Jini™ Transaction Specification

This document provides a two-phase commit protocol , allowing objects using that protocol to enter into distributed transactions. This specification defines the interfaces used by clients, participants, and managers of the protocol. Participants using the protocol may provide any service; they are not limited to databases or other persistent storage services. The default transaction semantics for services is also defined, along with associated semantics classes and interfaces.

Sun
microsystems

THE NETWORK IS THE COMPUTER™

901 San Antonio Road
Palo Alto, CA 94303 USA
415 960-1300
fax 415 969-9131

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TRADEMARKS

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Introduction 1

1.1 Overview

Transactions are a fundamental tool for many kinds of computing. A transaction allows a set of operations to be grouped in such a way that they either all succeed or all fail; further, the operations in the set appear from outside the transaction to occur simultaneously. Transactional behaviors are especially important in distributed computing, where they provide a means for enforcing consistency over a set of operations on one or more remote participants. If all the participants are members of a transaction, one response to a remote failure is to abort the transaction, thereby ensuring that no partial results are written.

Traditional transaction systems often center around transaction processing monitors that insure that the correct implementation of transactional semantics is provided by all of the participants in a transaction. Our approach to transactional semantics is somewhat different. Within our system, we leave it to the individual objects that take part in a transaction to implement the transactional semantics in the way that is best for that kind of object. What the system primarily provides is the coordination mechanism that can be used by those objects to communicate the information necessary for the set of objects to agree on the transaction. The goal of this system is to provide the *minimal* set of protocols and interfaces that *allow* objects to implement transaction semantics rather than the *maximal* set of interfaces, protocols, and policies that *ensure* the correctness of any possible transaction semantics. So the completion protocol is separate from the semantics of particular transactions.

This document presents this completion protocol, which consists of a two-phase commit protocol for distributed transactions. The two-phase commit protocol defines the communication patterns that allow distributed objects and resources to wrap a set of operations in such a way that they appear to be a single operation. The protocol requires a manager that will enable consistent resolution of the operations by a guarantee that all participants will eventually know whether they should commit the operations (roll forward) or abort them (roll backwards). A participant can be any object that supports the participant contract by implementing the appropriate interface. Participants are not limited to databases or other persistent storage services.

Clients and servers will also need to depend on specific transaction semantics. The default transaction semantics for participants is also defined in this document.

The two-phase commit protocol presented here, while common in many traditional transaction systems, has the potential to be used in more than just traditional transaction processing applications. Since the semantics of the individual operations, and the mechanisms that are used to insure various properties of the meta-operation joined by the protocol, are left up to the individual objects, variations of the usual properties required by transaction processing systems are possible using this protocol, as long as those variances can be resolved by this protocol. A group of objects could use the protocol, for example, as part of a process allowing synchronization of data that have been allowed to drift for efficiency reasons. While this use is not generally considered to be a classical use of transactions, the protocol defined here could be used for this purpose. Some variations will not be possible under these protocols, requiring subinterfaces and subclasses of the ones provided, or entirely new interfaces and classes.

Because of the possibility of application to situations that are beyond the usual use of transactions, calling the two-phase commit protocol a transaction mechanism is somewhat misleading. However, since the most common use of such a protocol is in a transactional setting, and because we do define a particular set of default transaction semantics, we will follow the usual naming conventions used in such systems rather than attempting to invent a new, parallel vocabulary.

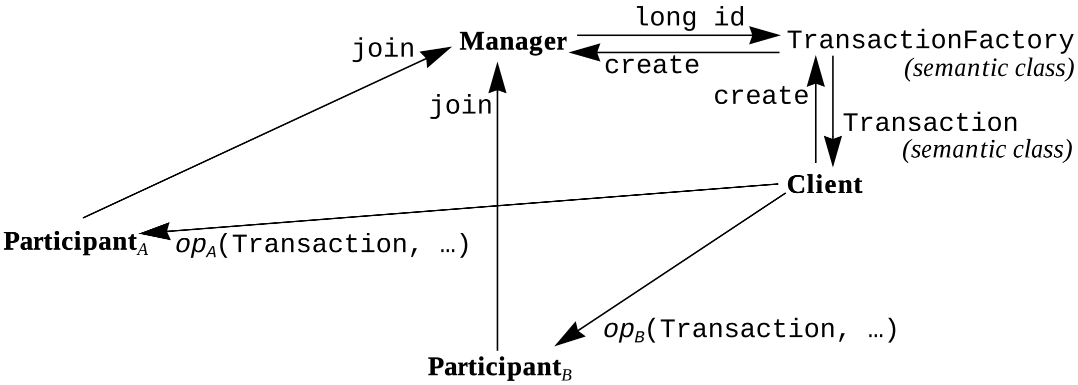
The classes and interfaces defined by this specification are in the packages `net.jini.core.transaction` and `net.jini.core.transaction.server`. In this document you will usually see these types used without a package prefix; as each type is defined, the package it is in is specified.

1.2 Model and Terms

A transaction is created and overseen by a *manager*. Each manager implements the interface `TransactionManager`. Each *transaction* is represented by a `long` identifier that is unique with respect to the transaction's manager.

Semantics are represented by *semantic* transaction objects, such as the ones that represent the default semantics for services. Even though the manager only needs to know how to complete transactions, clients and participants need to share a common view of the semantics of the transaction. Therefore, clients typically create, pass, and operate on semantic objects that contain the transaction identifier instead of using the transaction's identifier directly, and transactable services typically accept parameters of a particular semantic type, such as the `Transaction` interface used for the default semantics.

A *client* creates a transaction by a request to the manager, typically by using a semantic factory class such as `TransactionFactory` to create a semantic object. The semantic object created is then passed as a parameter when performing operations on a service. If the service is to accept this transaction and govern its operations thereby, it must *join* the transaction as a *participant*. Participants in a transaction must implement the `TransactionParticipant`



interface. Particular operations associated with a given transaction are said to be *performed under* that transaction. The client which created the transaction may or may not be a participant in the transaction.

A transaction *completes* when any entity either *commits* or *aborts* the transaction. If a transaction commits successfully, then all operations performed under that transaction will complete. Aborting a transaction means that all operations performed under that transaction will appear never to have happened.

Committing a transaction requires each participant to *vote,* where a vote is either *prepared* (ready to commit), *not changed* (read-only), or *aborted* (the transaction should be aborted). If all participants vote "prepared" or "not changed," the transaction manager will tell each "prepared" participant to *roll forward,* thus committing the changes. Participants that voted "not changed" need do nothing more. If the transaction is ever aborted, the participants are told to *roll back* any changes made under the transaction.

1.3 Distributed Transactions and ACID Properties

The two-phase commit protocol is designed to enable objects to provide ACID properties. The default transaction semantics define one way to preserve these properties. The ACID properties are:

- *Atomicity:* All the operations grouped under a transaction occur or none of them do. The protocol allows participants to discover which of these alternatives is expected by the other participants in the protocol. However, it is up to the individual object to determine if it wishes to operate in concert with the other participants.
- *Consistency:* The completion of a transaction must leave the system in a consistent state. Consistency includes issues known only to humans, such as that an employee should always have a manager. The enforcement of consistency is outside of the realm of the transaction itself—a transaction is a tool to allow consistency guarantees, and not itself a guarantor of consistency.
- *Isolation:* Ongoing transactions should not affect each other. Participants in a transaction should only see intermediate states resulting from the operations of their own transaction, not the intermediate states of other transactions. The protocol allows participating objects to know what operations are being done within the scope of a transaction. However, it is up to the individual

object to determine if such operations are to be reflected only within the scope of the transaction or can be seen by others who are not participating in the transaction.

- *Durability:* The results of a transaction should be as persistent as the entity on which the transaction commits. However, such guarantees are up to the implementation of the object.

The dependency on the participant's implementation for the ACID properties is the greatest difference between this two-phase commit protocol and more traditional transaction processing systems. Such systems attempt to insure that the ACID properties are met, and go to considerable trouble to insure that no participant can violate any of the properties.

This approach differs for both philosophical and practical reasons. The philosophical reason is centered around the basic tenet of object-oriented programming, which is that the implementation of an object should be hidden from any part of the system outside the object. Ensuring the ACID properties generally requires that an object's implementation correspond to certain patterns. We believe that, if these properties are needed, the object (or, more precisely, the programmer implementing the object) will know best how to guarantee the properties. For this reason, the manager is solely concerned with completing transactions properly. Clients and participants must agree on semantics separately.

The practical reason for leaving the ACID properties up to the object is that there are situations in which only some of the ACID properties make sense, but which can still make use of the two-phase commit protocol. A group of transient objects may wish to group a set of operations in such a way that they appear atomic; in such a situation it makes little sense to require that the operations be durable. An object might want to enable the monitoring of the state of some long-running transactions; such monitoring would violate the isolation requirement of the ACID properties. Binding the two-phase commit protocol to all of these properties limits the use of such a protocol.

We also know that particular semantics are needed for particular services. The default transaction semantics provide useful general-purpose semantics built on the two-phase commit completion protocol.

Distributed transactions differ from single-system transactions in the same way that distributed computing differs from single-system computing. The clearest difference is that a single system can have a single view of the state of several services. It is possible in a single system to make it appear to any observer that all operations performed under a transaction have occurred or none have, thereby achieving isolation. In other words, no observer will ever see part of the changes made under the transaction but not others. In a distributed system it is possible for a client using two servers to see the committed state of a transaction in one server and the pre-committed state of the same transaction in another server. This can only be prevented by coordination with the transaction manager or the client that committed the transaction. Coordination between clients is outside the scope of this specification.

1.4 Requirements

The transaction system has the following requirements:

- Define types and contracts that allow the two-phase commit protocol to govern operations on multiple servers of differing types or implementations.
- Allow participation in the two-phase commit protocol by any object in the Java programming language, where "participation" means to perform operations on that object under a given transaction.
- Each participant may provide ACID properties with respect to that participant to observers operating under a given transaction.
- Use standard Java™ programming language techniques and tools to accomplish these goals. Specifically, transactions will rely upon Java Remote Method Invocation (RMI) to communicate between participants.
- Define specific default transaction semantics for use by services.

1.5 Dependencies

This document relies upon the following other specifications:

- Java Remote Method Invocation Specification
- Jini™ Distributed Leasing Specification

1.6 Comments

Please direct comments to `jini-comments@java.sun.com`.

The Two-Phase Commit Protocol 2

The two-phase commit protocol is defined using three primary types:

- `TransactionManager` — A transaction manager creates new transactions and coordinates the activities of the participants.
- `NestableTransactionManager` — Some transaction managers are capable of supporting nested transactions.
- `TransactionParticipant` — When an operation is performed under a transaction, the participant must join the transaction, providing the manager with a reference to a `TransactionParticipant` object that will be asked to vote, roll forward, or roll back.

All code in this specification assumes that `java.rmi.Remote`, `java.rmi.RemoteException`, `java.rmi.NoSuchObjectException`, `java.io.Serializable`, `net.jini.core.lease.LeaseDeniedException`, and `net.jini.core.lease.Lease` have been imported. All methods defined to throw `RemoteException` will do so in the circumstances described by the RMI specification.

Each type is shown where it is first described. Each method is described where it occurs in the lifecycle of the two-phase commit protocol. By the end of this chapter, all methods, fields, and exceptions that can occur during the lifecycle of the protocol will be specified. The section in which each method or field is specified is shown in a comment.

2.1 Starting a Transaction

The TransactionManager interface is implemented by servers that manage the two-phase commit protocol:

```
package net.jini.core.transaction.server;

public interface TransactionManager
    extends Remote, TransactionConstants // §2.4
{
    public static class Created implements Serializable { // §2.1
        public final long id;
        public final Lease lease;
        public Created(long id, Lease lease);
    }
    Created create(long leaseFor) // §2.1
        throws LeaseDeniedException, RemoteException;
    void join(long id, TransactionParticipant part,
                long crashCount) // §2.3
        throws UnknownTransactionException, CannotJoinException,
                CrashCountException, RemoteException;
    int getState(long id) // §2.7
        throws UnknownTransactionException, RemoteException;
    void commit(long id) // §2.5
        throws UnknownTransactionException, CannotCommitException
                RemoteException;
    void commit(long id, long waitFor) // §2.5
        throws UnknownTransactionException, CannotCommitException,
                TimeoutExpiredException, RemoteException;
    void abort(long id) // §2.5
        throws UnknownTransactionException, CannotAbortException,
                RemoteException;
    void abort(long id, long waitFor) // §2.5
        throws UnknownTransactionException, CannotAbortException,
                TimeoutExpiredException, RemoteException;
}
```

A client obtains a reference to a TransactionManager object via a lookup service or some other means. The details of obtaining such a reference are outside the scope of this specification.

A client creates a new transaction by invoking the manager's create method, providing a desired leaseFor time in milliseconds. This invocation is typically indirect via creating a semantic object. The time is the client's expectation of how long the transaction will last before it completes. The manager may grant a shorter lease, or may deny the request by throwing LeaseDeniedException. If the granted lease expires or is cancelled before the transaction manager receives a commit or abort of the transaction the manager will abort the transaction.

The purpose of the Created nested class is to allow the create method to return two values—the transaction identifier and the granted lease. The constructor simply sets the two fields from its parameters.

2.2 Starting a Nested Transaction

The TransactionManager.create method returns a new *top-level* transaction. Managers that implement just the TransactionManager interface only support top-level transactions. *Nested* transactions, also known as *subtransactions*, can be created using managers that implement the NestableTransactionManager interface:

```
package net.jini.core.transaction.server;

public interface NestableTransactionManager
    extends TransactionManager
{
    TransactionManager.Created create(
                        NestableTransactionManager parentMgr,
                        long parentID, long leaseFor) // §2.2
        throws UnknownTransactionException, CannotJoinException,
                LeaseDeniedException, RemoteException;
    void promote(long id, TransactionParticipant[] parts,
                long[] crashCounts, TransactionParticipant drop)
        throws UnknownTransactionException, CannotJoinException,
                CrashCountException, RemoteException; // §2.7
}
```

The create method takes a *parent* transaction, represented by the manager for the parent transaction and the id for that transaction, and a desired lease time in milliseconds, and returns a new *nested* transaction that is *enclosed by* the specified parent along with the granted lease.

When you use a nested transaction you allow changes to a set of objects to abort without forcing an abort of the parent transaction, and you allow the commit of those changes to still be conditional on the commit of the parent transaction.

When a nested transaction is created, its manager joins the parent transaction. When the two managers are different, this is done explicitly via `join` (§2.3). When the two managers are the same this may be done in a manager-specific fashion.

The `create` method throws `UnknownTransactionException` if the parent transaction is unknown to the parent transaction manager, either because the transaction id is incorrect or the transaction is no longer active and its state has been discarded by the manager.

```
package net.jini.core.transaction;

public class UnknownTransactionException
        extends TransactionException
{
    public UnknownTransactionException();
    public UnknownTransactionException(String desc);
}
public class TransactionException extends Exception {
    public TransactionException();
    public TransactionException(String desc);
}
```

The `create` method throws `CannotJoinException` if the parent transaction is known to the manager but is no longer active.

```
package net.jini.core.transaction;

public class CannotJoinException extends TransactionException {
    public CannotJoinException();
    public CannotJoinException(String desc);
}
```

2.3 Joining a Transaction

The first time a client tells a participant to perform an operation under a given transaction, the participant must invoke the transaction manager's `join` method with an object that implements the `TransactionParticipant` interface. This object will be used by the manager to communicate with the participant about the transaction.

```
package net.jini.core.transaction.server;

public interface TransactionParticipant
    extends Remote, TransactionConstants // §2.4
{
    int prepare(TransactionManager mgr, long id) // §2.6
        throws UnknownTransactionException, RemoteException;
    void commit(TransactionManager mgr, long id) // §2.6
        throws UnknownTransactionException, RemoteException;
    void abort(TransactionManager mgr, long id) // §2.6
        throws UnknownTransactionException, RemoteException;
    int prepareAndCommit(TransactionManager mgr, long id) // §2.7
        throws UnknownTransactionException, RemoteException;
}
```

If the participant's invocation of the `join` method throws `RemoteException` the participant should not perform the operation requested by the client, and should rethrow the exception or otherwise signal failure to the client.

The `join` method's third parameter is a *crash count* that uniquely defines the version of the participant's storage that holds the state of the transaction. Each time the participant loses the state of that storage (for example because of a system crash, if the storage is volatile) it must change this count. For example, the participant could store the crash count in stable storage.

When a manager receives a `join` request, it checks to see if the participant has already joined the transaction. If it has, and the crash count is the same as the one specified in the original `join`, the `join` is accepted but is otherwise ignored. If the crash count is different, the manager throws `CrashCountException` and forces the transaction to abort.

```
package net.jini.core.transaction.server;

public class CrashCountException extends TransactionException {
    public CrashCountException();
    public CrashCountException(String desc);
}
```

The participant should reflect this exception back to the client. This check makes `join` idempotent when it should be, but forces an abort for a second `join` of a transaction by a participant that has no knowledge of the first `join`, and hence has lost whatever changes were made after the first `join`.

An invocation of `join` can throw `UnknownTransactionException`, which means the transaction is unknown to the manager, either because the transaction id was incorrect, or the transaction is no longer active and its state has been discarded by the manager. The `join` method throws `CannotJoinException` if the transaction is known to the manager but is no longer active. In either case the `join` has failed, and the method that was attempted under the transaction should reflect the exception back to the client. This is also the proper response if `join` throws a `NoSuchObjectException`.

2.4 Transaction States

The `TransactionConstants` interface defines constants used in the communication between managers and participants.

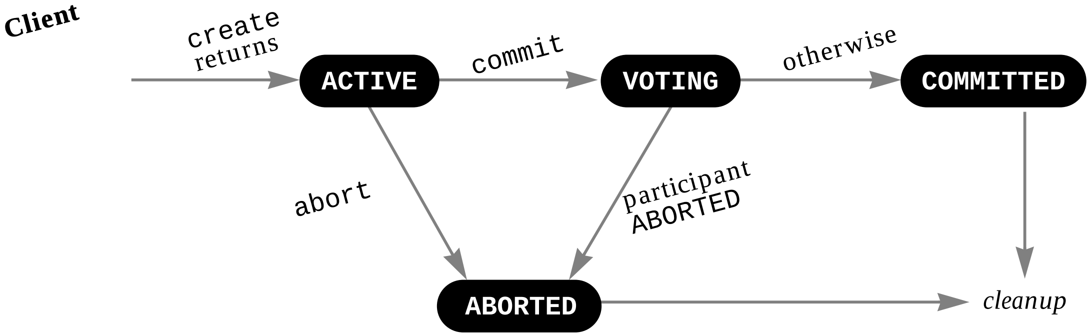
```
package net.jini.core.transaction.server;

public interface TransactionConstants {
    int ACTIVE = 1;
    int VOTING = 2;
    int PREPARED = 3;
    int NOTCHANGED = 4;
    int COMMITTED = 5;
    int ABORTED = 6;
};
```

These correspond to the states and votes that participants and managers go through during the lifecycle of a given transaction.

2.5 Completing a Transaction: The Client's View

In the client's view, a transaction goes through the following states:



For the client, the transaction starts out ACTIVE as soon as create returns. The client drives the transaction to completion by invoking commit or abort on the transaction manager, or by cancelling the lease or letting the lease expire (both of which are equivalent to an abort).

The one-parameter commit method returns as soon as the transaction successfully reaches the COMMITTED state, or if the transaction is known to have previously reached that state due to an earlier commit. If the transaction reaches the ABORTED state, or is known to have previously reached that state due to an earlier commit or abort, then commit throws CannotCommitException.

```
package net.jini.core.transaction;

public class CannotCommitException extends TransactionException
{
    public CannotCommitException();
    public CannotCommitException(String desc);
}
```

The one-parameter abort method returns as soon as the transaction successfully reaches the ABORTED state, or if the transaction is known to have previously reached that state due to an earlier commit or abort. If the transaction is known to have previously reached the COMMITTED state due to an earlier commit, then abort throws CannotAbortException.

```
package net.jini.core.transaction;

public class CannotAbortException extends TransactionException {
    public CannotAbortException();
    public CannotAbortException(String desc);
}
```

Both commit and abort can throw UnknownTransactionException, which means the transaction is unknown to the manager. This may be because the transaction id was incorrect, or because the transaction has proceeded to *cleanup* due to an earlier commit or abort, and has been forgotten.

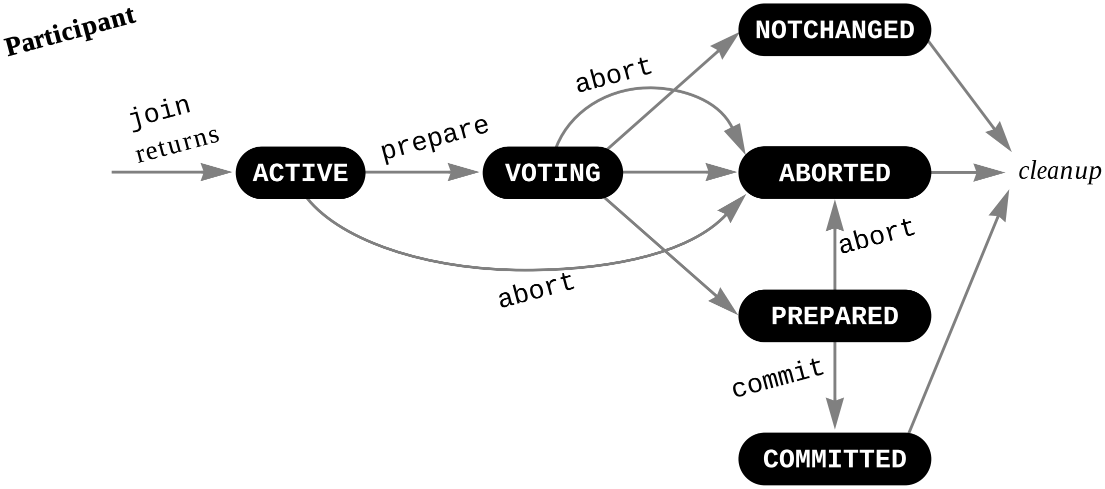
Overloads of the commit and abort methods take an additional waitFor timeout parameter specified in milliseconds that tells the manager to wait until it has successfully notified all participants about the outcome of the transaction before the method returns. If the timeout expires before all participants have been notified, a TimeoutExpiredException will be thrown. If the timeout expires before the transaction reaches the COMMITTED or ABORTED state, the manager must wait until one of those states is reached before throwing the exception. The `committed` field in the exception is set to `true` if the transaction committed or `false` if it aborted.

```
package net.jini.core.transaction;

public class TimeoutExpiredException extends TransactionException
{
    public boolean committed;
    public TimeoutExpiredException(boolean committed);
    public TimeoutExpiredException(String desc, boolean committed);
}
```

2.6 Completing a Transaction: A Participant's View

In a participant's view, a transaction goes through the following states:



For the participant, the transaction starts out ACTIVE as soon as `join` returns. Any operations attempted under a transaction are valid only if the participant has the transaction in the ACTIVE state. In any other state, a request to perform an operation under the transaction should fail, signaling the invoker appropriately.

When the manager asks the participant to prepare, the participant is VOTING until it decides what to return. There are three possible return values for prepare:

- The participant had no changes to its state made under the transaction—that is, for the participant the transaction was read-only. It should release any internal state associated with the transaction. It must signal this with a return of NOTCHANGED, effectively entering the NOTCHANGED state. As noted below, a well-behaved participant should stay in the NOTCHANGED state for some time to allow idempotency for prepare.
- The participant had its state changed by operations performed under the transaction. It must attempt to prepare to roll those changes forward in the event of a future incoming commit invocation. When the participant has successfully prepared itself to roll forward (§2.8), it must return PREPARED, thereby entering the PREPARED state.
- The participant had its state changed by operations performed under the transaction, but is unable to guarantee a future successful roll forward. It must signal this with a return of ABORTED, effectively entering the ABORTED state.

For top-level transactions, when a participant returns PREPARED it is stating that it is ready to roll the changes forward by saving the necessary record of the operations for a future commit call. The record of changes must be at least as durable as the overall state of the participant. The record must also be examined during recovery (§2.8) to ensure that the participant rolls forward or rolls back as the manager dictates. The participant stays in the PREPARED state until it is told to commit or abort. It cannot, having returned PREPARED, drop the record except by following the “roll decision” described for crash recovery (§2.8.1).

For nested transactions, when a participant returns PREPARED it is stating that it is ready to roll the changes forward into the parent transaction. The record of changes must be as durable as the record of changes for the parent transaction.

If a participant is currently executing an operation under a transaction when prepare is invoked for that transaction, the participant must either wait until that operation is complete before returning from prepare; know that the operation is guaranteed to be read-only, and so not affect its ability to prepare; or abort the transaction.

If a participant has not received any communication on or about a transaction, over an extended period, it may choose to invoke `getState` on the manager. If `getState` throws `UnknownTransactionException` or `NoSuchObjectException`, the participant may safely infer that the transaction has been aborted. If `getState` throws a `RemoteException` the participant may choose to believe that the manager has crashed and abort its state in the transaction—this is not to be done lightly, since the manager may save state across crashes, and transient network failures could cause a participant to drop out of an otherwise valid and committable transaction. A participant should only drop out of a transaction if the manager is unreachable over an extended period. However, in no case should a participant drop out of a transaction it has `PREPARED` but not yet rolled forward.

If a participant has joined a nested transaction and it receives a `prepare` call for an enclosing transaction, the participant must complete the nested transaction, using `getState` on the manager to determine the proper type of completion.

If a participant receives a `prepare` call for a transaction that is already in a post-`VOTING` state, the participant should simply respond with that state.

If a participant receives a `prepare` call for a transaction that is unknown to it, it should throw `UnknownTransactionException`. This may happen if the participant has crashed and lost the state of a previously active transaction, or if a previous `NOTCHANGED` or `ABORTED` response was not received by the manager and the participant has since forgotten the transaction.

Note that a return value of `NOTCHANGED` may not be idempotent. Should the participant return `NOTCHANGED` it may proceed directly to clean up its state. If the manager receives a `RemoteException` because of network failure, the manager will likely retry the `prepare`. At this point a participant that has dropped the information about the transaction will throw `UnknownTransactionException` and the manager will be forced to abort. A well-behaved participant should stay in the `NOTCHANGED` state for a while to allow a retry of `prepare` to again return `NOTCHANGED`, thus keeping the transaction alive, although this is not strictly required. No matter what it voted, a well-behaved participant should also avoid exiting for a similar period of time in case the manager needs to reinvoke `prepare`.

If a participant receives an `abort` call for a transaction, whether in the `ACTIVE`, `VOTING`, or `PREPARED` state, it should move to the `ABORTED` state and roll back all changes made under the transaction.

If a participant receives a `commit` call for a `PREPARED` transaction, it should move to the `COMMITTED` state, and roll forward all changes made under the transaction.

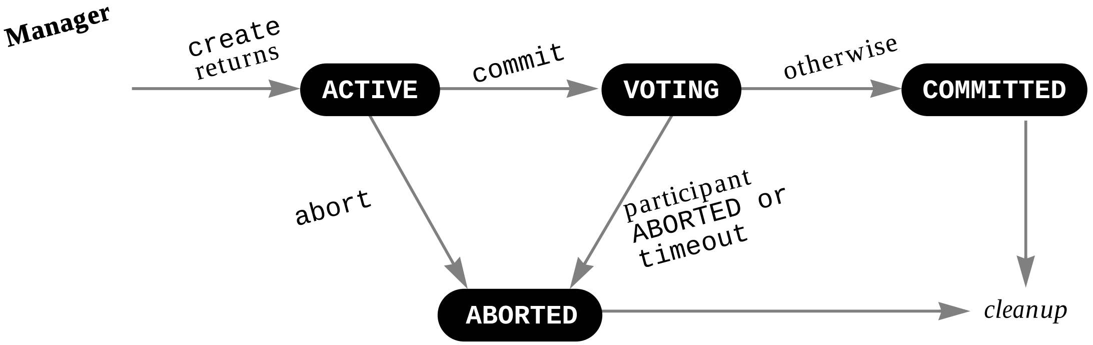
The participant's implementation of `prepareAndCommit` must be equivalent to the following:

```
public int prepareAndCommit(TransactionManager mgr, long id)
    throws UnknownTransactionException, RemoteException
{
    int result = prepare(mgr, id);
    if (result == PREPARED) {
        commit(mgr, id);
        result = COMMITTED;
    }
    return result;
}
```

The participant can often implement `prepareAndCommit` much more efficiently than shown, but it must preserve the above semantics. The manager's use of this method is described in the next section.

2.7 Completing a Transaction: The Manager's View

In the manager's view, a transaction goes through the following states:



When a transaction is created using `create`, the transaction is `ACTIVE`. This is the only state in which participants may `join` the transaction. Attempting to join the transaction in any other state throws a `CannotJoinException`.

Invoking the manager's commit method causes the manager to move to the VOTING state, where it attempts to complete the transaction by rolling forward. Each participant that has joined the transaction has its prepare method invoked to vote on the outcome of the transaction. The participant may return one of three votes: NOTCHANGED, ABORTED, or COMMITTED.

If a participant votes ABORTED, the manager must abort the transaction. If prepare throws UnknownTransactionException or NoSuchObjectException, the participant has lost its state of the transaction, and the manager must abort the transaction. If prepare throws RemoteException the manager may retry as long as it wishes until it decides to abort the transaction.

To abort the transaction, the manager moves to the ABORTED state. In the ABORTED state, the manager should invoke abort on all participants that have voted PREPARED. The manager should also attempt to invoke abort on all participants on which it has not yet invoked prepare. These notifications are not strictly necessary for the one-parameter forms of commit and abort, since the participants will eventually abort the transaction either by timing out or by asking the manager for the state of the transaction. However, informing the participants of the abort can speed up the release of resources in these participants, and so attempting the notification is strongly encouraged.

If a participant votes NOTCHANGED it is dropped from the list of participants, and no further communication will ensue. If all participants vote NOTCHANGED then the entire transaction was read-only and no participant has any changes to roll forward. The transaction moves to the COMMITTED state and then can immediately move to *cleanup*, where resources in the manager are cleaned up. There is no behavioral difference to a participant between a NOTCHANGED transaction and one that has completed the notification phase of the COMMITTED state.

If no participant votes ABORTED and at least one participant votes PREPARED, the transaction also moves to the COMMITTED state. In the COMMITTED state the manager must notify each participant who returned PREPARED to roll forward by invoking the participant's commit method. When the participant's commit method returns normally the participant has rolled forward successfully and the manager need not invoke commit on it again. As long as there exists at least one participant that has not rolled forward successfully, the manager must preserve the state of the transaction and repeat attempts to invoke commit at reasonable intervals. If a participant's commit method throws UnknownTransactionException this means that the participant has already successfully rolled the transaction forward even though the manager did not receive the notification, either due to a network failure on a previous invocation that was actually successful, or due to the participant calling getState directly.

If the transaction is a nested one, and the manager is prepared to roll the transaction forward, the members of the nested transaction must become members of the parent transaction. This *promotion* of participants into the parent manager must be atomic—all must be promoted simultaneously, or none must be. The multi-participant promote method is designed for this use in the case where the parent and nested transactions have different managers.

The promote method takes arrays of participants and crash counts, where crashCounts[i] is the crash count for parts[i]. If any crash count is different from a crash count already known to the parent transaction manager, the parent manager throws CrashCountException and the parent transaction must abort. The drop parameter allows the nested transaction manager to drop itself out of the parent transaction as it promotes its participants into the parent transaction if it no longer has any need to be a participant itself.

The manager for the nested transaction should remain available until it has successfully driven each participant to completion and promoted its participants into the parent transaction. If the nested transaction's manager disappears before a participant is positively informed of the transaction's completion, that participant will not know whether to roll forward or back, forcing it to vote ABORTED in the parent transaction. The manager may cease commit invocations on its participants if any parent transaction is aborted. Aborting any transaction implicitly aborts any uncommitted nested transactions. Additionally, since any committed nested transaction will also have its results dropped, any actions taken on behalf of that transaction can be abandoned.

Invoking the manager's abort method, cancelling the transaction's lease, or allowing the lease to expire also moves the transaction to the ABORTED state as described above. Any transactions nested inside that transaction are also moved directly to the ABORTED state.

The manager may optimize the VOTING state by invoking a participant's prepareAndCommit method if the transaction has only one participant that has not yet been asked to vote and all previous participants have returned NOTCHANGED. (Note that this includes the special case where the transaction has exactly one participant.) If the manager receives an ABORTED result from prepareAndCommit, it proceeds to the ABORTED state. In effect, a prepareAndCommit moves through the VOTING state straight to operating on the results.

A getState call on the manager can return any of ACTIVE, VOTING, ABORTED, NOTCHANGED, or COMMITTED. A manager is permitted, but not required, to return NOTCHANGED if it is in the COMMITTED state and all participants voted NOTCHANGED.

2.8 Crash Recovery

Crash recovery ensures that a top-level transaction will consistently abort or roll forward in the face of a system crash. Nested transactions are not involved.

The manager has one *commit point*, where it must save state in a durable fashion. This is when it enters the COMMITTED state with at least one PREPARED participant. The manager must, at this point, commit the list of PREPARED participants into durable storage. This storage must persist until all PREPARED participants successfully roll forward. A manager may choose to also store the list of PREPARED participants who have already successfully rolled forward or to rewrite the list of PREPARED participants as it shrinks, but this optimization is not required (although it is recommended as good citizenship). In the event of a manager crash, the list of participants must be recovered, and the manager must continue acting in the COMMITTED state until it can successfully notify all PREPARED participants.

The participant also has one commit point, which is prior to voting PREPARED. When it votes PREPARED, the participant must have durably recorded the record of changes necessary to successfully roll forward in the event of a future invocation of commit by the manager. It can remove this record when it is prepared to successfully return from commit.

Because of these commitments, manager and participant implementations should use durable forms of RMI references, such as the Activatable references introduced in the Java™ Development Kit software (JDK), version 1.2. An unreachable manager causes much havoc, and should be avoided as much as possible. A vanished PREPARED participant puts a transaction in an untenable permanent state where some, but not all, of the participants have rolled forward.

2.8.1 The “Roll Decision”

If a participant votes PREPARED for a top-level transaction, it must guarantee that it will execute a recovery process should it crash between completing its durable record and receiving a commit notification from the manager. This recovery process must read the record of the crashed participant and make a “roll decision”—whether to roll the recorded changes forward or roll them back.

To make this decision it invokes the getState method on the transaction manager. This can have the following results:

- getState returns COMMITTED — The recovery should move the participant to the COMMITTED state.
- getState throws UnknownTransactionException or NoSuchObjectException — The recovery should move the participant to the ABORTED state.
- getState throws RemoteException — The recovery should repeat the attempt after a pause.

2.9 Durability

Durability is a commitment, but it is not a guarantee. It is impossible to guarantee that any given piece of stable storage can *never* be lost; one can only achieve decreasing probabilities of loss. Data that is force-written to a disk may be considered durable, but it is less durable than data committed to two or more separate, redundant disks. When we speak of “durability” in this system it is always used relative to the expectations of the human who decided which entities to use for communication.

With multi-participant transactions it is entirely possible that different participants have different durability levels. The manager may be on a tightly replicated system with its durable storage duplicated on several host systems, giving a high degree of durability, while a participant may only be using one disk. Or a participant may always store its data in memory, expecting to lose it on a system crash (a database of people currently logged into the host, for example, need not survive a system crash). When humans make a decision to use a particular manager and set of participants for a transaction they must take into account these differences and be aware of the ramifications of committing changes that may be more durable on one participant than another. Determining, or even defining and exposing, varying levels of durability is outside the scope of this specification.

Default Transaction Semantics 3

The two-phase commit protocol defines how a transaction is created and later driven to completion by either committing or aborting. It is neutral with respect to the semantics of locking under the transaction or other behaviors that impart semantics to the use of the transaction. Specific clients and servers, however, must be written to expect specific transaction semantics. This model is to separate the completion protocol from transaction semantics, where transaction semantics are represented in the parameters and return values of methods by which clients and participants interact.

This chapter defines the default transaction semantics of services. These semantics preserve the traditional ACID properties (you will find a brief description of the ACID properties in §1.3). The semantics are represented by the `Transaction` and `NestableTransaction` interfaces and their implementation classes `ServerTransaction` and `NestableServerTransaction`. Any participant that accepts as a parameter or returns any of these types is promising to abide by the semantics defined in this chapter for any activities performed under that transaction.

3.1 `Transaction` and `NestableTransaction` Interfaces

The client's view of transactions is through two interfaces: `Transaction` for top-level transactions, and `NestableTransaction` for transactions under which nested transactions can be created. First, the `Transaction` interface:

```
package net.jini.core.transaction;

public interface Transaction {
    public static class Created implements Serializable {
        public final Transaction transaction;
        public final Lease lease;
        Created(Transaction transaction, Lease lease);
    }
    void commit() // §2.5
        throws UnknownTransactionException, CannotCommitException,
                RemoteException;
    void commit(long waitFor) // §2.5
        throws UnknownTransactionException, CannotCommitException,
                TimeoutExpiredException, RemoteException;
    void abort() // §2.5
        throws UnknownTransactionException, CannotAbortException,
                RemoteException;
    void abort(long waitFor) // §2.5
        throws UnknownTransactionException, CannotAbortException,
                TimeoutExpiredException, RemoteException;
}
```

The `Created` nested class is used in a factory `create` method for top-level transactions (defined in the next section) to hold two return values: the newly created `Transaction` object and the transaction's lease, which is the lease granted by the transaction manager. The `commit` and `abort` methods have the same semantics as discussed in §2.5.

Nested transactions are created using `NestableTransaction` methods:

```
package net.jini.core.transaction;

public interface NestableTransaction extends Transaction {
    public static class Created implements Serializable {
        public final NestableTransaction transaction;
        public final Lease lease;
        Created(NestableTransaction transaction, Lease lease);
    }
    Created create(long leaseFor) // §2.2
        throws UnknownTransactionException, CannotJoinException,
                LeaseDeniedException, RemoteException;
    Created create(NestableTransactionManager mgr,
                    long leaseFor) // §2.2
        throws UnknownTransactionException, CannotJoinException,
                LeaseDeniedException, RemoteException;
}
```

The Created nested class is used to hold two return values: the newly created Transaction object and the transaction's lease, which is the lease granted by the transaction manager. In both create methods, leaseFor is the requested lease time in milliseconds. In the one-parameter create method, the nested transaction is created with the same transaction manager as the transaction on which the method is invoked. The other create method can be used to specify a different transaction manager to use for the nested transaction.

3.2 *TransactionFactory Class*

The TransactionFactory class is used to create top-level transactions.

```
package net.jini.core.transaction;

public class TransactionFactory {
    public static Transaction.Created
        create(TransactionManager mgr, long leaseFor) // §2.1
            throws LeaseDeniedException, RemoteException;
    public static NestableTransaction.Created
        create(NestableTransactionManager mgr,
                long leaseFor) // §2.2
            throws LeaseDeniedException, RemoteException;
}
```

The first create method is usually used when nested transactions are not required. However, if the manager passed to this method is in fact a NestableTransactionManager, then the returned Transaction can in fact be cast to a NestableTransaction. The second create method is used when it is known that nested transactions need to be created. In both cases, a Created instance is used to hold two return values: the newly created transaction object and the granted lease.

3.3 *ServerTransaction and NestableServerTransaction Classes*

The ServerTransaction class exposes functionality necessary for writing participants that support top-level transactions. Participants can cast a Transaction to a ServerTransaction to obtain access to this functionality.

```
public class ServerTransaction implements Transaction, Serializable
{
    public final TransactionManager mgr;
    public final long id;
    public ServerTransaction(TransactionManager mgr, long id);
    public void join(TransactionParticipant part,
                     long crashCount) // §2.3
        throws UnknownTransactionException, CannotJoinException,
               CrashCountException, RemoteException;
    public int getState() // §2.7
        throws UnknownTransactionException, RemoteException;
    public boolean isNested(); // §3.3
}
```

The mgr field is a reference to the transaction manager that created the transaction. The id field is the transaction identifier returned by the transaction manager's create method.

The constructor should not be used directly; it is for use by the TransactionFactory implementation.

The methods join, commit, abort, and getState invoke the corresponding methods on the manager, passing the transaction identifier. They are provided as a convenience to the programmer, primarily to eliminate the possibility of passing an identifier to the wrong manager. For example, given a ServerTransaction object tr, the invocation

```
tr.join(participant, crashCount);
```

is equivalent to

```
tr.mgr.join(tr.id, participant, crashCount);
```

The isNested method returns true if the transaction is a nested transaction (that is, if it is a NestableServerTransaction with a non-null parent), and false otherwise. It is provided as a method on ServerTransaction for the convenience of participants that do not support nested transactions.

The hashCode method returns the id cast to an int XORed with the result of mgr.hashCode(). The equals method returns true if the specified object is a ServerTransaction object with the same manager and transaction identifier as the object on which it is invoked.

The NestableServerTransaction class exposes functionality necessary for writing participants that support nested transactions. Participants can cast a NestableTransaction to a NestableServerTransaction to obtain access to this functionality.

```
package net.jini.core.transaction.server;

public class NestableServerTransaction extends ServerTransaction
                            implements NestableTransaction
{
    public final NestableServerTransaction parent;
    public NestableServerTransaction(
                                NestableTransactionManager mgr,
                                long id,
                                NestableServerTransaction parent);
    public void promote(TransactionParticipant[] parts,
                        long[] crashCounts,
                        TransactionParticipant drop) // §2.7
        throws UnknownTransactionException, CannotJoinException,
                CrashCountException, RemoteException;
    public boolean enclosedBy(NestableTransaction enclosing);
}
```

The parent field is a reference to the parent transaction if the transaction is nested (§2.2) or null if it is top-level.

The constructor should not be used directly; it is for use by the TransactionFactory and NestableServerTransaction implementations.

Given a NestableServerTransaction object tr, the invocation

```
tr.promote(parts, crashCounts, drop)
```

is equivalent to

```
((NestableTransactionManager)tr.mgr).promote(tr.id, parts,
                                                  crashCounts, drop)
```

The enclosedBy method returns true if the specified transaction is an enclosing transaction (parent, grandparent, etc.) of the transaction on which the method is invoked; otherwise it returns false.

3.4 CannotNestException Class

If a service implements the default transaction semantics, but does not support nested transactions, it usually needs to throw an exception if a nested transaction is passed to it. The CannotNestException is provided as a convenience for this purpose, although a service is not required to use this specific exception.

```
package net.jini.core.transaction;

public class CannotNestException extends TransactionException {
    public CannotNestException();
    public CannotNestException(String desc);
}
```

3.5 Semantics

Activities performed as pure transactions (meaning all access to shared mutable state is performed under transactional control) are subject to sequential ordering, meaning the overall effect of executing a set of sibling (all at the same level, whether top-level or nested) pure transactions concurrently is always equivalent to some sequential execution.

Ancestor transactions can execute concurrently with child transactions, subject to the locking rules below.

Transaction semantics for objects are defined in terms of strict two-phase locking. Every transactional operation is described in terms of acquiring locks on objects; these locks are held until the transaction completes. The most typical locks are read and write locks, but others are possible. Whatever the lock types are, conflict rules are defined such that if two operations do not commute, then they acquire conflicting locks. For objects using standard read and write locks, read locks do not conflict with other read locks, but write locks conflict with both read locks and other write locks. A transaction can acquire a lock if the only conflicting locks are those held by ancestor transactions (or itself). If a necessary lock cannot be acquired and the operation is defined to proceed without waiting for that lock, then serializability might be violated. When a subtransaction commits, its locks are inherited by the parent transaction.

In addition to locks, transactional operations can be defined in terms of object creation and deletion visibility. If an object is defined to be created under a transaction, then the existence of the object is only visible within that transaction and its inferiors, but will disappear if the transaction aborts. If an object is defined to be deleted under a transaction, then the object is not visible to any transaction (including the deleting transaction) but will reappear if the transaction aborts. When a nested transaction commits, visibility state is inherited by the parent transaction.

Once a transaction reaches the `VOTING` stage, if all execution under the transaction (and its subtransactions) has finished, then the only reasons the transaction can abort are:

- The manager crashes (or has crashed)
- One or more participants crash (or have crashed)
- There is an explicit abort

Transaction deadlocks are not guaranteed to be prevented or even detected, but managers and participants are permitted to break known deadlocks by aborting transactions.

An active transaction is an *orphan* if it or one of its ancestors is guaranteed to abort. This can occur because an ancestor has explicitly aborted, or because some participant or manager of the transaction or an ancestor has crashed. Orphans are not guaranteed to be detected by the system, and as such programmers using transactions must be aware that orphans can see internally inconsistent state and take appropriate action.

Causal ordering information about transactions is not guaranteed to be propagated. First, given two sibling transactions (at any level), it is not possible to tell if they were created concurrently or sequentially (or in what order). Second, if two transactions are causally ordered and the earlier transaction has completed, the outcome of the earlier transaction is not guaranteed to be known at every participant used by the later transaction, unless the client is successful in using the variant of `commit` or `abort` that takes a timeout parameter. Programmers using non-blocking forms of operations must take this into account.

As long as a transaction persists in attempting to acquire a lock that conflicts with another transaction, the participant will persist in attempting to resolve the outcome of the transaction that holds the conflicting lock. Attempts to acquire a lock include making a blocking call, continuing to make non-blocking calls, and registering for event notification under a transaction.

3.6 Serialized Forms

The `serialVersionUID` for each class is as follows:

- `Transaction.Created`: -5199291723008952986
- `NestableTransaction.Created`: -2979247545926318953
- `TransactionManager.Created`: -4233846033773471113
- `ServerTransaction`: 4552277137549765374
- `NestableServerTransaction`: -3438419132543972925
- `TransactionException`: -5009935764793203986
- `CannotAbortException`: 3597101646737510009
- `CannotCommitException`: -4497341152359563957
- `CannotJoinException`: 5568393043937204939
- `CannotNestException`: 3409604500491735434
- `TimeoutExpiredException`: 3918773760682958000
- `UnknownTransactionException`: 443798629936327009
- `CrashCountException`: 4299226125245015671

In each case the serialized fields are the declared public fields, if any.