Transaction Service Specification 10

This chapter provides the following information about the Transaction Service:

- A description of the service, which explains the functional, design, and performance requirements that are satisfied by this specification.
- An overview of the Transaction Service that introduces the concepts used throughout this chapter.
- A description of the Transaction Service's architecture and a detailed definition of the Transaction Service, including definitions of its interfaces and operations.
- A user's view of the Transaction Service as seen by the application programmer, including client and object implementer.
- An implementer's view of the Transaction Service, which will interest Transaction Service and ORB providers.

This chapter also contains an appendix that explains the relationship between the Transaction Service and TP standards, and an appendix that contains transaction terms.

10.1 Service Description

The concept of transactions is an important programming paradigm for simplifying the construction of reliable and available applications, especially those that require concurrent access to shared data. The transaction concept was first deployed in commercial operational applications where it was used to protect data in centralized databases. More recently, the transaction concept has been extended to the broader context of distributed computation. Today it is widely accepted that transactions are the key to constructing reliable distributed applications.

The Transaction Service described in this specification brings the transaction paradigm, essential to developing reliable distributed applications, and the object paradigm, key to productivity and quality in application development, together to address the business problems of commercial transaction processing.

10.1.1 Overview of Transactions

The Transaction Service supports the concept of a transaction. A transaction is a unit of work that has the following (ACID) characteristics:

- A transaction is **atomic**; if interrupted by failure, all effects are undone (rolled back).
- A transaction produces **consistent** results; the effects of a transaction preserve invariant properties.
- A transaction is **isolated**; its intermediate states are not visible to other transactions. Transactions appear to execute serially, even if they are performed concurrently.
- A transaction is **durable**; the effects of a completed transaction are persistent; they are never lost (except in a catastrophic failure).

A transaction can be terminated in two ways: the transaction is either committed or rolled back. When a transaction is committed, all changes made by the associated requests are made permanent. When a transaction is rolled back, all changes made by the associated requests are undone.

The Transaction Service defines interfaces that allow multiple, distributed objects to cooperate to provide atomicity. These interfaces enable the objects to either commit all changes together or to rollback all changes together, even in the presence of (noncatastrophic) failure. No requirements are placed on the objects other than those defined by the Transaction Service interfaces.

Transaction semantics can be defined as part of any object that provides ACID properties. Examples are ODBMSs and persistent objects. The value of a separate transaction service is that it allows:

- Transactions to include multiple, separately defined, ACID objects.
- The possibility of transactions which include objects and resources from the non-object world.

10.1.2 Transactional Applications

The Transaction Service provides transaction synchronization across the elements of a distributed client/server application.

A transaction can involve multiple objects performing multiple requests. The scope of a transaction is defined by a transaction context that is shared by the participating objects. The Transaction Service places no constraints on the number of objects involved, the topology of the application or the way in which the application is distributed across a network.

In a typical scenario, a client first begins a transaction (by issuing a request to an object defined by the Transaction Service), which establishes a transaction context associated with the client thread. The client then issues requests. These requests are implicitly associated with the client's transaction; they share the client's transaction context. Eventually, the client decides to end the transaction (by issuing another

request). If there were no failures, the changes produced as a consequence of the client's requests would then be committed; otherwise, the changes would be rolled back.

In this scenario, the transaction context is transmitted implicitly to the objects, without direct client intervention—See Section 10.4.1. The Transaction Service also supports scenarios where the client directly controls the propagation of the transaction context. For example, a client can pass the transaction context to an object as an explicit parameter in a request. An implementation of the Transaction Service might limit the client's ability to explicitly propagate the transaction context, in order to guarantee transaction integrity (See 10.4.1, Subsection "Direct Context Management: Explicit Propagation").

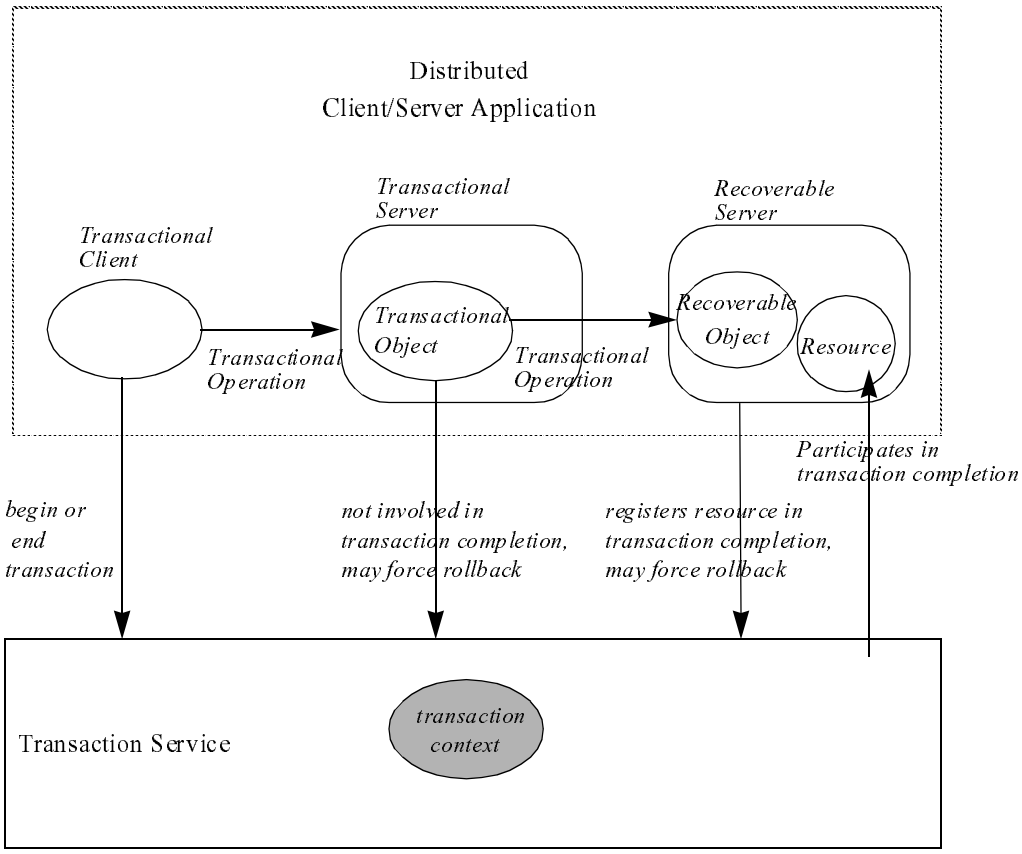
The Transaction Service does not require that all requests be performed within the scope of a transaction. A request issued outside the scope of a transaction has no associated transaction context. It is up to each object to determine its behavior when invoked outside the scope of a transaction; an object that requires a transaction context can raise a standard exception.

10.1.3 Definitions

Applications supported by the Transaction Service consist of the following entities:

- Transactional Client (TC)
- Transactional Objects (TO)
- Recoverable Objects
- Transactional Servers
- Recoverable Servers

The following figure shows a simple application which includes these basic elements.



Transactional Client

A transactional client is an arbitrary program that can invoke operations of many transactional objects in a single transaction.

The program that begins a transaction is called the transaction originator.

Transactional Object

We use the term *transactional object* to refer to an object whose behavior is affected by being invoked within the scope of a transaction. A transactional object typically contains or indirectly refers to persistent data that can be modified by requests.

The Transaction Service does not require that all requests have transactional behavior, even when issued within the scope of a transaction. An object can choose to not support transactional behavior, or to support transactional behavior for some requests but not others.

We use the term *nontransactional object* to refer to an object none of whose operations are affected by being invoked within the scope of a transaction.

If an object does not support transactional behavior for a request, then the changes produced by the request might not survive a failure and the changes will not be undone if the transaction associated with the request is rolled back.

An object can also choose to support transactional behavior for some requests but not others. This choice can be exercised by both the client and the server of the request.

The Transaction Service permits an interface to have both transactional and nontransactional implementations. No IDL extensions are introduced to specify whether or not an operation has transactional behavior. Transactional behavior can be a quality of service that differs in different implementations.

Transactional objects are used to implement two types of application servers:

- Transactional Server
- Recoverable Server

Recoverable Objects and Resource Objects

To implement transactional behavior, an object must participate in certain protocols defined by the Transaction Service. These protocols are used to ensure that all participants in the transaction agree on the outcome (commit or rollback) and to recover from failures.

To be more precise, an object is required to participate in these protocols only if it directly manages data whose state is subject to change within a transaction. An object whose data is affected by committing or rolling back a transaction is called a recoverable object.

A recoverable object is by definition a transactional object. However, an object can be transactional but not recoverable by implementing its state using some other (recoverable) object. A client is concerned only that an object is transactional; a client cannot tell whether a transactional object is or is not a recoverable object.

A recoverable object must participate in the Transaction Service protocols. It does so by registering an object called a *Resource* with the Transaction Service. The Transaction Service drives the commit protocol by issuing requests to the resources registered for a transaction.

A recoverable object typically involves itself in a transaction because it is required to retain in stable storage certain information at critical times in its processing. When a recoverable object restarts after a failure, it participates in a recovery protocol based on the contents (or lack of contents) of its stable storage.

A transaction can be used to coordinate non-durable activities which do not require permanent changes to storage.

Transactional Server

A transactional server is a collection of one or more objects whose behavior is affected by the transaction, but which have no recoverable states of their own. Instead, it implements transactional changes using other recoverable objects. A transactional server does not participate in the completion of the transaction, but it can force the transaction to be rolled back.

Recoverable Server

A recoverable server is a collection of objects, at least one of which is recoverable.

A recoverable server participates in the protocols by registering one or more *Resource* objects with the Transaction Service. The Transaction Service drives the commit protocol by issuing requests to the resources registered for a transaction.

10.1.4 Transaction Service Functionality

The Transaction Service provides operations to:

- Control the scope and duration of a transaction
- Allow multiple objects to be involved in a single, atomic transaction
- Allow objects to associate changes in their internal state with a transaction
- Coordinate the completion of transactions

Transaction Models

The Transaction Service supports two distributed transaction models: flat transactions and nested transactions. An implementation of the Transaction Service is not required to support nested transactions.

Flat Transactions

The Transaction Service defines support for a flat transaction model. The definition of the function provided, and the commitment protocols used, is modelled on the X/Open DTP transaction model definition.[1]

A flat transaction is considered to be a top-level transaction—see the next section—that cannot have a child transaction.

1. See *Distributed Transaction Processing: The XA Specification,* X/Open Document C193. X/Open Company Ltd., Reading, U.K., ISBN 1-85912-057-1.

Nested Transactions

The Transaction Service also defines a nested transaction model. Nested transactions provide for a finer granularity of recovery than flat transactions. The effect of failures that require rollback can be limited so that unaffected parts of the transaction need not rollback.

Nested transactions allow an application to create a transaction that is embedded in an existing transaction. The existing transaction is called the ***parent*** of the subtransaction; the subtransaction is called a ***child*** of the parent transaction.

Multiple subtransactions can be embedded in the same parent transaction. The children of one parent are called ***siblings***.

Subtransactions can be embedded in other subtransactions to any level of nesting. The ***ancestors*** of a transaction are the parent of the subtransaction and (recursively) the parents of its ancestors. The ***descendants*** of a transaction are the children of the transaction and (recursively) the children of its descendants.

A top-level transaction is one with no parent. A top-level transaction and all of its descendants are called a ***transaction family***.

A subtransaction is similar to a top-level transaction in that the changes made on behalf of a subtransaction are either committed in their entirety or rolled back. However, when a subtransaction is committed, the changes remain contingent upon commitment of all of the transaction's ancestors.

Subtransactions are strictly nested. A transaction cannot commit unless all of its children have completed. When a transaction is rolled back, all of its children are rolled back.

Objects that participate in transactions must support isolation of transactions. The concept of isolation applies to subtransactions as well as to top level transactions. When a transaction has multiple children, the children appear to other transactions to execute serially, even if they are performed concurrently.

Subtransactions can be used to isolate failures. If an operation performed within a subtransaction fails, only the subtransaction is rolled back. The parent transaction has the opportunity to correct or compensate for the problem and complete its operation. Subtransactions can also be used to perform suboperations of a transaction in parallel, without the risk of inconsistent results.

Transaction Termination

A transaction is terminated by issuing a request to commit or rollback the transaction. Typically, a transaction is terminated by the client that originated the transaction—the transaction originator. Some implementations of the Transaction Service may allow transactions to be terminated by Transaction Service clients other than the one which created the transaction.

Any participant in a transaction can force the transaction to be rolled back (eventually). If a transaction is rolled back, all participants rollback their changes. Typically, a participant may request the rollback of the current transaction after encountering a failure. It is implementation-specific whether the Transaction Service itself monitors the participants in a transaction for failures or inactivity.

Transaction Integrity

Some implementations of the Transaction Service impose constraints on the use of the Transaction Service interfaces in order to guarantee integrity equivalent to that provided by the interfaces which support the X/Open DTP transaction model. This is called *checked* transaction behavior.

For example, allowing a transaction to commit before all computations acting on behalf of the transaction have completed can lead to a loss of data integrity. Checked implementations of the Transaction Service will prevent premature commitment of a transaction.

Other implementations of the Transaction Service may rely completely on the application to provide transaction integrity. This is called *unchecked* transaction behavior.

Transaction Context

As part of the environment of each ORB-aware thread, the ORB maintains a transaction context. The transaction context associated with a thread is either null (indicating that the thread has no associated transaction) or it refers to a specific transaction. It is permitted for multiple threads to be associated with the same transaction at the same time, in the same execution environment or in multiple execution environments.

The transaction context can be implicitly transmitted to transactional objects as part of a transactional operation invocation. The Transaction Service also allows programmers to pass a transaction context as an explicit parameter of a request.

Synchronization

The Transaction Service defines support for a synchronization interface. This provides a protocol by which an object may be notified prior to the start of the two-phase commit protocol within the coordinator with which it is registered. An implementation of the Transaction Service is not required to support synchronization.

10.1.5 Principles of Function, Design, and Performance

The Transaction Service defined in this specification fulfills a number of functional, design, and performance requirements.

Functional Requirements

The Transaction Service defined in this specification addresses the following functional requirements:

Support for multiple transaction models. The flat transaction model, which is widely supported in the industry today, is a mandatory component of this specification. The nested transaction model, which provides finer granularity isolation and facilitates object reuse in a transactional environment, is an optional component of this specification.

Evolutionary Deployment. An important property of object technology is the ability to "wrapper" existing programs (coarse grain objects) to allow these functions to serve as building blocks for new business applications. This technique has been successfully used to marry object-oriented end-user interfaces with commercial business logic implemented using classical procedural techniques.

It can similarly be used to encapsulate the large body of existing business software on legacy environments and leverage that in building new business applications. This will allow customers to gradually deploy object technology into their existing environments, without having to reimplement all existing business functions.

Model Interoperability. Customers desire the capability to add object implementations to existing procedural applications and to augment object implementations with code that uses the procedural paradigm. To do so in a transaction environment requires that a single transaction be shared by both the object and procedural code. This includes the following:

- A single transaction which includes ORB and non-ORB applications and resources.
- Interoperability between the object transaction service model and the X/Open Distributed Transaction Processing (DTP) model.
- Access to existing (non-object) programs and resource managers by objects.
- Access to objects by existing programs and resource managers.
- Coordination by a single transaction service of the activities of both object and non-object resource managers.
- The network case: A single transaction, distributed between an object and non-object system, each of which has its own Transaction Service.

The Transaction Service accommodates this requirement for implementations where interoperability with X/Open DTP-compliant transactional applications is necessary.

Network Interoperability. Customers require the ability to interoperate between systems offered by multiple vendors:

- Single transaction service, single ORB - It must be possible for a single transaction service to interoperate with itself using a single ORB.
- Multiple transaction services, single ORB - It must be possible for one transaction service to interoperate with a cooperating transaction service using a single ORB.
- Single transaction service, multiple ORBs - It must be possible for a single transaction service to interoperate with itself using different ORBs

- Multiple transaction services, multiple ORBs - It must be possible for one transaction service to interoperate with a cooperating transaction service using different ORBs.

The Transaction Service specifies all required interactions between cooperating Transaction Service implementations necessary to support a single ORB. The Transaction Service depends on ORB interoperability (as defined by the CORBA specification) to provide cooperating Transaction Services across different ORBs.

Flexible transaction propagation control. Both client and object implementations can control transaction propagation:

- A client controls whether or not its transaction is propagated with an operation.
- A client can invoke operations on objects with transactional behavior and objects without transactional behavior within the scope of a single transaction.
- An object can specify transactional behavior for its interfaces.

The Transaction Service supports both implicit (system-managed) propagation and explicit (application-managed) propagation. With implicit propagation, transactional behavior is not specified in the operation's signature. With explicit propagation, applications define their own mechanisms for sharing a common transaction.

Support for TP Monitors. Customers need object technology to build mission-critical applications. These applications are deployed on commercial transaction processing systems where a TP Monitor provides both efficient scheduling and the sharing of resources by a large number of users. It must be possible to implement the Transaction Service in a TP monitor environment. This includes:

- The ability to execute multiple transactions concurrently.
- The ability to execute clients, servers, and transaction services in separate processes.

The Transaction Service is usable in a TP Monitor environment.

Design Requirements

The Transaction Service supports the following design requirements:

Exploitation of OO Technology. This specification permits a wide variety of ORB and Transaction Service implementations and uses objects to enable ORB-based, secure implementations. The Transaction Service provides the programmer with easy to use interfaces that hide some of the complexity inherent in general-use specifications. Meaningful user applications can be constructed using interfaces that are as simple or simpler than their procedural equivalents.

Low Implementation Cost. The Transaction Service specification considers cost from the perspective of three users of the service - clients, ORB implementers, and Transaction Service providers.

- For clients, it allows a range of implementations which are compliant with the proposed architecture. Many ORB implementations will exist in client workstations which have no requirement to understand transactions within themselves, but will find it highly desirable to interoperate with server platforms that implement transactions.
- The specification provides for minimal impact to the ORB. Where feasible, function is assigned to an object service implementation to permit the ORB to continue to provide high performance object access when transactions are not used.
- Since this Transaction Service will be supported by existing (procedural) transaction managers, the specification allows implementations that reuse existing procedural Transaction Managers.

Portability. The Transaction Service specification provides for portability of applications. It also defines an interface between the ORB and the Transaction Service that enables individual Transaction Service implementations to be ported between different ORB implementations.

Avoidance of OMG IDL interface variants. The Transaction Service allows a single interface to be supported by both transactional and non-transactional implementations. This approach avoids a potential "combinatorial explosion" of interface variants that differ only in their transactional characteristics. For example, the existing Object Service interfaces can support transactional behavior without change.

Support for both single-threaded and multi-threaded implementations. The Transaction Service defines a flexible model that supports a variety of programming styles. For example, a client with an active transaction can make requests for the same transaction on multiple threads. Similarly, an object can support multiple transactions in parallel by using multiple threads.

A wide spectrum of implementation choices. The Transaction Service allows implementations to choose the degree of checking provided to guarantee legal behavior of its users. This permits both robust implementations which provide strong assurances for transaction integrity and lightweight implementations where such checks are not warranted.

Performance Requirements

The Transaction Service is expected to be implemented on a wide range of hardware and software platforms ranging from desktop computers to massively parallel servers and in networks ranging in size from a single LAN to worldwide networks. To meet this wide range of requirements, consideration must be given to algorithms which scale, efficient communications, and the number and size of accesses to permanent storage. Much of this is implementation, and therefore not visible to the user of the service. Nevertheless, the expected performance of the Transaction Service was compared to its procedural equivalent, the X/Open DTP model in the following areas:

- The number of network messages required.
- The number of disk accesses required.
- The amount of data logged.

The objective of the specification was to achieve parity with the X/Open model for equivalent function, where technically feasible.

10.2 Service Architecture

Figure 10-1 illustrates the major components and interfaces defined by the Transaction Service. The transaction originator is an arbitrary program that begins a transaction. The recoverable server implements an object with recoverable state that is invoked within the scope of the transaction, either directly by the transaction originator or indirectly through one or more transactional objects.

The transaction originator creates a transaction using a *TransactionFactory*; a *Control* is returned that provides access to a *Terminator* and a *Coordinator*. The transaction originator uses the *Terminator* to commit or rollback the transaction. The *Coordinator* is made available to recoverable servers, either explicitly or implicitly (by implicitly propagating a transaction context with a request). A recoverable server registers a *Resource* with the *Coordinator*. The *Resource* implements the two-phase commit protocol which is driven by the Transaction Service. A recoverable server may register a *Synchronization* with the *Coordinator*. The *Synchronization* implements a dependent object protocol driven by the Transaction Service. A recoverable server can also register a specialized resource called a *SubtransactionAwareResource* to track the completion of subtransactions. A *Resource* uses a *RecoveryCoordinator* in certain failure cases to determine the outcome of the transaction and to coordinate the recovery process with the Transaction Service.

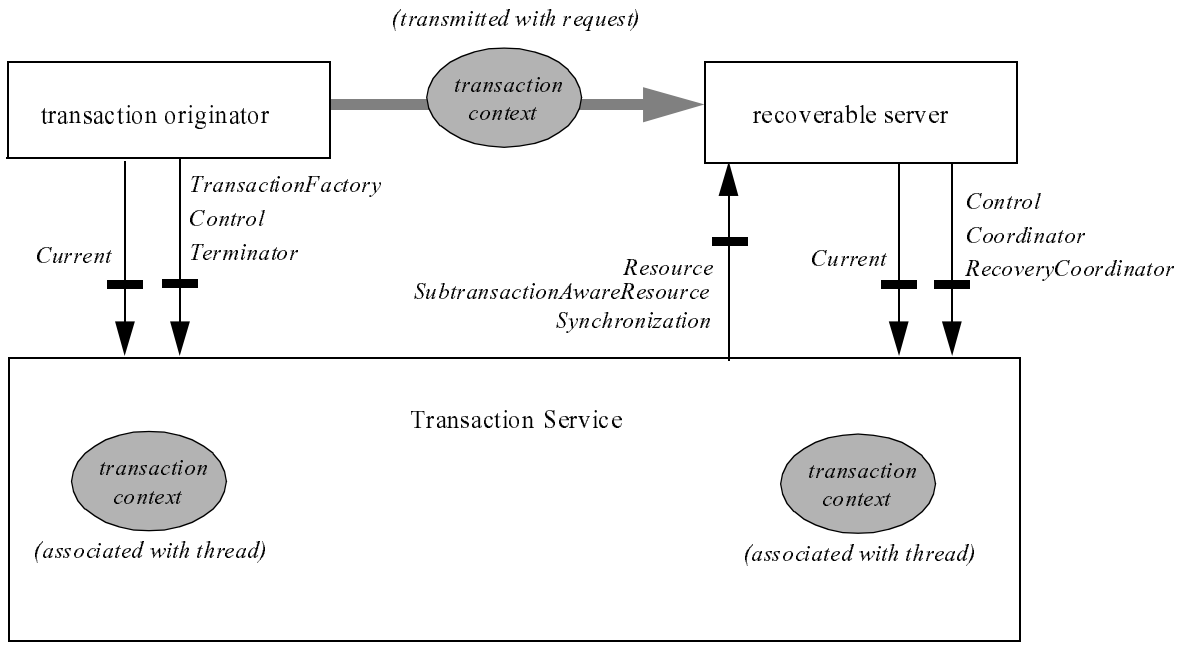


Figure 10-1 This figure illustrates the major components and interfaces of the Transaction Service.

To simplify coding, most applications use the *Current* pseudo object, which provides access to an implicit per-thread transaction context.

10.2.1 Typical Usage

A typical transaction originator uses the *Current* object to begin a transaction, which becomes associated with the transaction originator's thread.

The transaction originator then issues requests. Some of these requests involve transactional objects. When a request is issued to a transactional object, the transaction context associated with the invoking thread is automatically propagated to the thread executing the method of the target object. No explicit operation parameter or context declaration is required to transmit the transaction context. Propagation of the transaction context can extend to multiple levels if a transactional object issues a request to a transactional object.

Using the *Current* object, the transactional object can unilaterally rollback the transaction and can inquire about the current state of the transaction. Using the *Current* object, the transactional object also can obtain a *Coordinator* for the current transaction. Using the *Coordinator*, a transactional object can determine the relationship between two transactions, to implement isolation among multiple transactions.

Some transactional objects are also recoverable objects. A recoverable object has persistent data that must be managed as part of the transaction. A recoverable object uses the *Coordinator* to register a *Resource* object as a participant in the transaction. The resource represents the recoverable object's participation in the transaction; each resource is implicitly associated with a single transaction. The *Coordinator* uses the resource to perform the two-phase commit protocol on the recoverable object's data.

After the computations involved in the transaction have been completed, the transaction originator uses the *Current* object to request that the changes be committed. The Transaction Service commits the transaction using a two-phase commit protocol wherein a series of requests are issued to the registered resources.

10.2.2 Transaction Context

The transaction context associated with a thread is either null (indicating that the thread has no associated transaction) or it refers to a specific transaction. It is permitted for multiple threads to be associated with the same transaction at the same time.

When a thread in an object server is used by an object adapter to perform a request on a transactional object, the object adapter initializes the transaction context associated with that thread by effectively copying the transaction context of the thread that issued the request. An implementation of the Transaction Service may restrict the capabilities of the new transaction context. For example, an implementation of the Transaction Service might not permit the object server thread to request commitment of the transaction.

The object adapter is not required to initialize the transaction context of every request handler. It is required to initialize the transaction context only if the interface supported by the target object is derived from the *TransactionalObject* interface. Otherwise, the initial transaction context of the thread is undefined.

When a thread retrieves the response to a deferred synchronous request, an exception may be raised if the thread is no longer associated with the transaction that it was associated with when the deferred synchronous request was issued. (See 10.2.6, subsection "WRONG_TRANSACTION Exception" for a more precise definition.)

When nested transactions are used, the transaction context remembers the stack of nested transactions started within a particular execution environment (e.g., process) so that when a subtransaction ends, the transaction context of the thread is restored to the context in effect when the subtransaction was begun. When the context is transferred between execution environments, the received context refers only to one particular transaction, not a stack of transactions.

10.2.3 Context Management

The Transaction Service supports management and propagation of transaction context using objects provided by the Transaction Service. Using this approach, the transaction originator issues a request to a *TransactionFactory* to begin a new top-level transaction. The factory returns a *Control* object specific to the new transaction that allows an application to terminate the transaction or to become a participant in the transaction (by registering a *Resource*). An application can propagate a transaction context by passing the *Control* as an explicit request parameter.

The *Control* does not directly support management of the transaction. Instead, it supports operations that return two other objects, a *Terminator* and a *Coordinator*. The *Terminator* is used to commit or rollback the transaction. The *Coordinator* is used to enable transactional objects to participate in the transaction. These two objects can be propagated independently, allowing finer granularity control over propagation.

An implementation of the Transaction Service may restrict the ability for some or all of these objects to be transmitted to or used in other execution environments, to enable it to guarantee transaction integrity.

An application can also use the *Current* object operations `get_control`, `suspend`, and `resume` to obtain or change the implicit transaction context associated with its thread.

When nested transactions are used, a *Control* can include a stack of nested transactions begun in the same execution environment. When a *Control* is transferred between execution environments, the received *Control* refers only to one particular transaction, not a stack of transactions.

10.2.4 Datatypes

The `CosTransactions` module defines the following datatypes:

```
enum Status {
    StatusActive,
    StatusMarkedRollback,
    StatusPrepared,
    StatusCommitted,
    StatusRolledBack,
    StatusUnknown,
    StatusNoTransaction
    StatusPreparing,
    StatusCommitting,
    StatusRollingBack,
};

enum Vote {
    VoteCommit,
    VoteRollback,
    VoteReadOnly
};
```

10.2.5 Structures

The `CosTransactions` module defines the following structures:

```
struct otid_t {
    long formatID; /*format identifier. 0 is OSI TP */
    long bqual_length;
    sequence <octet> tid;
};
struct TransIdentity {
    Coordinator coordinator;
    Terminator terminator;
    otid_t otid;
};
struct PropagationContext {
    unsigned long timeout;
    TransIdentity current;
    sequence <TransIdentity> parents;
    any implementation_specific_data;
};
```

10.2.6 Exceptions

Standard Exceptions

The `CosTransactions` module adds new standard exceptions to CORBA for `TRANSACTION_REQUIRED`, `TRANSACTION_ROLLEDBACK`, and `INVALID_TRANSACTION`. These exceptions are defined in Section 3.5 of the CORBA specification.

****The following information belongs in Section 3.5 of the CORBA book. ***

```
exception TRANSACTION_REQUIRED ex_body;
exception TRANSACTION_ROLLEDBACK ex_body;
exception INVALID_TRANSACTION ex_body;
```

These exceptions are standard exceptions, meaning that any request can raise one of these exceptions even though the exception is not (and must not be) declared in the operation signature.

TRANSACTION_REQUIRED Standard Exception

Any operation can raise the `TRANSACTION_REQUIRED` exception to indicate that the request carried a null transaction context, but an active transaction is required.

TRANSACTION_ROLLEDBACK Standard Exception

Any operation can raise the `TRANSACTION_ROLLEDBACK` exception to indicate that the transaction associated with the request has already been rolled back or marked to rollback; thus, the requested operation either could not be performed or was not performed because further computation on behalf of the transaction would be fruitless.

INVALID_TRANSACTION Standard Exception

Any operation can raise the `INVALID_TRANSACTION` exception to indicate that the request carried an invalid transaction context. For example, this exception could be raised if an error occurred when trying to register a resource.

****End of Text to be moved to CORBA book. ***

Heuristic Exceptions

A heuristic decision is a unilateral decision made by one or more participants in a transaction to commit or rollback updates without first obtaining the consensus outcome determined by the Transaction Service. Heuristic decisions are normally made only in unusual circumstances, such as communication failures, that prevent normal processing. When a heuristic decision is taken, there is a risk that the decision will differ from the consensus outcome, resulting in a loss of data integrity.

The `CosTransactions` module defines the following exceptions for reporting incorrect heuristic decisions or the possibility of incorrect heuristic decisions:

```
exception HeuristicRollback {};
exception HeuristicCommit {};
exception HeuristicMixed {};
exception HeuristicHazard {};
```

HeuristicRollback Exception

The `commit` operation on *Resource* raises the `HeuristicRollback` exception to report that a heuristic decision was made and that all relevant updates have been rolled back.

HeuristicCommit Exception

The `rollback` operation on *Resource* raises the `HeuristicCommit` exception to report that a heuristic decision was made and that all relevant updates have been committed.

HeuristicMixed Exception

A request raises the `HeuristicMixed` exception to report that a heuristic decision was made and that some relevant updates have been committed and others have been rolled back.

HeuristicHazard Exception

A request raises the `HeuristicHazard` exception to report that a heuristic decision may have been made, the disposition of all relevant updates is not known, and for those updates whose disposition is known, either all have been committed or all have been rolled back. (In other words, the `HeuristicMixed` exception takes priority over the `HeuristicHazard` exception.)

WRONG_TRANSACTION Exception

The *CosTransactions* module adds the WRONG_TRANSACTION exception that can be raised by the ORB when returning the response to a deferred synchronous request. This exception is defined in Section 4.3.3 of the CORBA specification.

***The following belongs in Section 4.3.3 and 4.3.4 of the CORBA book. ***

```
exception WRONG_TRANSACTION {};
```

This exception can be raised only if the request is implicitly associated with a transaction (the current transaction at the time the request was issued).

The `get_response` operation (defined on the *Request* interface) may raise the `WRONG_TRANSACTION` exception if the transaction associated with the request is not the same as the transaction associated with the thread invoking `get_response`.

The `get_next_response` operation (defined on the *ORB* interface) may raise the `WRONG_TRANSACTION` exception if the thread invoking `get_next_response` has a non-null current transaction that is different than the one associated with the request.

****End of text which belongs in the CORBA book. ***

Other Exceptions

The CosTransactions module defines the following additional exceptions:

```
exception SubtransactionsUnavailable {};
exception NotSubtransaction {};
exception Inactive {};
exception NotPrepared {};
exception NoTransaction {};
exception InvalidControl {};
exception Unavailable {};
exception SynchronizationUnavailable {};
```

These exceptions are described below along with the operations that raise them.

10.3 Transaction Service Interfaces

The interfaces defined by the Transaction Service reside in the `CosTransactions` module. (OMG IDL for the `CosTransactions` module is shown in 10.6.) The interfaces for the Transaction Service are as follows:

- *Current*
- *TransactionFactory*
- *Terminator*
- *Coordinator*
- *RecoveryCoordinator*
- *Resource*
- *Synchronization*
- *Subtransaction Aware Resource*
- *Transactional Object*

No operations are defined in these interfaces for destroying objects. No application actions are required to destroy objects that support the Transaction Service because the Transaction Service destroys its own objects when they are no longer needed.

10.3.1 Current Interface

The *Current* interface defines operations that allow a client of the Transaction Service to explicitly manage the association between threads and transactions. The *Current* interface also defines operations that simplify the use of the Transaction Service for most applications. These operations can be used to begin and end transactions and to obtain information about the current transaction.

The *Current* interface is designed to be supported by a pseudo object whose behavior depends upon and may alter the transaction context associated with the invoking thread. It may be shared with other object services (e.g. security) and is obtained by using a `get_current` operation on the `CORBA::ORB` interface. *Current* supports the following operations:

```
interface Current : CORBA::ORB::Current {
    void begin()
        raises(SubtransactionsUnavailable);
    void commit(in boolean report_heuristics)
        raises(
            NoTransaction,
            HeuristicMixed,
            HeuristicHazard
        );
    void rollback()
        raises(NoTransaction);
    void rollback_only()
        raises(NoTransaction);

    Status get_status();
    string get_transaction_name();
    void set_timeout(in unsigned long seconds);

    Control get_control();
    Control suspend();
    void resume(in Control which)
        raises(InvalidControl);
};
```

begin

A new transaction is created. The transaction context of the client thread is modified so that the thread is associated with the new transaction. If the client thread is currently associated with a transaction, the new transaction is a subtransaction of that transaction. Otherwise, the new transaction is a top-level transaction.

The `SubtransactionsUnavailable` exception is raised if the client thread already has an associated transaction and the Transaction Service implementation does not support nested transactions.

commit

If there is no transaction associated with the client thread, the `NoTransaction` exception is raised. If the client thread does not have permission to commit the transaction, the standard exception `NO_PERMISSION` is raised. (The `commit` operation may be restricted to the transaction originator in some implementations.)

Otherwise, the transaction associated with the client thread is completed. The effect of this request is equivalent to performing the `commit` operation on the corresponding *Terminator* object (see Section 10.3.4); see Section 10.3.4 and Section 10.2.6 for a description of the exceptions that may be raised.

The client thread transaction context is modified as follows: If the transaction was begun by a thread (invoking `begin`) in the same execution environment, then the thread's transaction context is restored to its state prior to the `begin` request. Otherwise, the thread's transaction context is set to null.

rollback

If there is no transaction associated with the client thread, the `NoTransaction` exception is raised. If the client thread does not have permission to rollback the transaction, the standard exception `NO_PERMISSION` is raised. (The `rollback` operation may be restricted to the transaction originator in some implementations; however, the `rollback_only` operation, described below, is available to all transaction participants.)

Otherwise, the transaction associated with the client thread is rolled back. The effect of this request is equivalent to performing the `rollback` operation on the corresponding *Terminator* object (see Section 10.3.4).

The client thread transaction context is modified as follows: If the transaction was begun by a thread (invoking `begin`) in the same execution environment, then the thread's transaction context is restored to its state prior to the `begin` request. Otherwise, the thread's transaction context is set to null.

rollback_only

If there is no transaction associated with the client thread, the `NoTransaction` exception is raised. Otherwise, the transaction associated with the client thread is modified so that the only possible outcome is to rollback the transaction. The effect of this request is equivalent to performing the `rollback_only` operation on the corresponding *Coordinator* object (see Section 10.3.5).

get_status

If there is no transaction associated with the client thread, the `StatusNoTransaction` value is returned. Otherwise, this operation returns the status of the transaction associated with the client thread. The effect of this request is equivalent to performing the `get_status` operation on the corresponding *Coordinator* object (see Section 10.3.5).

get_transaction_name

If there is no transaction associated with the client thread, an empty string is returned. Otherwise, this operation returns a printable string describing the transaction. The returned string is intended to support debugging. The effect of this request is equivalent to performing the `get_transaction_name` operation on the corresponding *Coordinator* object (see Section 10.3.5).

set_timeout

This operation modifies a state variable associated with the target object that affects the time-out period associated with top-level transactions created by subsequent invocations of the `begin` operation. If the parameter has a nonzero value *n*, then top-level transactions created by subsequent invocations of `begin` will be subject to being rolled back if they do not complete before *n* seconds after their creation. If the parameter is zero, then no application specified time-out is established.

get_control

If the client thread is not associated with a transaction, a null object reference is returned. Otherwise, a *Control* object is returned that represents the transaction context currently associated with the client thread. This object can be given to the `resume` operation to reestablish this context in the same thread or a different thread. The scope within which this object is valid is implementation dependent; at a minimum, it must be usable by the client thread. This operation is not dependent on the state of the transaction; in particular, it does not raise the `TRANSACTION_ROLLEDBACK` exception.

suspend

If the client thread is not associated with a transaction, a null object reference is returned. Otherwise, an object is returned that represents the transaction context currently associated with the client thread. This object can be given to the `resume` operation to reestablish this context in the same thread or a different thread. The scope within which this object is valid is implementation dependent; at a minimum, it must be usable by the client thread. In addition, the client thread becomes associated with no transaction. This operation is not dependent on the state of the transaction; in particular, it does not raise the `TRANSACTION_ROLLEDBACK` exception.

resume

If the parameter is a null object reference, the client thread becomes associated with no transaction. Otherwise, if the parameter is valid in the current execution environment, the client thread becomes associated with that transaction (in place of any previous transaction). Otherwise, the `InvalidControl` exception is raised. See Section 10.3.3 for a discussion of restrictions on the scope of a *Control*. This operation is not dependent on the state of the transaction; in particular, it does not raise the `TRANSACTION_ROLLEDBACK` exception.

10.3.2 TransactionFactory Interface

The *TransactionFactory* interface is provided to allow the transaction originator to begin a transaction. This interface defines two operations, `create` and `recreate`, which create a new representation of a top-level transaction. A *TransactionFactory* is located using the *FactoryFinder* interface of the life cycle service and not by the `resolve_initial_reference` operation on the *ORB* interface defined in Section 2.6 of the CORBA specification.

```
interface TransactionFactory {
    Control create(in unsigned long time_out);
    Control recreate(in PropagationContext ctx);
};
```

create

A new top-level transaction is created and a *Control* object is returned. The *Control* object can be used to manage or to control participation in the new transaction. An implementation of the Transaction Service may restrict the ability for the *Control* object to be transmitted to or used in other execution environments; at a minimum, it can be used by the client thread.

If the parameter has a nonzero value *n*, then the new transaction will be subject to being rolled back if it does not complete before *n* seconds have elapsed. If the parameter is zero, then no application specified time-out is established.

recreate

A new representation is created for an existing transaction defined by the *PropagationContext* and a *Control* object is returned. The *Control* object can be used to manage or to control participation in the transaction. An implementation of the Transaction Service which supports interposition (see Section 10.5.2) uses `recreate` to create a new representation of the transaction being imported, subordinate to the representation in `ctx`. The `recreate` operation can also be use to import a transaction which originated outside of the Transaction Service.

10.3.3 Control Interface

The *Control* interface allows a program to explicitly manage or propagate a transaction context. An object supporting the *Control* interface is implicitly associated with one specific transaction.

```
interface Control {
    Terminator get_terminator()
        raises(Unavailable);
    Coordinator get_coordinator()
        raises(Unavailable);
};
```

The *Control* interface defines two operations, `get_terminator` and `get_coordinator`. The `get_terminator` operation returns a *Terminator* object, which supports operations to end the transaction. The `get_coordinator` operation returns a *Coordinator* object, which supports operations needed by resources to participate in the transaction. The two objects support operations that are typically performed by different parties. Providing two objects allows each set of operations to be made available only to the parties that require those operations.

A *Control* object for a transaction is obtained using the operations defined by the *TransactionFactory* interface or the `create_subtransaction` operation defined by the *Coordinator* interface. It is possible to obtain a *Control* object for the current transaction (associated with a thread) using the `get_control` or `suspend` operations defined by the *Current* interface (see Section 10.3.1). (These two operations return a null object reference if there is no current transaction.)

An implementation of the Transaction Service may restrict the ability for the *Control* object to be transmitted to or used in other execution environments; at a minimum, it can be used within a single thread.

get_terminator

An object is returned that supports the *Terminator* interface. The object can be used to rollback or commit the transaction associated with the *Control*. The `Unavailable` exception may be raised if the *Control* cannot provide the requested object. An implementation of the Transaction Service may restrict the ability for the *Terminator* object to be transmitted to or used in other execution environments; at a minimum, it can be used within the client thread.

get_coordinator

An object is returned that supports the *Coordinator* interface. The object can be used to register resources for the transaction associated with the *Control*. The `Unavailable` exception may be raised if the *Control* cannot provide the requested object. An implementation of the Transaction Service may restrict the ability for the *Coordinator* object to be transmitted to or used in other execution environments; at a minimum, it can be used within the client thread.

10.3.4 Terminator Interface

The *Terminator* interface supports operations to commit or rollback a transaction. Typically, these operations are used by the transaction originator.

```
interface Terminator {
    void commit(in boolean report_heuristics)
        raises(
            HeuristicMixed,
            HeuristicHazard
        );
    void rollback();
};
```

An implementation of the Transaction Service may restrict the scope in which a *Terminator* can be used; at a minimum, it can be used within a single thread.

commit

If the transaction has not been marked rollback only, and all of the participants in the transaction agree to commit, the transaction is committed and the operation terminates normally. Otherwise, the transaction is rolled back (as described below) and the `TRANSACTION_ROLLEDBACK` standard exception is raised.

If the `report_heuristics` parameter is true, the Transaction Service will report inconsistent or possibly inconsistent outcomes using the `HeuristicMixed` and `HeuristicHazard` exceptions (defined above in Section 10.2.6). A Transaction Service implementation may optionally use the Event Service to report heuristic decisions.

The `commit` operation may rollback the transaction if there are subtransactions of the transaction that have not themselves been committed or rolled back or if there are existing or potential activities associated with the transaction that have not completed. The nature and extent of such error checking is implementation-dependent.

When a top-level transaction is committed, all changes to recoverable objects made in the scope of this transaction are made permanent and visible to other transactions or clients. When a subtransaction is committed, the changes are made visible to other related transactions as appropriate to the degree of isolation enforced by the resources.

rollback

The transaction is rolled back.

When a transaction is rolled back, all changes to recoverable objects made in the scope of this transaction (including changes made by descendant transactions) are rolled back. All resources locked by the transaction are made available to other transactions as appropriate to the degree of isolation enforced by the resources.

10.3.5 Coordinator Interface

The *Coordinator* interface provides operations that are used by participants in a transaction. These participants are typically either recoverable objects or agents of recoverable objects, such as subordinate coordinators. Each object supporting the *Coordinator* interface is implicitly associated with a single transaction.

```
interface Coordinator {

    Status get_status();
    Status get_parent_status();
    Status get_top_level_status();

    boolean is_same_transaction(in Coordinator tc);
    boolean is_related_transaction(in Coordinator tc);
    boolean is_ancestor_transaction(in Coordinator tc);
    boolean is_descendant_transaction(in Coordinator tc);
    boolean is_top_level_transaction();

    unsigned long hash_transaction();
    unsigned long hash_top_level_tran();

    RecoveryCoordinator register_resource(in Resource r)
        raises(Inactive);

    void register_synchronization (in Synchronization sync)
        raises(Inactive, SynchronizationUnavailable);

    void register_subtran_aware(in SubtransactionAwareResource r)
        raises(Inactive, NotSubtransaction);

    void rollback_only()
        raises(Inactive);

    string get_transaction_name();

    Control create_subtransaction()
        raises(SubtransactionsUnavailable, Inactive);

    PropagationContext get_txcontext ()
        raises(Unavailable);
};
```

An implementation of the Transaction Service may restrict the scope in which a *Coordinator* can be used; at a minimum, it can be used within a single thread.

get_status

This operation returns the status of the transaction associated with the target object:

- `StatusActive` - A transaction is associated with the target object and it is in the active state. An implementation returns this status after a transaction has been started and prior to a coordinator issuing any prepares unless it has been marked for rollback.
- `StatusMarkedRollback` - A transaction is associated with the target object and has been marked for rollback, perhaps as the result of a `rollback_only` operation.
- `StatusPrepared` - A transaction is associated with the target object and has been prepared, i.e. all subordinates have responded `VoteCommit`. The target object may be waiting for a superior's instructions as to how to proceed.
- `StatusCommitted` - A transaction is associated with the target object and it has completed commitment. It is likely that heuristics exists, otherwise the transaction would have been destroyed and `StatusNoTransaction` returned.
- `StatusRolledBack` - A transaction is associated with the target object and the outcome has been determined as rollback. It is likely that heuristics exists, otherwise the transaction would have been destroyed and `StatusNoTransaction` returned.
- `StatusUnknown` - A transaction is associated with the target object, but the Transaction Service cannot determine its current status. This is a transient condition, and a subsequent invocation will ultimately return a different status.
- `StatusNoTransaction` - No transaction is currently associated with the target object. This will occur after a transaction has completed.
- `StatusPreparing` - A transaction is associated with the target object and it is the process of preparing. An implementation returns this status if it has started preparing, but has not yet completed the process, probably because it is waiting for responses to prepare from one or more resources.
- `StatusCommitting` - A transaction is associated with the target object and is in the process of committing. An implementation returns this status if it has decided to commit, but has not yet completed the process, probably because it is waiting for responses from one or more resources.
- `StatusRollingBack` - A transaction is associated with the target object and it is in the process of rolling back. An implementation returns this status if it has decided to rollback, but has not yet completed the process, probably because it is waiting for responses from one or more resources.

get_parent_status

If the transaction associated with the target object is a top-level transaction, then this operation is equivalent to the `get_status` operation. Otherwise, this operation returns the status of the parent of the transaction associated with the target object.

get_top_level_status

This operation returns the status of the top-level ancestor of the transaction associated with the target object. If the transaction is a top-level transaction, then this operation is equivalent to the `get_status` operation.

is_same_transaction

This operation returns true if and only if the target object and the parameter object both refer to the same transaction.

is_ancestor_transaction

This operation returns true if and only if the transaction associated with the target object is an ancestor of the transaction associated with the parameter object. A transaction T1 is an ancestor of a transaction T2 if and only if T1 is the same as T2 or T1 is an ancestor of the parent of T2.

is_descendant_transaction

This operation returns true if and only if the transaction associated with the target object is a descendant of the transaction associated with the parameter object. A transaction T1 is a descendant of a transaction T2 if and only if T2 is an ancestor of T1 (see above).

is_related_transaction

This operation returns true if and only if the transaction associated with the target object is related to the transaction associated with the parameter object. A transaction T1 is related to a transaction T2 if and only if there exists a transaction T3 such that T3 is an ancestor of T1 and T3 is an ancestor of T2.

is_top_level_transaction

This operation returns true if and only if the transaction associated with the target object is a top-level transaction. A transaction is a top-level transaction if it has no parent.

hash_transaction

This operation returns a hash code for the transaction associated with the target object. Each transaction has a single hash code. Hash codes for transactions should be uniformly distributed.

hash_top_level_tran

This operation returns the hash code for the top-level ancestor of the transaction associated with the target object. This operation is equivalent to the `hash_transaction` operation when the transaction associated with the target object is a top-level transaction.

register_resource

This operation registers the specified resource as a participant in the transaction associated with the target object. When the transaction is terminated, the resource will receive requests to commit or rollback the updates performed as part of the transaction. These requests are described in the description of the *Resource* interface. The `Inactive` exception is raised if the transaction has already been prepared. The standard exception `TRANSACTION_ROLLEDBACK` may be raised if the transaction has been marked rollback only.

If the resource is a subtransaction aware resource (it supports the *SubtransactionAwareResource* interface) and the transaction associated with the target object is a subtransaction, then this operation registers the specified resource with the subtransaction and indirectly with the top-level transaction when the subtransaction's ancestors have completed. Otherwise, the resource is registered as a participant in the current transaction. If the current transaction is a subtransaction, the resource will not receive prepare or commit requests until the top-level ancestor terminates.

This operation returns a *RecoveryCoordinator* that can be used by this resource during recovery.

register_synchronization

This operation registers the specified *Synchronization* object such that it will be notified to perform necessary processing prior to prepare being driven to resources registered with this *Coordinator*. These requests are described in the description of the *Synchronization* interface. The `Inactive` exception is raised if the transaction has already been prepared. The `SynchronizationUnavailable` exception is raised if the *Coordinator* does not support synchronization. The standard exception `TRANSACTION_ROLLEDBACK` may be raised if the transaction has been marked rollback only.

register_subtran_aware

This operation registers the specified subtransaction aware resource such that it will be notified when the subtransaction has committed or rolled back. These requests are described in the description of the *SubtransactionAwareResource* interface.

Note that this operation registers the specified resource only with the subtransaction. This operation can not be used to register the resource as a participant in the transaction.

The `NotSubtransaction` exception is raised if the current transaction is not a subtransaction. The `Inactive` exception is raised if the subtransaction (or any ancestor) has already been terminated. The standard exception `TRANSACTION_ROLLEDBACK` may be raised if the subtransaction (or any ancestor) has been marked rollback only.

rollback_only

The transaction associated with the target object is modified so that the only possible outcome is to rollback the transaction. The `Inactive` exception is raised if the transaction has already been prepared.

get_transaction_name

This operation returns a printable string describing the transaction associated with the target object. The returned string is intended to support debugging.

create_subtransaction

A new subtransaction is created whose parent is the transaction associated with the target object. The `Inactive` exception is raised if the target transaction has already been prepared. An implementation of the Transaction Service is not required to support nested transactions. If nested transactions are not supported, the exception `SubtransactionsUnavailable` is raised.

The `create_subtransaction` operation returns a *Control* object, which enables the subtransaction to be terminated and allows recoverable objects to participate in the subtransaction. An implementation of the Transaction Service may restrict the ability for the *Control* object to be transmitted to or used in other execution environments.

get_txcontext

The `get_txcontext` operation returns a *PropagationContext* object, which is used by one Transaction Service domain to export the current transaction to a new Transaction Service domain. An implementation of the Transaction Service may also use the *PropagationContext* to assist in the implementation of the `is_same_transaction` operation when the input *Coordinator* has been generated by a different Transaction Service implementation.

The `Unavailable` exception is raised if the Transaction Service implementation chooses to restrict the availability of the *PropagationContext*.

10.3.6 Recovery Coordinator Interface

A recoverable object uses a *RecoveryCoordinator* to drive the recovery process in certain situations. The object reference for an object supporting the *RecoveryCoordinator* interface, as returned by the `register_resource` operation, is implicitly associated with a single resource registration request and may only be used by that resource.

```
interface RecoveryCoordinator {
    Status replay_completion(in Resource r)
        raises(NotPrepared);
};
```

replay_completion

This operation can be invoked at any time after the associated resource has been prepared. The *Resource* must be passed as the parameter. Performing this operation provides a hint to the *Coordinator* that the `commit` or `rollback` operations have not been performed on the resource. This hint may be required in certain failure cases. This non-blocking operation returns the current status of the transaction. The `NotPrepared` exception is raised if the resource has not been prepared.

10.3.7 Resource Interface

The Transaction Service uses a two-phase commitment protocol to complete a top-level transaction with each registered resource. The *Resource* interface defines the operations invoked by the transaction service on each resource. Each object supporting the *Resource* interface is implicitly associated with a single top-level transaction. Note

that in the case of failure, the completion sequence will continue after the failure is repaired. A resource should be prepared to receive duplicate requests for the `commit` or `rollback` operation and to respond consistently.

```
interface Resource {
    Vote prepare()
        raises(
            HeuristicMixed,
            HeuristicHazard
        );
    void rollback()
        raises(
            HeuristicCommit,
            HeuristicMixed,
            HeuristicHazard
        );
    void commit()
        raises(
            NotPrepared,
            HeuristicRollback,
            HeuristicMixed,
            HeuristicHazard
        );
    void commit_one_phase()
        raises(
            HeuristicHazard
        );
    void forget();
};
```

prepare

This operation is invoked to begin the two-phase commit protocol on the resource. The resource can respond in several ways, represented by the `Vote` result.

If no persistent data associated with the resource has been modified by the transaction, the resource can return `VoteReadOnly`. After receiving this response, the Transaction Service is not required to perform any additional operations on this resource. Furthermore, the resource can forget all knowledge of the transaction.

If the resource is able to write (or has already written) all the data needed to commit the transaction to stable storage, as well as an indication that it has prepared the transaction, it can return `VoteCommit`. After receiving this response, the Transaction Service is required to eventually perform either the `commit` or the `rollback` operation on this object. To support recovery, the resource should store the *RecoveryCoordinator* object reference in stable storage.

The resource can return `VoteRollback` under any circumstances, including not having any knowledge about the transaction (which might happen after a crash). If this response is returned, the transaction must be rolled back. Furthermore, the Transaction Service is not required to perform any additional operations on this resource. After returning this response, the resource can forget all knowledge of the transaction.

The resource reports inconsistent outcomes using the `HeuristicMixed` and `HeuristicHazard` exceptions (described in Section 10.2.6). Heuristic outcomes occur when a resource acts as a sub-coordinator and at least one of its resources takes a heuristic decision after a `VoteCommit` return.

rollback

If necessary, the resource should rollback all changes made as part of the transaction. If the resource has forgotten the transaction, it should do nothing.

The heuristic outcome exceptions (described in Section 10.2.6) are used to report heuristic decisions related to the resource. If a heuristic outcome exception is raised, the resource must remember this outcome until the `forget` operation is performed so that it can return the same outcome in case `rollback` is performed again. Otherwise, the resource can immediately forget all knowledge of the transaction.

commit

If necessary, the resource should commit all changes made as part of the transaction. If the resource has forgotten the transaction, it should do nothing.

The heuristic outcome exceptions (described in Section 10.2.6) are used to report heuristic decisions related to the resource. If a heuristic outcome exception is raised, the resource must remember this outcome until the `forget` operation is performed so that it can return the same outcome in case `commit` is performed again. Otherwise, the resource can immediately forget all knowledge of the transaction.

The `NotPrepared` exception is raised if the `commit` operation is performed without first performing the `prepare` operation.

commit_one_phase

If possible, the resource should commit all changes made as part of the transaction. If it cannot, it should raise the `TRANSACTION_ROLLEDBACK` standard exception.

If a failure occurs during `commit_one_phase`, it must be retried when the failure is repaired. Since their can only be a single resource, the `HeuristicHazard` exception is used to report heuristic decisions related to that resource. If a heuristic exception is raised, the resource must remember this outcome until the `forget` operation is performed so that it can return the same outcome in case `commit_one_phase` is performed again. Otherwise, the resource can immediately forget all knowledge of the transaction.

forget

This operation is performed only if the resource raised a heuristic outcome exception to `rollback`, `commit`, or `commit_one_phase`. Once the coordinator has determined that the heuristic situation has been addressed, it should issue `forget` on the resource. The resource can forget all knowledge of the transaction.

10.3.8 Synchronization Interface

The Transaction Service provides a synchronization protocol which enables an object with transient state data that relies on an X/Open XA conformant Resource Manager for ensuring that data is made persistent, to be notified before the start of the two-phase commitment protocol, and after its completion. An object with transient state data that relies on a *Resource* object for ensuring that data is made persistent can also make use of this protocol, provided that both objects are registered with the same *Coordinator*. Each object supporting the *Synchronization* interface is implicitly associated with a single top-level transaction.

```
interface Synchronization : TransactionalObject {
    void before_completion();
    void after_completion(in Status status);
};
```

before_completion

This operation is invoked prior to the start of the two-phase commit protocol within the coordinator the *Synchronization* has registered with. This operation will therefore be invoked prior to `prepare` being issued to *Resource* objects or X/Open Resource Managers registered with that same coordinator. The *Synchronization* object must ensure that any state data it has that needs to be made persistent is made available to the resource.

Only standard exceptions may be raised. Unless there is a defined recovery procedure for the exception raised, the transaction should be marked rollback only.

after_completion

This operation is invoked after all commit or rollback responses have been received by this coordinator. The current status of the transaction (as determined by a `get_status` on the *Coordinator*) is provided as input.

Only standard exceptions may be raised and they have no effect on the outcome of the commitment process.

10.3.9 Subtransaction Aware Resource Interface

Recoverable objects that implement nested transaction behavior may support a specialization of the *Resource* interface called the *SubtransactionAwareResource* interface. A recoverable object can be notified of the completion of a subtransaction by registering a specialized resource object that offers the *SubtransactionAwareResource* interface with the Transaction Service. This registration is done by using the `register_resource` or the `register_subtran_aware` operation of the current *Coordinator* object. A recoverable object generally uses the `register_resource` operation to register a resource that will participate in the completion of the top-level transaction and the `register_subtran_aware` operation to be notified of the completion of a subtransaction.

Certain recoverable objects may want a finer control over the registration in the completion of a subtransaction. These recoverable objects will use the `register_resource` operation to ensure participation in the completion of the top-level transaction and they will use the `register_subtran_aware` operation to be notified of the completion of a particular subtransaction. For example, a recoverable object can use the `register_subtran_aware` operation to establish a "committed with respect to" relationship between transactions; that is, the recoverable object wants to be informed when a particular subtransaction is committed and then perform certain operations on the transactions that depend on that transaction's completion. This technique could be used to implement lock inheritance, for example.

The Transaction Service uses the *SubtransactionAwareResource* interface on each *Resource* object registered with a subtransaction. Each object supporting this interface is implicitly associated with a single subtransaction.

```
interface SubtransactionAwareResource : Resource {
    void commit_subtransaction(in Coordinator parent);
    void rollback_subtransaction();
};
```

commit_subtransaction

This operation is invoked only if the resource has been registered with a subtransaction and the subtransaction has been committed. The *Resource* object is provided with a *Coordinator* that represents the parent transaction. This operation may raise a standard exception such as `TRANSACTION_ROLLEDBACK`.

Note that the results of a committed subtransaction are relative to the completion of its ancestor transactions, that is, these results can be undone if any ancestor transaction is rolled back.

rollback_subtransaction

This operation is invoked only if the resource has been registered with a subtransaction and notifies the resource that the subtransaction has rolled back.

10.3.10 TransactionalObject Interface

The *TransactionalObject* interface is used by an object to indicate that it is transactional. By supporting the *TransactionalObject* interface, an object indicates that it wants the transaction context associated with the client thread to be associated with all operations on its interface.

```
interface TransactionalObject {
};
```

The *TransactionalObject* interface defines no operations. It is simply a marker.

10.4 The User's View

The audience for this section is object and client implementers; it describes application use of the Transaction Service functions.

10.4.1 Application Programming Models

A client application program may use direct or indirect context management to manage a transaction.

- With indirect context management, an application uses the *Current* object provided by the Transaction Service, to associate the transaction context with the application thread of control.
- In direct context management, an application manipulates the *Control* object and the other objects associated with the transaction.

Propagation is the act of associating a client's transaction context with operations on a target object. An object may require transactions to be either explicitly or implicitly propagated on its operations.

Implicit propagation means that requests are implicitly associated with the client's transaction; they share the client's transaction context. It is transmitted implicitly to the objects, without direct client intervention. Implicit propagation depends on indirect context management, since it propagates the transaction context associated with the *Current* object. ***Explicit propagation*** means that an application propagates a transaction context by passing objects defined by the Transaction Service as explicit parameters.

An object that supports implicit propagation would not typically expect to receive any Transaction Service object as an explicit parameter.

A client may use one or both forms of context management, and may communicate with objects that use either method of transaction propagation.

This results in four ways in which client applications may communicate with transactional objects. They are described below.

Direct Context Management: Explicit Propagation

The client application directly accesses the *Control* object, and the other objects which describe the state of the transaction. To propagate the transaction to an object, the client must include the appropriate Transaction Service object as an explicit parameter of an operation.

Indirect Context Management: Implicit Propagation

The client application uses operations on the *Current* object to create and control its transactions. When it issues requests on transactional objects, the transaction context associated with the current thread is implicitly propagated to the object.

Indirect Context Management: Explicit Propagation

For an implicit model application to use explicit propagation, it can get access to the *Control* using the `get_control` operation on *Current*. It can then use a Transaction Service object as an explicit parameter to a transactional object. This is explicit propagation.

Direct Context Management: Implicit Propagation

A client that accesses the Transaction Service objects directly can use the `resume` operation on *Current* to set the implicit transaction context associated with its thread. This allows the client to invoke operations of an object that requires implicit propagation of the transaction context.

10.4.2 Interfaces

Table 10-1 Use of Transaction Service functionality

Function	Used by	Context management: Direct	Context management: Indirect[1]

Create a transaction	Transaction originator	`TransactionFactory::create`
		`Control::get_terminator`
		`Control::get_coordinator`
			`begin, set_timeout`

Terminate a transaction	Transaction originator—*implicit* All—*explicit*	`Terminator::commit` `Terminator::rollback`	`commit` `rollback`
Rollback a transaction	Server	`Terminator::rollback_only`	`rollback_only`
Control propagation of transaction to a server	Server	Declaration of method parameter	`TransactionalObject` interface

Control by client of transaction propagation to a server	All	Request parameters	`get_control`
			`suspend`
			`resume`

Become a participant in a transaction	Recoverable Server	`Coordinator::register_resource`	Not applicable

Miscellaneous	All	`Coordinator::get_status`
		`Coordinator::get_transaction_name`
		`Coordinator::is_same_transaction`
		`Coordinator::hash_transaction`
			`get_status`
			`get_transaction_name`
			Not applicable
			Not applicable

1. All Indirect context management operations are on the *Current* object interface

Note – For clarity, subtransaction operations are not shown.

10.4.3 Checked Transaction Behavior

Some Transaction Service implementations will enforce checked behavior for the transactions they support, to provide an extra level of transaction integrity. The purpose of the checks is to ensure that all transactional requests made by the application have completed their processing before the transaction is committed. A checked Transaction Service guarantees that commit will not succeed unless all transactional objects involved in the transaction have completed the processing of their transactional requests.

There are many possible implementations of checking in a Transaction Service. One provides equivalent function to that provided by the request/response inter-process communication models defined by X/Open.

The X/Open Transaction Service model of checking is particularly important because it is widely implemented. It describes the transaction integrity guarantees provided by many existing transaction systems. These transaction systems will provide the same level of transaction integrity for object-based applications by providing a Transaction Service interface that implements the X/Open checks.

10.4.4 X/Open Checked Transactions

In X/Open, completion of the processing of a request means that the object has completed execution of its method and replied to the request.

The level of transaction integrity provided by a Transaction Service implementing the X/Open model of checking provides equivalent function to that provided by the XATMI and TxRPC interfaces defined by X/Open for transactional applications. X/Open DTP Transaction Managers are examples of transaction management functions that implement checked transaction behavior.

This implementation of checked behavior depends on implicit transaction propagation. When implicit propagation is used, the objects involved in a transaction at any given time may be represented as a tree, the request tree for the transaction. The beginner of the transaction is the root of the tree. Requests add nodes to the tree, replies remove the replying node from the tree. Synchronous requests, or the checks described below for deferred synchronous requests, ensure that the tree collapses to a single node before commit is issued.

If a transaction uses explicit propagation, the Transaction Service cannot know which objects are or will be involved in the transaction; that is, a request tree cannot be constructed or assured. Therefore, the use of explicit propagation is not permitted by a Transaction Service implementation that enforces X/Open-style checked behavior.

Applications that use synchronous requests implicitly exhibit checked behavior. For applications that use deferred synchronous requests, in a transaction where all clients and objects are in the domain of a checking Transaction Service, the Transaction Service can enforce this property by applying a reply check and a commit check.

The Transaction Service must also apply a resume check to ensure that the transaction is only resumed by application programs in the correct part of the request tree.

Reply Check

Before allowing an object to reply to a transactional request, a check is made to ensure that the object has received replies to all its deferred synchronous requests that propagated the transaction in the original request. If this condition is not met, an exception is raised and the transaction is marked as rollback-only, that is, it cannot be successfully committed.

A Transaction Service may check that a reply is issued within the context of the transaction associated with the request.

Commit Check

Before allowing commit to proceed, a check is made to ensure that:

1. The commit request for the transaction is being issued from the same execution environment that created the transaction.

2. The client issuing commit has received replies to all the deferred synchronous requests it made that caused the propagation of the transaction.

Resume Check

Before allowing a client or object to associate a transaction context with its thread of control, a check is made to ensure that this transaction context was previously associated with the execution environment of the thread. This would be true if the thread either created the transaction or received it in a transactional operation.

10.4.5 Implementing a Transactional Client: Heuristic Completions

The `commit` operation takes the boolean `report_heuristics` as input. If the `report_heuristics` argument is `false`, `commit` can complete as soon as the root coordinator has made its decision to commit or rollback the transaction. The application is not required to wait for the coordinator to complete the commit protocol by informing all the participants of the outcome of the transaction. This can significantly reduce the elapsed time for the commit operation, especially where participant *Resource* objects are located on remote network nodes. However, no heuristic conditions can be reported to the application in this case.

Using the `report_heuristics` option guarantees that the `commit` operation will not complete until the coordinator has completed the commit protocol with all resources involved in the transaction. This guarantees that the application will be informed of any non-atomic outcomes of the transaction via the `HeuristicMixed` or `HeuristicHazard` exceptions, but increases the application-perceived elapsed time for the commit operation.

10.4.6 Implementing a Recoverable Server

A Recoverable Server includes at least one recoverable object and one *Resource* object. The responsibilities of each of these objects are explained in the following sections.

Recoverable Object

The responsibilities of the recoverable object are to implement the object's operations, and to register a *Resource* object with the *Coordinator* so commitment of the recoverable object's resources, including any necessary recovery, can be completed.

The *Resource* object identifies the involvement of the recoverable object in a particular transaction. This means a *Resource* object may only be registered in one transaction at a time. A different *Resource* object must be registered for each transaction in which a recoverable object is concurrently involved.

A recoverable object may receive multiple requests within the scope of a single transaction. It only needs to register its involvement in the transaction once. The `is_same_transaction` operation allows the recoverable object to determine if the transaction associated with the request is one in which the recoverable object is already registered.

The `hash_transaction` operations allow the recoverable object to reduce the number of transaction comparisons it has to make. All coordinators for the same transaction return the same hash code. The `is_same_transaction` operation need only be done on coordinators which have the same hash code as the coordinator of the current request.

Resource Object

The responsibilities of a *Resource* object are to participate in the completion of the transaction, to update the Recoverable Server's resources in accordance with the transaction outcome, and ensure termination of the transaction, including across failures. The protocols that the *Resource* object must follow are described in Section 10.5.1.

Reliable Servers

A Reliable Server is a special case of a Recoverable Server. A Reliable Server can use the same interface as a Recoverable Server to ensure application integrity for objects that do not have recoverable state. In the case of a Reliable Server, the recoverable object can register a *Resource* object that replies `VoteReadOnly` to `prepare` if its integrity constraints are satisfied (e.g. all debits have a corresponding credit), or replies `VoteRollback` if there is a problem. This approach allows the server to apply integrity constraints which apply to the transaction as a whole, rather than to individual requests to the server.

10.4.7 Application Portability

This section considers application portability across the broadest range of Transaction Service implementations.

Flat Transactions

There is one optional function of the Transaction Service, support for nested transactions. For an application to be portable across all implementations of the Transaction Service, it should be designed to use the flat transaction model. The Transaction Service specification treats flat transactions as top-level nested transactions.

X/Open Checked Transactions

Transaction Service implementations may implement checked or unchecked behavior. The transaction integrity checks implemented by a Transaction Service need not be the same as those defined by X/Open. However, many existing transaction management systems have implemented the X/Open model of interprocess communication, and will implement a checked Transaction Service that provides the same guarantee of transaction integrity.

Applications written to conform to the transaction integrity constraints of X/Open will be portable across all implementations of an X/Open checked Transaction Service, as well as all Transaction Service implementations which support unchecked behavior.

10.4.8 Distributed Transactions

The Transaction Service can be implemented by multiple components located across a network. The different components can be based on the same or on different implementations of the Transaction Service.

A single transaction can involve clients and objects supported by more than one instance of the Transaction Service. The number of Transaction Service instances involved in the transaction is not visible to the application implementer. There is no change in the function provided.

10.4.9 Applications Using Both Checked and Unchecked Services

A single transaction can include objects supported by both checked and unchecked Transaction Service implementations. Checked transaction behavior cannot be applied to the transaction as a whole.

It is possible to provide useful, limited forms of checked behavior for those subsets of the transaction's resources in the domain of a checked Transaction Service.

- First, a transactional or recoverable object, whose resources are managed by a checked Transaction Service, may be accessed by unchecked clients. The checked Transaction Service can ensure, by registering itself in the transaction, that the transaction will not commit before all the integrity constraints associated with the request have been satisfied.
- Second, an application whose resources are managed by a checked Transaction Service may act as a client of unchecked objects, and preserve its checked semantics.

10.4.10 Examples

Note – All the examples are written in pseudo code based on C++. In particular they do not include implicit parameters such as the `ORB::Environment`, which should appear in all requests. Also, they do not handle the exceptions that might be returned with each request.

A Transaction Originator: Indirect and Implicit

In the code fragments below, a transaction originator uses indirect context management and implicit transaction propagation; `txn_crt` is an example of an object supporting the *Current* interface; the client uses the begin operation to start the transaction which becomes implicitly associated with the originator's thread of control:

```
...
txn_crt.begin();
// should test the exceptions that might be raised
...
// the client issues requests, some of which involve
// transactional objects;
BankAccount1->makeDeposit(deposit);
...
```

The program `commit`s the transaction associated with the client thread. The `report_heuristics` argument is set to `false` so no report will be made by the Transaction Service about possible heuristic decisions.

```
....
txn_crt.commit(false);
...
```

Transaction Originator: Direct and Explicit

In the following example, a transaction originator uses direct context management and explicit transaction propagation. The client uses a factory object supporting the `CosTransactions::TransactionFactory` interface to create a new transaction and uses the returned *Control* object to retrieve the *Terminator* and *Coordinator* objects.

```
...
CosTransactions::Control c;
CosTransactions::Terminator t;
CosTransactions::Coordinator co;

c = TFactory->create(0);
t = c->get_terminator();
...
```

The client issues requests, some of which involve transactional objects, in this case explicit propagation of the context is used. The *Control* object reference is passed as an explicit parameter of the request; it is declared in the OMG IDL of the interface.

```
...
transactional_object->do_operation(arg, c);
```

The transaction originator uses the *Terminator* object to commit the transaction; the `report_heuristics` argument is set to `false`: so no report will be made by the Transaction Service about possible heuristic decisions.

```
...
t->commit(false);
```

Example of a Recoverable Server

BankAccount1 is an object with internal resources. It inherits from both the *TransactionalObject* and the *Resource* interfaces:

```
interface BankAccount1:

CosTransactions::TransactionalObject,CosTransactions::Resource
{
...
   void makeDeposit (in float amt);
...
};


class BankAccount1
{
public:
...
void makeDeposit(float amt);
...
}
```

Upon entering, the context of the transaction is implicitly associated with the object's thread. The pseudo object supporting the *Current* interface is used to retrieve the *Coordinator* object associated with the transaction.

```
void makeDeposit (float amt)
{
CosTransactions::Control c;
CosTransactions::Coordinator co;

c = txn_crt.get_control();
co = c->get_coordinator();
...
```

Before registering the *Resource,* the object must check whether it has already been registered for the same transaction. This is done using the `hash_transaction` and `is_same_transaction` operations on the current *Coordinator* to compare a list of saved coordinators representing currently active transactions. In this example, the object registers itself as a *Resource*. This requires the object to durably record its

registration before issuing `register_resource` to handle potential failures and imposes the restriction that the object may only be involved in one transaction at a time.

If more parallelism is required, separate *Resource* objects can be registered for each transaction the object is involved in.

```
RecoveryCoordinator r;
r = co->register_resource (this);

// performs some transactional activity locally
balance = balance + f;
num_transactions++;
...
// end of transactional operation
};
```

Example of a Transactional Object

BankAccount2 is an object with external resources that inherits from the *TransactionalObject* interface:

```
interface BankAccount2: CosTransactions::TransactionalObject
{
...
   void makeDeposit(in float amt);
...
};


class BankAccount2
{
public:
...
void makeDeposit(float amt);
...
}
```

Upon entering, the context of the transaction is implicitly associated with the object's thread. The `makeDeposit` operation performs some transactional requests on external, recoverable servers. The objects `res1` and `res2` are recoverable objects. The current transaction context is implicitly propagated to these objects.

```
void makeDeposit(float amt)
{
    balance = res1->get_balance(amt);
    balance = balance + amt;
    res1->set_balance(balance);

    res2->increment_num_transactions();
} // end of transactional operation
```

10.4.11 Model Interoperability

The Transaction Service supports interoperability between Transaction Service applications using implicit context propagation and procedural applications using the X/Open DTP model. A single transaction management component may act as both the Transaction Service and an X/Open Transaction Manager.

Interoperability is provided in two ways:

- Importing transactions from the X/Open domain to the Transaction Service domain.
- Exporting transactions from the Transaction Service domain to the X/Open domain.

Importing Transactions

X/Open applications can access transactional objects. This means that an existing application, written to use X/Open interfaces, can be extended to invoke transactional operations. This causes the X/Open transaction to be imported into the domain of the Transaction Service. The X/Open application may be a client or a server.

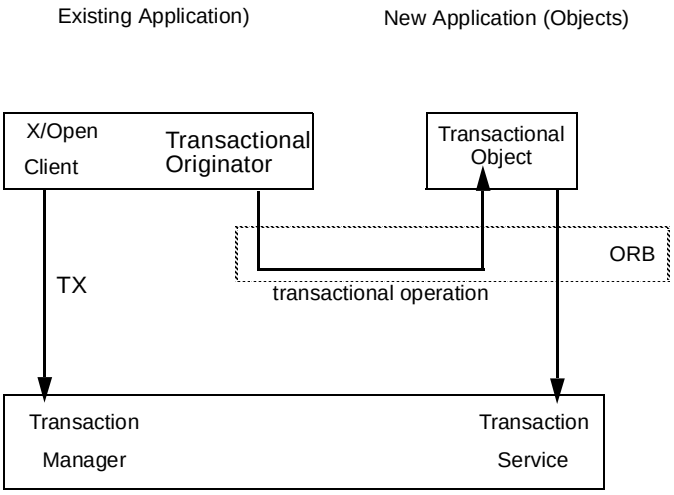


Figure 10-2 X/Open client

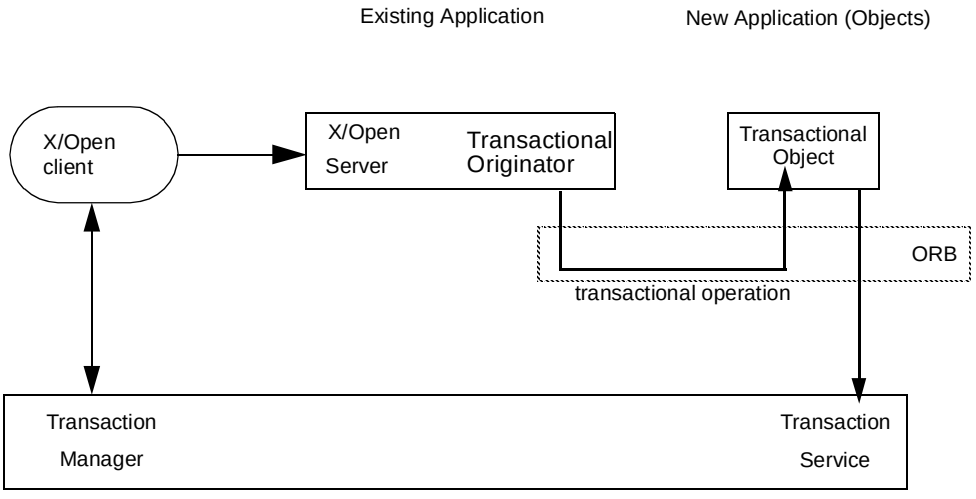
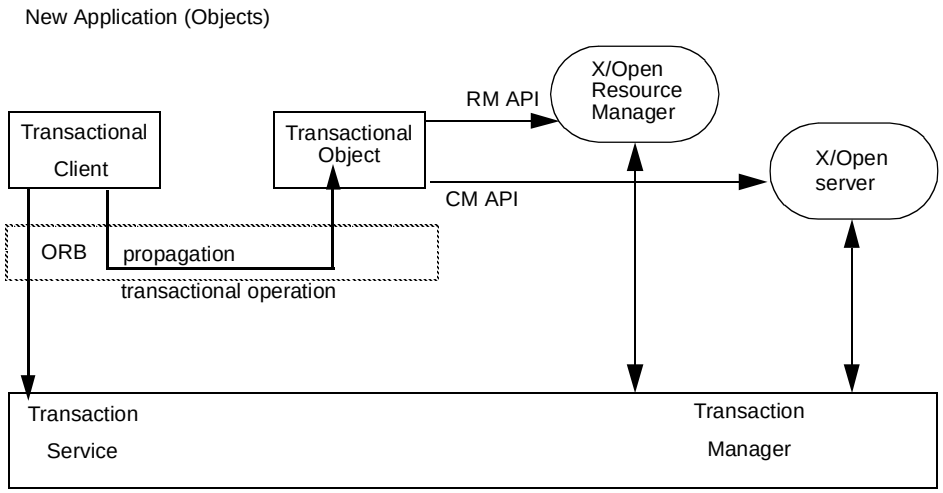


Figure 10-3 X/Open server

Exporting Transactions

Transactional objects can use X/Open communications and resource manager interfaces, and include the resources managed by these components in a transaction managed by the Transaction Service. This causes the Transaction Service transaction to be exported into the domain of the X/Open transaction manager.

Figure 10-4 Example



Programming Rules

Model interoperability results in application programs that use both X/Open and Transaction Service interfaces.

A transaction originator may use the X/Open TX interface or the Transaction Service interfaces to create and terminate a transaction. Only one style may be used in one originator.

A single application may inherit a transaction with an application request either by using the X/Open server interfaces, or by being a transactional object.

Within a single transaction, an application program can be a client of both X/Open resource manager interfaces and transactional object interfaces.

An X/Open client or server may invoke operations of transactional objects. The X/Open transaction is imported into the Transaction Service domain using the `recreate` operation on *TransactionFactory*.

A transactional object with a *Current* object that associates a transaction context with a thread of control, can call X/Open Resource Managers. How requests to the X/Open Resource managers become associated with the transaction context of the *Current* object is implementation-dependent.

10.4.12 Failure Models

The Transaction Service provides atomic outcomes for transactions in the presence of application, system or communication failures. This section describes the behavior of application entities when failures occur. The protocols used to achieve this behavior are described in Section 10.5.1.

From the viewpoint of each user object role, two types of failure are relevant: a failure affecting the object itself (local failure) and a failure external to the object (external failure), such as failure of another object or failure in the communication with that object.

Transaction Originator

Local Failure

A failure of a transaction originator prior to the originator issuing `commit` will cause the transaction to be rolled back. A failure of the originator after issuing `commit` and before the outcome is reported may result in either commitment or rollback of the transaction depending on timing; in this case completion of the transaction takes place without regard to the failure of the originator.

External Failure

Any external failure affecting the transaction prior to the originator issuing `commit` will cause the transaction to be rolled back; the standard exception `TRANSACTION_ROLLEDBACK` will be raised in the originator when it issues `commit`.

A failure after commit and before the outcome has been reported will mean that the client may not be informed of the transaction outcome, depending on the nature of the failure, and the use of the `report_heuristics` option of `commit`. For example, the transaction outcome will not be reported to the client if communication between the client and the coordinator fails.

A client may use `get_status` on the *Coordinator* to determine the transaction outcome. However, this is not reliable because the status `NoTransaction` is ambiguous: it could mean that the transaction committed and has been forgotten, or that the transaction rolled back and has been forgotten.

If an originator needs to know the transaction outcome, including in the case of external failures, then either the originator's implementation must include a *Resource* object so that it will participate in the two-phase commit procedure (and any recovery), or the originator and coordinator must be located in the same failure domain (for example, the same execution environment).

Transactional Server

Local Failure

If the Transactional Server fails then optional checks by a Transaction Service implementation may cause the transaction to be rolled back; without such checks, whether the transaction is rolled back depends on whether the commit decision has already been made (this would be the case where an unchecked client invokes `commit` before receiving all replies from servers).

External Failure

Any external failure affecting the transaction during the execution of a Transactional Server will cause the transaction to be rolled back. If this occurs while the transactional object's method is executing, the failure has no effect on the execution of this method. The method may terminate normally, returning the reply to its client. Eventually the `TRANSACTION_ROLLEDBACK` exception will be returned to a client issuing `commit`.

Recoverable Server

Behavior of a recoverable server when failures occur is determined by the two phase commit protocol between the coordinator and the recoverable server's *Resource* object(s). This protocol, including the local and external failure models and the required behavior of the Resource, is described in Section 10.5.1.

10.5 The Implementers' View

This section contains three major categories of information.

1. Section 10.5.1 defines in more detail the protocols of the Transaction Service for ensuring atomicity of transactions, even in the presence of failure.

   This section is *not* a formal part of the specification but is provided to assist in building valid implementations of the specification. These protocols affect implementations of Recoverable Servers and the Transaction Service.

2. Section 10.5.2 provides additional information for implementers of ORBs and Transaction Services in those areas where cooperation between the two is necessary to realize the Transaction Service function.

   The following aspects of ORB and Transaction Service implementation are covered:
   - transaction propagation.
   - interoperation between different transaction service implementations.
   - ORB changes necessary to support portability of transaction service implementations.

3. Section 10.5.3 describes how an implementation achieves interoperation between the Transaction Service and procedural transaction managers.

10.5.1 Transaction Service Protocols

The Transaction Service requires that certain protocols be followed to implement the atomicity property. These protocols affect the implementation of recoverable servers, (recoverable objects that register for participation in the two-phase commit process) and the coordinators that are created by a transaction factory. These responsibilities ensure the execution of the two-phase commit protocol and include maintaining state information in stable storage, so that transactions can be completed in case of failures.

General Principles

The first coordinator created for a specific transaction is responsible for driving the two-phase commit protocol. In the literature, this is referred to as the *root Transaction Coordinator* or simply root coordinator. Any coordinator that is subsequently created for an existing transaction (for example, as the result of interposition) becomes a subordinate in the process. Such a coordinator is referred to as a *subordinate Transaction Coordinator* or simply subordinate coordinator and by registering a resource becomes a transaction participant. Recoverable servers are always transaction participants. The root coordinator initiates the two-phase commit protocol; participants respond to the operations that implement the protocol. The specification is based on the following rules for commitment and recovery:

1. The protocol defined by this specification is a two-phase commit with presumed rollback.

   This permits efficient implementations to be realized since the root coordinator does not need to log anything before the commit decision and the participants (i.e. *Resource* objects) do not need to log anything before they prepare.

2. *Resource* objects—including subordinate coordinators—do not start commitment by themselves, but wait for `prepare` to be invoked.

3. The `prepare` operation is issued at most once to each resource.

4. Participants must remember heuristic decisions until the coordinator or some management application instructs them to `forget` that decision.

5. A coordinator knows which *Resource* objects are registered in a transaction and so is aware of resources that have completed commitment.

   In general, the coordinator must remember this information if a transaction commits in order to ensure proper completion of the transaction. Resources can be forgotten early if they do not vote to commit the transaction.

6. A participant should be able to request the outcome of a transaction at any time, including after failures occurring subsequent to its *Resource* object being prepared.

7. Participants should be able to report the completion of the transaction (including any heuristic condition).

The recording of information relating to the transaction which is required for recovery is described as if it were a log file for clarity of description; an implementation may use any suitable persistent storage mechanism.

Normal Transaction Completion

Transaction completion can occur in two ways; as part of the normal execution of the `Current::commit` or `Terminator::commit` operations or independent of these operations if a failure should occur before normal execution can complete. This section describes the normal (no failure) case. "Failures and Recovery" on page 10-58 describes the failure cases.

Coordinator Role

The root coordinator implements the following protocol:

- When the client asks to `commit` the transaction, and no prior attempt to rollback the transaction has been made, the coordinator issues the `before_completion` request to all registered synchronizations.
- When all registered synchronizations have responded, the coordinator issues the `prepare` request to all registered resources.
- If all registered resources reply `VoteReadOnly`, then the root coordinator replies to the client that the transaction committed (assuming that the client can still be reached).

  Before doing so, however, it first issues `after_completion` to any registered synchronizations and, after all responses are received, replies to the client. There is no requirement for the coordinator to log in this case.
- If any registered resource replies `VoteRollback` or cannot be reached then the coordinator will decide to rollback and will so inform those registered resources which already replied `VoteCommit.`
- Once a `VoteRollback` reply is received, a coordinator need not send `prepare` to the remaining resources. `Rollback` will be subsequently sent to resources that replied `VoteCommit`.

  If the `report_heuristics` parameter was specified on `commit`, the client will be informed of the rollback outcome when any heuristic reports have been collected (and logged if required).
- Once at least one registered resource has replied `VoteCommit` and all others have replied `VoteCommit` or `VoteReadOnly`, a root coordinator may decide to commit the transaction.
- Before issuing `commit` operations on those registered resources which replied `VoteCommit`, the coordinator must ensure that the commit decision and the list of registered resources—those that replied `VoteCommit`—is stored in stable storage.

- If the coordinator receives `VoteCommit` or `VoteReadOnly` responses from each registered resource, it issues the `commit` request to each registered resource that responded `VoteCommit`.
- After having received all `commit` or `rollback` responses, if synchronizations exist, the root coordinator issues `after_completion` to each of them passing the transaction outcome as status before responding to the client.
- The root coordinator issues `forget` to a resource after it receives a heuristic exception.
- This responsibility is not affected by failure of the coordinator. When receiving commit replies containing heuristic information, a coordinator constructs a composite for the transaction.
- The root coordinator forgets the transaction after having logged its heuristic status if heuristics reporting was requested by the originator.
- The root coordinator can now trigger the sending of the reply to the commit operation if heuristic reporting is required. If no heuristic outcomes were recorded, the coordinator can be destroyed.

One Phase Commit

If a coordinator has only a single registered resource, it can perform the `commit_one_phase` operation on the resource instead of performing `prepare` and then `commit` or `rollback`. If a synchronization exists, `before_completion` is issued prior to `commit_one_phase` and `after_completion` is issued when the response to `commit_one_phase` has been received. If a failure occurs, the coordinator will not be informed of the transaction outcome.

Subtransactions

When completing a subtransaction, the subtransaction coordinator must notify any registered subtransaction aware resources of the subtransaction's commit or rollback status using the `commit_subtransaction` or `rollback_subtransaction` operations of the *SubtransactionAwareResource* interface.

A transaction service implementation determines how it chooses to respond when a resource responds to `commit_subtransaction` with a system exception. The service may choose to rollback the subtransaction or it may ignore the exceptional condition. The *SubtransactionAwareResource* operations are used to notify the resources of a subtransaction when the subtransaction commits in the case where the resource needs to keep track of the commit status of its ancestors. They are not used to direct the resources to commit or rollback any state. The operations of the *Resource* interface are used to commit or rollback subtransaction resources registered using the `register_resource` operation of the *Coordinator* interface.

When the subtransaction is committed and after all of the registered subtransaction aware resources have been notified of the commitment, the subtransaction registers any resources registered using `register_resource` with its parent *Coordinator* or it may register a subordinate coordinator to relay any future requests to the resources.

From the application programmer point of view, the same rules that apply to the completion of top-level transactions also apply to subtransactions. The `report_heuristics` parameter on `commit` is ignored since heuristics are not produced when subtransactions are committed.

Recoverable Server Role

A recoverable server includes at least one recoverable object and one *Resource* object. The recoverable object has state that demonstrates at least the atomicity property. The *Resource* object implements the two-phase commit protocol as a participant on behalf of the recoverable object. The responsibilities of each of these objects is described below.

Synchronization Registration

A recoverable server may need to register a *Synchronization* object to ensure that object state data which is persistently managed by a resource is returned to the resource prior to starting the commitment protocol.

Top-Level Registration

A recoverable object registers a *Resource* object with the *Coordinator* so commitment of the transaction including any necessary recovery can be completed.

A recoverable object uses the `is_same_transaction` operation to determine whether it is already registered in this transaction. It can also use `hash_transaction` to reduce the number of comparisons. This relies on the definition of the `hash_transaction` operation to return the same value for all coordinators in the same transaction even if they are generated by multiple Transaction Service implementations.

Once registered, a recoverable server assumes the responsibilities of a transaction participant.

Subtransaction Registration

A Recoverable Server registers for subtransaction completion only if it needs to take specific actions at the time a subtransaction commits. An example would be to change ownership of locks acquired by this subtransaction to its parent.

A recoverable object uses the `is_same_transaction` operation to determine whether it is already registered in this subtransaction. It can also use `hash_transaction` to reduce the number of comparisons.

Top Level Synchronization

Synchronization objects ensure that persistent state data is returned to the recoverable object managed by a resource or to the underlying database manager. To do so they implement a protocol which moves the data prior to the prepare phase and does necessary processing after the outcome is complete.

Top-Level Completion

Resource objects implement a recoverable object's involvement in transaction completion. To do so, they must follow the two-phase commit protocol initiated by their coordinator and maintain certain elements of their state in stable storage. The responsibilities of a *Resource* object with regard to a particular transaction depend on how it will vote:

1. Returning `VoteCommit` to `prepare`

   Before a *Resource* object replies `VoteCommit` to a `prepare` operation, it must implement the following:

   - make persistent the recoverable state of its recoverable object.

     The method by which this is accomplished is implementation dependent. If a recoverable object has only transient state, it need not be made persistent.
   - ensure that its object reference is recorded in stable storage to allow it to participate in recovery in the event of failure.

     How object references are made persistent and then regenerated after a failure is outside the scope of this specification. The Persistent Object Service or some other mechanism may be used. How persistent *Resource* objects get restarted after a failure is also outside the scope of this specification.
   - record the *RecoveryCoordinator* object reference so that it can initiate recovery of the transaction later if necessary.
   - the *Resource* then waits for the coordinator to invoke `commit` or `rollback`.
   - A *Resource* with a heuristic outcome must not discard that information until it receives a `forget` from its coordinator or some administrative component.

2. Returning `VoteRollback` to `prepare`

   A *Resource* which replies `VoteRollback` has no requirement to log. Once having replied, the *Resource* can return recoverable resources to their prior state and forget the transaction.

3. Returning `VoteReadOnly` to `prepare`

   A *Resource* which replies `VoteReadOnly` has no requirement to log. Once having replied, the *Resource* can release its resources and forget the transaction.

Subtransaction Completion

The role of the subtransaction aware resource at subtransaction completion are defined by the subtransaction aware resource itself. The coordinator only requires that it respond to `commit_subtransaction` or `rollback_subtransaction`.

All resources need to be notified when a transaction commits or is rolled back. But some resources need to know when subtransactions commit so that they can update local data structures and track the completion status of ancestors. The resource may have rules that are specific to ancestry and must perform some work as all or some ancestors complete. The nested semantics and effort required by the *Resource* object are defined by the object and not the Transaction Service.

Once the resource has been told to prepare, the resource's obligations are exactly the same as a top-level resource.

For example, in the Concurrency Control Service, a resource in a nested transaction might want to know when the subtransaction commits because another subtransaction may be waiting for a lock held by that subtransaction. Once that subtransaction commits, others may be granted the lock. There is no requirement to make lock ownership persistent until a `prepare` message is received.

For the Persistent Object Service, it is important to keep separate update information associated with a subtransaction. When that subtransaction commits, the Persistent Object Service may need to reorganize its information (such as undo information) in case the parent subtransaction chooses to rollback. Again, the Persistent Object Service resource need not make updates permanent until a `prepare` message is received. At that point, it has the same responsibilities as a top-level resource.

Subordinate Coordinator Role

An implementation of the Transaction Service may interpose subordinate coordinators to optimize the commit tree for completing the transaction. Such coordinators behave as transaction participants to their superiors and as coordinators to their resources or inferior coordinators.

Synchronization

A subordinate coordinator may register a *Synchronization* object with its superior coordinator if it needs to perform processing before its prepare phase begins.

Registration

A subordinate coordinator registers a *Resource* with its superior coordinator. Once registered, a subordinate coordinator assumes the responsibilities of a transaction participant and implements the behavior of a recoverable server.

Subtransaction Registration

If any of the resources registered with the subordinate coordinator support the *SubtransactionAwareResource* interface, the subordinate coordinator must register a subtransaction aware resource with its parent coordinator. If any of the resources registered with the subordinate using the `register_resource` operation, the subordinate must register a *Resource* with its superior. If both types of resources were registered with the subordinate, the subordinate only needs to register a subtransaction aware resource with its superior.

Top-level Completion

A subordinate coordinator implements the completion behavior of a recoverable server.

Subtransaction Completion

A subordinate coordinator implements the subtransaction completion behavior of a recoverable server.

Subordinate Coordinator

A subordinate coordinator does not make the commit decision but simply relays the decision of its superior (which may also be a subordinate coordinator) to resources registered with it. A subordinate coordinator acts as a recoverable server as described previously, in terms of saving its state in stable storage. A subordinate coordinator (or indeed any resource) may log the commit decision once it is known (as an optimization) but this is not essential.

- A subordinate coordinator issues the `before_completion` operation to any synchronizations when it receives `prepare` from its superior.
- When all responses to `before_completion` have been received, a subordinate coordinator issues the `prepare` operation to its registered resources.
- If all registered resources reply `VoteReadOnly`, then the subordinate coordinator will decide to reply `VoteReadOnly`.

  Before doing so, however, it first issues `after_completion` to any registered synchronizations and, after all responses are received, replies `VoteReadOnly` to its superior. There is no requirement for the subordinate coordinator to log in this case; the subordinate coordinator takes no further part in the transaction and can be destroyed.
- If any registered resource replies `VoteRollback` or cannot be reached then the subordinate coordinator will decide to rollback and will so inform those registered resources which already replied `VoteCommit.`

  Once a `VoteRollback` reply is received, the subordinate coordinator need not send `prepare` to the remaining resources. The subordinate coordinator issues `after_completion` to any synchronizations and, after all responses have been received, replies `VoteRollback` to its superior.
- Once at least one registered resource has replied `VoteCommit` and all others have replied `VoteCommit` or `VoteReadOnly`, a subordinate coordinator may decide to reply `VoteCommit.`

  The subordinate coordinator must record the prepared state, the reference of its superior *RecoveryCoordinator* and its list of resources that responded `VoteCommit` in stable storage before responding to `prepare`.
- A subordinate coordinator issues the `commit` operation to its registered resources which replied `VoteCommit` when it receives a `commit` request from its superior.
- If any resource reports a heuristic outcome, the subordinate coordinator must report a heuristic outcome to its superior.

  Before doing so, however, it first issues `after_completion` to any registered synchronizations and, after all responses are received, reports the heuristic outcome to its superior. The specific outcome reported depends on the other heuristic outcomes received. The subordinate coordinator must record the heuristic outcome in stable storage.
- After having received all `commit` replies, a subordinate coordinator logs its heuristic status (if any).

- The subordinate coordinator then replies to the `commit` from its superior coordinator.

  Before doing so, it issues `after_completion` to any registered synchronizations and, after all responses have been received, it then replies to its superior. If no heuristic report was sent the *Coordinator* is destroyed.

- A subordinate coordinator performs the `rollback` operation on its registered resources when it receives a `rollback` request from its superior.

  If any resource reports a heuristic outcome, the subordinate coordinator records the appropriate heuristic outcome in stable storage and will report this outcome to its superior. Before doing so, however, it issues `after_completion` to any registered synchronizations and, after receiving all the responses, reports the heuristic outcome to its superior.

- The subordinate coordinator then replies to the `rollback` from its superior coordinator.

  Before doing so, it issues `after_completion` to any registered synchronizations and, after all responses have been received, it then replies to its superior. If no heuristic report was sent the *Coordinator* is destroyed.

- If a subordinate coordinator receives a `commit_one_phase` request, and it has a single registered resource, it can simply perform the `commit_one_phase` request on its resource. Before doing so, if a synchronization exists, it issues `before_completion` to the synchronization, then, after receiving the `commit_one_phase` response, issues `after_completion` to the synchronization.

  If it has multiple registered resources, it behaves like a superior coordinator, issuing `before_completion` to any synchronizations and, after receiving the responses, issuing `prepare` to each resource to determine the outcome, then issuing `commit` or `rollback` requests, followed by `after_completion` requests if synchronizations exist.

- A subordinate coordinator performs the `forget` operation on those registered resources that reported a heuristic outcome when it receives a `forget` request from its superior.

Subtransactions

A subordinate coordinator for a subtransaction relays `commit_subtransaction` and `rollback_subtransaction` requests to any subtransaction aware resources registered with it. In addition, it performs the same roles as a top-level subordinate coordinator when the top-level transaction commits. It must relay `prepare` and `commit` requests to each of the resources that registered with it using the `register_resource` operation.

Failures and Recovery

The previous descriptions dealt with the protocols associated with the Transaction Service when a transaction completes without failure. To ensure atomicity and durability in the presence of failure, the transaction service defines additional protocols to ensure that transactions, once begun, always complete.

Failure Processing

The unit of failure is termed the failure domain. It may consist of the coordinator and some local resources registered with it, or the coordinator and the resources may each be in its own failure domain.

Local Failure

Any failure in the transaction during the execution of a coordinator prior to the commit decision being made will cause the transaction to be rolled back.

A coordinator is restarted only if it has logged the commit decision.

- If the coordinator only contains heuristic information, nothing is done.
- If the transaction is marked rollback only, a coordinator can send `rollback` to its resources and inferior coordinators.
- If the transaction outcome is commit, the coordinator sends `commit` to prepared registered resources and the regular commitment procedure is started.
- If any registered resources exist but cannot be reached then the coordinator must try again later.

If registered resources no longer exist then this means that they completed commitment before the coordinator failed and have no heuristic information.

- If a subordinate coordinator is prepared, then it must contact its superior coordinator to determine the transaction outcome.
- If the superior coordinator exists but cannot be reached, then the subordinate must retry recovery later.
- If the superior coordinator no longer exists then the outcome of the transaction can be presumed to be rollback.

The subordinate will inform its registered resources.

External Failure

Any failure in the transaction during the execution of a coordinator prior to the commit decision being made will cause the transaction to be rolled back.

Transaction Completion after Failure

In general, the approach is to continue the completion protocols at the point where the failure occurred. That means that the coordinator will usually have the responsibility for sending the commit decision to its registered resources. Certain failure conditions will require that the resource initiate the recovery procedure—recall that the resource might also be a subordinate coordinator. These are described in more detail below.

Resources

A resource represents some collection of recoverable data associated with a transaction. It supports the *Resource* interface described in Section 10.3.7. When recovering from failure after its changes have been prepared, a resource uses the `replay_completion` operation on the *RecoveryCoordinator* to determine the outcome of the transaction and continue completion.

Heuristic Reporting

If the coordinator does not complete the two-phase commit in a timely manner, a subordinate (i.e. a resource or a subordinate coordinator) in the transaction may elect to commit or rollback the resources registered with it in a prepared transaction (take a ***heuristic decision***). When the coordinator eventually sends the outcome, the outcome may differ from that heuristic decision. The result is referred to as `HeuristicMixed` or `HeuristicHazard`.The result is reported by the root coordinator to the client only when the `report_heuristics` option on `commit` is selected. In these circumstances, the participant (subordinate) and the coordinator must obey a set of rules that define what they report.

Coordinator Role

A root coordinator that fails prior to logging the commit decision can unilaterally rollback the transaction. If its resources have also rolled back because they were not prepared, the transaction is returned to its prior state of consistency. If any resources are prepared, they are required to initiate the recovery process defined below.

- A root coordinator that has a committed outcome will continue the completion protocol by sending `commit`.
- A root coordinator that has a rolled back outcome will continue the completion protocol by sending `rollback`.

Synchronizations

Synchronization objects are not persistent so they are not restarted after failure and, as a result, their operations are not invoked during failure processing.

Subtransactions

Subtransactions are not durable, so there is no completion after failure. However, once the top-level coordinator issues `prepare`, a subtransaction subordinate coordinator has the same responsibilities as a top-level subordinate coordinator.

Recoverable Server role

The Transaction Service imposes certain requirements on the recoverable objects participating in a transaction. These requirements include an obligation to retain certain information at certain times in stable storage (storage not likely to be damaged as the result of failure). When a recoverable object restarts after a failure, it participates in a recovery protocol based on the contents (or lack of contents) of its stable storage.

Once having replied `VoteCommit`, the resource remains responsible for discovering the outcome of the transaction, i.e. whether to commit or rollback. If the resource subsequently makes a heuristic decision, this does not change its responsibilities to discover the outcome.

If No Heuristic Decision is Made

A resource that is prepared is responsible for initiating recovery. It does so by issuing `replay_completion` to the *RecoveryCoordinator*. The reply tells the resource the outcome of the transaction. The coordinator can continue the completion protocol allowing the resource to either commit or rollback. The resource can resend `replay_completion` if the completion protocol is not continued.

- If the resource having replied `VoteCommit` initiates recovery and receives `StExcep::OBJECT_NOT_EXIST`, it will know that the *Coordinator* no longer exists and therefore the outcome was to rollback (presumed rollback).
- If the resource having replied `VoteCommit` initiates recovery and receives `StExcep::COMM_FAILURE`, it will know only that the *Coordinator* may or may not exist. In this case the resource retains responsibility for initiating recovery again at a later time

When a Heuristic Decision is Made

Before acting on a heuristic decision, it must record the decision in stable storage.

- If the heuristic decision turns out to be consistent with the outcome, then all is well and the transaction can be completed and the heuristic decision can be forgotten.
- If the heuristic decision turns out to be wrong, the heuristic damage is recorded in stable storage and one of the heuristic outcome exceptions (`HeuristicCommit`,`HeuristicRollback`,`HeuristicMixed`, or `HeuristicHazard`) is returned when completion continues.

The heuristic outcome details must be retained persistently until the resource is instructed to forget. Thus in this case the resource remains persistent until the `forget` is received.

Subordinate Coordinator Role

The behavior of a subordinate coordinator after a failure of its superior coordinator is implementation-dependent, however it does follow the following protocols:

- Since it appears as a resource to its superior coordinator, the protocol defined for recoverable servers applies to subordinate coordinators.
- Since it is also a subordinate coordinator for its own registered resources, it is permitted to send duplicate `commit`, `rollback`, and `forget` requests to its registered resources.
- It is required to (eventually) perform either `commit` or `rollback` on any resource to which it has received a `VoteCommit` response to `prepare`.
- It[2] is required to (eventually) perform the `forget` operation on any resource that reported a heuristic outcome.

Since subtransactions are not durable, it has no responsibility in this area for failure recovery.

10.5.2 ORB/TS Implementation Considerations

The Transaction Service and the ORB must cooperate to realize certain Transaction Service function. This is discussed in greater detail in the following sections.

Transaction Propagation

The transaction is represented to the application by the *Control* object. Within the Transaction Service, an implicit context is maintained for all threads associated with a transaction. Although there is some common information, the implicit context is not the same as the *Control* object defined in this specification and is distinct from the ORB Context defined by CORBA. It is the implicit context that must be transferred between execution environments to support transaction propagation.

The objects using a particular Transaction Service implementation in a system form a Transaction Service domain. Within the domain, the structure and meaning of the implicit context information can be private to the implementation. When leaving the domain, this information must be translated to a common form if it is to be understood by the target Transaction Service domain, even across a single ORB. When the implicit context is transferred, it is represented as a *PropagationContext*.

No OMG IDL declaration is required to cause propagation of the implicit context with a request. The minimum amount of information that could serve as a implicit context is the object reference of the *Coordinator*. However, an identifier (e.g. an X/Open XID) is also required to allow efficient (local) execution of the `is_same_transaction` and `hash_transaction` operations when interposition is done. Implementations may choose to also include the *Terminator* object reference if they support the ability for ending the transaction in other execution environments than the originator's. Transferring the implicit context requires interaction between the Transaction Service and the ORB to add or extract the implicit context from ORB messages. This interaction is also used to implement the checking functions described in Section 10.4.4, "X/Open Checked Transactions," on page 10-38.

When the *Control* object is passed as an operation argument (explicit propagation), no special transfer mechanism is required.

Interposition

When a transaction is propagated, the implicit context is exported and can be used by the importing Transaction Service implementation to create a new *Control* object which refers to a new (local) *Coordinator*. This technique, *interposition*, allows a

2. or some "agent" acting on its behalf: for example a system management application.

surrogate to handle the functions of a coordinator in the importing domain. These coordinators act as subordinate coordinators. When interposition is performed, a single transaction is represented by multiple *Coordinator* objects.

Interposition allows cooperating Transaction Services to share the responsibility for completing a transaction and can be used to minimize the number of network messages sent during the completion process. Interposition is required for a Transaction Service implementation to implement the `is_same_transaction` and `hash_transaction` operations as local method invocations, thus improving overall systems performance.

An interposed coordinator registers as a participant in the transaction with the *Coordinator* identified in the *PropagationContext* of the received request. The relationships between coordinators in the transaction form a tree. The root coordinator is responsible for completing the transaction.

Many implementations of the Transaction Service will want to perform interposition and thus create *Control* objects and subsequently *Coordinator* objects for each execution environment participating in the transaction. To create a new (local) *Control*, an importing Transaction Service uses the information in the propagation context to `recreate` a *Control* object using a *TransactionFactory*. Interposition must be complete before the `get_control` operation can complete in the target object. An object adaptor is one possible place to implement interposition.

Subordinate Coordinator Synchronization

A subordinate coordinator may register with its superior coordinator to ensure that any local state data maintained by the subordinate coordinator is returned to the underlying resource prior to the subordinate coordinator's associated *Resource* seeing `prepare`.

Subordinate Coordinator Registration

A subordinate coordinator must register with its superior coordinator to orchestrate transaction completion for its local resources. The `register_resource` operation of the *Coordinator* can be used to perform this function. The subordinate coordinator can either support the *Resource* interface itself or provide another *Resource* object which will support transaction completion. Some implementations of the Transaction Service may wish to perform this function as a by-product of invoking the first operation on an object in a new domain as is done with the X/Open model. This requires that the information necessary to perform registration be added to the reply message of that first operation.

Transaction Service Interoperation

The Transaction Service can be implemented by multiple components at different locations. The different components can be based on the same or different implementations of the Transaction Service. As stated in Section 10.1.5, "Principles of Function, Design, and Performance," on page 10-8, it is a requirement that multiple Transaction Services interoperate across the same ORB and different ORBs.

Transaction Service interoperation is specified by defining the data structures exported between different implementations of the Transaction Service. When the implicit context is propagated with a request, the destination uses it to locate the superior coordinator. That coordinator may be implemented by a foreign Transaction Service. By registering a resource with that coordinator, the destination arranges to receive two-phase commit requests from the (possibly foreign) Transaction Service.

The Transaction Service permits many configurations; no particular configuration is mandated. Typically, each program will be directly associated with a single Transaction Service. However, when requests are transmitted between programs in different Transaction Service domains, both Transaction Services must understand the shared data structures to interoperate.

An interface between the ORB and the Transaction Service is defined that arranges for the implicit context to be carried on messages that represent method invocations made within the scope of a transaction.

Structure of the Propagation Context

The *PropagationContext* structure is defined in Section 10.2.5 on Page 15. For the functions defined within the base section of the propagation context, it is necessary only to send it with requests. Implementations may used the vendor specific portion for additional functions (for example, to register an interposed coordinator with its superior), which may require the propagation context to be returned. Whether it is returned or not, is implementation specific.

otid_t

The `otid_t` structure is a more efficient OMG IDL version of the X/Open defined transaction identifier (XID). The `otid_t` can be transformed to an X/Open XID and vice versa.

TransIdentity

A structure that defines information for a single transaction. It consists of a `coordinator`, an optional `terminator`, and an `otid`.

coordinator

The *Coordinator* for this transaction in the exporting Transaction Service domain.

terminator

The *Terminator* for this transaction in the exporting Transaction Service domain. Transaction Services that do not allow termination by other than the originator will set this field to a null reference (`OBJECT_NIL`).

otid

An identifier specific to the current transaction or subtransaction. This value is intended to support efficient (local) execution of the `is_same_transaction` and `hash_transaction` operations when the importing Transaction Service does interposition.

timeout

The timeout value associated with the transaction in the relevant `set_timeout` operation (or the default timeout).

<TransIdentity>parents

A sequence of `TransIdentity` structures representing the parent(s) of the current transaction. The ordering of the sequence starts at the parent of the current transaction and includes all ancestors up to the top-level transaction. An implementation that does not support nested transactions would send an empty sequence. This allows a non-nested transaction implementation to know when a nested transaction is being imported. It also supports efficient (local) execution of the *Coordinator* operations which test parentage when the importing Transaction Service does interposition.

implementation_specific_data

This information is exported from an implementation and is required to be passed back with the rest of the context if the transaction is re-imported into that implementation.

Appearance of the Propagation Context in Messages

To specify how the propagation context appears in messages, it is regarded as an extra, implicit argument which is effectively added to the signatures of transactional operations. The specification simply describes how the original operation signature is transformed with the new argument.

A transactional ORB supporting the target object will receive a request with a signature defined as:

```
    result_type op(arg1,..., argN);
```

but will actually receive, and must reply, as though the signature were:

```
    result_type op(
        arg1,..., argN,
        inout CosTransactions::PropagationContext ctx);
```

Transaction Service Portability

This section describes the way in which the ORB and the Transaction Service cooperate to enable the *PropagationContext* to be passed and any X/Open-style checking to be performed on transactional requests.

Because it is recognized that other object services and future extensions to the CORBA specification may require similar mechanisms, this component is specified separately from the main body of the Transaction Service to allow it to be revised or replaced by a mechanism common to several services independently of any future Transaction Service revisions.

To enable a single Transaction Service to work with multiple ORBs, it is necessary to define a specific interface between the ORB and the Transaction Service, which conforming ORB implementations will provide, and demanding Transaction Service implementations can rely on. The remainder of this section describes these interfaces. There are two elements of the required interfaces:

1. An additional ORB interface that allows the Transaction Service to identify itself to the ORB when present in order to be involved in the transmission of transactional requests.

2. A collection of Transaction Service operations (the Transaction Service callbacks) that the ORB invokes when a transactional request is sent and received.

These interfaces are defined as pseudo-IDL to allow them to be implemented as procedure calls.

Identification of the Transaction Service to the ORB

Prior to the first transactional request, the Transaction Service will identify itself to the ORB within its domain to establish the transaction callbacks to be used for transactional requests and replies.

***The following information belongs in Section 7.7 of the CORBA book**

The Transaction Service identifies itself to the ORB using the following interface.

```
interface TSIdentification { // PIDL
    exception NotAvailable {};
    exception AlreadyIdentified {};

    void identify_sender(in CosTSPortability::Sender sender)
        raises (NotAvailable, AlreadyIdentified);
    void identify_receiver(in CosTSPortability::Receiver receiver)
        raises (NotAvailable, AlreadyIdentified);
};
```

The callback routines identified in this operation are always in the same addressing domain as the ORB. On most machine architectures, there are a unique set of callbacks per address space. Since invocation is via a procedure call, independent failures cannot occur.

NotAvailable

The `NotAvailable` exception is raised if the ORB implementation does not support the *CosTSPortability* module.

AlreadyIdentified

The `AlreadyIdentified` exception is raised if the `identify_sender` or `identify_receiver` operation had previously identified callbacks to the ORB for this addressing domain.

identify_sender

The `identify_sender` operation provides the interface that defines the callbacks to be invoked by the ORB when a transactional request is sent and its reply received.

identify_receiver

The `identify_receiver` operation provides the interface that defines the callbacks to be invoked by the ORB when a transactional request is received and its reply sent.

The Transaction Service must identify itself to the ORB at least once per Transaction Service domain. Sending and receiving transactional requests are separately identified. If the callback interfaces are different for different processes within a Transaction Service domain, they are identified to the ORB on a per process basis. Only one Transaction Service implementation per addressing domain can identify itself to the ORB.

A Transaction Service implementation that only sends transactional request can identify only the sender callbacks. A Transaction Service that only receives transactional requests can identify only the receiver callbacks.

End of information that belongs in Section 7.7 of the CORBA specification.

The Transaction Service Callbacks

The *CosTSPortability* module defines two interfaces. Both interfaces are defined as PIDL. The *Sender* interface defines a pair of operations which are called by the ORB sending the request before it is sent and after its reply is received. The *Receiver*

interface defines a pair of operations which are called by the ORB receiving the request when the request is received and before its reply is sent. Both interfaces use the *PropagationContext* structure defined in Section 10.2.5 on Page 15.

```
module CosTSPortability { // PIDL
    typedef long ReqId;

    interface Sender {
        void sending_request(in ReqId id,
            out CosTransactions::PropagationContext ctx);
        void received_reply(in ReqId id,
            in CosTransactions::PropagationContext ctx,
            in CORBA::Environment env);
    };

    interface Receiver {
        void received_request(in ReqId id,
            in CosTransactions::PropagationContext ctx);
        void sending_reply(in ReqId id,
            out CosTransactions::PropagationContext ctx);
    };
};
```

ReqId

The `ReqId` is an unique identifier generated by the ORB which lasts for the duration of the processing of the request and its associated reply to allow the Transaction Service to correlate callback requests and replies.

Sender::sending_request

A request is about to be sent. The Transaction Service returns a *PropagationContext* to be delivered to the Transaction Service at the server managing the target object. The `TRANSACTION_REQUIRED` standard exception is raised when invoked outside the scope of a transaction.

Sender::received_reply

A reply has been received. The *PropagationContext* from the server is passed to the Transaction Service along with the returned environment. The Transaction Service examines the `Environment` to determine whether the request was successfully performed. If the `Environment` indicates the request was unsuccessful, the `TRANSACTION_ROLLEDBACK` standard exception is raised.

Receiver::received_request

A request has been received. The *PropagationContext* defines the transaction making the request. It is associated with the target object only if the target object inherits from the *TransactionalObject* interface.

Receiver::sending_reply

A reply is about to be sent. A checking transaction service determines whether there are outstanding deferred requests or subtransactions and raises a system exception using the normal mechanisms. The exception data from the callback operation needs to be re-raised by the calling ORB.

Behavior of the Callback Interfaces

The following sections describe the protocols associated with the callback interfaces:

Requirements on the ORB

The ORB will invoke the sender callbacks only when a transactional operation is issued for an object in a different process. Objects within the same process implicitly share the same transaction context. The receiver callbacks are invoked when the ORB receives a transactional request from a different process.

The ORB must generate a request identifier for each outgoing request and be able to associate the identifier with the reply when it is returned. For deferred synchronous invocations, this allows the Transaction Service to correlate the reply with the request to implement checked behavior. The request identifier is passed on synchronous invocations to permit the same interface to be used.

The callbacks are invoked in line with the processing of requests and replies. This means that the callbacks will be executed on the same thread that issued or processed the actual request or reply. When the DII is used, the `received_reply` callback must be invoked on the same thread that will subsequently process the response.

Requirements on the Transaction Service

Within a single process, the transaction context is part of the thread specific state. Multiple threads executing on behalf of the same transaction will share the same transaction context since a thread can only execute on behalf of a single transaction at a time. Since the callbacks are defined as PIDL (procedure calls), they are invoked on the client's thread when sending and the server's thread when receiving. This enables the Transaction Service to locate the proper transaction context when sending and associate the received transaction context with the thread that will process the transactional operation. The callback interfaces may only raise standard exceptions and may not make additional object invocations using the ORB.

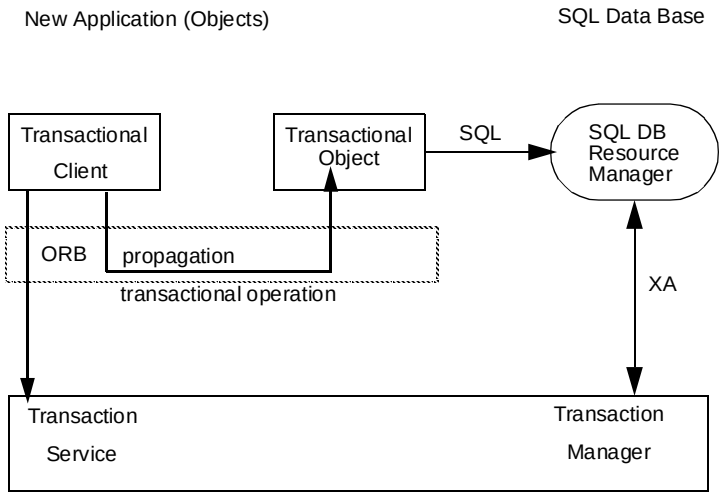
10.5.3 Model Interoperability

The indirect context management programming model of the Transaction Service is designed to be compatible with the X/Open DTP standard, and implementable by existing Transaction Managers. In X/Open DTP, a current transaction is associated with a ***thread of control***. Some X/Open Transaction Managers support a single thread of control in a ***process***, others allow multiple threads of control per process.

Model interoperability is possible because the Transaction Service design is compatible with the X/Open DTP model of a Transaction Manager. X/Open associates an implicit current transaction with each thread of control.

This means that a single transaction management service can provide the interfaces defined for the Transaction Service and also provide the TX and XA interfaces of X/Open DTP. This is illustrated in Figure 10-5.

Figure 10-5 Model interoperability example



The transactional object making the SQL call, and the SQL Resource manager, are both executing on the same thread of control. The transaction manager is able to recognize the relationship between the transaction context of the object, and the transaction associated with the SQL DB.

The *Current* and *Coordinator* interfaces of the Transaction Service implement two-phase commit for the objects in the transaction. The Resource Manager will participate in the two-phase commitment process via the X/Open XA interface.

10.6 The CosTransactions Module

```
module CosTransactions {
// DATATYPES
enum Status {
    StatusActive,
    StatusMarkedRollback,
    StatusPrepared,
    StatusCommitted,
    StatusRolledBack,
    StatusUnknown,
    StatusNoTransaction
    StatusPreparing,
    StatusCommitting,
    StatusRollingBack,
};

enum Vote {
    VoteCommit,
    VoteRollback,
    VoteReadOnly
};

// Structure definitions
struct otid_t {
    long formatID; /*format identifier. 0 is OSI TP */
    long bqual_length;
    sequence <octet> tid;
};
struct TransIdentity {
    Coordinator coordinator;
    Terminator terminator;
    otid_t otid;
};
struct PropagationContext {
    unsigned long timeout;
    TransIdentity current;
    sequence <TransIdentity> parents;
    any implementation_specific_data;
};

// Heuristic exceptions
exception HeuristicRollback {};
exception HeuristicCommit {};
exception HeuristicMixed {};
exception HeuristicHazard {};
```

```
// Other transaction-specific exceptions
exception SubtransactionsUnavailable {};
exception NotSubtransaction {};
exception Inactive {};
exception NotPrepared {};
exception NoTransaction {};
exception InvalidControl {};
exception Unavailable {};

// Forward references for interfaces defined later in module
interface Current;
interface TransactionFactory;
interface Control;
interface Terminator;
interface Coordinator;
interface RecoveryCoordinator;
interface Resource;
interface Synchronization;
interface SubtransactionAwareResource;
interface TransactionalObject;


// Current transaction
interface Current : CORBA::ORB::Current {
    void begin()
        raises(SubtransactionsUnavailable);
    void commit(in boolean report_heuristics)
        raises(
            NoTransaction,
            HeuristicMixed,
            HeuristicHazard
        );
    void rollback()
        raises(NoTransaction);
    void rollback_only()
        raises(NoTransaction);

    Status get_status();
    string get_transaction_name();
    void set_timeout(in unsigned long seconds);

    Control get_control();
    Control suspend();
    void resume(in Control which)
        raises(InvalidControl);
};

interface TransactionFactory {
    Control create(in unsigned long time_out);
    Control recreate(in PropagationContext ctx);
```

```
interface Control {
    Terminator get_terminator()
        raises(Unavailable);
    Coordinator get_coordinator()
        raises(Unavailable);
};

interface Terminator {
    void commit(in boolean report_heuristics)
        raises(
            HeuristicMixed,
            HeuristicHazard
        );
    void rollback();
};

interface Coordinator {

    Status get_status();
    Status get_parent_status();
    Status get_top_level_status();

    boolean is_same_transaction(in Coordinator tc);
    boolean is_related_transaction(in Coordinator tc);
    boolean is_ancestor_transaction(in Coordinator tc);
    boolean is_descendant_transaction(in Coordinator tc);
    boolean is_top_level_transaction();

    unsigned long hash_transaction();
    unsigned long hash_top_level_tran();

    RecoveryCoordinator register_resource(in Resource r)
        raises(Inactive);

    void register_synchronization (in Synchronization sync)
        raises(Inactive, SynchronizationUnavailable);

    void register_subtran_aware(in SubtransactionAwareResource r)
        raises(Inactive, NotSubtransaction);

    void rollback_only()
        raises(Inactive);

    string get_transaction_name();

    Control create_subtransaction()
        raises(SubtransactionsUnavailable, Inactive);

    PropagationContext get_txcontext ()
        raises(Inactive);
};
```

```
interface RecoveryCoordinator {
    Status replay_completion(in Resource r)
        raises(NotPrepared);
};

interface Resource {
    Vote prepare()
            raises(
            HeuristicMixed,
            HeuristicHazard
        );
    void rollback()
        raises(
            HeuristicCommit,
            HeuristicMixed,
            HeuristicHazard
        );
    void commit()
        raises(
            NotPrepared,
            HeuristicRollback,
            HeuristicMixed,
            HeuristicHazard
        );
    void commit_one_phase()
        raises(
            HeuristicHazard
        );
    void forget();
};

interface Synchronization : TransactionalObject {
    void before_completion();
    void after_completion(in Status status);
};

interface SubtransactionAwareResource : Resource {
    void commit_subtransaction(in Coordinator parent);
    void rollback_subtransaction();
};

interface TransactionalObject {
};

}; // End of CosTransactions Module
```

10.6.1 The CosTSPortability Module

```
module CosTSPortability { // PIDL
    typedef long ReqId;

    interface Sender {
        void sending_request(in ReqId id,
            out CosTransactions::PropagationContext ctx);
        void received_reply(in ReqId id,
            in CosTransactions::PropagationContext ctx,
            in CORBA::Environment env);
    };

    interface Receiver {
        void received_request(in ReqId id,
            in CosTransactions::PropagationContext ctx);
        void sending_reply(in ReqId id,
            out CosTransactions::PropagationContext ctx);
    };
};
```

Appendix 10A Relationship of Transaction Service to TP Standards

This appendix discusses the relationship and possible interactions with the following related standards:

- X/Open TX interface
- X/Open XA interface
- OSI TP protocol
- LU 6.2 protocol
- ODMG standard

A.1 Support of X/Open TX Interface

A.1.1 Requirements

The X/Open DTP model[3] is now widely known and implemented.

Since the Transaction Service and the X/Open DTP models are interoperable, an application using transactional objects could use the TX interface, the X/Open-defined interface to delineate transactions, to interact with a Transaction Manager. (The Transaction Manager is the access point of the Transaction Service.)

A.1.2 TX Mappings

The correspondence between the TX interface primitives and the Transaction Service operations (*Current* interface) are as follows:

Table 10-1 TX mappings

TX interface	***Current* interface**
`tx_open()`	*no equivalent*
`tx_close()`	*no equivalent*
`tx_begin()`	`Current::begin()`
`tx_rollback()`	`Current::rollback()` or `Current::rollback_only()`
`tx_commit()`	`Current::commit()`
`tx_set_commit_return()`	`report_heuristics` parameter of `Current::commit()`
`tx_set_transaction_control()`	*no equivalent (chained transactions not supported)*
`tx_set_transaction_timeout()`	`Current::set_timeout()`

3. See "Distributed Transaction Processing: The XA Specification, X/Open Document C193." X/Open Company Ltd., Reading, U.K., ISBN 1-85912-057-1.

Table 10-1 TX mappings

TX interface	*Current* interface
`tx_info() - XID`	`Coordinator::get_txcontext()` `Current::get_name()`[1]
`tx_info() - COMMIT_RETURN`	*no equivalent*
`tx_info() - TRANSACTION_TIME_OUT`	*no equivalent*
`tx_info() - TRANSACTION_STATE`	`Current::get_status()`

1. A printable string is output: not guaranteed to be the XID in all implementations.

tx_open

`tx_open()` provides a way to open, in a given execution environment, the Transaction Manager and the set of Resource Managers that are linked to it. Such an operation does not exist in the Transaction Service; such processing may be implicitly executed when the first operation of the Transaction Service is executed in the execution environment.

This processing is also related to a future Initialization Service.

tx_close

`tx_close()` provides a way to close, in a given execution environment, the Transaction Manager and the set of Resource Managers that are linked to it. Such an operation does not exist in the Transaction Service.

tx_begin

`tx_begin()` corresponds to `Current::begin`() or to `TransactionFactory::create`().

tx_rollback

`tx_rollback()` corresponds to `Current::rollback()`, `Terminator::rollback()`, `Current::rollback_only()` or `Coordinator::rollback_only()` . In TX, when a server calls `tx_rollback()`, the transaction may be rolled back or set as rollback only, as in the Transaction Service

tx_commit and tx_set_commit_return

`tx_commit()` corresponds to `Current::commit(.` The Transaction Service operations have a parameter, `report_heuristics`, corresponding to the `commit_return` parameter of TX.

tx_set_transaction_control

`tx_set_transaction_control()` is used, in TX, to switch between unchained and chained mode; this function is not needed in the Transaction Service environment because it does not support chained transactions.

tx_set_transaction_timeout

`tx_set_transaction_timeout()` corresponds to `Current::set_timeout()` or `TransactionFactory::create()`.

tx_info

`tx_info()` returns information related to the current transaction. In the Transaction Service:

- the XID may be retrieved by `Coordinator::get_txcontext()`;
- the XID (in effect) may be retrieved by `Current::get_transaction_name()`;
- the transaction state may be retrieved by `Current::get_status()`;
- the commit return attribute is not needed because this attribute is given in the `commit()` operation;
- the timeout attribute cannot be obtained.

A.2 Support of X/Open Resource Managers

A.2.1 Requirements

X/Open DTP-compliant Resource Managers, simply called X/Open Resource Managers or RMs, are Resource Managers that can be involved in a distributed transaction by allowing their two-phase commit protocol to be controlled via the X/Open XA Interface. Many RDBMS suppliers currently offer (or intend to offer) X/Open Resource Managers. Many OODBMS' intend also to support the XA Interface (some have already implemented it).

The Transaction Service must therefore be able to interact with X/Open Resource Managers. This section will illustrate how an X/Open Resource Manager may be used by a Transaction Service-compliant system.

The architecture of Transaction Service, based on the same concepts as the X/Open DTP Model, allows mapping of Transaction Service operations to and from XA interactions.

A.2.2 XA Mappings

This section gives an overall view of a possible mapping between XA primitives offered by an X/Open Resource Manager (called RM hereafter) and the interfaces of the Transaction Service and their operations in the different phases of a transaction and during recovery.

The mappings are summarized in the following table:

Table 10-2 XA mappings

X/Open	Object Transaction Service
`xa_start()` `ax_reg()`	`Receiver::received_request` `Current::resume`
`xa_end()`	`Receiver::sending_reply` `Current::suspend`
`ax_unreg()`	*`no equivalent`*
`xa_prepare()`	`Resource::prepare`
`xa_commit()`	`Resource::commit`
`xa_rollback()`	`Resource::rollback`
`xa_recover()`	*`no equivalent`*
`no equivalent`	`RecoveryCoordinator::replay_completion()`
`xa_forget()`	`Resource::forget()`

In the X/Open DTP model all the interactions are made in the same X/Open thread of control.

A.2.3 XID

An XID is the Transaction Identifier. As defined by X/Open, this XID is the only information used by Resource Managers to associate logged information to the transaction, including objects' before images, after images, locks, and transaction state.

The contents of an XID is defined by X/Open as follows:

```
#define XIDDATASIZE 128 /* size in bytes */
#define MAXGTRIDSIZE 64
       /* maximum size in bytes of gtrid */
#define MAXBQUALSIZE 64
       /* maximum size in bytes of bqual */

struct xid_t {
      long formatID;/* format identifier */
      long gtrid_length;
               /* value not to exceed 64 */
      long bqual_length;
               /* value not to exceed 64 */
      char data [XIDDATASIZE];
};
typedef struct xid_t XID;
```

Figure 10-1 X/Open XID

The XID uniquely and unambiguously identifies a distributed transaction (information contained in the `gtrid` part of the XID) and a transaction-branch, the work performed by a node in the transaction tree (information contained in the `bqual` part of the XID).

To facilitate the use of distributed transaction in heterogeneous environments, X/Open has adopted the structure of the Transaction Identifier used in OSI TP but allows the use of other Transaction Identifiers formats, which may be defined by the value of a Format Identifier field contained in the XID structure. The OSI TP Transaction Identifier contains information about the initiator of the transaction and the superior in the transaction tree; this information may be used, during recovery, to contact these entities and obtain the outcome of the transaction.

In the Transaction Service, tightly-coupled concurrency is assumed (a lock held by a transaction may be accessed by any participant of the same transaction) and the transaction branch part of the XID must not be given to RMs.

Interactions with an XA-compliant RM

Model

To model the relationship between the XA interface and the Transaction Service operation, an X/Open Transaction Manager has been modelled; this component is used here as a way to describes the interactions and may be implemented in a different manner.

Propagation of a Transaction to an RM

An RM may support two kinds of involvement interactions:

- Static registration, in which the Transaction Service involves the RM whenever it is itself involved in a new transaction.
- Dynamic registration, in which the RM notifies the Transaction Service that it has been requested to perform some work and request the XID of the current transaction.

An RM gets involved in a transaction when it has to perform some new work for this transaction. This happens in one of the following situations:

- A request carrying a transaction context has just been received and the RM has to perform work for the target object of this request;
- A method performing a request that is carrying a transaction context is resumed (by a `Current::resume()` operation).

An object may receive several requests carrying a transaction context for the same transaction. An RM may also perform work for several objects in the same transaction. Thus an RM may be involved several times in the same transaction; the “resume” and the “join” concepts of XA may be used to notify the RM of any multiple involvement. When an RM has to get involved in a transaction, it must obtain the corresponding XID from the Transaction Service through an `xa_start()` primitive or by a return parameter of an `ax_reg()` primitive. This XID is transmitted to the RM as a parameter to `xa_start()` or `ax_reg()` and is used by the RM to relate any work performed or any lock obtained to the transaction.

If the Transaction Service is called by an `ax_reg()` while it is not aware of any transaction, it returns a null XID to the RM. The RM is then free to start a local transaction of its own, and no Transaction Service transaction will be accepted until the RM issues an `ax_unreg()`.

Refer to X/Open documents for more information about propagation of a transaction to an RM.

First phase of Commitment

When the first phase of commitment is started, the Transaction Service issues an `xa_prepare()` primitive and process its results to determine its decision.

Second Phase of Commitment

When the second phase of commitment is started, the Transaction Service issues an `xa_commit()` primitive and process its results to determine the heuristic situation.

One-phase commitment

When the Transaction Service wants to perform a one-phase commitment, it issues an `xa_commit()` primitive and process its results to determine the heuristic situation.

In the XA interface, there is no specific primitive for one-phase commitment: an RM must consider an `xa_commit()` without preceding `xa_prepare()` as a request to perform a one-phase commitment.

Rollback

When a rollback has to be performed, the Transaction Service issues an `xa_rollback()` primitive and process its results to determine the heuristic situation.

Recovery

In the XA interface, the recovery of an RM is triggered by the Transaction Manager which issues an `xa_recover()`; the RM then gives back a list of all XIDs that are either in the Ready state or have been heuristically completed.

In the Transaction Service recovery is performed by a resource that issues a `replay_completion` operation to a *Coordinator* (see Subsection "Transaction Completion after Failure" in Section 10.5.1).

Failure of an Operation

Any failure of an operation typically leads to a rollback of the transaction, especially if it is not possible to determine whether the operation has been performed or not. However, in the decided commit state, the `commit` operation must be retried until the reply has been received (unless a heuristic hazard condition is detected).

Failure of an RM

If an RM fails, the Transaction Service detecting the failure will issue an xa_recover(). The Transaction Service will then get a list of XIDs of transactions for which the RM is in the ready state and transactions that have been heuristically completed.

The Transaction Service will then:

- Call `xa_rollback()` for all transactions that it knows to be neither in the prepared state nor in the decided commit state.
- Call `xa_commit()` for all transactions that it knows to be in the decided commit state.
- Wait for the decisions commit or rollback for the other.

Failure of Transaction Service

Upon warm restart of the Transaction Service and retrieval of the states of transactions needing recovery from stable storage, the Transaction Service will call `xa_recover()` to get the list of transactions for which the RM needs recovery (see failure of an RM, here above).

A.3 Interoperation with Transactional Protocols

Transactional Protocols

A CORBA application may sometimes need to interoperate with one or more applications using one of the de-facto standard transactional protocol: OSI TP and SNA LU 6.2. In this case, the Transaction Service must be able to import or export transactions using one of these protocols.

Export is the ability to relate a transaction of the Transaction Service to a transaction of a foreign transactional protocol. Importing means relating a Transaction Service transaction to a transaction started on a remote application and propagated via the foreign transactional protocol.

Since the model used by the Transaction Service is similar to the model of OSI TP and the X/Open DTP model, the interactions with OSI TP are straightforward. Since OSI TP is a compatible superset of SNA LU 6.2, a mapping to SNA communications is easily accomplished.

To interoperate, a mapping should be defined for the two-phase commit, rollback, and recovery mechanisms, and for the transaction identifiers.

Notice that neither OSI TP nor SNA LU 6.2 supports nested transactions.

A.3.1 OSI TP Interoperability

OSI TP [ISO92] is the transactional protocol defined by ISO. It has been selected by X/Open to allow the distribution of transactions by one of the communication interfaces: remote procedure call[4], client-server [5] or peer-to-peer (CPI-C Level-2 API [CIW93]).

The Transaction Service supports only unchained transactions. The use of dialogues using the Chained Transactions functional unit is possible only if restrictive rules are defined. These rules are not described in this document.

OSI TP Transaction Identifiers

In OSI TP, loosely-coupled transactions are supported and every node of the transaction tree possesses a transaction branch identifier which is composed of the transaction identifier (or atomic action identifier) and a branch identifier (the branch identifier being null for the root node of the transaction tree). Both the transaction identifier and the branch identifier contains an AE-Title (Application Entity Title) and a suffix that make it unique within a certain scope.

The format of the standard X/Open XID is compatible with the OSI TP identifiers, the `gtrid` corresponding to the atomic action identifier and the `bqual` corresponding to the branch identifier.

Incoming OSI TP Communications (Imported Transactions)

The Transaction Service is a subordinate in an OSI TP transaction tree and interacts with its superior by regular PDUs as defined by the OSI TP protocol. The Transaction Service introduces the transaction identifier received on the OSI TP dialogue using the `TransactionFactory::recreate` operation.

The Transaction Service maps the OSI TP commitment, rollback and recovery procedures to the Transaction Service commitment procedure as follows:

- The Transaction Service, upon reception of an OSI TP Prepare message, will enter the first phase of commitment procedure.
- When it enters the prepared state for the transaction, the Transaction Service will trigger the sending of an OSI TP Ready message to its superior. (It may trigger a Recover (Ready) message when normal communications are broken with the superior).
- The Transaction Service, upon reception of an OSI TP Commit message, enters the second phase of commitment procedure. (It may receive a Recover (Commit) when normal communications are broken with the superior.)
- The Transaction Service, upon reception of an OSI TP Rollback message (it may be a Recover (Unknown) when normal communications are broken with the superior or any other rollback-initiating condition) will enter its rollback procedure (unless a rollback is already in progress).
- The Transaction Service, upon reception of the last rollback reply, will trigger the sending of a Rollback Response/Confirm message to its superior.

4. See "Distributed Transaction Processing: The TxRPC Specification, X/Open Document P305." X/Open Company Ltd., Reading, U.K..

5. See "Distributed Transaction Processing: The XATMI Specification, X/Open Document P306." X/Open Company Ltd., Reading, U.K..

Outgoing OSI TP Communications (Exported Transactions)

The Transaction Service behaves as a superior in an OSI TP transaction tree and interacts with its subordinates by regular PDUs as defined by the OSI TP protocol.

The Transaction Service will map the OSI TP commitment procedure as follows:

- The Transaction Service, during the first phase of commitment procedure will invoke an OSI TP Prepare message to all its subordinates.
- Upon reception of an OSI TP Ready message, the Transaction Service will process this message as a successful reply to prepare.
- The Transaction Service, upon entering the second phase of the commitment procedure will send an OSI TP Commit message (it may be a Recover (Commit) when normal communications are broken with the subordinate) to all subordinates.
- The Transaction Service, upon reception of an OSI TP Rollback message (it may be any other rollback-initiating condition) will enter its rollback procedure (unless a rollback is already in progress).
- The Transaction Service, upon reception of the last Rollback Response/Confirm message from its subordinates, will process this message as a reply to a rollback operation and determine the heuristic situation.

A.3.2 SNA LU 6.2 Interoperability

SNA LU 6.2 ([SNA88a], [SNA88b]) is a transactional protocol defined by IBM. It is widely used for transaction distribution. The standard interface to access LU 6.2 communications is CPI-C (Common Programming Interface for Communications) defined by IBM in the context of SAA [CPIC93] and currently being evolved by the CPI-C Implementers' Workshop to become CPI-C level 2, a modern interface usable for LU 6.2 and OSI TP communications [CIW93].

LU 6.2 supports only chained transactions but, at a given node, a transaction is started only when resources have been involved in the transaction. LU 6.2 can be used for a portion of an “unchained” transaction tree if the LU 6.2 conversations are ended after each transaction by any node that has both LU 6.2 conversations and dialogues of an unchained transaction.

LU 6.2 Transaction Identifiers

SNA LU 6.2 also supports loosely-coupled transactions and uses a specific format for transaction identifiers: the Logical Unit of Work (LUWID) corresponds to the OSI Transaction Identifier. The LUWID is composed of:

- The Fully Qualified Logical Unit Name, which is composed of up to 17 bytes, is unique in an SNA network or a set of interconnected SNA networks.
- An instance number which is unique at the LU that create the transaction.
- The sequence number that is incremented whenever the transaction is committed.

The Conversation Correlator corresponds to the OSI TP Branch Identifier; it is a string of 1 to 8 bytes which are unique within the context of the LU having established the conversation and is meaningful when combined with the Fully Qualified LU Name of this Logical Unit.

Incoming LU 6.2 Communications

The LU 6.2 two-phase commit protocol is different from the OSI TP protocol: the system sending a Prepare message has to perform logging and is responsible for recovery. LU 6.2 does also support features like last-agent optimization, read-only and allows any node in the transaction tree to request commitment..

The Transaction Service is a subordinate in an LU 6.2 transaction tree and interacts with its superior using SNA requests and responses as defined by the LU 6.2 protocol. The Transaction Service maps the LUWID corresponding to the incoming conversation to an OMG `otid_t` and issues `TransactionFactory::recreate` to import the transaction.

The Transaction Service maps the LU 6.2 commitment, rollback and recovery procedures to the Transaction Service commitment procedure as follows:

- The Transaction Service, upon reception of an LU 6.2 Prepare message will enter the first phase of commitment procedure.
- The Transaction Service, upon entering the prepared state for the transaction, the Transaction Service will trigger the sending of a Request Commit message to is superior.
- The Transaction Service, upon reception of an LU 6.2 Committed message (it may be a Compare States (Committed) when normal communications are broken with the superior) will enter the second phase of commitment procedure.
- The Transaction Service, upon leaving the decided commit state, will trigger the sending of a Forget message to is superior (it may be a Reset when normal communications are broken with the superior).

Due to the two-phase commit difference, the Transaction Service will never send the equivalent of the Recover(Ready) unless prompted by the superior.

The last-agent and read-only features may also be supported by the Transaction Service.

Outgoing LU 6.2 Communications

The Transaction Service has to log when the Prepare message is sent and, in case of communication failure or restart of the Transaction Service, a recovery is needed.

ODMG Standard

ODMG-93 is a standard defined by ODMG (Object Database Management Group) describing portable interface to access Object Database Management Systems (ODBMS).

Since it is likely that, in the future, many objects involved in transactions will be handled by an ODBMS, this standard has a strong relationship with the Transaction Service.

A.4 ODMG Model

The ODMG model defines optional transactions and supports the nested transaction concept. The ODMG model does not cover the integration of ODBMS with an external Transaction Service, allowing other resources and communications to be involved in a transaction. No two-phase commit or recovery protocol is described.

A transaction object must be created. The transactional operations are:

- Begin (or start) to begin a transaction (or a subtransaction).
- Commit to request commitment of a transaction.
- Abort to rollback a transaction.
- Checkpoint to commit the transaction but keep the locks. This feature is not supported by the current version of the Transaction Service.
- abort_to_top_level to request rollback of a nested transaction family. The Transaction Service does not directly support this feature but does provide means to perform this functionality by resuming the context of the top-level transaction and then requesting rollback.

If the transaction object is destroyed, the transaction is rolled back.

Integration of ODMG ODBMSs with the Transaction Service

Since ODMG-93 does not define any way to integrate an ODBMS into an existing transaction, the integration is difficult unless the ODBMS supports the XA interface, in which case the section on XA-compliant RM is applicable.

In the future, it is anticipated that ODBMS will implement the Transaction Service-defined interfaces and be considered as a recoverable server.

A possibility is to use, at a root node, an ODBMS as a last resource and, after all subordinates are prepared, to request a one-phase commitment to the ODBMS. If the outcome for the ODBMS is commit, the transaction will be committed, if it is rollback, the transaction will be rolled back. The mechanism may work if it is possible to determine, after a crash, whether the ODBMS committed or rolled back; this may be done at application level.

Appendix 10B Transaction Service Glossary

2PC: See *Two-phase commit.*

Abort: See *Rollback*

Active: the state of a transaction when processing is in progress and *completion* of the transaction has not yet commenced.

Atomicity: a transaction property that ensures that if work is interrupted by failure, any partially completed results will be undone. A transaction whose work completes is said to commit. A transaction whose work is completely undone is said to rollback (abort).

Begin: An operation on the Transaction Service which establishes the initial boundary of a transaction.

Commit: Commit has two definitions as follows:

a. An operation in the *Current* and *Terminator* interfaces that a program uses to request that the current transaction terminate normally and that the effects of that transaction be made permanent.

b. An operation in the *Resource* interface which causes the effects a transaction to be made permanent

Commit coordinator: In a two-phase commit protocol, the program that collects the vote from the participants.

Commit participant: In a two-phase commit protocol, the program that returns a vote on the completion of a transaction.

Committed: the property of a transaction or a transactional object, when it has successfully performed the commit protocol. See also *in-doubt*, *active*, and *rolled back*.

Completion: the processing required (either by *commit* or *rollback*) to obtain the durable outcome of a transaction.

Coordinator: a coordinator involves *Resource* objects in a transaction when they are registered. A coordinator is responsible for driving the two-phase commit protocol. See also *Commit coordinator* and *Commit participant.*

Consistency: a property of a transaction that ensures that the transaction's actions, taken as a group, do not violate any of the integrity constraints associated with the state of its associated objects. This requires that the application program be implemented correctly: the Transaction Service provides the functionality to support application data consistency.

Decided commit state: a root coordinator enters the decided commit state when it has written a log-commit record; a subordinate coordinator or resource is in the decided commit state when it has received the commit instruction from its superior; in the latter case, a log-commit record may be written but this is not essential.

Decided rollback state: a coordinator or resource enters the decided rollback state when it decides to rollback the transaction or has received a signal to do so.

Direct context management: an application manipulates the *Control* object and the other objects associated with the transaction. See also *Indirect context management.*

Durability: A transaction property that ensures the results of a successfully completed transaction will never be lost, except in the event of catastrophe. It is generally implemented by a combination of persistent storage and a logging service that provides a backup copy of permanent changes.

Execution environment: an implementation-dependent factor that may determine the outcome of certain operations on the Transaction Service. Typically the execution environment is the scope within which shared state is managed.

Flat Transaction: A transaction that has no subtransactions—and that cannot have subtransactions.

Forgotten "state": this is not really a transaction state at all, because there is no memory of the transaction: it has either completed or rolled back and all records on permanent storage have been deleted

Heuristic Commit or Rollback: To unilaterally make the commit or rollback decision about *in-doubt* transactions when the coordinator fails or contact with the coordinator fails.

Indirect context management: an application uses the *Current* object, provided by the Transaction Service, to associate the transaction context with the application thread of control. See also *Direct context management.*

In-doubt: The state of a transaction if it is controlled by a transaction manager that can not be contacted, so the commit decision is in doubt. See also *active*, *committed*, *rolled back*.

Interposition: adding a sequence of one or more *subordinate coordinators* between a *root coordinator* and its participants.

Isolation: A transaction property that allows concurrent execution, but the results will be the same as if execution was serialized. Isolation ensures that concurrently executing transactions cannot observe inconsistencies in shared data.

Lock service: Called the Concurrency Control Service, it is an Object Service used by resources to control access to shared objects by concurrently executing methods.

Log-ready record (and contents): for an intermediate coordinator a log-ready record contains identification of the (superior) coordinator and of *Resource* objects (including subordinate coordinators) registered with the coordinator which replied `VoteCommit` (i.e. it excludes registered objects which replied `VoteReadOnly`); for a *Resource* object a log-ready record includes identification of the coordinator with which it is registered

Log-commit record (and contents): a log-commit record contains identification of all registered *Resource* objects which replied `VoteCommit`.

Log-heuristic record: this contains a record of a heuristic decision either `HeuristicCommit` or `HeuristicRollback`.

Log-damage record: this contains a record of heuristic damage i.e. where it is known that a heuristic decision conflicted with the decided outcome (`HeuristicMixed`) or where there is a risk that a heuristic decision conflicted with the decided outcome (`HeuristicHazard`).

Log service: A service used by resource managers for recording recovery information and the Transaction Service for recording transaction state durably.

Nested transaction: A transaction that either has subtransaction or is a subtransaction on some other transaction.

Participant: See *Commit participant.*

Persistent storage: generally speaking, a synonym for *Stable storage*. In the context of the OMA, the Persistent Object Service (POS) provides an object representation of stable storage.

Prepared: The state that a transaction is in when phase one of a two-phase commit has completed.

Presumed rollback: An optimization of the two-phase commit protocol that results in more efficient performance as the *root coordinator* does not need to log anything before the commit decision and the *Participants* (i.e. *Resource* objects) do not need to log anything before they prepare. So called because, at restart, if no record of the transaction is found, it is safe to assume the transaction rolled back.

Propagation: A function of the Transaction Service that allows the *Transaction context* of a client to be associated with a transactional operation on a server object. The Transaction Service supports both implicit and explicit propagation of transaction context.

Recoverable Object: An object whose data is affected by committing or rolling back a transaction.

Recoverable Server: A transactional object with recoverable state that registers a *Resource* (not necessarily itself) with a *Coordinator* to participate in transaction completion.

Recovery Service: A service used by resource managers for restoring the state of objects to a prior state of consistency.

Resource: an object in the Transaction Service that is registered for involvement in two-phase commit—*2PC*. Corresponds to a *Resource Manager.*

Resource Manager: An X/Open term for a component which manages the integrity of the state of a set of related resources.

Rollback: Rollback (also known as *Abort*) has two definition as follows

1. An operation in the *Current* and *Terminator* interfaces used to indicate that the current transaction has terminated abnormally and its effects should be discarded.

2. An operation in the *Resource* interface which causes all state changes in the transaction to be undone

Rolled Back: the property of a transaction or a transactional object when it has discarded all changes made in the current transaction. See also *in-doubt*, *active*, and *committed*.

Root Coordinator: the first coordinator in a sequence of coordinators where there is interposition. The coordinator associated with the transaction originator.

Security Service: An object service which provides identifications of users (authentication), controls access to resources (authorization), and provides auditing of resource access.

Stable storage: storage not likely to be damaged as the result of node failure.

Sub-coordinator: See *Subordinate Coordinator*.

Subordinate Coordinator: a coordinator subordinate to the *root coordinator* when *interposition* has been performed. A subordinate coordinator appears as a *Resource* object to its superior. Also known as a *Sub-coordinator*.

Synchronization: An object in the Transaction Service which controls the transfer of persistent object state data so it can be made durable by its associated resource.

Thread: The entity that is currently in control of the processor.

Thread Service: A service which enables methods to be executed concurrently by the same process. Where two or more methods can execute concurrently each method is associated with its own thread of control.

TP monitor: A system component that accepts input work requests and associates resources with the programs that act upon these requests to provide a run-time environment for program execution.

Transaction: A collection of operations on the physical and abstract application state.

Transactional client: an arbitrary program that can invoke operations of many transactional objects in a single transaction. Not necessarily the *Transaction originator*.

Transaction Context: the transaction information associated with a specific thread. See *Propagation*.

Transactional operation: An operation on an object that participates in the propagation of the current transaction.

Transaction originator: an arbitrary program—typically, a transactional client, but not necessarily an object—that begins a transaction.

Transaction Manager: A system component that implements the protocol engine for 2-phase commit protocol. See also *Transaction Service*.

Transactional object: An object whose operations are affected by being invoked within the scope of a transaction.

Transactional server: a collection of one or more objects whose behavior is affected by the transaction, but has no recoverable state of its own.

Transaction Service: An Object Service that implements the protocols required to guarantee the ACID (Atomicity, Consistency, Isolation, and Durability) properties of transactions. See also *Transaction Manager*.

TSPortability: an interface of the Transaction Service which allows it to track transactional operations and propagate transaction context to another Transaction Service implementation.

Two-Phase commit: A transaction manager protocol for ensuring that all changes to recoverable resources occur atomically and furthermore, the failure of any resource to complete will cause all other resource to undo changes. Also called *2PC*.