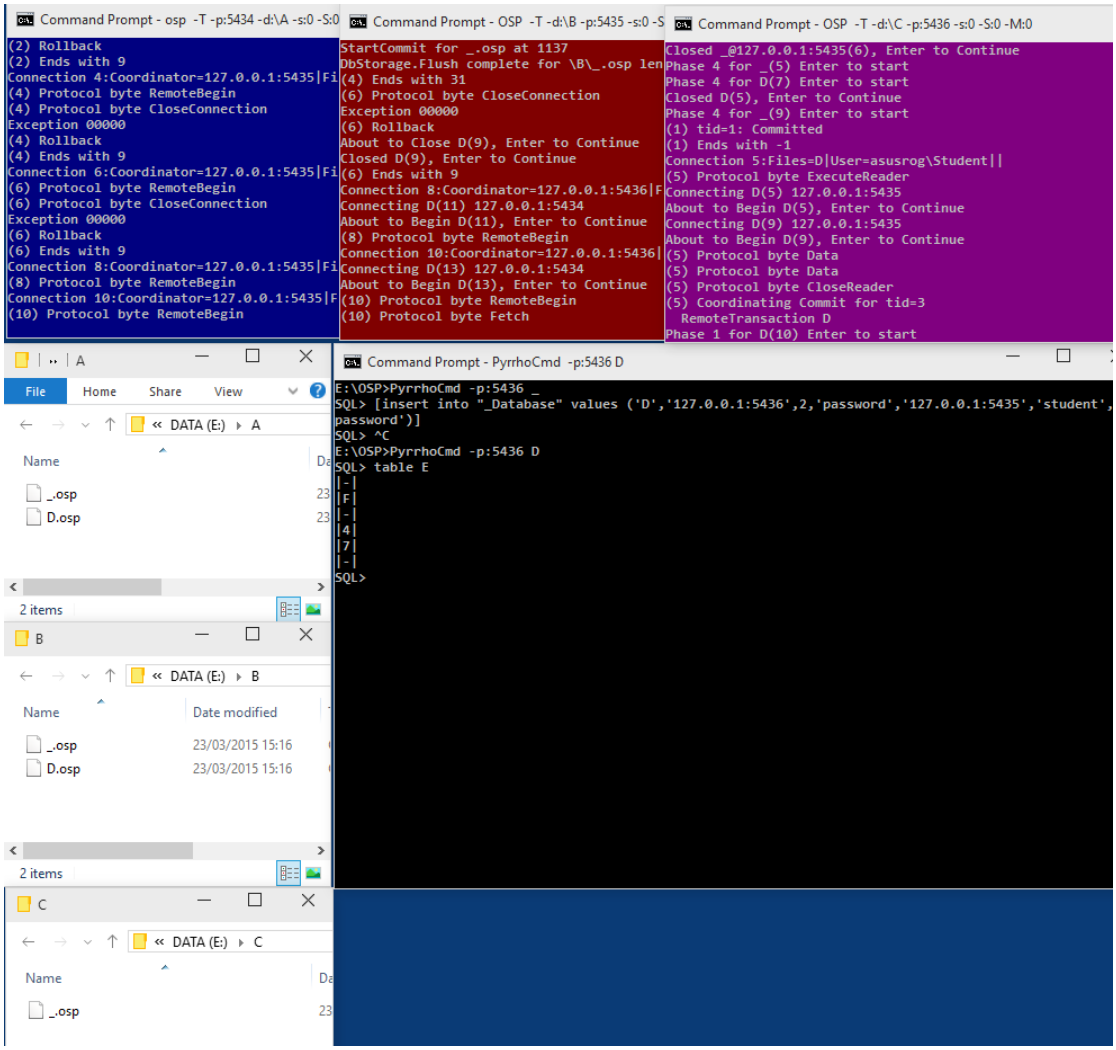
Server C immediately opens a connection to B in order to synchronise D. B in turn will check it is synchronised with A. In B's window press Enter once:



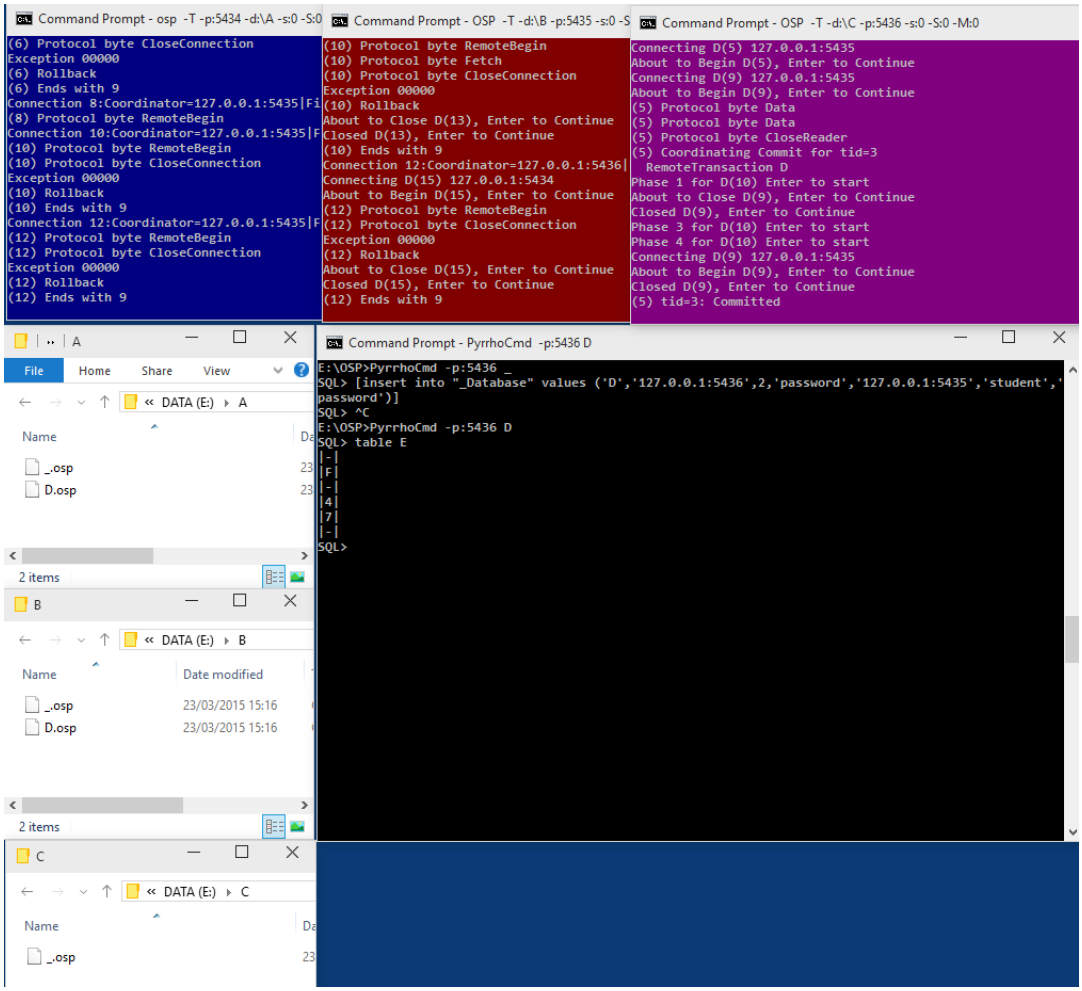
and in C's window, press Enter once:



We see another connection to A. In B's window press Enter and similarly in C

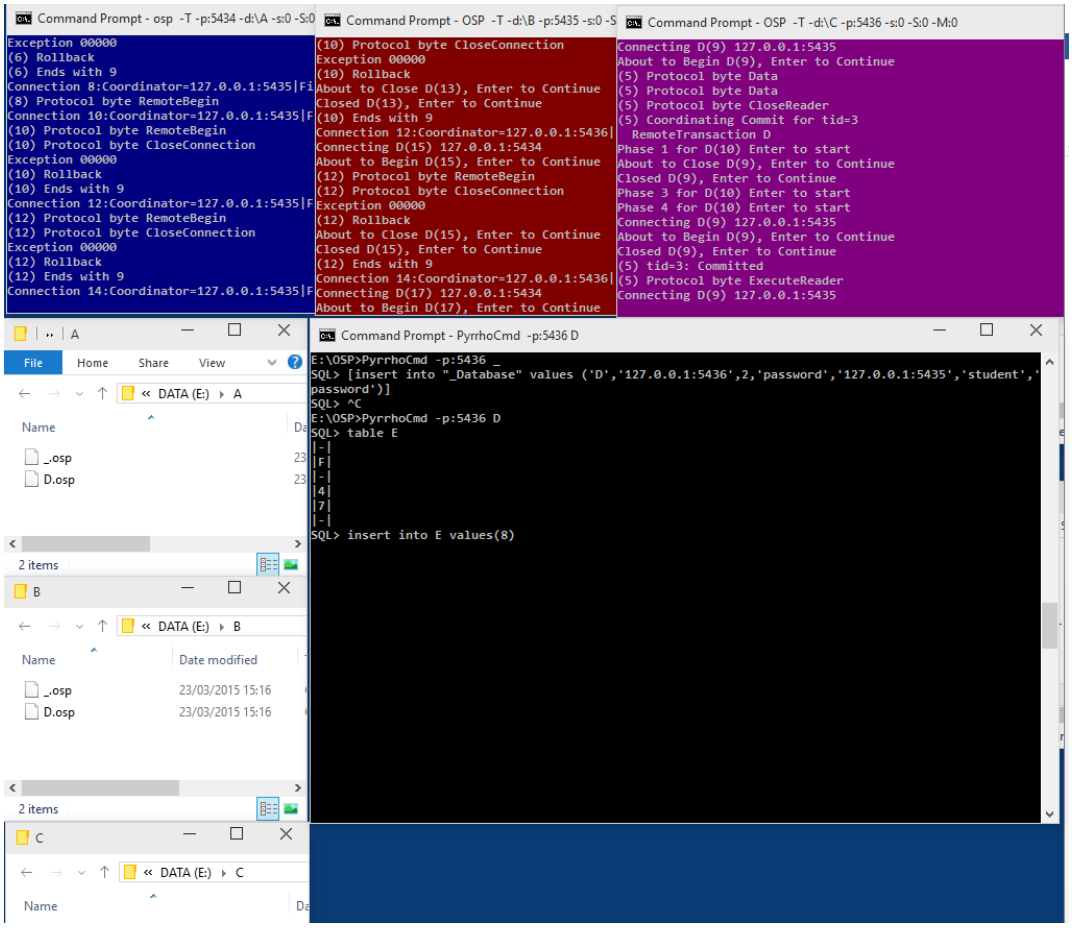


Notice that data is fetched only from B. In B's and C's windows press Enter more times to finish the read-only commit.

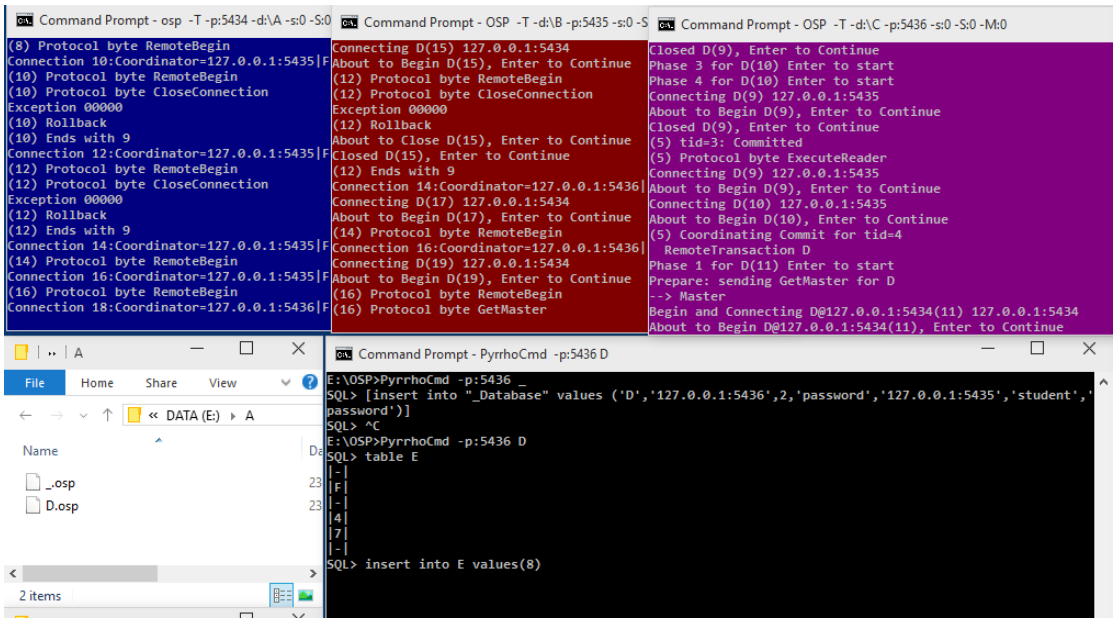


Let's now watch what happens when we make a change from C: the change needs to get made by the master server A (not by B!).

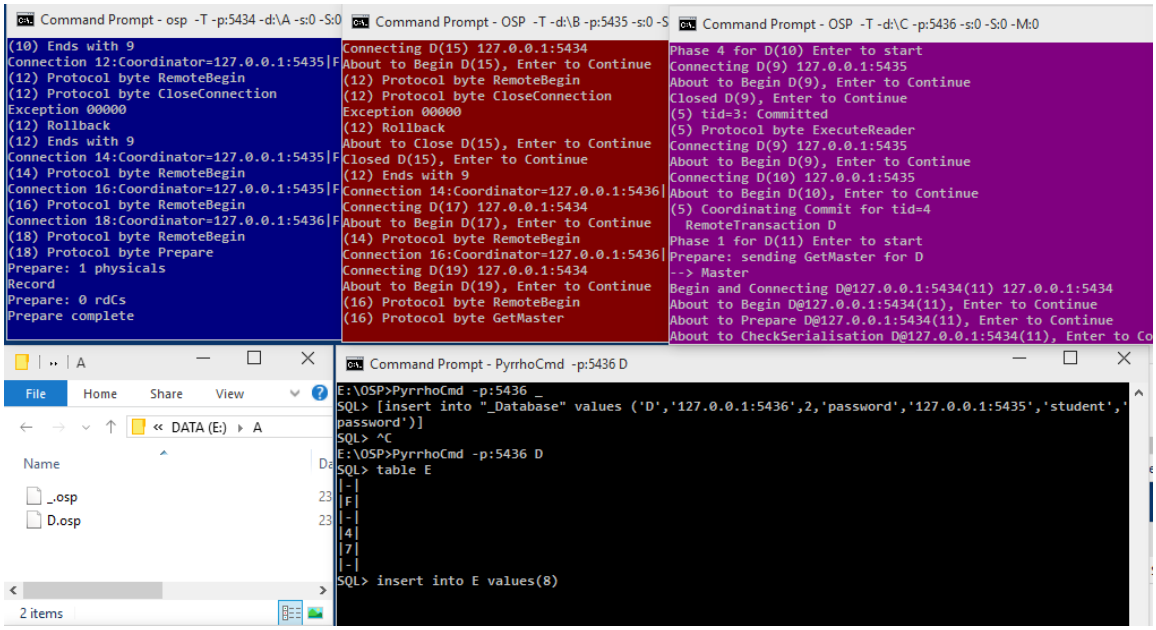
SQL> **insert into E values(8)**



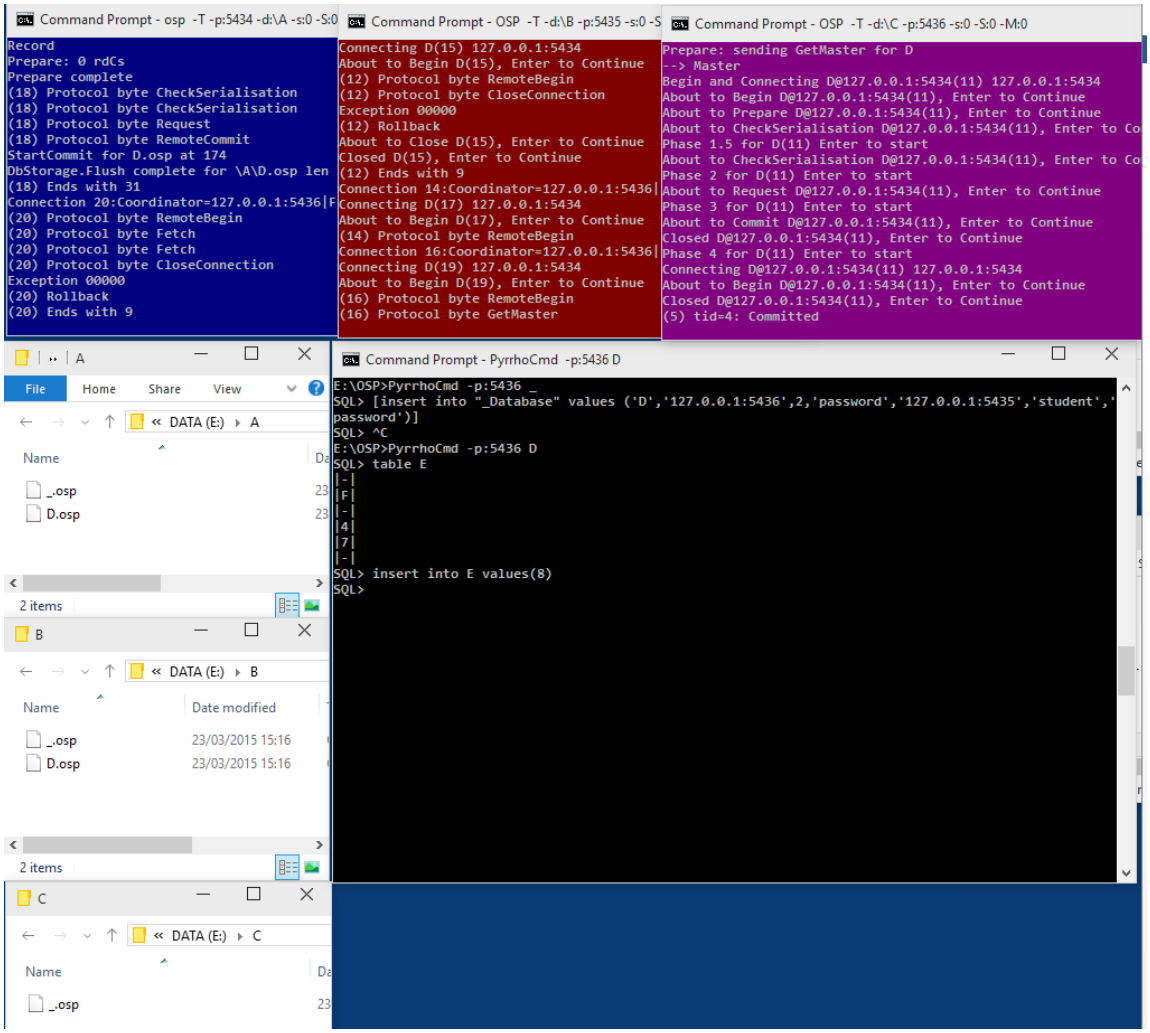
Do Enter once in B's window and a few ties in C's, and note the GetMaster request from C to B:



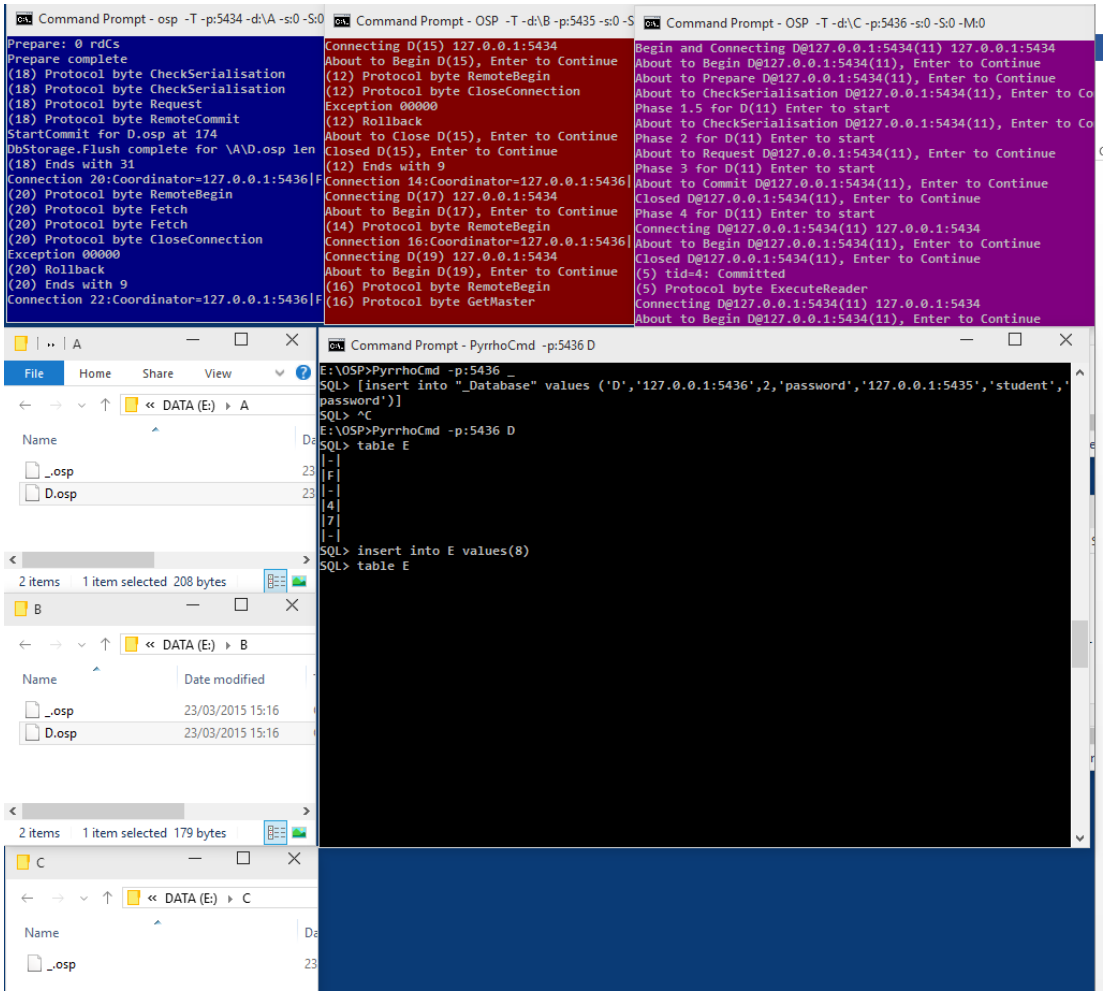
And the connection direct from C to A (which was not in the configuration files). In C's window press Enter twice:



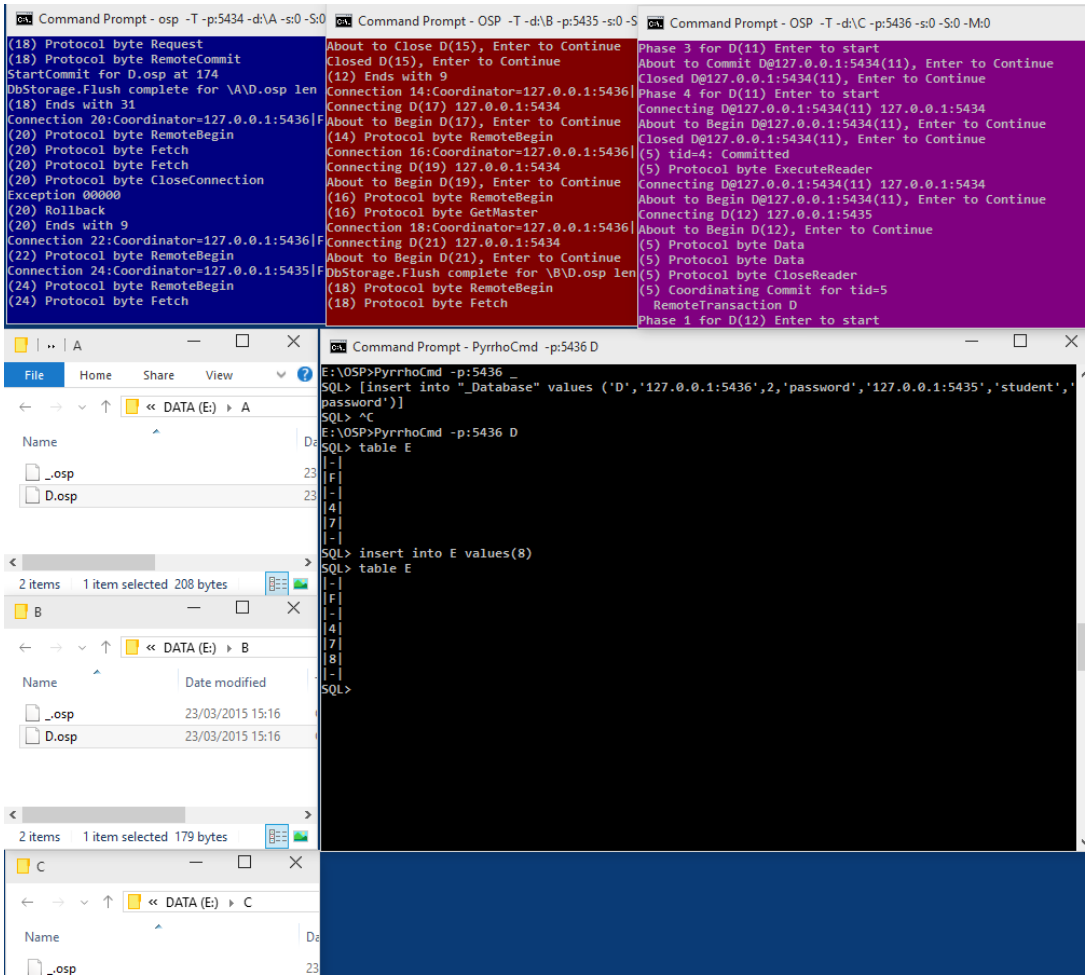
We see that C has sent its transaction data direct to A. Use the Enter key 11 more times to complete the transaction and get the SQL> prompt. This time no temporary transaction files are written. This is because only A is recording the details: B is a slave, and C has no storage for D.



At this precise point B is out of sync with A, and this will be discovered next time anything connects to D on B. In the PyrrhoCmd window, let us check table E:



After 3 Enters in the C server window we have:



And further Enters for B's and C's windows to complete the transaction. At this point B is once again synchronised with A.

Most of short-lived connections in this narrative are simple handshakes to get database length. Distributed databases win out when large data sets and effective indexes are stored close to where they are needed and the ratio of reads to writes is favourable. If there are a lot of writes to big data, partitioned database are indicated, since each partition can have its own master, and replication can often be avoided.

Appendix 5: Partitioned Database Tutorial

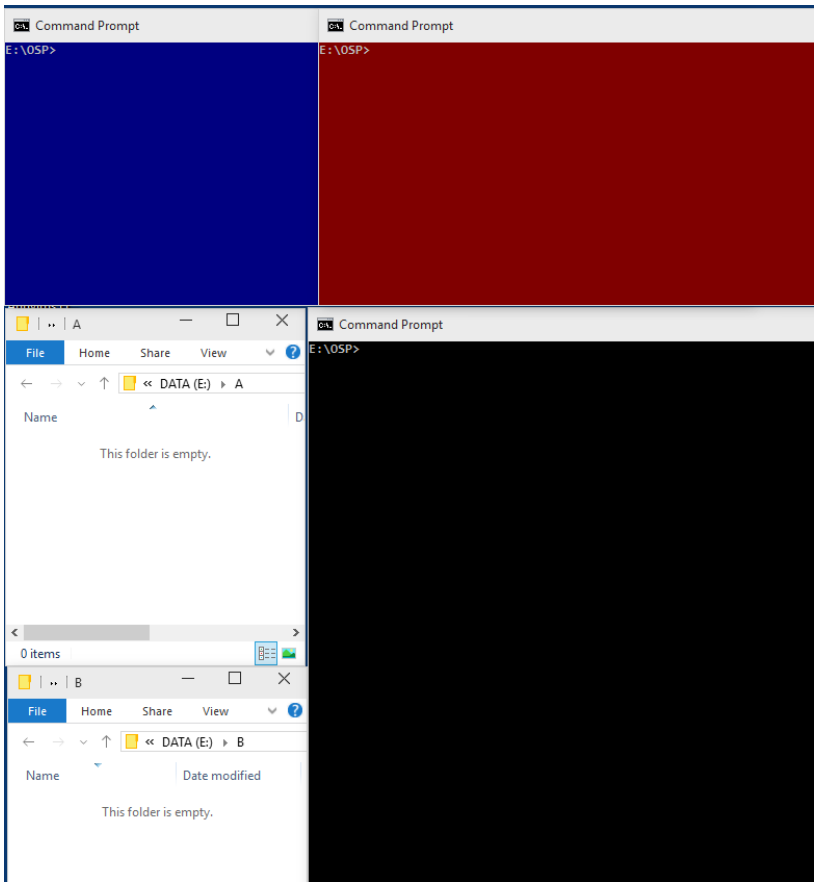
The exercise follows the blog at http://pyrrhodb.blogspot.com, just with more detailed instructions.

In both this and the Distributed Database Tutorial it is important to realise that the very complex distributed transactions documented here mostly happen when the database is reconfigured. With good design, most normal operations on the distributed or partitioned databases will not require distributed transactions. They will in general involve some synchronisation between the transaction master, the replication hosts and/or base database, but full 3-phase commit only occurs when data on two or more databases or partitions are changed in a single transaction – and this will be relatively unusual.

This version of the tutorial is for OSP v5.2 (27 March 2015) on Windows. On this system my userid is Student with password password, and Pyrrho has been installed in \OSP , where the student user has full control. To replace the installed version of Pyrrho on this system with the latest version, copy the Pyrrho distribution at http://pyrrhodb.com/OSP52.zip into C:\ . Make sure there is no existing folder called OSP (delete it if there is). Then right click on OSP52.zip and select "Extract here".

A5.1 Start up the servers

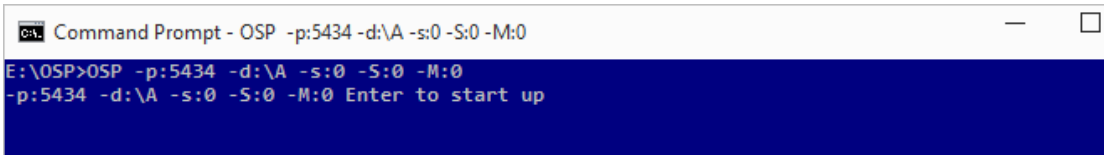
For this exercise we will use 2 servers, both on the local machine (127.0.0.1), but in separate database folders. So I have created **empty** folders \A, and \B (i.e. directly on the root of the drive, not in \OSP). To keep security aspects simple, everything is owned by student, and student's password is password. (On my system everything is in E: instead of C:.)



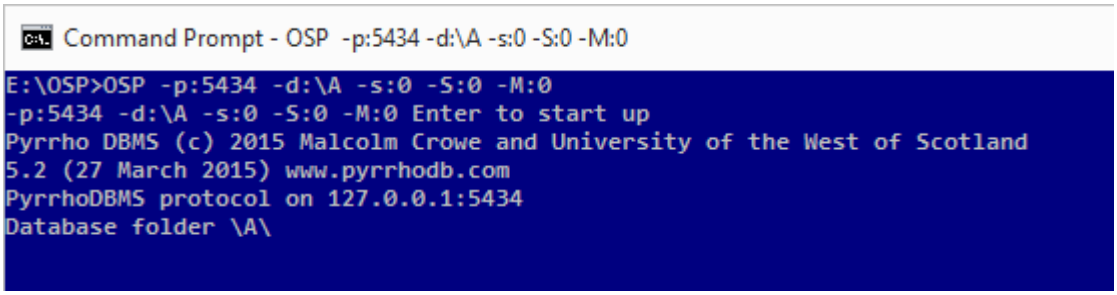
For the 2 servers, we will use 2 command prompt windows. On the first we issue the following commands:

cd \OSP

OSP -p:5434 -d:\A -s:0 -S:0 -M:0

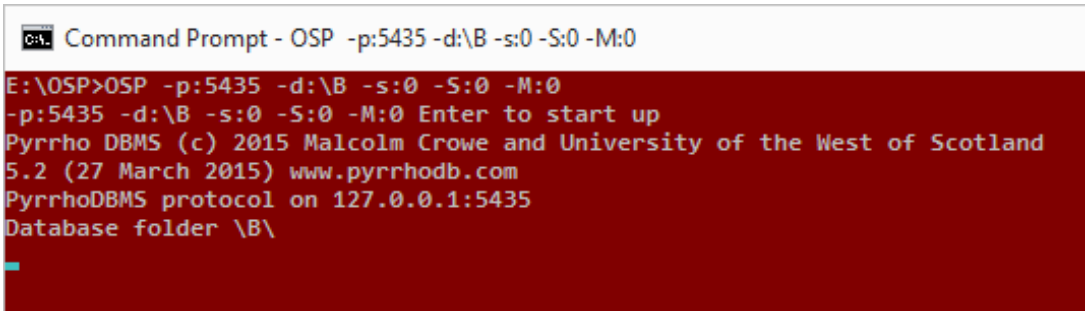


The –s, -S and –M flags prevent the server starting the http, https, and Mongo services, as we would need to allocate non-conflicting ports for these. The arguments are echoed to the terminal window with the advice Enter to start up. Type enter to start up the server.



We should see output from the OSP server announcing that it is using port 5434 and directory \A\ , as shown in the screenshot. If the port or folder is wrong, review the above setup and try again. Leave this server running and the terminal window open.

Similarly (in a different terminal window) start up a server on port 5435 using folder \B. Leave this open also. (These windows will occasionally show diagnostic output, as it is sometimes useful to know where a problem is first reported.)



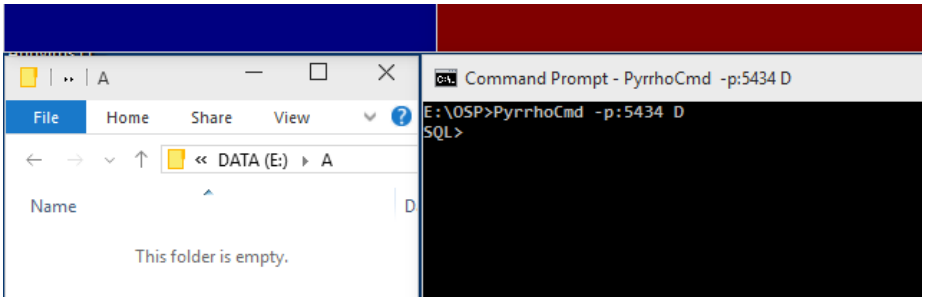
Now open two file browsers, and change directory to the A and B folders. We will use these window to check folder contents as we go along.

A5.2. Create a sample database on A

In a third terminal window change to \OSP, and create database D on server A

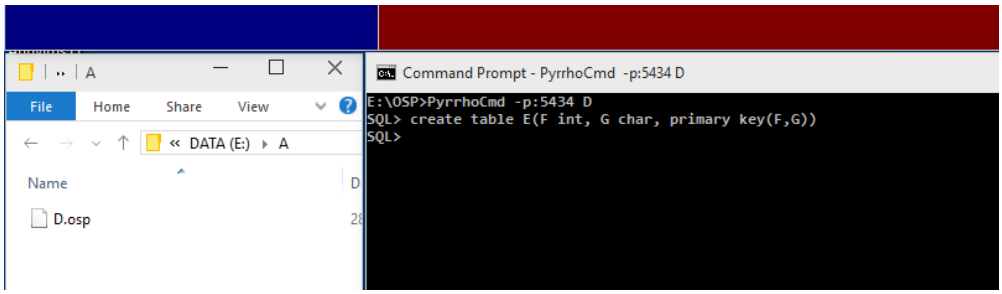
cd \OSP

PyrrhoCmd -p:5434 D



The database does not appear in the folder until the first transaction to it is committed. At the SQL>prompt create a table E, and then add some sample data:

create table E(F int, G char, primary key(F,G))



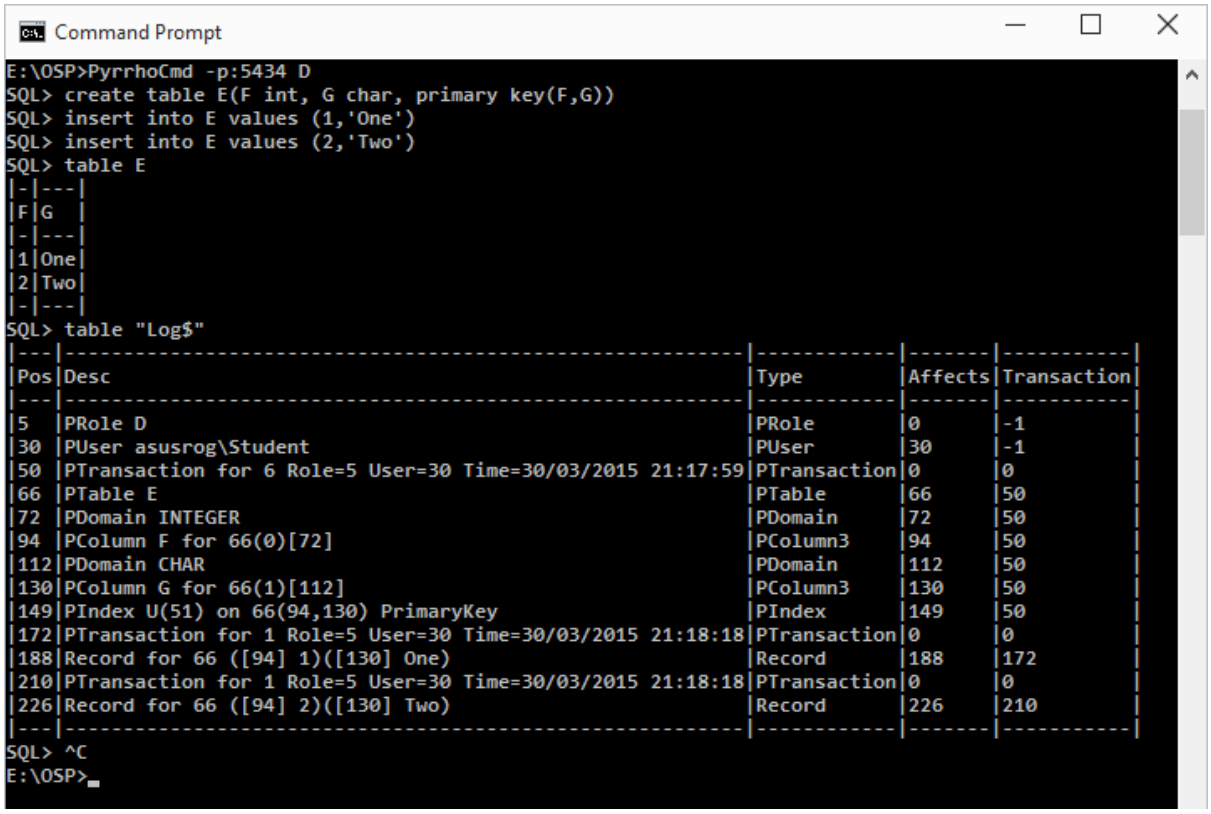
insert into E values (1,'One')

insert into E values (2,'Two')

table E

table "Log$"

Use ^C (control-C) to end the session.



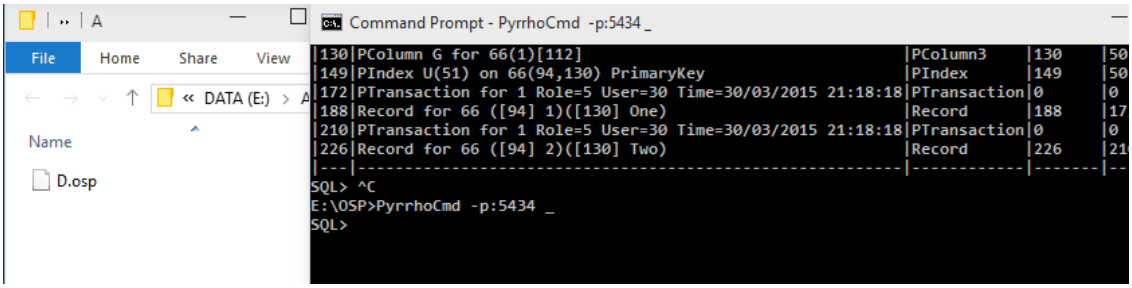
There is of course nothing special about this log file, but things get more interesting soon.

A5.3 Partition the table

Still on A, create the configuration database:

PyrrhoCmd -p:5434 _

This will create a configuration database on A, with autocreated tables _Client, _Database and _Partition in the configuration database as soon as we do something.

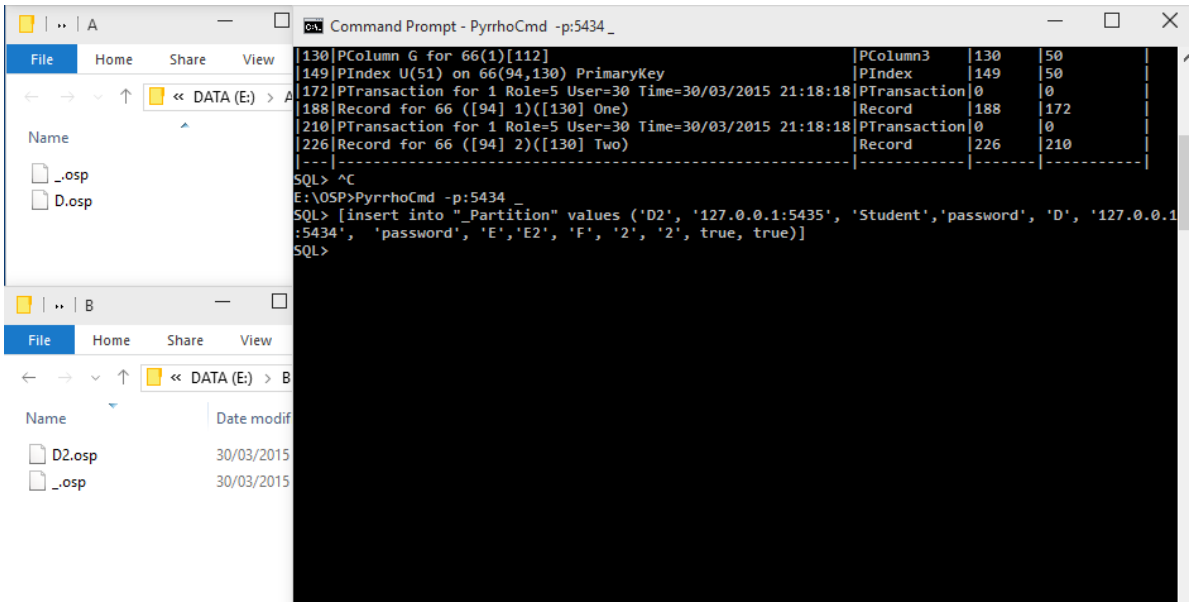


Now at the SQL> prompt define a new partition D2 on B containing a single table segment E2 as follows (Note: the command is rather long for one line, so enclose it in [ ] and note the > prompts when you take a new line)

[insert into "_Partition" values ('D2', '127.0.0.1:5435', 'Student','password', 'D', '127.0.0.1:5434', 'password', 'E','E2', 'F', '2', '2', true, true)]

For the full details of all of the columns in the _Partition table, see the manual. But reading it from left to right this says: "Create a new segment in a partition called **D2** on server B using these credentials, whose base partition is **D** on server A, partitioning table **E** with a segment called **E2**, containing rows where column **F** has values from **2** to **2** including both ends of this range."

Note in the file browsers the creation not only of A_.osp by the command line, but the creation of the new partition D2 and another configuration file on B:



The credentials supplied must be sufficient to create or open database D2 on server B and create objects in D2. (In general partition changes need several changes to the _Partition table, and changes need to be batched together in transactions of one of the following four kinds: NewSegments, DeleteSegments, MoveSegments, SplitSegment.)

Close the session with ^C.

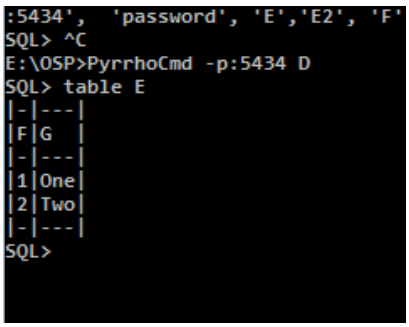
A5.4 Examine the database and partition

At first sight, it seems that the database on D is unchanged.

PyrrhoCmd -p:5434 D

table E

as table E still appears to have the same two rows as its contents (partitioning is transparent):



But if we look at

table "Sys$Table"

we see that there now only one row in table E on this server.

```
|1|One|
|2|Two|
|-|---|
SQL> table "Sys$Table"
|---|----|-------|----|--------|----------------|----------|------|
|Pos|Name|Columns|Rows|Triggers|CheckConstraints|References|RowIri|
|---|----|-------|----|--------|----------------|----------|------|
|66 |E   |2      |1   |0       |0               |0         |      |
|---|----|-------|----|--------|----------------|----------|------|
SQL>
```

And if we look at the Log$ file:

table "Log$"

we will see that the second entry in table E, the record for 'Two', has been deleted.

```
               |PTransaction |0      |0          |
|226|Record for 66 ([94] 2)([130] Two)
               |Record       |226    |210        |
|248|PTransaction for 1 Role=5 User=30 Time=30/03/2015 21:21:24_@127.0.0.1-5434=974,_@127.0.0.1-5435
=974,D=248,D2=39|PTransaction2|0      |0          |
|320|Delete Record (Record for 66 ([94] 2)([130] Two)) [226]
               |Delete       |226    |248        |
|---|-----------------------------------------------------------------------------------------------
----------------|-------------|-------|-----------|
SQL>
```

In fact it has been moved to the new partition D2 on B as we requested. Close reading of the PTransaction record shows that this actually a distributed transaction involving the configuration file and the partition. (The previous entries in the Log$ file record the setting up of database D the creation of table E with its initial two entries.)

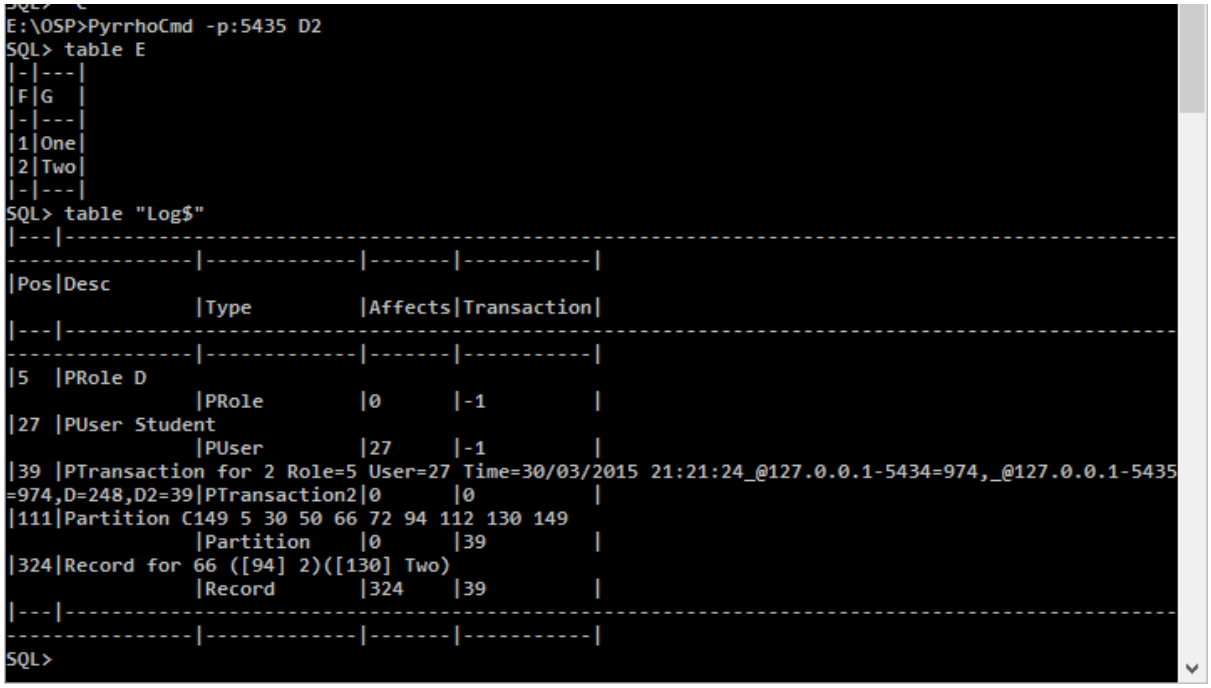
Close the session with ^C, and examine the new partition now:

PyrrhoCmd -p:5435 D2

table E

table "Log$"

Again we see both rows in the partitioned table, but only one record in the partition:



And in this log file we see the setting up of the partition D2 whose base is D, a summary of the binary database schema for the partition (provided by D), and the single record that was copied across. Note that both these events are in a single distributed transaction.

A5.5 From A insert some more records in E

Again close the session with ^C.

Pyrrhocmd -p:5434 D

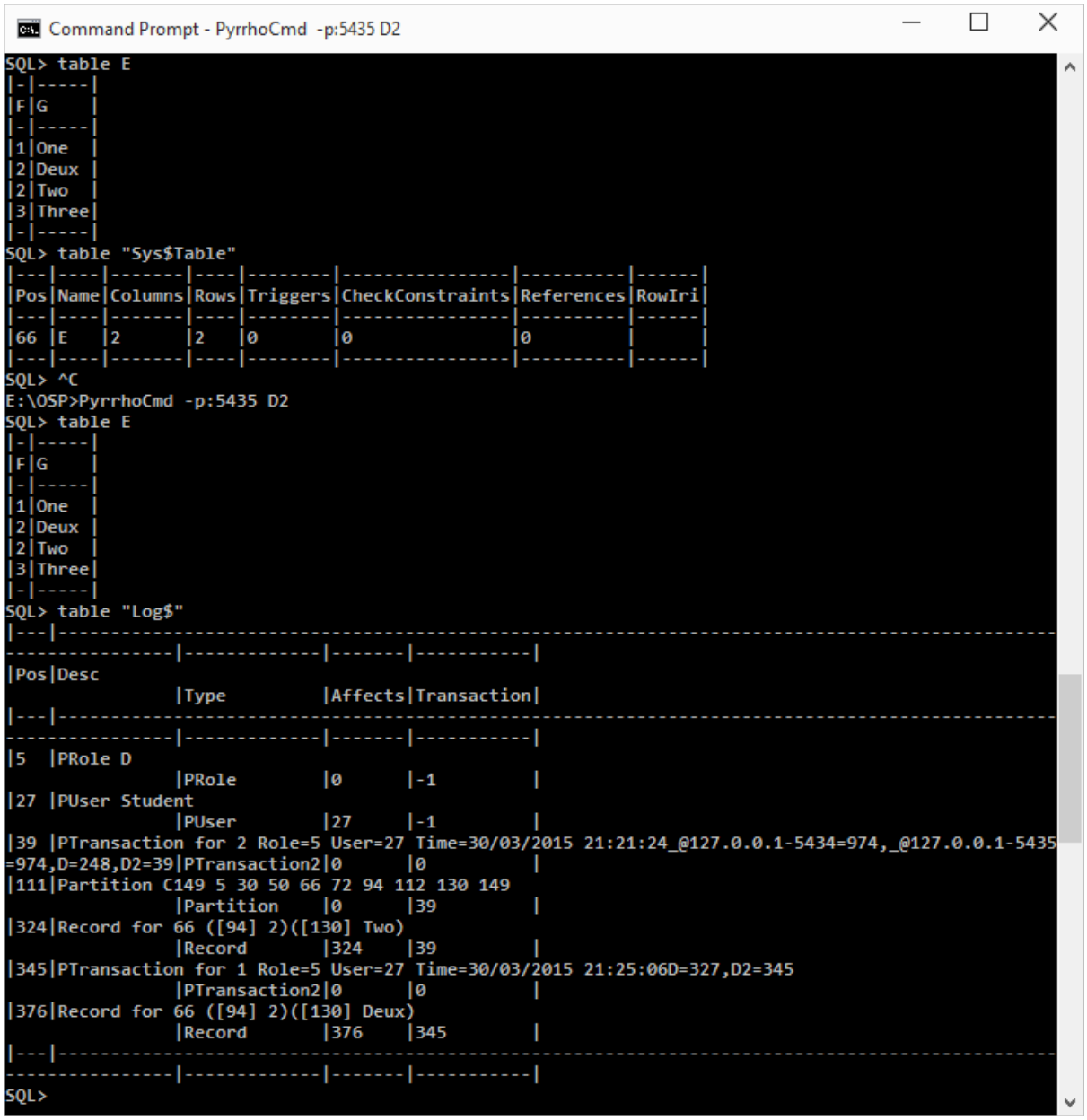
insert into E values (3,'Three'),(2,'Deux')

table E

table "Sys$Table"

Check all four records show up in E when viewed from D on A or D2 on B,

and verify from the logfiles that one new record each has been added to databases D and D2. The transaction is a distributed one (here D=327,D2=345).



At this point Sys$Table for D on A and for D2 on B will both show 2 rows in E. Again close the session with ^C.

Before we go on, let us check what records we have in the two configuration databases. We find the one record we placed in the _Partition table on A, slightly modified:

```
E:\OSP>PyrrhoCmd -p:5434 _
SQL> table "Sys$Table"
|---|----------|-------|----|--------|----------------|----------|------|
|Pos|Name      |Columns|Rows|Triggers|CheckConstraints|References|RowIri|
|---|----------|-------|----|--------|----------------|----------|------|
|50 |_Client   |4      |0   |0       |0               |0         |      |
|221|_Database |7      |0   |0       |0               |0         |      |
|475|_Partition|14     |1   |0       |0               |0         |      |
|---|----------|-------|----|--------|----------------|----------|------|
SQL> table "_Partition"
|----|---------------|-------------------------|-----------------------------|----|-------------|--
----------|-----|-----------|------|--------|--------|----------|----------|
|Name|PartitionServer|PartitionServerConfigUser|PartitionServerConfigPassword|Base|BaseServer    |Ba
sePassword|Table|SegmentName|Column|MinValue|MaxValue|IncludeMin|IncludeMax|
|----|---------------|-------------------------|-----------------------------|----|-------------|--
----------|-----|-----------|------|--------|--------|----------|----------|
|D2  |127.0.0.1:5435 |Student                  |********                     |D   |127.0.0.1:5434|**
******    |66   |E2         |94    |2       |2       |True      |True      |
|----|---------------|-------------------------|-----------------------------|----|-------------|--
----------|-----|-----------|------|--------|--------|----------|----------|
SQL> ^C
E:\OSP>
```

The changes are that the names ‘E’ and ‘F’ for the partitioning table and column have been replaced by the strings ‘66’ and ‘94’ respectively, as these are the defining positions in the base partition for these objects.. Passwords are hidden as usual.

On B we see a record generated by the Reconfigure process in B’s _Database table that tells B that D2 is a partition based on D on A:

```
E:\OSP>PyrrhoCmd -p:5435 _
SQL> table "Sys$Table"
|---|----------|-------|----|--------|----------------|----------|------|
|Pos|Name      |Columns|Rows|Triggers|CheckConstraints|References|RowIri|
|---|----------|-------|----|--------|----------------|----------|------|
|50 |_Client   |4      |0   |0       |0               |0         |      |
|221|_Database |7      |1   |0       |0               |0         |      |
|475|_Partition|14     |0   |0       |0               |0         |      |
|---|----------|-------|----|--------|----------------|----------|------|
SQL> table "_Database"
|----|--------------|----------|--------|--------------|---------------|--------------|
|Name|Server        |ServerRole|Password|Remote        |RemoteUser     |RemotePassword|
|----|--------------|----------|--------|--------------|---------------|--------------|
|D2  |127.0.0.1:5435|15        |********|127.0.0.1:5434|asusrog\Student|********      |
|----|--------------|----------|--------|--------------|---------------|--------------|
SQL> table "_Partition"
|----|---------------|-------------------------|-----------------------------|----|-------------|--
----------|-----|-----------|------|--------|--------|----------|----------|
|Name|PartitionServer|PartitionServerConfigUser|PartitionServerConfigPassword|Base|BaseServer    |Ba
sePassword|Table|SegmentName|Column|MinValue|MaxValue|IncludeMin|IncludeMax|
|----|---------------|-------------------------|-----------------------------|----|-------------|--
----------|-----|-----------|------|--------|--------|----------|----------|
|D2  |127.0.0.1:5435 |Student                  |********                     |D   |127.0.0.1:5434|**
******    |66   |E2         |94    |2       |2       |True      |True      |
|----|---------------|-------------------------|-----------------------------|----|-------------|--
----------|-----|-----------|------|--------|--------|----------|----------|
SQL> ^C
E:\OSP>
```

Don’t worry about asusrog here: it’s just the name of the PC I am using. The ServerRole 15 contains the bits 7 that we saw in a previous tutorial, together with 8 indicating BaseIsRemote. The entry does not give the name of the base database: this is actually written at the start of the binary partition file, as can be seen in the “Log$” for D2 shown on the previous page. But on both servers, as in the previous tutorial, the servers show the same list in the _Database and _Partition table, by collecting data from other servers in the lists.

A5.6 On A, delete the partition

On A, delete the single partition record in _ :

PyrrhoCmd -p:5434 _

delete from "_Partition"

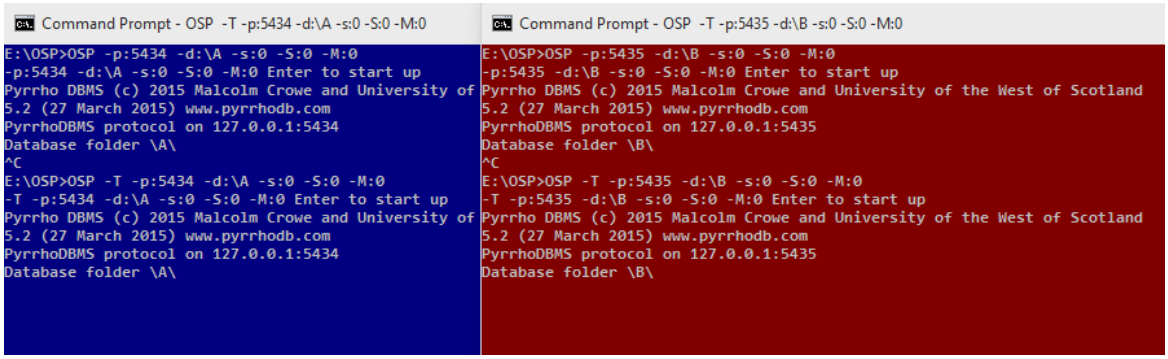
```
SQL> ^C
E:\OSP>PyrrhoCmd -p:5434 _
SQL> Delete from "_Partition"
1 records affected
SQL> ^C
E:\OSP>_
```

6. Verify that E still shows the correct contents on both servers (!), but the logfile or “Sys$Table” for D2 shows that the records in this partition have been deleted, Sys$Table for D on A shows 4 rows in E, and Sys$Table for D2 on B shows 0 rows in E (Partitions that are no longer in use are not actually deleted from the file system as the transaction logs should remain accessible.)

```
SQL> ^C
E:\OSP>PyrrhoCmd -p:5434 _
SQL> Delete from "_Partition"
1 records affected
SQL> ^C
E:\OSP>PyrrhoCmd -p:5434 D
SQL> table E
|-|-----|
|F|G    |
|-|-----|
|1|One  |
|2|Deux |
|2|Two  |
|3|Three|
|-|-----|
SQL> ^C
E:\OSP>PyrrhoCmd -p:5435 D2
SQL> table E
|-|-----|
|F|G    |
|-|-----|
|1|One  |
|2|Deux |
|2|Two  |
|3|Three|
|-|-----|
SQL> table "Sys$Table"
|---|----|-------|----|--------|----------------|----------|------|
|Pos|Name|Columns|Rows|Triggers|CheckConstraints|References|RowIri|
|---|----|-------|----|--------|----------------|----------|------|
|66 |E   |2      |0   |0       |0               |0         |      |
|---|----|-------|----|--------|----------------|----------|------|
SQL>
```

A5.7 Step 3 in detail

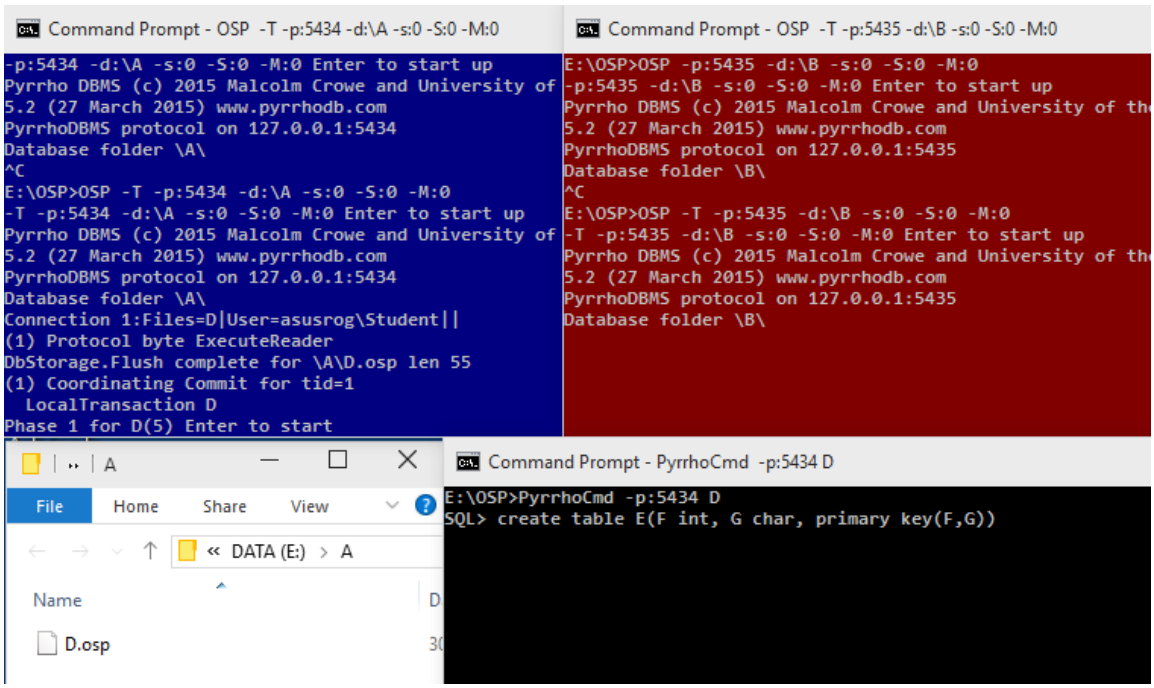
The following steps during setting up the partition can be observed by using the –T (Tutorial) flag on both servers. Stop the servers, clear the folders A and B, and repeat steps 1 to 3, but add the –T flag when starting the servers.



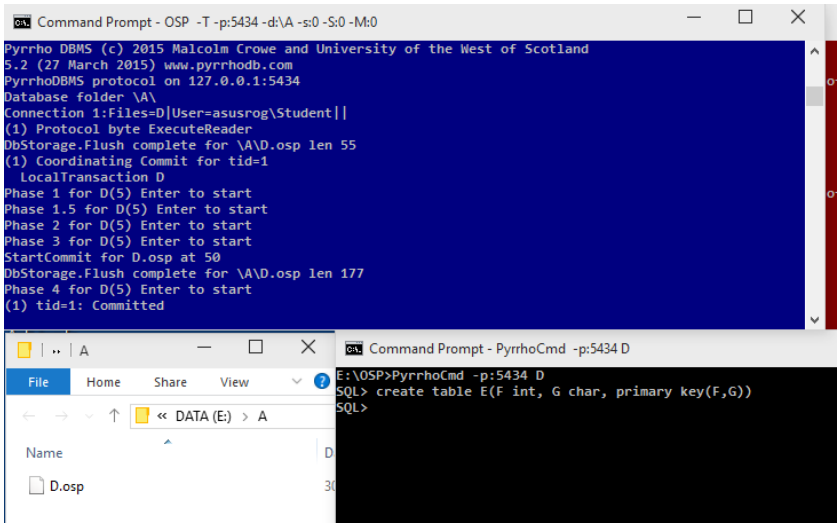
When you repeat step 3 now, server A will pause, waiting for you to confirm the first step of the transaction commit process (the reason for this will become a little clearer below):

PyrrhoCmd -p:5434 D

create table E(F int, G char, primary key(F,G))



In A's window, press the Enter key 5 times to complete the commit and get the next SQL> prompt in the command window:



You can see that server A has been dealing with a connection (1) to database D by Student, created an empty database D.osp in the A folder of length 55 bytes (just role and user information), and the 5 phases of committing the transaction for database D. The last line says that transaction 1 on connection 1 has been committed. The connection is to the command processor and will end with the session (as we will see later).

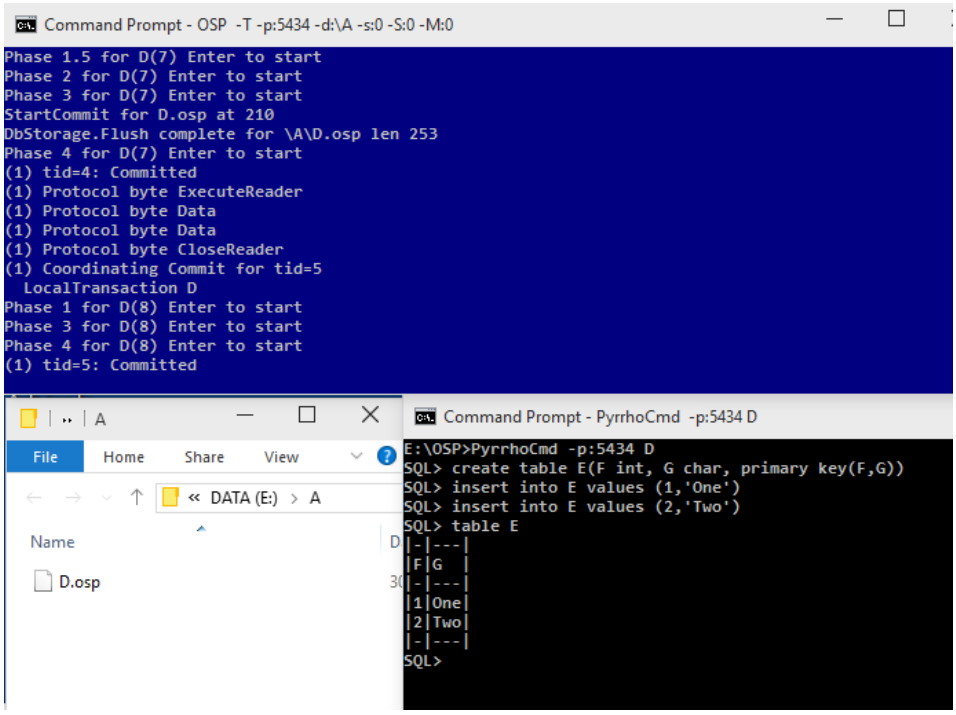
Similarly use the Enter key 5 times each for the next two steps:

insert into E values (1,'One')

insert into E values (2,'Two')

and 3 times for the read-only transaction (no need for phases 1.5 or 2)

table E



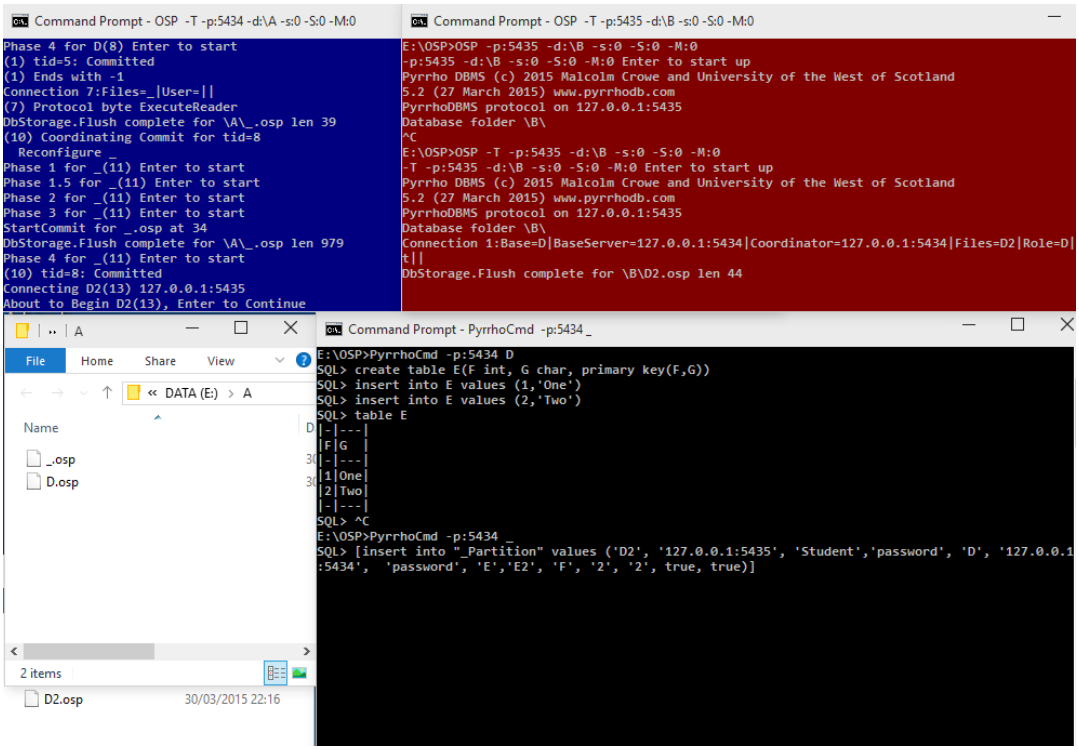
Show the Log$ file etc again if you want, and close the session with ^C.

A5.8 Step 4 in detail

PyrrhoCmd -p:5434 _

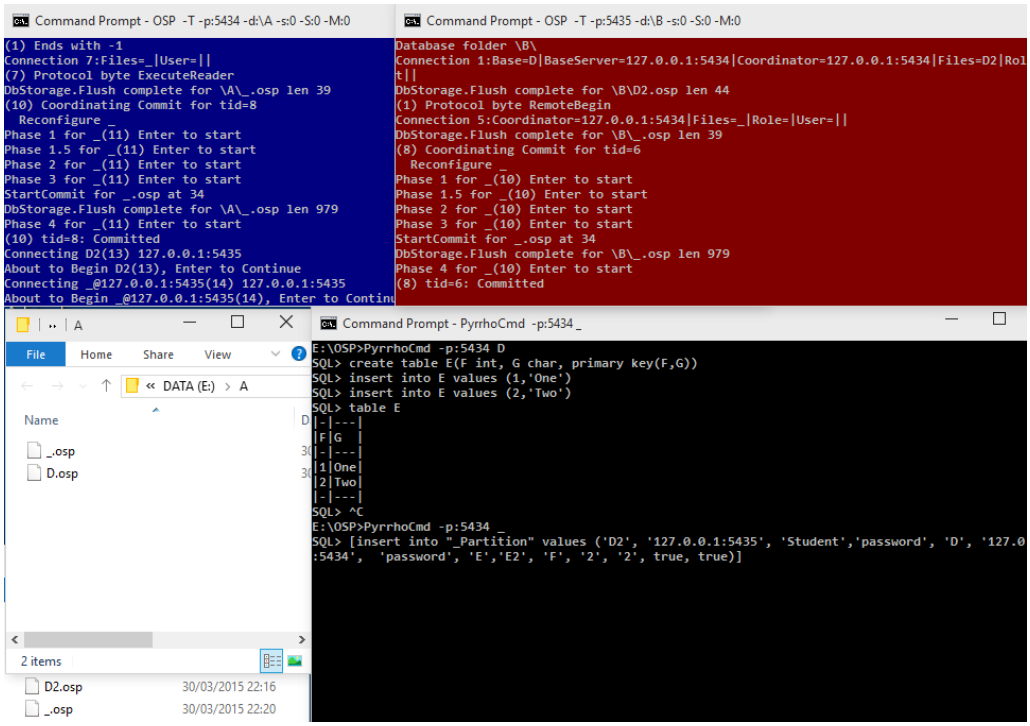
[insert into "_Partition" values ('D2', '127.0.0.1:5435', 'Student','password', 'D', '127.0.0.1:5434', 'password', 'E','E2', 'F', '2', '2', true, true)]

This time, when you issue this command the first stage is to construct the configuration file on A. (Enter 5 times). On the sixth Enter, A begins the connection (1) to B and B creates the new partition D2 on B. You can see that B's connection is coordinated by A, and the role D for the new database D2 identifies it as a partition with base D:

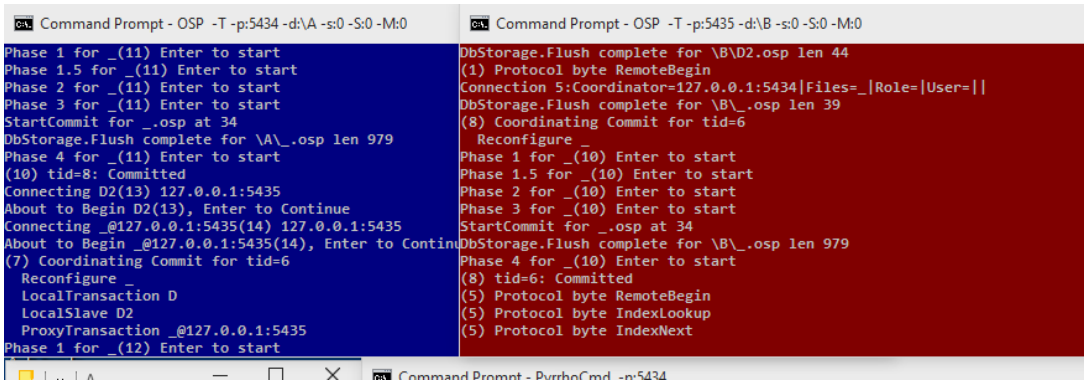


On the next Enter (on A) A starts a new connection (5) to the configuration database on B, so B starts to create this.[9] Since there are three empty tables to add to the new configuration database, we need five Enters in B's window:

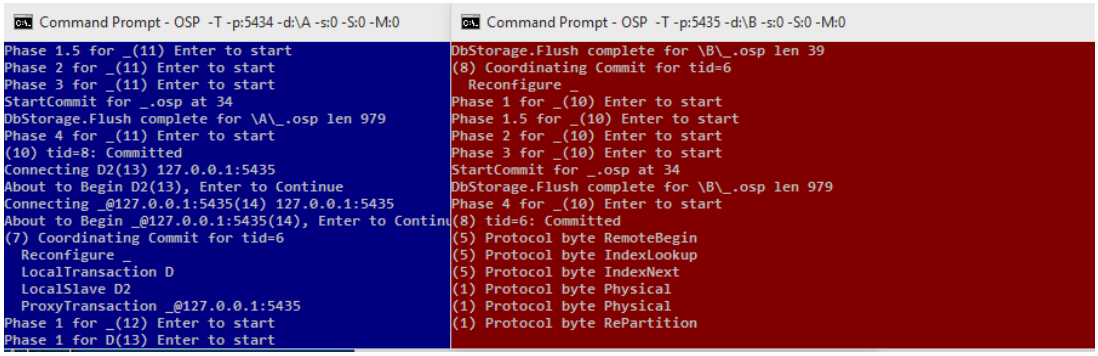
[9] It is probably an unnecessary complication that A is coordinating *two* separate remote transactions on B. At the moment servers create new remote connections for each remote database in a distributed transaction. Possibly a future version of Pyrrho will enable the coordinating server to open a multi-database connection on any remote server in the transaction.



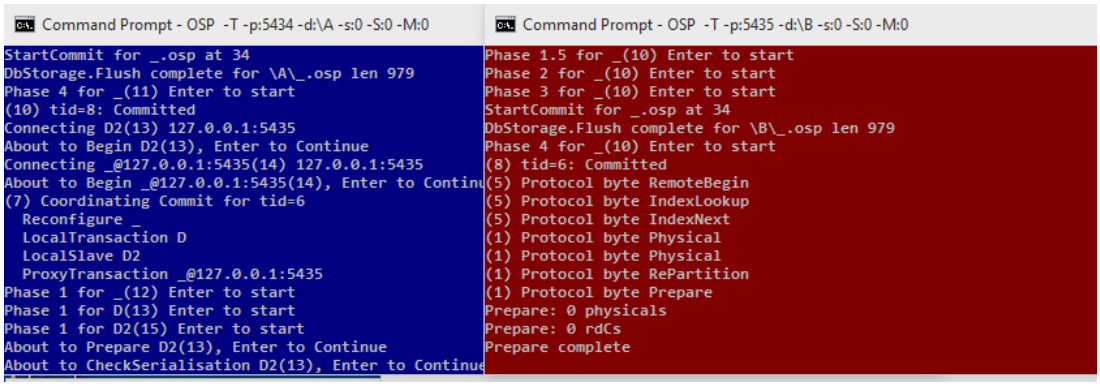
The next Enter on A's window begins the commit for the distributed transaction: Reconfigure on A, a change (LocalTransaction) to D on A, to A's LocalSlave proxy for the new Partition on B (which is a Master), and the remote configuration file. The verification step requires B to tell A about the databases it already has (A is examining B's indexes):



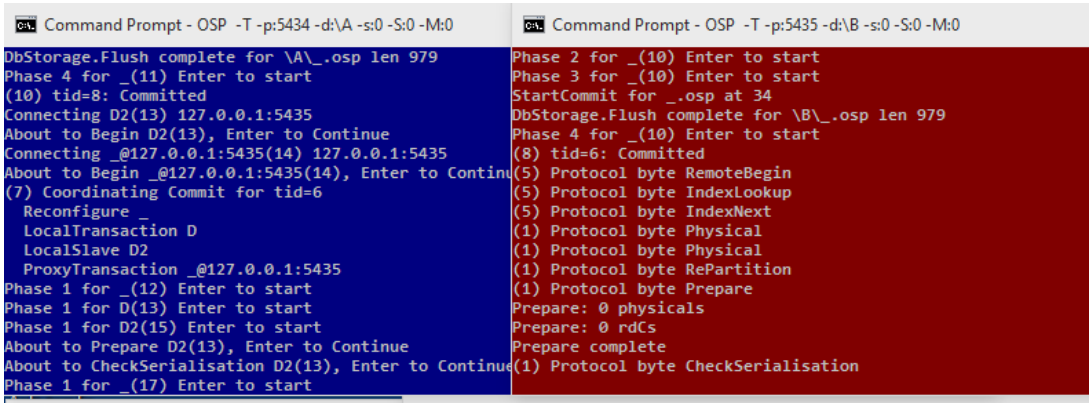
The next Enter on A send the Partition information from D to B for RePartition action:



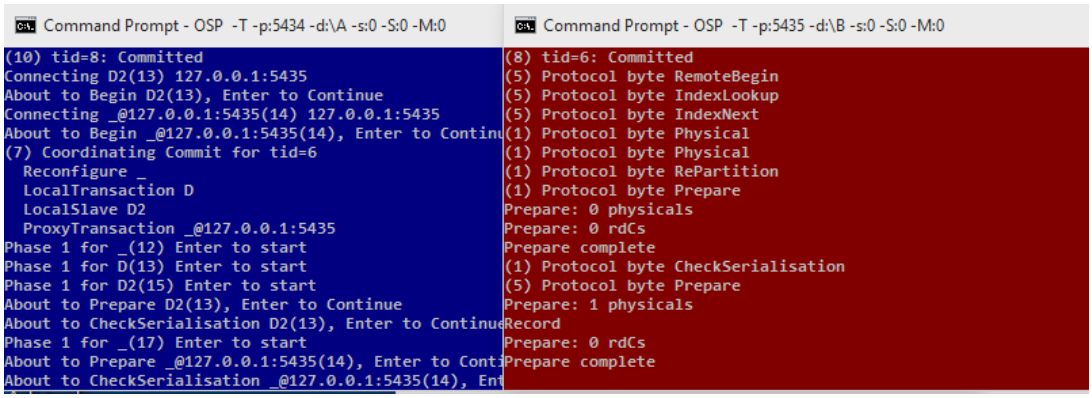
3 more enters and we see the Prepare step for B: A sends no physicals to B just now.



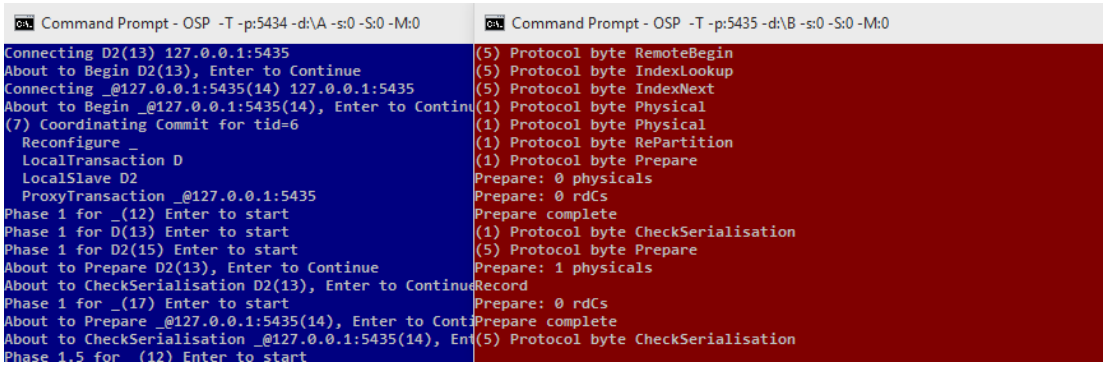
Enter on A: CheckSerialisation succeeds:



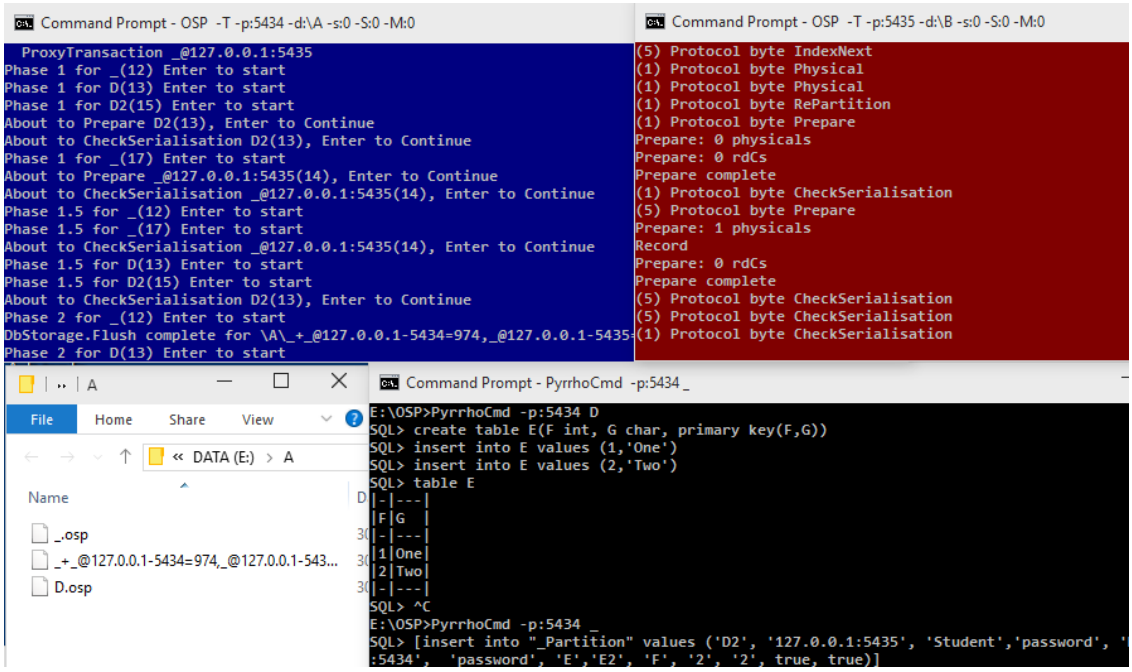
Now A starts to send the new information for the B's other connection, for the configuration file:



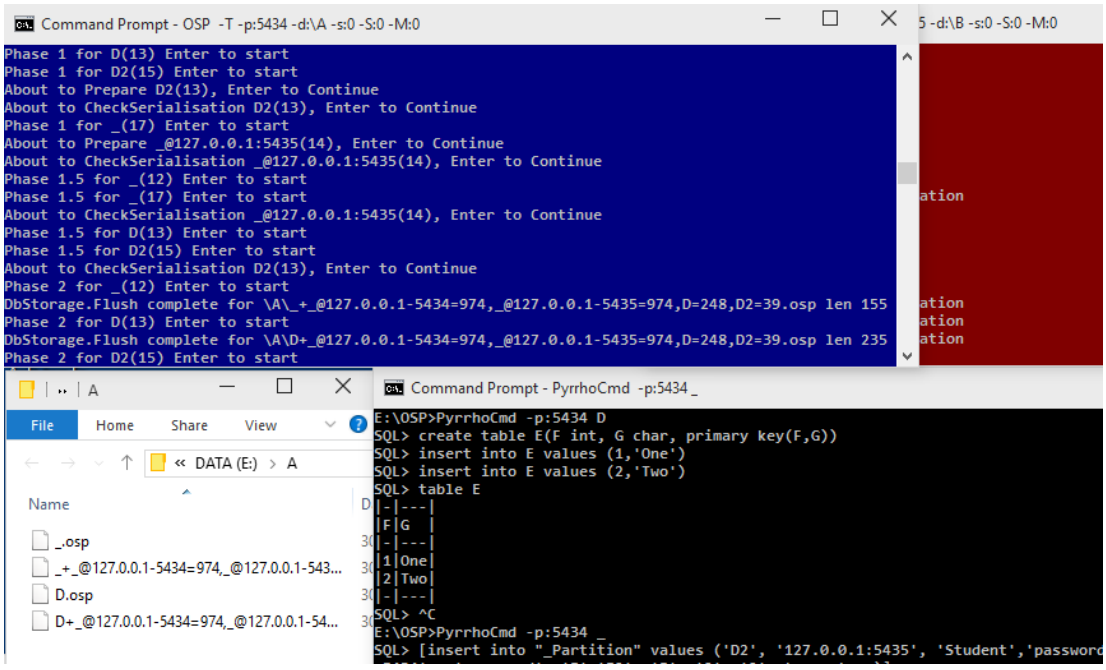
Enter to perform CheckSerialisation for this remote transaction:



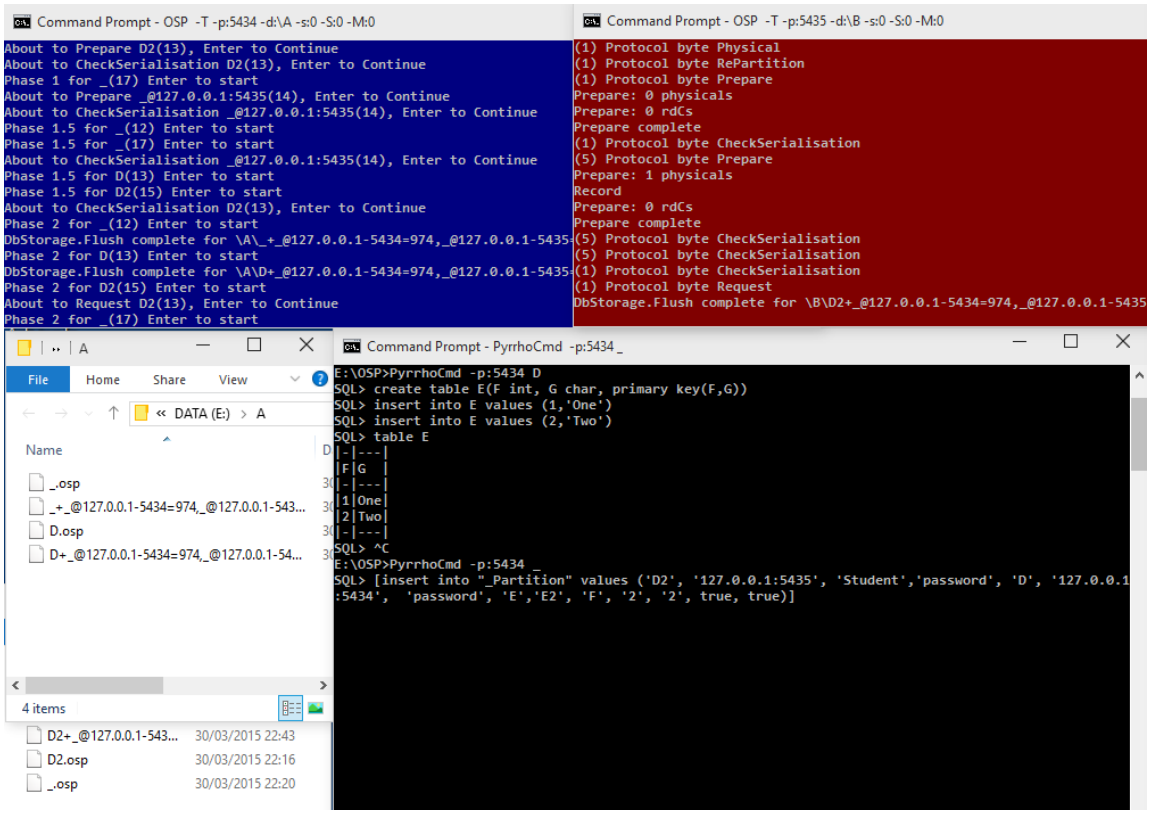
After a few more Enters we see the completion of checking and the saving of transaction data (3 phase commit) on A for the configuration part:



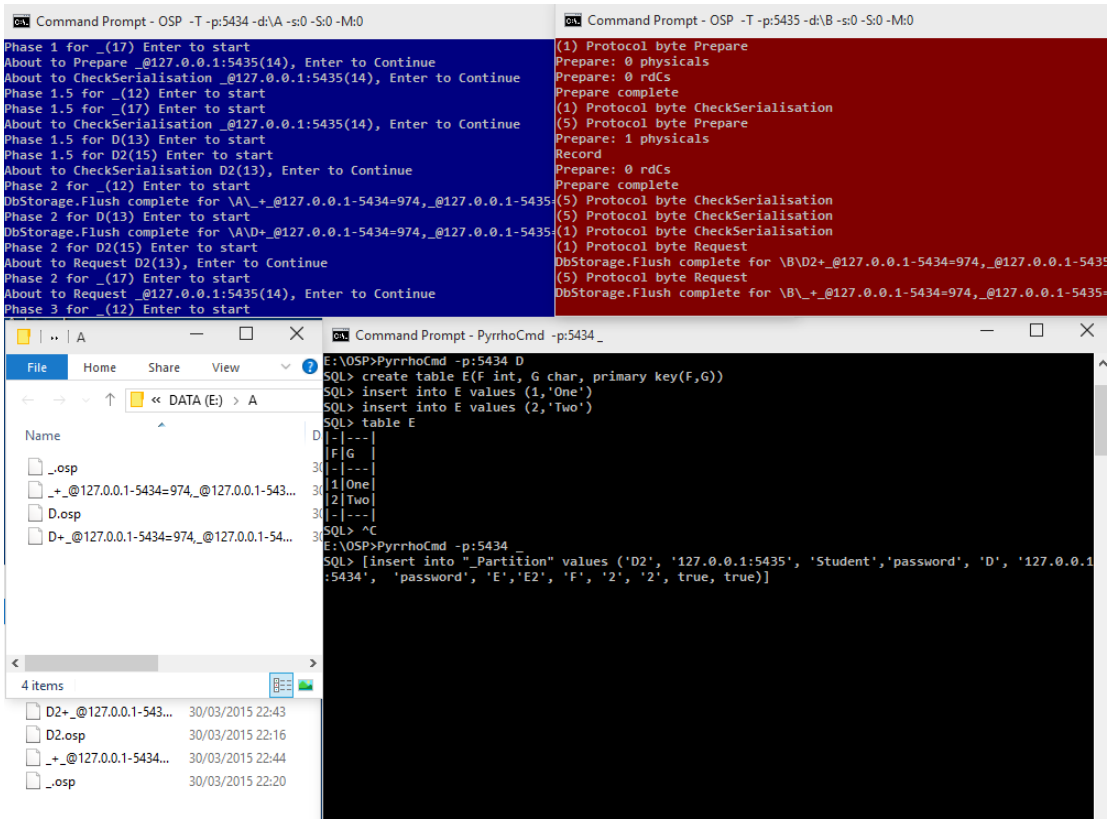
And (Enter) saves a similar file for D:



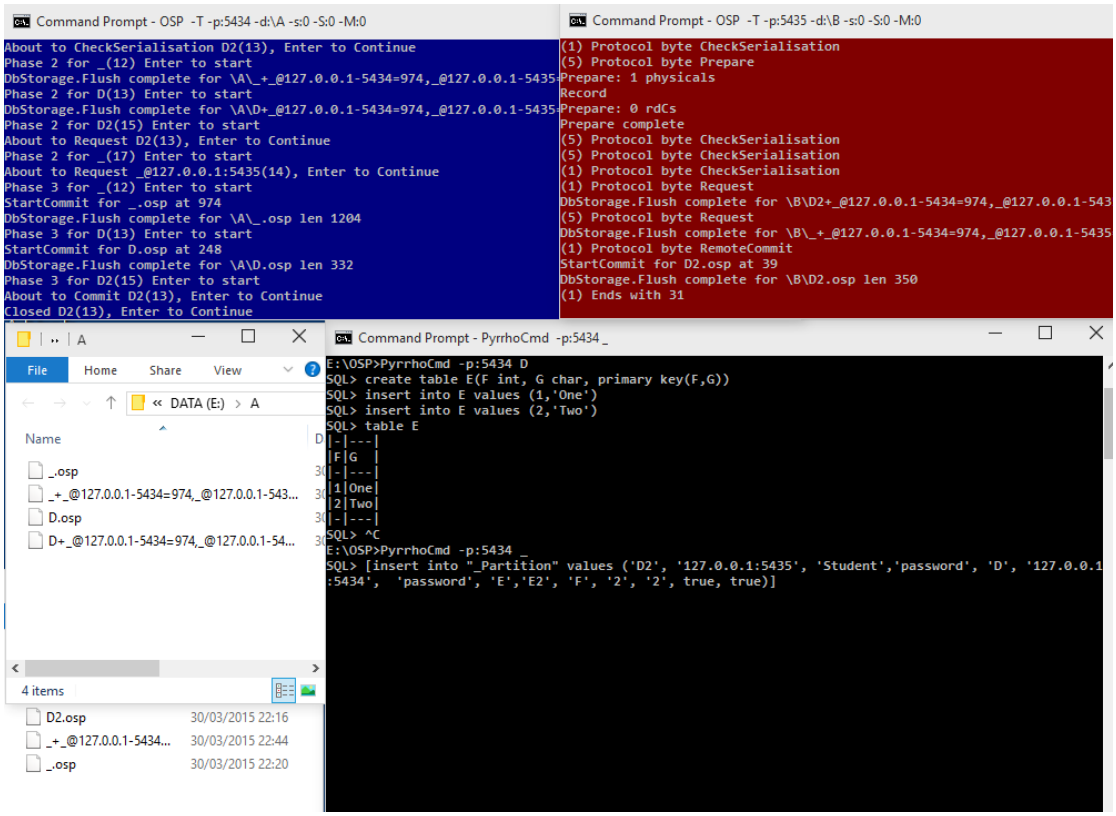
We now start to commit the remote transaction for D2: Enter twice, and a Request goes to B, which now saves its transaction information for D2.



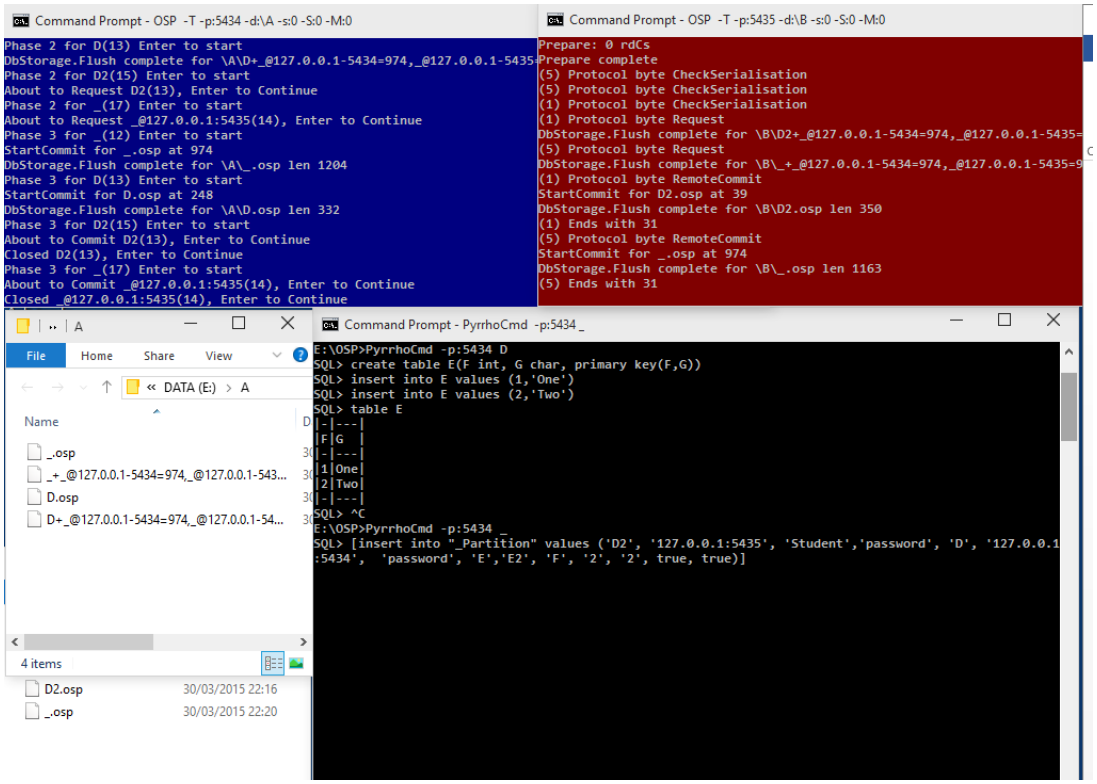
Another 2 Enters, and A sends the corresponding Request for the other remote transaction (the configuration file on B), which B also saves:



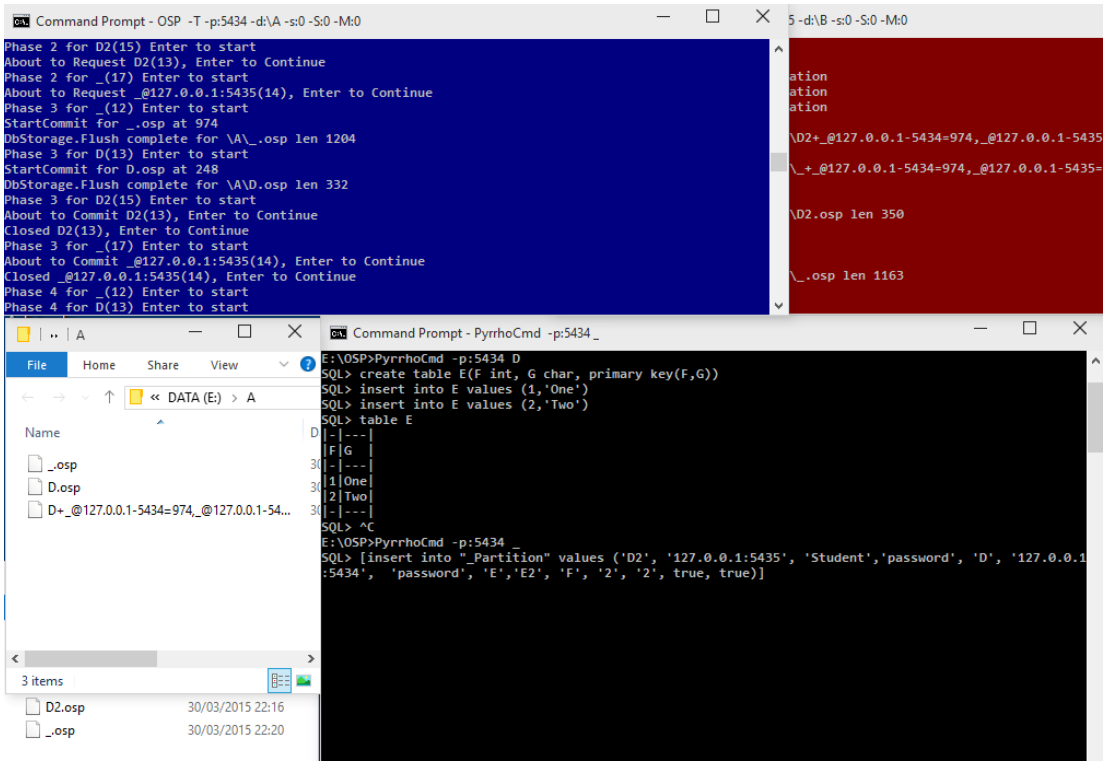
A few more Enters, and A now send the Commit for the D2 transaction on B. B commits, and removes the Saved data:

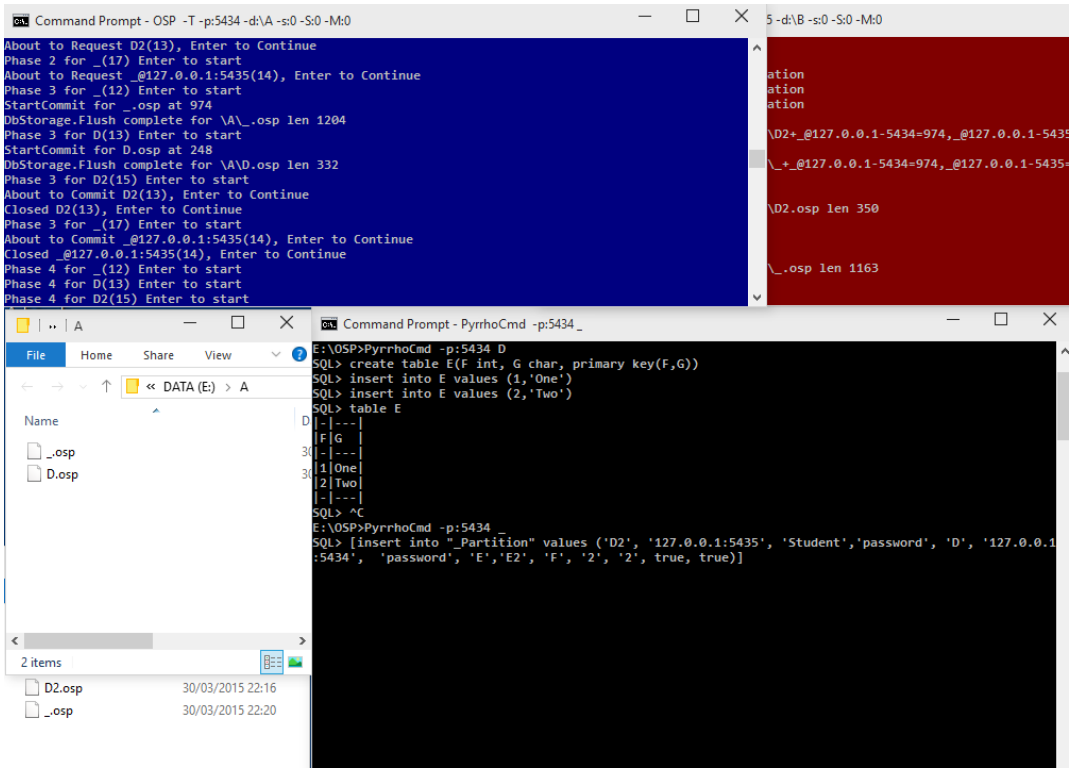


Three more Enters, and the other transaction is committed, and the saved data removed:

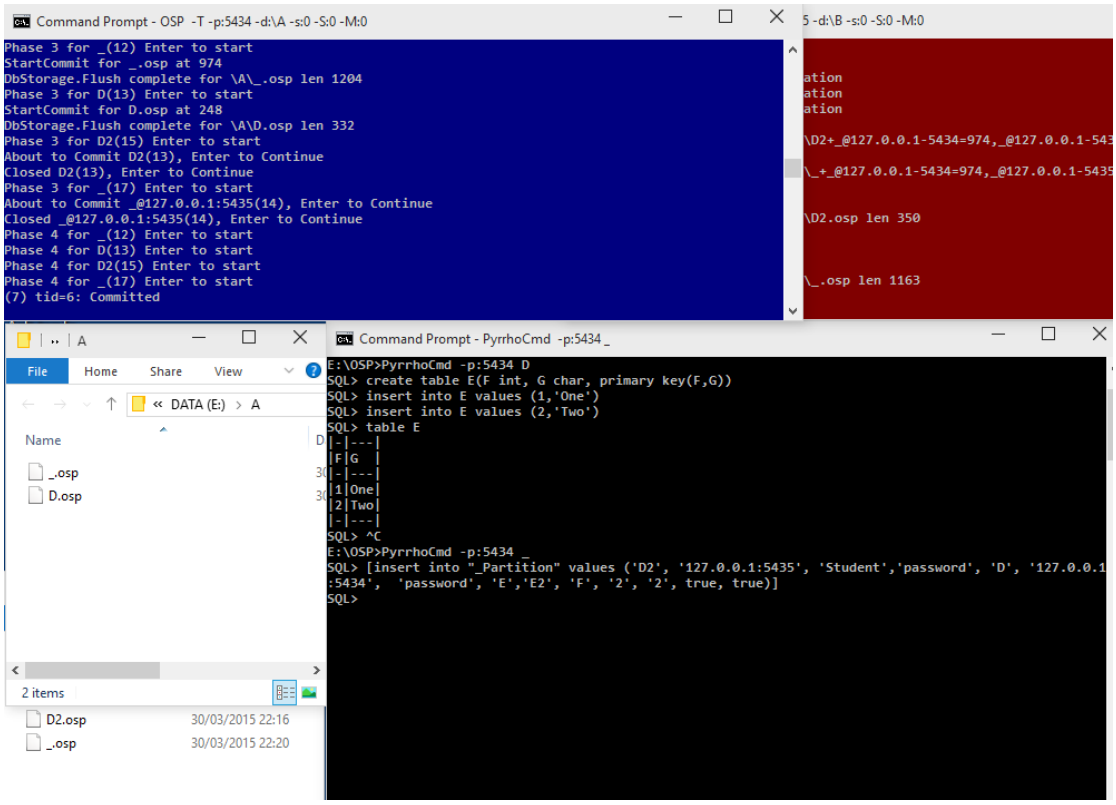


Now A begins to remote its Saved data:





Two more Enters and everything is done, and we get the SQL> prompt in the command window.



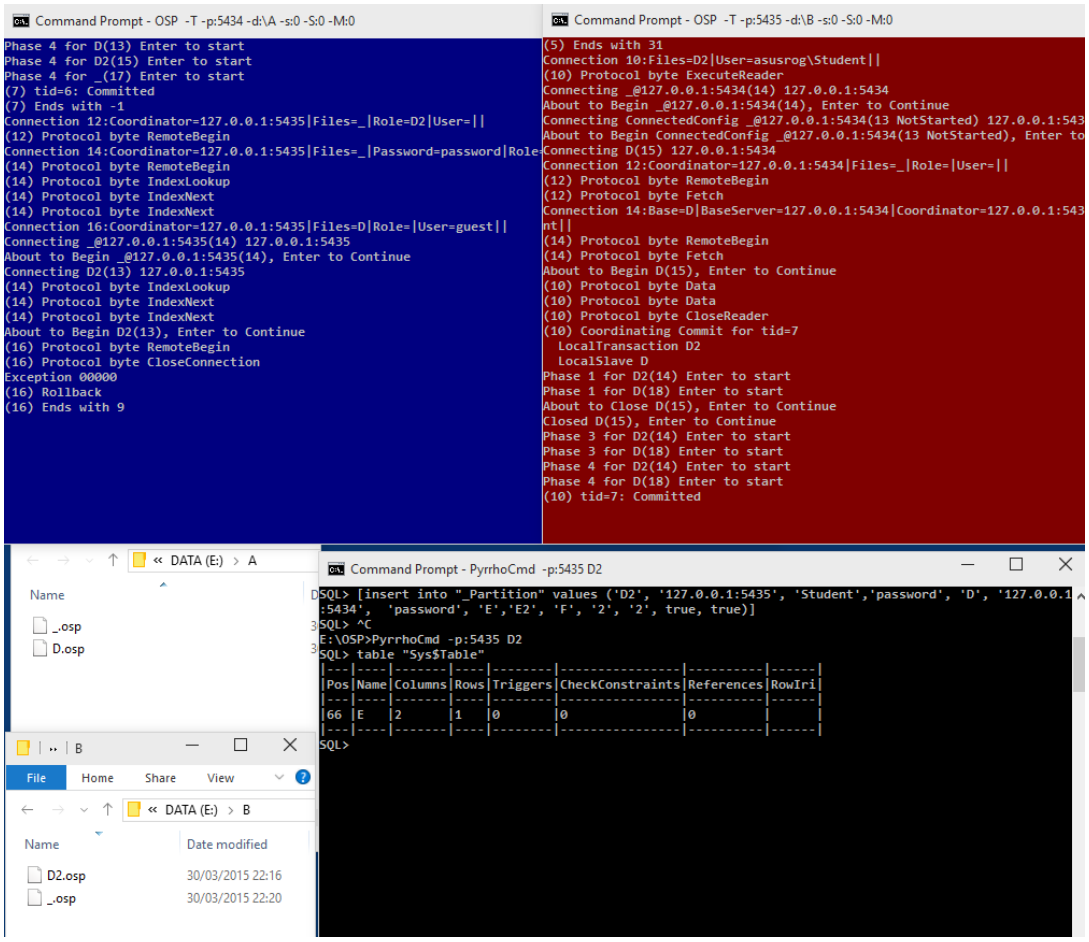
Close the session with ^C. ((7) Ends with -1 on A's window)

Now check that we have a record in the partition on D2

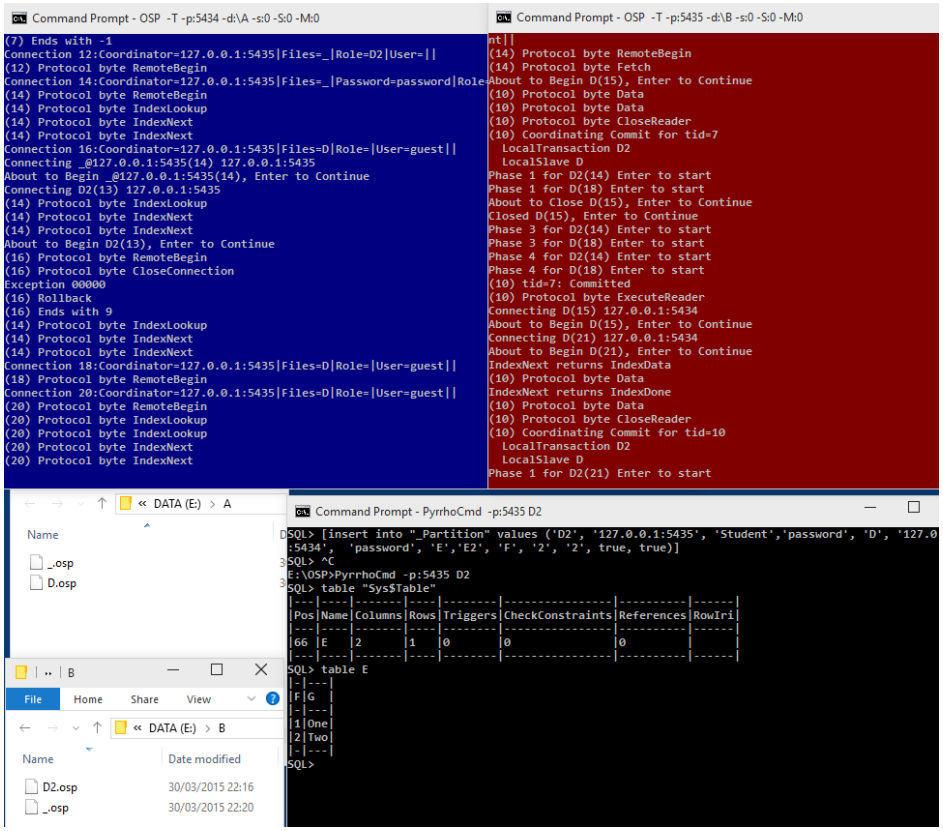
PyrrhoCmd -p:5435 D2

table "Sys$Table"

(needs Enters in both server windows):



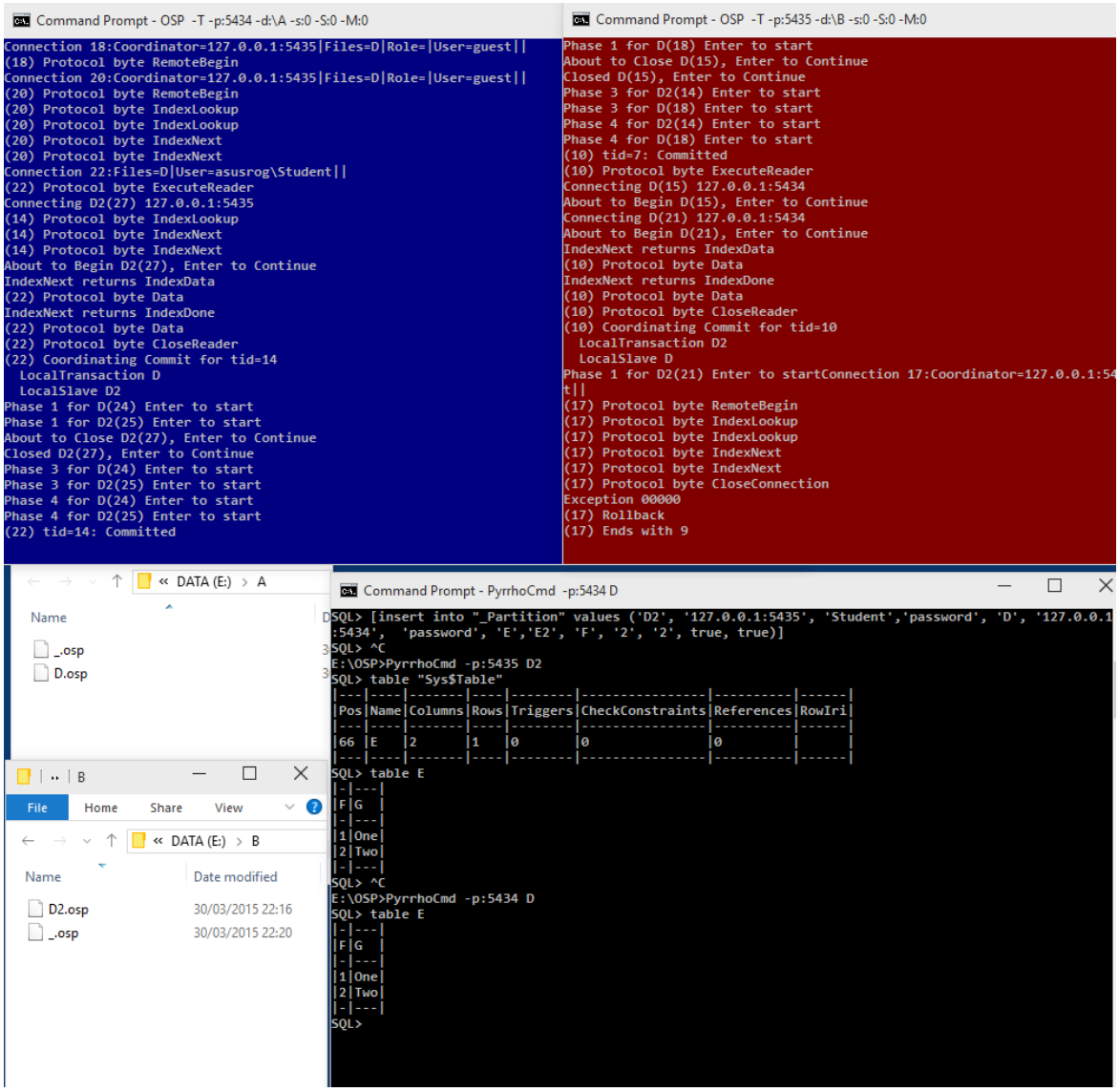
And table E on B:



And on A

PyrrhoCmd -p:5434 D

table E



Notice the interaction between the servers when we do almost anything: as a minimum the partitions check that the base server is not trying to do further partitioning, and obviously collecting the data for table E needs cooperation of both servers.

A5.9 Step 5 in detail

You can continue the tutorial to the next phases where we add further records and delete the partition segment. Quite a few more applications of the Enter key are required!

Appendix 6: Pyrrho SQL Syntax

A clickable HTML version of these details is available at www.pyrrhodb.com.

In this section capital letters indicate key words: many of these words are reserved words (see the website for a list of reserved words). Tokens such as id, int, string are shown as all lower case words. Mixed case is used for grammar symbols defined in the following productions. The characters = . [ ] { } are part of the production syntax. Characters that appear in the input are enclosed in single quotes, thus ',' . Where an identifier representing an object name is required, and the type of object is not obvious from the context, locutions such as Role_id are used.

There are three tokens: xmlname, iri and xml, which are used in XPath below, which are extensions to SQL2011. These tokens are not enclosed in single or double quotes, but may contain string literals that are enclosed in quotes. xmlname represents a case-sensitive sequence of letters and digits, iri is an IRI enclosed in <> and xml represents any Xml content not including an exposed ,] or). In SQL all string literals are enclosed in single quotes, case-sensitive identifiers or containing special characters are enclosed in double quotes.

A6.1 Statements

Sql = SqlStatement [';'] .

SqlStatement = Alter
| BEGIN TRANSACTION [WITH PROVENANCE string]
| Call
| COMMIT
| CreateClause
| CursorSpecification
| DeleteSearched
| DropStatement
| Grant
| Insert
| Rename
| Revoke
| ROLLBACK
| SET AUTHORIZATION '=' CURATED
| SET PROFILING '=' Value
| SET ROLE id [FOR DATABASE id]
| SET TIMEOUT '=' int
| UpdateSearched
| HTTP HttpRest .

The above statements can be issued at command level. You SELECT multiple rows from tables using the CursorSpecification. Inside procedures and functions there is a different set. (Note that "direct SQL" statements are in both lists.)

Apart from SET ROLE, the above SET statements are available only to the database owner. SET AUTHORIZATION = CURATED makes all further transaction log information PUBLIC (it is not reversible).

Statement = Assignment

```
        |       Call
        |       CaseStatement
        |       Close
        |       CompoundStatement
        |       BREAK
        |       Declaration
        |       DeletePositioned
        |       DeleteSearched
        |       Fetch
        |       ForStatement
        |       GetDiagnostics
        |       IfStatement
        |       Insert
        |       ITERATE label
        |       LEAVE label
        |       LoopStatement
        |       Open
        |       Repeat
        |       RETURN Value
        |       ROLLBACK
        |       SelectSingle
        |       Signal
        |       UpdatePositioned
        |       UpdateSearched
        |       While
        |       HTTP HttpRest .

HttpRest =      (ADD|UPDATE) url_Value data_Value [AS mime_string]
        |       DELETE url_Value .
```

Here ADD and UPDATE are used as the SQL analogues of POST and PUT. For Http GET see Value . By design in Pyrrho, the execution of ROLLBACK causes immediate exit of the current transaction with SQLSTATE 25005, and premature COMMIT is not supported, so that while ROLLBACK is in both lists above, COMMIT is nly in one.

A6.2 Data Definition

As is usual for a practical DBMS Pyrrho's Alter statements are richer than SQL2011.

```
Alter =         ALTER DOMAIN id AlterDomain
        |       ALTER FUNCTION id '(' Parameters ')' RETURNS Type AlterBody
        |       ALTER PROCEDURE id '(' Parameters ')' AlterBody
        |       ALTER Method AlterBody
        |       ALTER TABLE id AlterTable
        |       ALTER TYPE id AlterType
        |       ALTER VIEW id AlterView .
```

Procedures, functions and methods are distinguished by their name and arity (number of parameters) .

```
Method =        MethodType METHOD id '(' Parameters ')' [RETURNS Type] [FOR id].

Parameters = Parameter {',' Parameter } .
```

Parameter = id Type .

The specification of IN, OUT, INOUT and RESULT is not (yet) supported.

MethodType = [OVERRIDING | INSTANCE | STATIC | CONSTRUCTOR] .

The default method type is INSTANCE. All OVERRIDING methods are instance methods.

AlterDomain = SET DEFAULT Default
| DROP DEFAULT
| TYPE Type
| AlterCheck .

AlterBody = AlterOp { ',' AlterOp } .

AlterOp = TO id
| Statement
| [ADD|DROP] { Metadata } .

Default = Literal | DateTimeFunction | CURRENT_USER | CURRENT_ROLE | NULL | ARRAY'('')'
| MULTISET'('')' .

AlterCheck = ADD CheckConstraint
| [ADD|DROP] { Metadata }
| DROP CONSTRAINT id .

Note that anonymous constraints can be dropped by finding the system-generated id in the Sys$TableCheck, Sys$ColumnCheck or Sys$DomainCheck table (see section 8.1).

CheckConstraint = [CONSTRAINT id] CHECK '(' [XMLOption] SearchCondition ')' .

XMLOption = WITH XMLNAMESPACES '(' XMLNDec {',' XMLNDec } ')' .

XMLNDec = (string AS id) | (DEFAULT string) | (NO DEFAULT) .

The following standard namespaces and prefixes are predefined:
'http://www.w3.org/1999/02/22-rdf-syntax-ns#' AS rdf
'http://www.w3.org/2000/01/rdf-schema#' AS rdfs
'http://www.w3.org/2001/XMLSchema#' AS xsd
'http://www.w3.org/2002/07/owl#' AS owl

AlterTable = TO id
| ADD ColumnDefinition
| ALTER [COLUMN] id AlterColumn
| DROP [COLUMN] id DropAction
| (ADD|DROP) (TableConstraintDef | VersioningClause)
| ADD TablePeriodDefinition [AddPeriodColumnList]
| ALTER PERIOD id TO id
| DROP TablePeriodDefinition
| AlterCheck
| [ADD|DROP] { Metadata }.

AlterColumn = TO id
| POSITION int

| (SET|DROP) ((NOT NULL)|ColumnConstraint)
| AlterDomain
| GenerationRule
| [ADD|DROP] { Metadata } .

When columns are renamed, Pyrrho cascades the change to SQL referring to the columns.

AlterType = TO id
| ADD (Member | Method)
| DROP (Member_id | Routine)
| Representation
| [DROP] { Metadata }
| ALTER Member_id AlterMember .

Other details of a Method can be changed with the ALTER METHOD statement (see Alter above).

Member = id Type [DEFAULT Value] Collate .

AlterMember = TO id
| [DROP] { Metadata }
| TYPE Type
| SET DEFAULT Value
| DROP DEFAULT .

AlterView = SET (INSERT|UPDATE|DELETE|) TO SqlStatement
| SET SOURCE TO QueryExpression
| TO id
| [ADD|DROP] { Metadata } .

Metadata = ATTRIBUTE | CAPTION | ENTITY | HISTOGRAM | LEGEND | LINE | POINTS | PIE | X | Y | CAPPED | USEPOWEROF2SIZES | BACKGROUND | DROPDUPS | SPARSE | MAX'('int')' | SIZE'('int')' | string | iri .

The Metadata flags and the string "constraint" are Pyrrho extensions., Attribute and Entity affect XML output in the role, Histogram, Legend, Line, Points, Pie (for table, view or function metadata), Caption, X and Y (for column or subobject metadata) affect HTML output in the role. HTML responses will have JavaScript added to draw the data visualisations specified. Other metadata keywords are for MongoDB. The string is for a description, and for X and Y columns is used to label the axes of charts. If the table's description string begins with a < it will be included in the HTML so that it can supply CSS style or script. If the table's string metadata begins with <? it should be an XSL transform, and Pyrrho will generate and then transform the return data as XML.

AddPeriodColumnList = ADD [COLUMN] Start_ColumnDefinition ADD [COLUMN] End_ColumnDefinition .

Create = CREATE ROLE id [Description_string]
| CREATE DOMAIN id [AS] DomainDefinition
| CREATE FUNCTION id '(' Parameters ')' RETURNS Type Statement
| CREATE ORDERING FOR UDType_id (EQUALS ONLY|ORDER FULL) BY Ordering
| CREATE PROCEDURE id '(' Parameters ')' Statement
| CREATE Method Statement
| CREATE TABLE id TableContents [UriType] {Metadata}

| CREATE TRIGGER id (BEFORE|AFTER) Event ON id [RefObj] Trigger
| CREATE TYPE id ((UNDER id)|AS Representation)[Method {‘,’ Method}]
| CREATE ViewDefinition
| CREATE XMLNAMESPACES XMLNDec { ‘,’ XMLNDec }
| CREATE INDEX Table_id Name_id [UNIQUE] Cols Metadata .

Method bodies in SQL2011 are specified by CREATE METHOD once the type has been created...In Pyrrho types UNDER or Representation must be specified (not both). CREATE XMLNAMESPACES is for creating a persistent association of namespace uris with identifiers.

Representation = (StandardType|Table_id|‘(‘ Member {‘,’ Member }’)’)[UriType] {CheckConstraint} .

UriType = [Abbrev_id]‘^^’([Namespace_id] ‘:’ id | uri) .

Syntax with UriType is a Pyrrho extension. Abbrev_id can only be supplied within a CREATE DOMAIN statement. See section 5.2.1.

DomainDefinition = StandardType [UriType] [DEFAULT Default] { CheckConstraint } Collate .

Ordering = (RELATIVE|MAP) WITH Routine
| STATE .

TableContents = ‘(‘ TableClause {‘,’ TableClause } ‘)’ { VerisoningClause }
| OF Type_id [‘(‘ TypedTableElement {‘,’ TypedTableElement} ‘)’]
| AS Subquery .

VersioningClause = WITH (SYSTEM|APPLICATION) VERSIONING .

WITH APPLICATION VERSIONING is Pyrrho specific: see section 5.2.3.

TableClause = ColumnDefinition {Metadata} | TableConstraint | TablePeriodDefinition .

ColumnDefinition = id Type [DEFAULT Default] {ColumnConstraint|CheckConstraint} Collate
| id GenerationRule
| id Table_id ‘.’ Column_id.

The last version is a convenience form for lookup tables, e.g. if a.b has domain int then a.b is a shorthand for int check (value in (select b from a)).

GenerationRule = GENERATED ALWAYS AS ‘(‘Value‘)’ [UPDATE ‘(‘ Assignments ‘)’]
| GENERATED ALWAYS AS ROW (START| END) .

The update option here is an innovation in Pyrrho.

ColumnConstraint = [CONSTRAINT id] ColumnConstraintDef .

ColumnConstraintDef = NOT NULL
| PRIMARY KEY
| REFERENCES id [Cols] [USING ‘(‘Values’)’] { ReferentialAction }
| UNIQUE
| DEFAULT Value
| GenerationRule .

The Using expression here is an extension to SQL2011 behaviour. See section 5.2.2. A column default value overrides a domain default value.

TableConstraint = [CONSTRAINT id] TableConstraintDef .

TableConstraintDef= UNIQUE Cols
| PRIMARY KEY Cols
| FOREIGN KEY Cols REFERENCES id [Cols] [USING '('Values')'] { ReferentialAction } .

The Using expression here is an extension to SQL2011 behaviour. See section 5.2.2.

TablePeriodDefinition= PERIOD FOR PeriodName '(' Column_id ',' Column_id ')' .

PeriodName = SYSTEM_TIME | id .

TypedTableElement = ColumnOptionsPart | TableCnstraint .

ColumnOptionsPart = id WITH OPTIONS '(' ColumnOption {',' ColumnOption } ')' .

ColumnOption = (SCOPE Table_id) | (DEFAULT Value) | ColumnConstraint .

Values = Value {',' Value } .

Cols = '('ColRef { ','ColRef } [',' PERIOD ApplicationTime_id] ')'.

The period syntax here can only be used in a foreign key constraint declaration where both tables have application time period definitions, and allows them to be matched up.

ColRef = Column_id { '.' Field_id } [DESC] .

The Field_id syntax is Pyrrho specific and can be used to reference fields of structured types or documents. The desc option is for the MongoDB Create Index syntax and is allowed only for document field references.

ReferentialAction = ON (DELETE|UPDATE) (CASCADE| SET DEFAULT|RESTRICT) .

The default ReferentialAction is RESTRICT. Constraints are retrospective: they cannot be applied if existing data conflicts with them A new default value will be applied to any existing null values, but dropping or changing a default value has no retrospective effect (since there are no null values to apply it to).

ViewDefinition = VIEW id AS QueryExpression [UPDATE SqlStatement] [INSERT SqlStatement] [DELETE SqlStatement] {Metadata} .

This is an extension to SQL2011 syntax to provide simpler mechanisms for indirect tables. Note that all of these can use Web services to access remote data.

TriggerDefinition = TRIGGER id (BEFORE|(INSTEAD OF)|AFTER) Event ON id [RefObj] Trigger .

In Pyrrho, triggers can be defined on views: this is very useful when used with roles.

Event = INSERT | DELETE | (UPDATE [OF id { ',' id }]) .

RefObj = REFERENCING { (OLD|NEW)[ROW|TABLE][AS] id } .

In this syntax, the default is ROW; TABLE cannot be specified for a BEFORE trigger; OLD cannot be specified for an INSERT trigger; NEW cannot be specified for a DELETE trigger.

Trigger = FOR EACH (ROW|STATEMENT)[TriggerCond](Statement|(BEGIN ATOMIC Statements END)) .

TriggerCond = WHEN '(' SearchCondition ')' .

DropStatement = DROP DropObject DropAction .

DropObject = ObjectName
| ORDERING FOR id
| ROLE id
| TRIGGER id
| XMLNAMESPACES (id|DEFAULT) {',' (id|DEFAULT) }
| INDEX id .

DropAction = | RESTRICT | CASCADE .

The default DropAction is RESTRICT.

Rename =SET ObjectName TO id .

A6.3 Access Control

Grant = GRANT Privileges TO GranteeList [WITH GRANT OPTION]
| GRANT Role_id { ',' Role_id } TO GranteeList [WITH ADMIN OPTION] .

Grant can only be used in single-database connections (section 3.4). For roles see section 5.5.

Revoke = REVOKE [GRANT OPTION FOR] Privileges FROM GranteeList
| REVOKE [ADMIN OPTION FOR] Role_id { ',' Role_id } FROM GranteeList .

Revoke can only be used in single-database connections. Revoke withdraws the specified privileges in a cascade, irrespective of the origin of any privileges held by the affected grantees: this is a change to SQL2011 behaviour. (See also sections 5.5 and 7.13.)

Privileges = ObjectPrivileges ON ObjectName.

ObjectPrivileges = ALL PRIVILEGES | Action { ',' Action } .

Action = SELECT ['(' id { ',' id } ')']
| DELETE
| INSERT ['(' id { ',' id } ')']
| UPDATE ['(' id { ',' id } ')']
| REFERENCES ['(' id { ',' id } ')']
| USAGE
| TRIGGER
| EXECUTE
| OWNER .

The owner privilege (Pyrrho-specific) can only be granted by the owner of the object (or the database) and results in a transfer of ownership of that object to a single user or role (not PUBLIC).. Ownership always implies grant option for the owner privilege. References here can be to columns, methods, fields or properties depending on the type of object referenced by the objectname.

ObjectName = TABLE id
| DOMAIN id
| TYPE id
| Routine
| VIEW id

| DATABASE .

The Pyrrho-specific OWNER Privilege is the only grantable privilege on the Pyrrho-specific DATABASE ObjectName, and results in a transfer of ownership of the database to the grantee, who must be a user (not a role).

GranteeList = PUBLIC | Grantee { ',' Grantee } .

Grantee = [USER] id
| ROLE id .

See section 5.5 for the use of roles in Pyrrho.

Routine = PROCEDURE id ['('Type, {',' Type }')']
| FUNCTION id ['('Type, {',' Type }')']
| [MethodType] METHOD id ['('Type, {',' Type }')'] [FOR id]
| TRIGGER id .

A6.4 Type

Type = (StandardType | DefinedType | Domain_id | Type_id)[UriType] .

StandardType = BOOLEAN | CharacterType | FloatType | IntegerType | LobType | NumericType | DateTimeType | IntervalType | XML | PASSWORD | DOCUMENT | DOCARRAY | OBJECT .

The last four types are Pyrrho-specific: Password values show as *******, Document is as in http://bsonspec.org, DocArray is for the array variant used in Bson, and Object is ObjectId as in MongoDB, Documents and ObjectIds are transmitted to clients as subtypes of byte[] data, using Bson and byte[12] format respectively. All four types have automatic conversion from strings: Json to Bson for Document and DocArray, while ObjectId strings can be of hex digits or have four integer fields separated by colons: time:machine:process:count . A top-level document without an _id will be given an _id similar to MongoDB for the local machine. Documents are considered equal if corresponding fields match .

CharacterType = (([NATIONAL] CHARACTER) | CHAR | NCHAR | VARCHAR) [VARYING] ['('int ')'] [CHARACTER SET id] Collate .

National and varying are ignored, and the names are regarded as equivalent in Pyrrho .

Collate = [COLLATE id] .

There is no need to specify COLLATE UNICODE, since this is the default collation. COLLATE UCS_BASIC is supported but deprecated. For the list of available collations, see .NET documentation.

FloatType = (FLOAT|REAL|DOUBLE PRECISION) ['('int','int')'] .

The names here are regarded as equivalent in Pyrrho .

IntegerType = INT | INTEGER | BIGINT | SMALLINT .

All these integer types are regarded as equivalent in Pyrrho .

LobType = ([NATIONAL] CHARACTER |BINARY) LARGE OBJECT | BLOB | CLOB | NCLOB .

National is ignored, the character large object types are regarded as equivalent to CHAR since they represent unbounded character strings, and of course BINARY LARGE OBJECT is the same as BLOB.

NumericType = (NUMERIC|DECIMAL|DEC) [‘(‘int’,’int’)’] .

The names here are regarded as equivalent in Pyrrho .

DateTimeType = (DATE | TIME | TIMESTAMP) ([IntervalField [TO IntervalField]] | ['(' int ')']).

The use of IntervalFields when declaring DateTimeType is an addition to the SQL standard.

IntervalType = INTERVAL IntervalField [TO IntervalField] .

IntervalField = YEAR | MONTH | DAY | HOUR | MINUTE | SECOND [‘(‘ int ‘)’] .

DefinedType = (ROW|TABLE) Representation
| Type ARRAY
| Type MULTISET .

The TABLE alternative here is a Pyrrho extension to SQL2011, but currently there is no difference.

A6.5 Data Manipulation

Insert = INSERT [WITH PROVENANCE string] [XMLOption] INTO Table_id [Cols] Table_Value
.

For example is INSERT INTO t VALUES (4,5) , or is INSERT INTO t SELECT c,d FROM e .

UpdatePositioned = UPDATE [XMLOption] Table_id Assignment WHERE CURRENT OF Cursor_id .

UpdateSearched = UPDATE [XMLOption] Table_id Assignment [WhereClause] .

DeletePositioned = DELETE [XMLOption] FROM Table_id WHERE CURRENT OF Cursor_id .

DeleteSearched = DELETE [XMLOption] FROM Table_id [WhereClause] .

CursorSpecification = [XMLOption] QueryExpression [FOR ((READ ONLY)|(UPDATE [OF id {‘,’ id}))] .

A simple table query is defined (SQL2011-02 14.1SR18c) as a CursorSpecification in which the QueryExpression is a QueryTerm that is a QueryPrimary that is a QuerySpecification.

QueryExpression = QueryExpressionBody [OrderByClause][FetchFirstClause] .

QueryExpressionBody = QueryTerm
| QueryExpression (UNION | EXCEPT) [ALL | DISTINCT] QueryTerm .

DISTINCT is the default and discards duplicates from both operands.

QueryTerm = QueryPrimary | QueryTerm INTERSECT [ALL | DISTINCT] QueryPrimary .

DISTINCT is the default.

QueryPrimary = SimpleTable | ‘(‘ QueryExpressionBody [OrderByClause][FetchFirstClause] ‘)’ .

SimpleTable = QuerySpecification | Value | TABLE id .

QuerySpecification = SELECT [ALL | DISTINCT] SelectList TableExpression .

SelectList = ‘*’ | SelectItem { ‘,’ SelectItem } .

SelectItem = (Value [AS id]) | ([id{‘.’id}’.’]‘*’) .

TableExpression = FromClause [WhereClause] [GroupByClause] [HavingClause] [WindowClause] .

GroupByClause and HavingClause are used with aggregate functions.

FromClause = FROM TableReference { ‘,’ TableReference } .

WhereClause = WHERE BooleanExpr .

GroupByClause = GROUP BY [DISTINCT|ALL] GroupingSet { ‘,’ GroupingSet } .

GroupingSet = OrdinaryGroup | RollCube | GroupingSpec | ‘(‘)’.

OrdinaryGroup = ColumnRef [Collate] | ‘(‘ ColumnRef [Collate] { ‘,’ ColumnRef [Collate] } ‘)’ .

RollCube = (ROLLUP|CUBE) ‘(‘ OrdinaryGroup { ‘,’ OrdinaryGroup } ‘)’ .

GroupingSpec = GROUPING SETS ‘(‘ GroupingSet { ‘,’ GroupingSet } ‘)’ .

HavingClause = HAVING BooleanExpr .

WindowClause = WINDOW WindowDef { ‘,’ WindowDef } .

Window clauses are only useful with window functions, which are discussed in section A6.7.

WindowDef = id AS ‘(‘ WindowDetails ‘)’ .

WindowDetails = [Window_id] [PartitionClause] [OrderByClause] [WindowFrame] .

PartitionClause = PARTITION BY OrdinaryGroup .

WindowFrame = (ROWS|RANGE) (WindowStart|WindowBetween) [Exclusion] .

WindowStart = ((Value | UNBOUNDED) PRECEDING) | (CURRENT ROW) .

WindowBetween = BETWEEN WindowBound AND WindowBound .

WindowBound = WindowStart | ((Value | UNBOUNDED) FOLLOWING) .

Exclusion = EXCLUDE ((CURRENT ROW)|GROUP|TIES|(NO OTHERS)) .

TableReference = TableFactor Alias | JoinedTable .

```
TableFactor =   Table_id [FOR SYSTEM_TIME [TimePeriodSpecification ]]
        |       View_id
        |       ROWS '(' int [ ',' int ] ')'
        |       Table_FunctionCall
        |       Subquery
        |       '(' TableReference ')'
        |       TABLE ‘(‘ Value ‘)’
        |       UNNEST ‘(‘ Value ‘)’
        |       XMLTABLE ‘(‘ [XMLOption] xml [PASSING NamedValue {‘,’ NamedValue}]
XmlColumns ‘)’
        |       STATIC
        |       ‘[‘ [ Document_Value { ‘,’ Document_Value }] ‘]’ .
```

ROWS(..) is a Pyrrho extension (for table and cell logs), and the last two options above are also Pyrrho-specific: static is for a single query that does not access a table, and the other allows a specific list of documents to be supplied (static is actually equaivalent to [{}]).

Alias = [[AS] id [Cols]] .

TimePeriodSpecification = AS OF Value
| BETWEEN [ASYMMETRIC|SYMMETRIC] Value AND Value
| FROM Value TO Value .

This syntax is slightly more general than in SQL2011 – see section 5.2.3.

Subquery = '(' QueryExpression ')' .

Subqueries return different sorts of values depending on the context, including simple values (scalars, structures, arrays, multisets, etc), rows and tables.

JoinedTable = TableReference CROSS JOIN TableFactor
| TableReference NATURAL [JoinType] JOIN TableFactor
| TableReference [JoinType] JOIN TableFactor USING '('Cols')' [TO '('Cols')']
| TableReference [JoinType] JOIN TableReference ON SearchCondition .

The TO part is an extension to named column joins for cases where the tables being joined are related using an adapter function (see section 5.2.1), and then both sets of named columns are in the result rowset.

JoinType = INNER | (LEFT | RIGHT | FULL) [OUTER] .

SearchCondition = BooleanExpr .

OrderByClause = ORDER BY OrderSpec { ',' OrderSpec } .

OrderSpec = Value [ASC | DESC] [NULLS (FIRST | LAST)] .

The default order is ascending, nulls first.

FetchFirstClause = FETCH FIRST [int] (ROW|ROWS) ONLY .

XmlColumns = COLUMNS XmlColumn { ',' XmlColumn }.

XmlColumn = id Type [DEFAULT Value] [PATH str] .

A6.6 Value

Value = Literal
| Value BinaryOp Value
| '-' Value
| '(' Value ')'
| Value Collate
| Value '[' Value ']'
| Value AS Type
| ColumnRef
| VariableRef
| (SYSTEM_TIME|Period_id|(PERIOD'('Value,Value')'))
| VALUE
| ROW
| Value '.' Member_id
| MethodCall
| NEW MethodCall
| FunctionCall
| VALUES '(' Value { ',' Value } ')' { ',' '(' Value { ',' Value } ')' }

```
|       QueryExpression
|       Subquery
|       ROW '(' Value { ',' Value } ')'
|       '{' mongo_spec '}'
|       (MULTISET |ARRAY) (('['Value { ',' Value } ']')| Subquery)
|       TREAT '(' Value AS Sub_Type ')'
|       CURRENT_USER
|       CURRENT_ROLE
|       HTTP GET url_Value [ AS mime_string ] .
```

The VALUE keyword is used in Check Constraints, ROW if not followed by '(' can be used for testing the type of the currently selected row. Subqueries that are mulitset-valued must be part of the MULTISET constructor syntax, and if row-valued must be part of the TABLE constructor syntax above. Collate if specified applies to an immediately preceding Boolean expression, affecting comparison operands etc. HTTP GET gives a string value by default unless used within an INSERT statement, in which case Pyrrho will attempt to convert to the expected row type. The mime string is used for retrieval of a particular content type from the server. QueryExpression and VALUES.. give a Table_Value whose type is contextually determined. The AS syntax above is allowed only in parameter lists and methodcalls. A mongo_spec is like the comma-separated key-value list in a JavaScript objects (Json): keys are case-sensitive and are enclosed in single or double quotes, and values are numerics, or single-or double-quoted strings, or regular expressions, or embedded JavaScript objects or arrays enclosed in []. Strings starting with $ have special meanings and can be used in SelectItems to refer to values in the curret context (e.g. "$a.b").

```
BinaryOp =      '+' | '-' | '*' | '/' | '||' | MultisetOp .
```

|| is used in array and string concatenation.

```
VariableRef =   { Scope_id '.' } Variable_id .
```

```
ColumnRef =     [ TableOrAlias_id '.' ]  ColRef
        |       TableOrAlias_id '.' (PROVENANCE| CHECK).
```

The use of the PROVENANCE and CHECK pseudo-columns is a change to SQL2011 behaviour. CHECK is a row versioning cookie derived from a string type.

```
MultisetOp = MULTISET ( UNION | INTERSECT | EXCEPT ) ( ALL | DISTINCT ) .
```

```
Literal =       int
        |       float
        |       string
        |       TRUE | FALSE
        |       'X' "'" { hexit } "'"
        |       id '^^' (Domain_id|Type_id|[Namepsace_id]':'id|uri)
        |       DATE date_string
        |       TIME time_string
        |       TIMESTAMP timestamp_string
        |       INTERVAL ['-'] interval_string IntervalQualifier .
```

Strings are enclosed in single quotes. Two single quotes in a string represent one single quote. Hexits are hexadecimal digits 0-9, A-F, a-f and are used for binary objects.

The syntax with ^^ is special in Pyrrho and is added for RDF/OWL support, e.g. "2.5"^^units:ampere). In the RDF/OWL syntax, @ in the double quoted part is a special character and introduces a locale. Note however that without the ^^, “2.5” would be an id and not a string, and the <> do not normally behave like quotes.

Dates, times and intervals use string (single quoted) values and are not locale-dependent. For full details see SQL2011: e.g.

- a date has format like DATE ‘yyyy-mm-dd’ ,
- a time has format like TIME ‘hh:mm:ss’ or TIME ‘hh:mm:ss.sss’ ,
- a timestamp is like TIMESTAMP ‘yyyy-mm-dd hh:mm:ss.ss’,
- an interval is like e.g.
  - INTERVAL ‘yyy’ YEAR,
  - INTERVAL ‘yy-mm’ YEAR TO MONTH,
  - INTERVAL ‘m’ MONTH,
  - INTERVAL ‘d hh:mm:ss’ DAY(1) TO SECOND,
  - INTERVAL ‘sss.ss’ SECOND(3,2) etc.

IntervalQualifier = StartField TO EndField
| DateTimeField .

StartField = IntervalField [‘(‘ int ‘)’] .

EndField = IntervalField | SECOND [‘(‘ int ‘)’] .

DateTimeField = StartField | SECOND [‘(‘ int [‘,’ int]’)’] .

The ints here represent precision for the leading field and/or the fractional seconds.

IntervalField = YEAR | MONTH | DAY | HOUR | MINUTE .

A6.7 Boolean Expressions

BooleanExpr = BooleanTerm | BooleanExpr OR BooleanTerm .

BooleanTerm = BooleanFactor | BooleanTerm AND BooleanFactor .

BooleanFactor = [NOT] BooleanTest .

BooleanTest = Predicate | ‘(‘ BooleanExpr ‘)’ | Boolean_Value .

Predicate = Any | Between | Comparison | Contains | Every | Exists | In | Like | Like_Regex | Member | Null | Of | PeriodBinary | Similar | Some | Unique.

Any = ANY ‘(‘ [DISTINCT|ALL] Value) ’)’ FuncOpt .

Between = Value [NOT] BETWEEN [SYMMETRIC|ASYMMETRIC] Value AND Value .

Comparison = Value CompOp Value .

CompOp = ‘=’ | ‘<>’ | ‘<’ | ‘>’ | ‘<=’ | ‘>=’ .

Contains = PeriodPredicand CONTAINS (PeriodPredicand | DateTime_Value) .

Every = EVERY ‘(‘ [DISTINCT|ALL] Value) ’)’ FuncOpt .

Exists = EXISTS Table_Subquery | XMLEXISTS ‘(‘ XmlQuery ‘)’.

FuncOpt = [FILTER '(' WHERE SearchCondition ')'] [OVER WindowSpec] .

The presence of the OVER keyword makes a window function. In accordance with SQL2011-02 section 4.15.3, window functions can only be used in the select list of a QuerySpecification or SelectSingle or the order by clause of a "simple table query" as defined in section 7.5 above. Thus window functions cannot be used within expressions or as function arguments.

In = Value [NOT] IN '(' Table_Subquery | (Value { ',' Value }) ')' .

Like = Value [NOT] LIKE Value [ESCAPE Value].

Like_Regex = Value [NOT] LIKE_REGEX Pattern_Value [FLAG Value]

Member = Value [NOT] MEMBER OF Value .

Null = Value IS [NOT] NULL .

Of = Value IS [NOT] (OF '(' [ONLY] Type {','[ONLY] Type } ')' | (CONTENT | DOCUMENT | VALID)).

Similar = Value [NOT] SIMILAR TO Regex_Value [ESCAPE char].

The Regex_Value is an expression, whose value is a character string that parses recursively as follows: RE = RT {'|' RT } . RT = RF { RF } . RF = RP ['*'|'+'|'?'| '{' unsigned [',' unsigned] '}'] . RP = {RC} | ['RR {RR} | ['^' {RR}]']'|'('[unsigned]RE')'. RR =RC | (char'-'char)|('[' ':' id ':'']'). RC= char | '\'char .

Some = SOME '(' [DISTINCT|ALL] Value) ')' FuncOpt .

Unique = UNIQUE Table_Subquery .

PeriodBinary = PeriodPredicand (OVERLAPS | EQUALS | [IMMEDIATELY] (PRECEDES | SUCCEEDS)) PeriodPredicand .

See also Contains above.

PreiodPredicand = { id '.' } id | PERIOD '(' Value ',' Value ')' .

A6.8 SQL Functions

FunctionCall = NumericValueFunction | StringValueFunction | DateTimeFunction | SetFunctions | TypeCast | XMLFunction | UserFunctionCall | MethodCall .

NumericValueFunction = AbsoluteValue | Avg | Ceiling | Coalesce | Correlation | Count | Covariance | Exponential | Extract | Floor | Grouping | Last | LengthExpression | Maximum | Minimum | Modulus | NaturalLogarithm | Next | Nullif | Occurrences_Regex | Percentile | Position | Position_Regex | PowerFunction | Rank | Regression | RowNumber | Schema | SquareRoot | StandardDeviation | Sum | Variance .

AbsoluteValue = ABS '(' Value ')' .

Avg = AVG '(' [DISTINCT|ALL] Value) ')' FuncOpt .

Ceiling = (CEIL|CEILING) '(' Value ')' .

Coalesce = COALESCE '(' Value {',' Value } ')'

Correlation = CORR '(' Value ',' Value ')' FuncOpt .

Count = COUNT '(' '*' ')'

| COUNT ‘(‘ [DISTINCT|ALL] Value) ’)’ FuncOpt .

Covariance = (COVAR_POP|COVAR_SAMP) ‘(‘ Value ‘,’ Value ‘)’ FuncOpt .

Exponential = EXP ‘(‘ Value ‘)’ .

Extract = EXTRACT ‘(‘ ExtractField FROM Value ‘)’ .

ExtractField = YEAR | MONTH | DAY | HOUR | MINUTE | SECOND.

Floor = FLOOR ‘(‘ Value ‘)’ .

Grouping = GROUPING ‘(‘ ColumnRef { ‘,’ ColumnRef } ‘)’ .

Last = LAST ['(' ColumnRef ')' OVER WindowSpec] .

LengthExpression = (CHAR_LENGTH|CHARACTER_LENGTH|OCTET_LENGTH) ‘(‘ Value ‘)’ .

Maximum = MAX ‘(‘ [DISTINCT|ALL] Value) ’)’ FuncOpt .

Minimum = MIN ‘(‘ [DISTINCT|ALL] Value) ’)’ FuncOpt .

Modulus = MOD ‘(‘ Value ‘,’ Value ‘)’ .

NaturalLogarithm = LN ‘(‘ Value ‘)’ .

Next = NEXT ['(' ColumnRef ')' OVER WindowSpec] .

Nullif = NULLIF ‘(‘ Value ‘,’ Value ‘)’ .

Occurrences_Regex = OCCURRENCES_REGEX ‘(‘Pattern_Value [FLAG Options_Value] IN String_Value [FROM StartPos_Value] [USING (CHARACTERS|OCTETS)] ‘)’ .

Percentile = (PERCENTILE_CONT|PERCENTILE_DISC) ‘(‘ Value ‘)’ WithinGroup .

WindowSpec = Window_id | ‘(‘ WindowDetails ‘)’ .

WithinGroup = WITHIN GROUP ‘(‘ OrderByClause ‘)’ .

Position = POSITION [‘(‘Value IN Value ‘)’] .

Without parameters POSITION gives a Pyrrho log entry (see section 3.5).

Position_Regex = POSITION_REGEX ‘(‘ [START|AFTER] Pattern_Value [FLAG Options_Value] IN String_Value [FROM StartPos_Value] [USING (CHARACTERS|OCTETS)] [OCCURRENCE RegexOccurrence_Value] [GROUP RegexCaptureGroup_Value] ‘)’ .

PowerFunction = POWER ‘(‘ Value ‘,’ Value ‘)’ .

Rank = (CUME_DIST|DENSE_RANK|PERCENT_RANK|RANK) ‘(‘’)’ OVER WindowSpec
| (DENSE_RANK|PERCENT_RANK|RANK|CUME_DIST) ‘(‘ Value {‘,’ Value } ‘)’ WithinGroup .

Regression = (REGR_SLOPE|REGR_INTERCEPT|REGR_COUNT|REGR_R2|REGR_AVVGX|REGR_AVGY|REGR_SXX|REGR_SXY|REGR_SYY) ‘(‘ Value ‘,’ Value ‘)’ FuncOpt .

RowNumber = ROW_NUMBER ‘(‘’)’ OVER WindowSpec .

Schema = SCHEMA ‘(‘ ObjectName [COLUMN id]‘)’ .

Added for Pyrrho: returns a number identifying the most recent schema change affecting the specified object (including any change to this object by another name in another role). Note the sytax of ObjectName given in sec 7.4 above above uses keyword prefixes such as TABLE. The COLUMN syntax shown can only be used with tables.

SquareRoot = SQRT '(' Value ')' .

StandardDeviation = (STDDEV_POP|STDDEV_SAMP) '(' [DISTINCT|ALL] Value) ')' FuncOpt .

Sum = SUM '(' [DISTINCT|ALL] Value) ')' FuncOpt .

Variance = (VAR_POP|VAR_SAMP) '(' [DISTINCT|ALL] Value) ')' FuncOpt .

DateTimeFunction = CURRENT_DATE | CURRENT_TIME | LOCALTIME | CURRENT_TIMESTAMP | LOCALTIMESTAMP .

StringValueFunction = Normalize | Substring | Substring_Regex | Translate_Regex | Fold | Trim | Provenance | XmlAgg .

Normalize= NORMALIZE '(' Value ')' .

Substring = SUBSTRING '(' Value FROM Value [FOR Value] ')'
| SUBSTRING '(' Value SIMILAR Value ESCAPE Value ')'.

Substring_Regex = SUBSTRING_REGEX '(' Pattern_Value [FLAG Flag_Value] IN Value [FROM StartPos_Value] [USING (CHARACTERS|OCTETS)] [OCCURRENCE RegexOccurrence_Value] [GROUP RegexCaptreGroup_Value] ')'.

Translate_Regex = TRANSLATE_REGEX '(' Pattern_Value [FLAG Flag_Value] IN Value [WITH Replacement_Value] [FROM StartPos_Value] [USING (CHARACTERS|OCTETS)] [OCCURRENCE RegexOccurrence_Value] [GROUP RegexCaptreGroup_Value] ')'.

Fold = (UPPER|LOWER) '(' Value ')' .

Trim = TRIM '(' [[LEADING|TRAILING|BOTH] [character] FROM] Value ')' .

Provenance = PROVENANCE | TYPE_URI ['(' Value ')'] .

XmlAgg = XMLAGG '(' Value [OrderByClause] ')' .

SetFunction = Cardinality | Collect | Element | Fusion | Intersect | Set .

Collect = COLLECT '(' [DISTINCT|ALL] Value) ')' FuncOpt .

Fusion = FUSION '(' [DISTINCT|ALL] Value) ')' FuncOpt .

Intersect = INTERSECTION '(' [DISTINCT|ALL] Value) ')' FuncOpt .

Cardinality = CARDINALITY '(' Value ')' .

Element = ELEMENT '(' Value ')' .

Set = SET '(' Value ')' .

Typecast = (CAST | XMLCAST) '(' Value AS Type ')' | TREAT '(' Value AS Sub_Type ')' .

A6.9 Statements

Assignment = SET Target '=' Value { ',' Target '=' Value }

| SET '(' Target { ',' Target } ')' '=' Value .

For a simple assignment of form Target = Value, the keyword SET can be omitted.

Target = id { '.' id } .

Targets which directly contain parameter lists are not supported in the SQL2011 standard.

Call = CALL Procedure_id '(' [Value { ',' Value }] ')'
| MethodCall .

Inside a procedure declaration the CALL keyword can be omitted.

CaseStatement = CASE Value { WHEN Values THEN Statements }[ELSE Statements]END CASE
| CASE { WHEN SearchCondition THEN Statements } [ELSE Statements] END CASE .

There must be at least one WHEN in the forms shown above.

Close = CLOSE id .

CompoundStatement = Label BEGIN [XMLDec] Statements END .

XMLDec = DECLARE Namespace ';' .

Declaration = DECLARE id { ',' id } Type
| DECLARE id CURSOR FOR CursorSpecification
| DECLARE HandlerType HANDLER FOR ConditionList Statement .

Declarations of identifiers, cursors, and handlers are specific to a scope in a SQL routine.

HandlerType = CONTINUE | EXIT | UNDO .

ConditionList = Condition { ',' Condition } .

Condition = ConditionCode | SQLEXCEPTION | SQLWARNING | (NOT FOUND) .

The ConditionCode not_found is acceptable as an alternative to not found.

Signal = SIGNAL ConditionCode [SET CondInfo'='Value{','CondInfo'='Value}]
| RESIGNAL [ConditionCode] [SET CondInfo'='Value{','CondInfo'='Value}] .

ConditionCode = Condition_id | SQLSTATE string .

CondInfo = CLASS_ORIGIN|SUBCLASS_ORIGIN|CONSTRAINT_CATALOG|
CONSTRAINT_SCHEMA| CONSTRAINT_NAME|CATALOG_NAME|SCHEMA_NAME|
TABLE_NAME|COLUMN_NAME|CURSOR_NAME|MESSAGE_TEXT .

GetDiagnostics = GET DIAGNOSTICS Target '=' ItemName { ',' Target '=' ItemName }.

ItemName = NUMBER | MORE | COMMAND_FUNCTION | COMMAND_FUNCTION_CODE |
DYNAMIC_FUNCTION | DYNAMIC_FUNCTION_CODE | ROW_COUNT | TRANSACTIONS_COMMITTED
| TRANSACTIONS_ROLLED_BACK | TRANSACTION_ACTIVE | CATALOG_NAME | CLASS_ORIGIN |
COLUMN_NAME | CONDITION_NUMBER | CONNECTION_NAME | CONSTRAINT_CATALOG |
CONSTRAINT_NAME | CONSTRAINT_SCHEMA | CURSOR_NAME | MESSAGE_LENGTH |
MESSAGE_OCTET_LENGTH | MESSAGE_TEXT | PARAMETER_MODE | PARAMETER_NAME |
PARAMETER_ORDINAL_POSITION | RETURNED_SQLSTATE | ROUTINE_CATALOG | ROUTINE_NAME

| ROUTINE_SCHEMA | SCHEMA_NAME | SERVER_NAME | SPECIFIC_NAME | SUBCLASS_ORIGIN | TABLE_NAME | TRIGGER_CATALOG | TRIGGER_NAME | TRIGGER_SCHEMA .

SQLSTATE strings are 5 characters in length, comprising a 2-character class and and a 3 character subclass. See the table in section 8.1.1.

Fetch = FETCH [How] Cursor_id INTO VariableRef { ‘,’ VariableRef } .

How = NEXT | PRIOR | FIRST | LAST | ((ABSOLUTE | RELATIVE) Value)) .

ForStatement = Label FOR [For_id AS][id CURSOR FOR] QueryExpression DO Statements END FOR [Label_id] .

IfStatement = IF BooleanExpr THEN Statements { ELSEIF BooleanExpr THEN Statements } [ELSE Statements] END IF .

Label = [label ‘:’] .

LoopStatement = Label LOOP Statements END LOOP .

Open = OPEN id .

Repeat = Label REPEAT Statements UNTIL BooleanExpr END REPEAT .

SelectSingle = QueryExpresion INTO VariableRef { ‘,’ VariableRef } .

Statements = Statement { ‘;’ Statement } .

While = Label WHILE SearchCondition DO Statements END WHILE .

UserFunctionCall = Id ‘(‘ [Value {‘,’ Value}] ‘)’ .

MethodCall = Value ‘.’ Method_id ‘(‘ [Value { ‘,’ Value }] ‘)’
| ‘(‘ Value AS Type ‘)’ ‘.’ Method_id ‘(‘ [Value { ‘,’ Value }] ‘)’
| Type’::’ Method_id ‘(‘ [Value { ‘,’ Value }] ‘)’ .

A6.10 XML Support

XMLFunction = XMLComment | XMLConcat | XMLDocument | XMLElement | XMLForest | XMLParse | XMLProc | XMLQuery | XMLText | XMLValidate.

XMLComment = XMLCOMMENT ‘(‘ Value ‘)’ .

XMLConcat = XMLCONCAT ‘(‘ Value {‘,’ Value } ‘)’ .

XMLDocument = XMLDOCUMENT ‘(‘ Value ‘)’ .

XMLElement = XMLELEMENT ‘(‘ NAME id [‘,’ Namespace] [‘,’ AttributeSpec]{ ‘,’ Value } ‘)’ .

Namespace = XMLNAMESPACES ‘(‘ NamespaceDefault |(string AS id {‘,’ string AS id }) ‘)’ .

NamespaceDefault = (DEFAULT string) | (NO DEFAULT) .

AttributeSpec = XMLATTRIBUTES ‘(‘ NamedValue {‘,’ NamedValue }‘)’ .

NamedValue = Value [AS id] .

XMLForest = XMLFOREST ‘(‘ [Namespace ‘,’] NamedValue { ‘,’ NamedValue } ‘)’ .

XMLParse = XMLPARSE ‘(‘ CONTENT Value ‘)’ .

XMLProc = XMLPI ‘(‘ NAME id [‘,’ Value] ‘)’ .

XMLQuery = XMLQUERY ‘(‘ Value , xpath_xml ‘)’ .

This syntax seems to be non-standard in Pyrrho but allows extraction from an xml Value using an XPath expression

XMLText = XMLTEXT‘(‘ xml ‘)’ .

XMLValidate = XMLVALIDATE‘(‘ (DOCUMENT|CONTENT|SEQUENCE) Value ‘)’ .

Appendix 7 Pyrrho's condition codes

Standard SQL exception handling allows stored procedures to set up handlers for various conditions that arise in the database engine. The SQL standard specifies a number of these, but most in the list below are specific to Pyrrho. Diagnostic information about the causes of the condition is also available through use of the GET DIAGNOSTICS mechanisms.

SQLSTATE	Message Template (and comments)
01010	Warning: column cannot be mapped
02000	Not found
0U000	Attempt to assign to non-updatable column
21000	*Cardinaility error*
21101	Element requires a singleton multiset
22000	*Data and incompatible type error*
22003	Numeric value out of range
22004	Illegal null value
22005	Wrong types: expected ? got ?
22007	Expected keyword ? at ?
22008	Minus sign expected (DateTime)
22009	DateTime format error: ?
2200D	Invalid escape octet
2200G	Type mismatch: expected ? got ? at ?
2200J	Nonidentical notations with the same name
2200K	Nonidentical unparsed entities with the same name
2200N	Invalid XML content
2200S	Invalid XML comment
22010	Invalid indicator parameter value
22011	Substring error
22012	Divide by zero
22013	Invalid preceding or following size in window function
22014	Year out of range
22015	Interval field overflow
22018	Invalid character value for cast
22019	Invalid escape character
2201B	Invalid regular expression
2201M	Namespace ? not defined
22021	Illegal character for this char set
22022	Bad document format
22023	Too few arguments
22024	Too many arguments
22025	Type expected
22101	Bad row compare
22102	Type mismatch on concatenate
22103	Multiset element not found
22104	Incompatible multisets for union
22105	Incompatible multisets for intersection
22106	Incompatible multisets for except
22107	Exponent expected
22108	Type error in aggregation operation
22201	Unexpected type ? for comparison with Decimal
22202	Incomparable types
22203	Loss of precision on conversion
22204	Query expected
22205	Null value found in table ?
22206	Null value not allowed in column ?
22207	Row has incorrect length
22208	Mixing named and unnamed columns is not supported

23000	*Integrity constraint violation*
23001	RESTRICT: ? referenced in ? (A referenced object cannot be deleted)
23101	Integrity constraint on referencing table ? (delete)
23102	Integrity constraint on referencing table ? (update)
23103	(This record cannot be updated, usually integrity violation)
23201	? cannot be updated
23202	BEFORE data is not updatable
24000	*Cursor status error*
24101	Cursor is not open
25000	*Transaction status error*
25001	A transaction is in progress
26000	*Invalid SQL statement name/*Unexpected label ?
27000	*Triggered data change violation*
28000	No role ? in database ?
28101	Unknown grantee kind
28102	Unknown grantee ?
28103	Adding a role to a role is not supported
28104	Users can only be added to roles
28105	Grant of select: entire row is nullable
28106	Grant of insert must include all notnull columns
28107	Grant of insert cannot include generated column ?
28108	Grant of update : column ? is not updatable
2D000	*Invalid transaction termination*
2E000	*Incorrect Pyrrho connection or security violation*
2E103	This server disallows database creation by ?
2E104	Database is read-only
2E105	Invalid user ? for database ?
2E106	This operation requires a single-database session
2E108	Stop time was specified, so database is read-only
2E109	Invalid role ? for database ?
2E110	DataType ? requires database ? which is not connected
2E111	User ? can access no columns of table ?
2E112	Local and remote tables cannot be mixed in a query (subqueries are ok)
2E113	DataType ? cannot be exported to database ?
2E201	Connection is not open
2E202	A reader is already open
2E203	Unexpected reply
2E204	Bad data type ? (internal)
2E205	Stream closed
2E206	Internal error: ?
2E207	Connection failed
2E208	Badly formatted connection string ?
2E209	Unexpected element ? in connection string
2E210	Pyrrho service on ? at port ? not available (or not reachable)
2E211	Feature {0} is not available in this edition of Pyrrho
2E212	Database ? is loading. Please try later.
2E213	Unsupported configuration operation
2E214	Schema changes must be on base database
2E215	Overlapping partitions
2E216	Configuration update can only be for local server
2E217	This server does not provide a Query service for ?
2E218	Index ? is incompatible with the partitioning scheme
2E219	Schema and data changes cannot be mixed in a partitioned transaction
2E300	The calling assembly does not have type ?
2E301	Type ? doesn’t have a default constructor
2E302	Type ? doesn’t define field ?
2E303	Types ? and ? do not match

2E304	Get rurl should begine with /
2E305	No data returned by rurl ?
2F003	Prohibited SQL-statement attempted
2H000	*Non-existent collation/Collate on non-string*
34000	*No such cursor*
34001	Cursor is not updatable
3D000	Could not use database ? (database not found or damaged)
3D001	Database ? not open
3D002	Cannot detach preloaded databases
3D003	Remote database no longer accessible
3D004	Exception reported by remote database: ?
3D005	Requested operation not supported by this edition of Pyrrho
3D006	Database ? incorrectly terminated or damaged
3D007	Pathname not supported by this edition of Pyrrho
3D008	Database file ? has been damaged
3D009	(Automatic database recovery from file damage failed)
3D010	Invalid Password
40000	*Transaction rollback*
40001	Transaction Serialisation Failure
42000	*Syntax error at ?*
42101	Illegal character ?
42102	Name cannot be null
42103	Key must have at least one column
42104	Proposed name conflicts with existing database object (e.g. table already exists)
42105	Access denied ?
42106	Undefined variable ?
42107	Table ? undefined
42108	Procedure ? not found
42109	Table-valued function expected
42110	Column list has incorrect length: expected ?, got ?
42111	The given key is not found in the referenced table
42112	Column ? not found
42113	Multiset operand required, not ?
42114	Object name expected for GRANT, got ?
42115	Unexpected object type ? ? for GRANT
42116	Role revoke has ADMIN option not GRANT
42117	Privilege revoke has GRANT option not ADMIN
42118	Unsupported CREATE ?
42119	Domain ? not found in database ?
4211A	Unknown privilege ?
42120	Domain or type must be specified for base column ?
42121	Cannot specify collate if domain name given
42123	NO ACTION is not supported
42124	Colon expected ..
42125	Unknown Alter type ?
42126	Unknown SET operation
42127	Table expected
42128	Illegal aggregation operation
42129	WHEN expected
42130	Ambiguous table or column reference ?
42131	Invalid POSITION ?
42132	Method ? not found in type ?
42133	Type ? not found
42134	FOR phrase is required
42135	Object ? not found
42136	Ambiguous field selector
42137	Field selector ? on non-structured type

42138	Field selector ? not defined for ?
42139	:: on non-type
42140	:: requires a static method
42141	? requires an instance method
42142	NEW requires a user-defined type constructor
42143	? specified more than once
42144	Method selector on non-structured type ?
42145	Cannot supply value for generated column ?
42146	OLD specified on insert trigger or NEW specified on delete trigger
42147	Cannot have two primary keys for table ?
42148	FOR EACH ROW not specified
42149	Cannot specify OLD/NEW TABLE for before trigger
42150	Malformed SQL input (non-terminated string)
42151	Bad join condition
42152	Column ? must be aggregated or grouped
42153	Table ? already exists
42154	Unimplemented or illegal function ?
42155	Nested types are not supported
42156	Column ? is already in table ?
42157	END label ? does not match start label ?
42158	? is not the primary key for ?
42159	? is not a foreign key for ?
42160	? has no unique constraint
42161	? expected at ?
42162	Table period definition for ? has not been defined
42163	Generated column ? cannot be used in a contraint
42164	Table ? has no primary key
42165	Versioning for ? for table ? has not been enabled
42166	Domain ? already exists
42167	A routine with name ? and arity ? already exists
44000	Check condition ? fails
44001	Domain check ? fails for column ? in table ?
44002	Table check ? fails for table ?
44003	Column check ? fails for column ? in table ?
44004	Column ? in Table ? contains null values, not null cannot be set
44005	Column ? in Table ? contains values, generation rule cannot be set

Appendix 8: Pyrrho's System Tables

There are three sets of system tables, and these give read-only access using SQL for the database owner to internal information held in the DBMS engine as seen from the current transaction. For more details, see the Pyrrho Manual Pyrrho.docx. Since the names of these tables contain a $, they need to be enclosed in double-quotes in SQL. For some of the tables the information is for the databases stored on the server, but generally, these system tables are for a single current database; the Role$ tables give the properties as seen from the current role; while the Log$ tables give access to the defining records.

All of these table are virtual in the sense that the contents are generated in this form only transiently and when required from the DBMS engine's internal data structures.

System Table Name	Type of information
Sys$Connection	Details of the current connection
Sys$Horizontal	Horizontal partitioning information for partitions on the server
Sys$KnownRoles	Databases/Partitions and Roles available to the current user on this server
Sys$Role	Roles available for the current database
Sys$RoleUser	Authorised users for roles on the current database
Sys$Server	A list of all servers known to this server
Sys$User	A list of all users known in the current database
Role$Class	Base tables, key columns, and C# class definitions
Role$Column	Columns of base tables
Role$ColumnCheck	Column check constraints
Role$ColumnPrivilege	Role access privileges on table columns
Role$Domain	Domain and type information accessible from the current role
Role$DomainCheck	Domain check constraints
Role$Index	With standard SQL indexes are created to implement integrity and referential constraints
Role$IndexKey	Key information for indexes
Role$Method	Methods defined for user-defined types
Role$Object	Metadata for database objects
Role$Parameter	Parameter information for user-defined methods and procedures
Role$PrimaryKey	Primary key information for base tables
Role$Privilege	Access privileges that have been granted on database objects
Role$Procedure	User-defined Procedures
Role$Subobject	Metadata for database subobjects (e.g. view columns)
Role$Table	Base tables in the current database
Role$TableCheck	Table check constraints
Role$TablePeriod	User-defined periods
Role$Trigger	User-defined triggers
Role$TriggerUpdateColumn	Column update information specified for user-defined triggers
Role$Type	User-defined types
Role$View	User-defined Views
Log$	The transaction log: a readable synopsis of each entry in the log
Log$Alter	Details for ALTER records in the log (see also CHANGE, EDIT, MODIFY)
Log$Change	Details for CHANGE records in the log
Log$Check	Details for user-defined check conditions
Log$Column	Details for column definitions

Log$Conflicts	Details of conflicting log entries for each log entry
Log$DateType	Details for user-defined date types
Log$Delete	Details for DELETE records in the log
Log$Domain	Details for DOMAINS specified in this database
Log$Drop	Details for DROP entries in the log
Log$Edit	Details for EDIT records in the log
Log$Grant	Details for GRANT records in the log
Log$Index	Details for INDEX records in the log (when indexes are created)
Log$IndexKey	Details for keys of indexes
Log$Insert	Details for INSERT records in the log
Log$InsertField	Details for fields in INSERT records
Log$Metadata	Details of METADATA entries in the log
Log$Modify	Details of MODIFY entries in the log
Log$Ordering	Details of user-defined orderings
Log$Procedure	Details of user-defined procedures
Log$Revoke	Details of REVOKE records in the log
Log$Table	Details of metadata for user-defined tables
Log$TablePeriod	Details of table period definition
Log$Transaction	Details of all transactions in the Log
Log$TransactionParticipant	Details of participants for distributed transactions
Log$Trigger	Details of user-defined triggers
Log$TriggerUpdateColumn	Update column details for user-defined triggers
Log$Type	User-defined types. See also Log$Domain, and Log$TypeMethod
Log$TypeMethod	Details of methods defined for user-defined types
Log$Update	Details of UPDATE records in the log
Log$User	Details of USER records in the log
Log$View	Details of VIEW definitions in the log
ROWS(*nnn*)	Details of operations involving table defined at *nnn* in the log
ROWS(*rrr*,*ccc*)	Details of operations involving the table cell at the row defined at *rrr* and column defined at *ccc* in the log.
Profile$	If profiling is turned on these tables are available: profile identity
Profile$ReadConstraint	
Profile$Record	
Profile$RecordColumn	
Profile$Table	

Appendix 9: The Pyrrho Class Library Reference

Any application using Pyrrho should include just one of: PyrrhoLink.dll, OSPLink.dll, EmbeddedPyrhho.dll, OSP.dll, xxxOSP.dll. The following classes are defined:

SQL2011 API:

Class	Subclass of	Description
Date		Data type used for dates.
PyrrhoArray		Data type used for ARRAY and MULTISET if a column of type ARRAY or MULTISET has been added to the table.
PyrrhoColumn		Helps to describe the columns of a table or structured type
PyrrhoConnect	System.Data.IDbConnection	Establishes a connection with a Pyrrho DBMS server, and provides additional methods and properties.
PyrrhoDocument		This class allows editing of embedded Documents (in the sense of MongoDB)
PyrrhoInterval		This class is used to represent a time interval
PyrrhoRow		Data type used for ROW fields in a database table, a column of type ROW can be added to the table. (SQL2011)

Exceptions:

Class	Subclass of	Description
DatabaseError	System.Exception	Used for “user” exceptions, e.g. a specified table or column does not exist, an attempt is made to create a table or column that already exists, incorrect SQL etc. The message property gives a readable explanation. The SQLSTATE string is also available: see section 8.1.
TransactionConflict	DatabaseError	The action attempted has conflicted with a concurrent transaction, e.g. two users have attempted to update the same cell in a table. The changes proposed by the current transaction have been rolled back, because the database contents have been changed by the other transaction.

Class	Subclass of	Description
PyrrhoTable		
PyrrhoTable<T>	PyrrhoTable	

PHP support:

Class	Subclass of	Description
ScriptConnect		Provided for PHP support (section 6.7)
ScriptReader		Provided for PHP support (section 6.7)

A9.1 DatabaseError

The methods and properties of DatabaseError are:

Method or Property	Explanation
Dictionary<string,string> info	Information placed in the error: the keys specified in the SQL standard are CLASS_ORIGIN, SUBCLASS_ORIGIN, CONSTRAINT_CATALOG, CONSTRAINT_SCHEMA, CONSTRAINT_NAME, CATALOG_NAME, SCHEMA_NAME, TABLE_NAME, COLUMN_NAME, CURSOR_NAME, MESSAGE_TEXT. Pyrrho adds PROFILE_ID if profiling is enabled.
String Message	The reason for the exception (inherited from Exception): this can be localised as described in section 3.8.
String SQLSTATE	The signal sent from the DBMS: usually a five character string beginning with a digit such as “2N000”. Many of these codes are defined in the SQL standard.

A9.2 Date

The methods and properties of Date are:

Method or Property	Explanation
DateTime date	The underlying DateTime value
Date(DateTime d)	Constructor.
string ToString()	Overridden: Formats the date using DateTime.ToShortDate() which is locale-specific

For the embedded editions, Pyrrho.Common.Date is equivalent.

A9.3 PyrrhoArray

PyrrhoConnect.Get/Post/Put/Delete can be used for whole Arrays. This class can be used to access fields within Documents and to convert to and from Json and XML Note: this class remembers the connection to the database if any, and all these changes are transacted in the database unless the Document is detached.

Method or Property	Explanation
PyrrhoArray(object[])	
string kind	“ARRAY” or “MULTISET”
void Add(int i	
object[] data	The values of the array or multiset. Note that the ordering of multiset values is non-deterministic and not significant.

A9.4 PyrrhoColumn

The methods and properties of PyrrhoColumn are:

Method or Property	Explanation
bool AllowDBNull	Whether the column can contain a null value
string Caption	The name of the column
string DataType	The domain or type name of the column
bool ReadOnly	Whether the column is read-only

A9.5 PyrrhoCommand

PyrrhoCommand implements IDbCommand or imitates ir.

Method or Property	Explanation
string CommandText	The SQL statement for the Command
PyrrhoReader ExecuteReader()	Initiates a database SELECT and returns a reader for the returned data (as in IDataReader)
PyrrhoReader ExecuteReaderCrypt()	Initiates a database SELECT and returns a reader for the returned data (as in IDataReader). The results are not encrypted.
object ExecuteScalar()	Initiates a database SELECT for a single value
object ExecuteScalarCrypt()	Initiates a database SELECT for a single value.
int ExecuteNonQuery()	Initiates some other sort of Sql statement and returns the number of rows affected.
Int ExecuteNonQueryCrypt()	Initiates some other sort of Sql statement and returns the number of rows affected.

A9.6 PyrrhoConnect

Depending on the Pyrrho version, PyrrhoConnect implements or imitates the IDbConnection interface and supplies some additional functionality.

Method or Property	Explanation
int Act(string sql)	Convenient shortcut to construct a PyrrhoCommand and call ExecuteNonQuery on it.

Activity activity	(AndroidOSP) Set only. Set the Activity into PyrrhoConnect.This must be done before the connection is opened. E.g. in Activity.OnCreate(bundle) use code such as
	`conn = new PyrrhoConnect("Files=mydb");`
	`conn.activity = this;`
	`conn.Open();`
	Note that mydb (without the osp extension) needs to be an AndroidAsset to be copied to the device.

PyrrhoTransaction BeginTransaction()	Start a new isolated transaction (like IDbTransaction)
bool Check(string ch)	Check to see if a given CHECK pseudocolumn value is still current, i.e. the row has not been modified by a later transaction. (See sec 5.2.3)
void Close()	Close the channel to the database engine
string ConnectionString	Get the connection string for the connection
PyrrhoCommand CreateCommand()	Create an object for carrying out an Sql command (as in IDbCommand)
void Delete(object ob)	Delete the row corresponding to this object.*
void Get(object ob,string rurl)	The rurl should be a partial REST url (the portion following the Role component), and ob should be a new instance of the target class.*
object[] Get(string rurl)	The rurl should be a partial REST url (the portion following the Role component), that targets a class in the client application.*
string[] GetFileNames	Returns the names of accessible databases.
void Open()	Open the channel to the database engine
void Post(object ob)	The object should be a new row for a base table.*

void Put(object old, object ob)	The first object should hold the content of a bast table row that was obtained from the database. The second object should be an updated version.*
PyrrhoConnect(string cs)	Create a new PyrrhoConnect with the given connection string. Documentation about the connection string is in section 6.4.
void ResetReader()	Repositions the IDataReader to just before the start of the data
void SetRole(string s)	Set the role for the connection

* The Get, Put, Post and Delete methods assume that the classes corresponding to the relevant database tables have been installed in the application, for example using the sources provided by the Role$Class system table (sec 8.4.1).. These methods use .NET Reflection machinery to access public fields in the supplied object. If you add other fields and properties to these classes, do not make them public (e.g. make them internal).

A9.7 PyrrhoDocument

PyrrhoConnect.Get/Post/Put/Delete can be used for whole Documents and BSON, Json and XML formats are supported. This class can be used to access fields within Documents and to convert to and from Json and XML Note: this class remembers the connection to the database if any, and all these changes are transacted in the database unless the Document is detached or the connection is closed.

Method or Property	Explanation
PyrrhoDocument(byte[])	Constructor: the binary data should be BSON
PyrrhoDocument(string)	Constructor: the string should be Json or XML
object this[string]	Access a field of the document.
void Add(string,object)	Add or update a field to a Document
void Attach(string)	Attach the document to the given relative url in the database
void Detach()	Forget the connection from this document to the database
void Remove(string)	Remove a field from a document
string ToString()	Convert a document to Json
byte[] ToBytes()	Convert a document to BSON
String ToXML()	Convert a document to XML

A9.8 PyrrhoInterval

The methods and properties of PyrrhoInterval are:

Method or Property	Explanation
int years	The years part of the time interval
int months	The months part of the time interval
long ticks	The ticks part of the time interval
static long TicksPerSecond	Gets the constant number of ticks per second
static string ToString()	Formats the above data as e.g. (0yr,3mo,567493820000ti)

A9.9 PyrrhoReader

This class is Pyrrho's implementation of IDataReader. The only additional members of PyrrhoReader are (from version 4.4):

Method or Property	Explanation
string DataSubtypeName(int i)	Returns the domain or type name of the actual type of the ith column in the current row. (Usually this will be the same as DataTypeName.)

string Description(int i)	Returns the description metadata of the ith column
T GetEntity<T>()	Used in strongly-typed PyrrhoReaders (as in ExecuteTable<T>)
string Output(int i)	Returns the output flag of the ith column
string Url(int i)	Returns the web metadata url of the ith column

A9.10 PyrrhoRow

PyrrhoRow is used only when required for values of structured types. The methods and properties of PyrrhoRow are:

Method or Property	Explanation
List<PyrrhoColumn> columns	The names of the fields of the row
object[] data	The values of the fields (may be null). This is the indexer for PyrrhoRow (indexed by column number or column name).
string[] subTypes	The names of the actual types for the current row

A9.11 PyrrhoTable

A PyrrhoTable is constructed internally by every invocation of ExecuteReader. As in ADO.NET DataTable there are properties called Rows and Columns, and an array of PrimaryKey columns.

There is a strongly-typed subclass PyrrhoTable<T>, which has a public property Instances of type Dictionary<IComparable, object>. For tables with a simple primarykey this dictionary can be used to find a single entity of type T. These correspond one-to-one with the Rows, but updates are not synchronised with the database.

A9.12 PyrrhoTransaction

This class imitates IDbTransaction

Method or Property	Explanation
void Commit()	Commit the transaction
bool Conflict	Gets whether a conflicting transaction has been committed since the start of this transaction. (Requires a round trip to the transaction master server.) If Conflict is true, a subsequent Commit will fail, but the transaction is not closed.
void Rollback()	Roll back the transaction

Appendix 10: Pyrrho's Connection String

Pyrrho allows multi-database connections (with some limitations: see section 2.8.3). More than one database on the same server can be specified using a comma-separated list of Files, but two mechanisms are provided for more complex scenarios. In Android and embedded editions of Pyrrho, the Host and Port fields are not provided, but remote hosts and ports can be specified for a database using the syntax *file@host*[:*port*:[*user*[:*role*]]] . And the connections string can be compound using a Json-like notation, see below.

By default, only the first database in a multi-database connection is modifiable using the connection, but the Modify flag is available for changing this behaviour. In addition, a Role can be specified per database.

The syntax of ConnectionString is similar to ADO.NET.

ConnectionString = Setting {';'Setting} .

Setting = id'='val{','val} .

The possible fields in the connection string are as follows:

Field	Default value	Explanation
Base		*Used by server-server communication to create a new partition remotely.Not for client-server use.*
Coordinator		*Used in server-server communications: the transaction coordinator server*
Files		One or more comma-separated database file names (excluding the .pfl or .osp extension). Characters ,;= within names are not allowed. If the only field in the connection string is Files, the prefix Files= can be omitted.
Host	127.0.0.1	The name of the machine providing the service.
Locale		The name of the locale to be used for error reporting. The default is supplied by the .NET framework.
Modify		The default value is true for the first file in the connection, and false for others. If the value true is specified then it applies to all of the Files in the current connection string.
Port	5433	The port on which the server is listening
Provider	PyrrhoDBMS	
Role	*databasename*	A role name selected as the session role. If this field is not specified, the session role will be the default database role if the user is the database owner or has been granted this role (it has the same name as the database), or else the guest role, which can access only PUBLIC objects.
Stop		If a value is specified, this means that Pyrrho is to load the database as it was at some past time.
User		*This field is supplied by infrastructure*

A CompoundConnectionString format is available for complicated multi-file connections.

CompoundConnectionString = ConnectionString | '[{' ConnectionString {'},{' ConnectionString }'}]' .

If *cs1* and *cs2* are ConnectionStrings as specified above, then [{*cs1*},{*cs2*}] is permitted. For example [{A},{Files=B,Modify=true},{C}] . For this purpose the 3 separator sequences "[{" "},{" "}]"are assumed not to occur anywhere in the individual connection strings (in particular they must not themselves be

compound). The User field is supplied by infrastructure for the first of these connection strings but applies to all.

Index to Syntax