```
    long getExpiration();
    void cancel() throws UnknownLeaseException,
                         RemoteException;
    void renew(long duration) throws LeaseDeniedException,
                                     UnknownLeaseException,
                                     RemoteException;
    void setSerialFormat(int format);
    int getSerialFormat();
    LeaseMap createLeaseMap(long duration);
    boolean canBatch(Lease lease);
}
```

Particular instances of the `Lease` type will be created by the grantors of a lease and returned to the holder of the lease as part of the return value from a call that allocates a leased resource. The actual implementation of the object, including the way (if any) in which the `Lease` object communicates with the grantor of the lease, is determined by the lease grantor and is hidden from the lease holder.

The interface defines two constants that can be used when requesting a lease. The first, `FOREVER`, can be used to request a lease that never expires. When granted such a lease, the lease holder is responsible for ensuring that the leased resource is freed when no longer needed. The second constant, `ANY`, is used by the requestor to indicate that no particular lease time is desired and that the grantor of the lease should supply a time that is most convenient for the grantor.

If the request is for a particular duration, the lease grantor is required to grant a lease of no more than the requested period of time. A lease may be granted for a period of time shorter than that requested.

A second pair of constants is used to determine the format used in the serialized form for a `Lease` object; in particular, the serialized form that is used to represent the time at which the lease expires. If the serialized format is set to the value `DURATION`, the serialized form will convert the time of lease expiration into a duration (in milliseconds) from the time of serialization. This form is best used when transmitting a `Lease` object from one address space to another (such as via an RMI call) where it cannot be assumed that the address spaces have sufficiently synchronized clocks. If the serialized format is set to `ABSOLUTE`, the time of expiration will be stored as an absolute time, calculated in terms of milliseconds since the beginning of the epoch.

The first method in the `Lease` interface, `getExpiration`, returns a `long` that indicates the time, relative to the current clock, that the lease will expire. Following the usual convention in the Java programming language, this time is represented as milliseconds from the beginning of the epoch, and can be used to

Leasing (LE)

compare the expiration time of the lease with the result of a call to obtain the current time, `java.lang.System.currentTimeMillis`.

The second method, `cancel`, can be used by the lease holder to indicate that it is no longer interested in the resource or information held by the lease. If the leased information or resource could cause a callback to the lease holder (or some other object on behalf of the lease holder), the lease grantor should not issue such a callback after the lease has been cancelled. The overall effect of a `cancel` call is the same as lease expiration, but instead of happening at the end of a pre-agreed duration, it happens immediately. If the lease being cancelled is unknown to the lease grantor, an `UnknownLeaseException` is thrown. The method can also throw a `RemoteException` if the implementation of the method requires calling a remote object that is the lease holder.

The third method, `renew`, is used to renew a lease for an additional period of time. The length of the desired renewal is given, in milliseconds, in the parameter to the call. This duration is not added to the original lease, but is used to determine a new expiration time for the existing lease. This method has no return value; if the renewal is granted, this is reflected in the lease object on which the call was made. If the lease grantor is unable or unwilling to renew the lease, a `RenewFailedException` is thrown. If a renewal fails, the lease is left intact for the same duration that was in force prior to the call to `renew`. If the lease being renewed is unknown to the lease grantor, an `UnknownLeaseException` is thrown. The method can also throw a `RemoteException` if the implementation of the method requires calling a remote object that is the lease holder.

Two methods are concerned with the serialized format of a `Lease` object. The first, `setSerialFormat`, takes an integer that indicates the appropriate format to use when serializing the format. The current supported formats are a duration format that stores the length of time (from the time of serialization) before the lease expires, and an absolute format, which stores the time (relative to the current clock) that the lease will expire. The absolute format should be used when serializing a `Lease` object for transmission from one machine to another; the durational format should be used when storing a `Lease` object on stable store that will be read back later by the same process or machine. The default serialization format is durational. The second method, `getSerialForm`, returns an integer indicating the format that will be used to serialize the `Lease` object.

The last two methods are used to aid in the batch renewal or cancellation of a group of `Lease` objects. The first of these, `createLeaseMap`, creates a `Map` object that can contain leases whose renewal or cancellation can be batched, and adds the current lease to that map. The current lease will be renewed for the duration indicated by the argument to the method when all of the leases in the `LeaseMap` are renewed. The second method, `batchWith(Lease lease)`, returns a boolean value indicating whether or not the lease given as an argument to the method can be batched (in renew and cancel calls) with the current lease. Whether or not two Lease objects can be batched is an implementation detail determined by the objects.

Three types of Exception objects are associated with the basic lease interface. All of these are used in the Lease interface itself, and two can be used by methods that grant access to a leased resource.

The RemoteException is imported from the package java.rmi. This exception is used to indicate a problem with any communication that might occur between the lease holder and the lease grantor if those objects are in separate virtual machines. The full specification of this exception can be found in the *Java Remote Method Invocation Specification.*

The UnknownLeaseException is used to indicate that the Lease object used is not known to the grantor of the lease. This can occur when a lease expires, or when a copy of a lease has been cancelled by some other lease holder. This exception is defined as:

```
package net.jini.core.lease;

public class UnknownLeaseException extends LeaseException {
    public UnknownLeaseException() {
        super();
    }
    public UnknownLeaseException(String reason) {
        super(reason);
    }
}
```

The final exception defined is the LeaseDeniedException, which can be thrown by either a call to renew or a call to an interface that grants access to a leased resource. This exception indicates that the requested lease has been denied by the resource holder. The exception is defined as:

```
package net.jini.core.lease;

public class LeaseDeniedException extends LeaseException {
    public LeaseDeniedException() {
        super();
    }
    public LeaseDeniedException(String reason) {
        super(reason);
    }
}
```

The LeaseException superclass is defined as:

```
package net.jini.core.lease;

public class LeaseException extends Exception {
    public LeaseException() {
        super();
    }
    public LeaseException(String reason) {
        super(reason);
    }
}
```

The final basic interface defined for leasing is that of a LeaseMap, which allows groups of Lease objects to be renewed or cancelled using a single operation. The LeaseMap interface is:

```
package net.jini.core.lease;

import java.rmi.RemoteException;

public interface LeaseMap extends java.util.Map {
    boolean canContainKey(Object key);
    void renewAll() throws LeaseMapException, RemoteException;
    void cancelAll() throws LeaseMapException,RemoteException;
}
```

A LeaseMap is an extension of the java.util.Map class that associates a Lease object with a Long. The Long is the duration for which the lease should be renewed whenever it is renewed. Lease objects and associated renewal durations can be entered and removed from a LeaseMap using the usual Map methods. An attempt to add a Lease object to a map containing other Lease objects for which Lease.canBatch would return false will cause an IllegalArgumentException to be thrown, as will attempts to add a key that is not a Lease object or a value that is not a Long.

The first method defined in the LeaseMap interface, canContainKey, takes a Lease object as an argument and returns true if that Lease object can be added to the Map and false otherwise. A Lease object can be added to a Map if that Lease object can be renewed in a batch with the other objects in the LeaseMap. The requirements for this depends on the implementation of the Lease object.

The second method, renewAll, will attempt to renew all of the Lease objects in the LeaseMap for the duration associated with the Lease object. If all of the Lease objects are successfully renewed, the method will return nothing. If some

Lease objects fail to renew, those objects will be removed from the LeaseMap and will be contained in the thrown LeaseMapException.

The third method, cancelAll, cancels all the Lease objects in the LeaseMap. If all cancels are successful, the method returns normally and leaves all leases in the map. If any of the Lease objects cannot be cancelled, they are removed from the LeaseMap and the operation throws a LeaseMapException.

The LeaseMapException class is defined as:

```
package net.jini.core.lease;

import java.util.Map;

public class LeaseMapException extends LeaseException {
    public Map exceptionMap;
    public LeaseMapException(String s, Map exceptionMap) {
        super(s);
        this.exceptionMap = exceptionMap;
    }
}
```

Objects of type LeaseMapException contain a Map object that maps Lease objects (the keys) to Exception objects (the values). The Lease objects are the ones that could not be renewed or cancelled, and the Exception objects reflect the individual failures. For example, if a LeaseMap.renew call fails because one of the leases has already expired, that lease would be taken out of the original LeaseMap and placed in the Map returned as part of the LeaseMapException object with an UnknownLeaseException object as the corresponding value.

LE.2.3 Leasing and Time

The duration of a lease is determined when the lease is granted (or renewed). A lease is granted for a duration rather than until some particular moment of time, since such a grant does not require that the clocks used by the client and the server be synchronized.

The difficulty of synchronizing clocks in a distributed system is well known. The problem is somewhat more tractable in the case of leases, which are expected to be for periods of minutes to months, as the accuracy of synchronization required is expected to be in terms of minutes rather than nanoseconds. Over a particular local group of machines, a time service could be used that would allow this level of synchronization.

However, leasing is expected to be used by clients and servers that are widely distributed and might not share a particular time service. In such a case, clock drift of many minutes is a common occurrence. Because of this, the leasing specification has chosen to use durations rather than absolute time.

The reasoning behind such a choice is based on the observation that the accuracy of the clocks used in the machines that make up a distributed system is matched much more closely than the clocks on those systems. While there may be minutes of difference in the notion of the absolute time held by widely separated systems, there is much less likelihood of a significant difference over the rate of change of time in those systems. While there is clearly some difference in the notion of duration between systems (if there were not, synchronization for absolute time would be much easier), that difference is not cumulative in the way errors in absolute time are.

This decision does mean that holders of leases and grantors of leases need to be aware of some of the consequences of the use of durations. In particular, the amount of time needed to communicate between the lease holder and the lease grantor, which may vary from call to call, needs to be taken into account when renewing a lease. If a lease holder is calculating the absolute time (relative to the lease holder's clock) at which to ask for a renewal, that time should be based on the sum of the duration of the lease and the time at which the lease holder requested the lease, not on the duration and the time that the lease holder received the lease.

LE.2.4 Serialized Forms

Class	serialVersionUID	Serialized Fields
`LeaseException`	–7902272546257490469L	*all public fields*
`UnknownLeaseException`	–2921099330511429288L	*none*
`LeaseDeniedException`	5704943735577343495L	*none*
`LeaseMapException`	–4854893779678486122L	*none*

LE.3 Example Supporting Classes

THE basic `Lease` interface allows leases to be granted by one object and handed to another as the result of a call that creates or provides access to some leased resource. The goal of the interface is to allow as much freedom as possible in implementation to both the party that is granting the lease (and thus is giving out the implementation that supports the `Lease` interface) and the party that receives the lease.

However, a number of classes can be supplied that can simplify the handling of leases in some common cases. We will describe examples of these supporting classes and show how these classes can be used with leased resources.

LE.3.1 A Renewal Class

One of the common patterns with leasing is for the lease holder to request a lease with the intention of renewing the lease until it is finished with the resource. The period of time during which the resource is needed is unknown at the time of requesting the lease, so the requestor wants the lease to be renewed until an undetermined time in the future. Alternatively, the lease requestor might know how long the lease needs to be held, but the lease holder might be unwilling to grant a lease for the full period of time. Again, the pattern will be to renew the lease for some period of time.

If the lease continues to be renewed, the lease holder doesn't want to be bothered with knowing about it, but if the lease is not renewed for some reason, the lease holder wants to be notified. Such a notification can be done using the usual inter-address space mechanisms for event notifications, by registering a listener of the appropriate type. This functionality can be supplied by a class with an interface like the following

```
class LeaseRenew {
    LeaseRenew(Lease toRenew,
               long renewTil,
               LeaseExpireListener listener) {…}
```

```
    void addRenew(Lease toRenew,
                  long renewTil,
                  LeaseExpireListener listener) {…}
    long getExpiration(Lease forLease)
        throws UnknownLeaseException {…}
    void setExpiration(Lease forLease,long toExpire)
        throws UnknownLeaseException {…}
    void cancel(Lease toCancel)
        throws UnknownLeaseException {…}
    void setLeaseExpireListener(Lease forLease,
                                LeaseExpireListener listener)
        throws UnknownLeaseException {…}
    void removeLeaseExpireListener(Lease forLease)
        throws UnknownLeaseException {…}
}
```

The constructor of this class takes a Lease object, presumably returned from some call that reserved a leased resource; an initial time indicating the time until which the lease should be renewed; and an object that is to be notified if a renewal fails before the time indicated in renewTil. This returns a LeaseRenew object, which will have its own thread of control that will do the lease renewals.

Once a LeaseRenew object has been created, other leases can be added to the set that are renewed by that object using the addRenew call. This call takes a Lease object, an expiration time or overall duration, and a listener to be informed if the lease cannot be renewed prior to the time requested. Internally to the LeaseRenew object, leases that can be batched can be placed into a LeaseMap.

The duration of a particular lease can be queried by a call to the method getExpiration. This method takes a Lease object and returns the time at which that lease will be allowed to expire by the LeaseRenew object. Note that this is different from the Lease.getExpiration method, which tells the time at which the lease will expire if it is not renewed. If there is no Lease object corresponding to the argument for this call being handled by the LeaseRenew object, an UnknownLeaseException will be thrown. This can happen either when no such Lease has ever been given to the LeaseRenew object, or when a Lease object that has been held has already expired or been cancelled. Notice that since this object is assumed to be in the same address space as the object that acquired the lease, we can assume that it shares the same clock with that object, and hence can use absolute time rather than a duration-based system.

The setExpiration method allows the caller to adjust the expiration time of any Lease object held by the LeaseRenew object. This method takes as arguments the Lease whose time of expiration is to be adjusted and the new expiration time.

If no lease is held by the LeaseRenew object corresponding to the first argument, an UnknownLeaseException will be thrown.

A call to cancel will result in the cancellation of the indicated Lease held by the LeaseRenew object. Again, if the lease has already expired on that object, an UnknownLeaseException will be thrown. It is expected that a call to this method will be made if the leased resource is no longer needed, rather than just dropping all references to the LeaseRenew object.

The methods setLeaseExpireListener and removeLeaseExpireListener allow setting and unsetting the destination of an event handler associated with a particular Lease object held by the LeaseRenew object. The handler will be called if the Lease object expires before the desired duration period is completed. Note that one of the properties of this example is that only one LeaseExpireListener can be associated with each Lease.

LE.3.2 A Renewal Service

Objects that hold a lease that needs to be renewed may themselves be activatable, and thus unable to ensure that they will be capable of renewing a lease at some particular time in the future (since they might not be active at that time). For such objects it might make sense to hand the lease renewal duty off to a service that could take care of lease renewal for the object, allowing that object to be deactivated without fear of losing its lease on some other resource.

The most straightforward way of accomplishing this is to hand the Lease object off to some object whose job it is to renew leases on behalf of others. This object will be remote to the objects to which it offers its service (otherwise it would be inactive when the others become inactive) but might be local to the machine; there could even be such services that are located on other machines.

The interface to such an object might look something like:

```
interface LeaseRenewService extends Remote {
    EventRegistration renew(Lease toRenew,
                            long renewTil,
                            RemoteEventListenter notifyBeforeDrop,
                            MarshalledObject returnOnNotify)
        throws RemoteException;
    void onRenewFailure(Lease toRenew,
                            RemoteEventListenter toNotify,
                            MarshalledObject returnOnNotify)
        throws RemoteException, UnknownLeaseException;
}
```

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The first method, renew, is the request to the object to renew a particular lease on behalf of the caller. The Lease object to be renewed is passed to the LeaseRenewService object, along with the length of time for which the lease is to be renewed. Since we are assuming that this service might not be on the same machine as the object that acquired the original lease, we return to a duration-based time system, since we cannot assume that the two systems have synchronized clocks.

Requests to renew a Lease are themselves leased. The duration of the lease is requested in the duration argument to the renew method, and the actual time of the lease is returned as part of the EventRegistration return value. While it might seem odd to lease the service of renewing other leases, this does not cause an infinite regress. It is assumed that the LeaseRenewService will grant leases that are longer (perhaps significantly longer) than those in the leases that it is renewing. In this fashion, the LeaseRenewService can act as a concentrator for lease renewal messages.

The renew method also takes as parameters a RemoteEventListener and MarshalledObject objects to be passed to that RemoteEventListener. This is because part of the semantics of the renew call is to register interest in an event that can occur within the LeaseRenewService object. The registration is actually for a notification before the lease granted by the renewal service is dropped. This event notification can be directed back to the object that is the client of the renewal service, and will (if so directed) cause the object to be activated (if it is not already active). This gives the object a chance to renew the lease with the LeaseRenewService object before that lease is dropped.

The second method, onRenewFailure, allows the client to register interest in the LeaseRenewService being unable to renew the Lease supplied as an argument to the call. This call also takes a RemoteEventListener object that is the target of the notification, and a MarshalledObject that will be passed as part of the notification. This allows the client to be informed if the LeaseRenewService is denied a lease renewal during the lease period offered to the client for such renewal. This call does not take a time period for the event registration, but instead will have the same duration as the leased renewal associated with the Lease object passed into the call, which should be the same as the Lease object that was supplied in a previous invocation of the method renew. If the Lease is not known to the LeaseRenewService object, an UnknownLeaseException will be thrown.

There is no need for a method allowing the cancellation of a lease renewal request. Since these requests are themselves leased, cancelling the lease with the LeaseRenewService will cancel both the renewing of the lease and any event registrations associated with that lease.

Leasing (LE)

The Jini Distributed Event Specification defines the distributed event programming model used throughout the Jini architecture. These are general-purpose events that can be used by any service for event notifications. The event model is specifically designed to allow for useful third parties that help either the sender or receiver of the event. As you will see, the lookup service uses these events to notify interested parties of changes to its contents.

EV
The Jini Distributed Event Specification

EV.1 Introduction

THE purpose of the distributed event interfaces specified in this document is to allow an object in one Java virtual machine (JVM) to register interest in the occurrence of some event occurring in an object in some other JVM, perhaps running on a different physical machine, and to receive a notification when an event of that kind occurs.

EV.1.1 Distributed Events and Notifications

Programs based on an object that is reacting to a change of state somewhere outside the object are common in a single address space. Such programs are often used for interactive applications in which user actions are modeled as events to which other objects in the program react. Delivery of such *local events* can be assumed to be well ordered, very fast, predictable, and reliable. Further, the entity that is interested in the event can be assumed to always want to know about the event as soon as the event has occurred.

The same style of programming is useful in distributed systems, where the object reacting to an event is in a different JVM, perhaps on a different physical machine, from the one on which the event occurred. Just as in the single-JVM case, the logic of such programs is often reactive, with actions occurring in response to some change in state that has occurred elsewhere.

A distributed event system has a different set of characteristics and requirements than a single-address-space event system. Notifications of events from remote objects may arrive in different orders on different clients, or may not arrive at all. The time it takes for a notification to arrive may be long (in comparison to the time for computation at either the object that generated the notification or the object interested in the notification). There may be occasions in which the object wishing the event notification does not wish to have that notification as soon as possible, but only on some schedule determined by the recipient. There may even be times when the object that registered interest in the event is not the object to which a notification of the event should be sent.

Unlike the single-address-space notion of an event, a distributed event cannot be guaranteed to be delivered in a timely fashion. Because of the possibilities of network delays or failures, the notification of an event may be delayed indefinitely and even lost in the case of a distributed system.

Indeed, there are times in a distributed system when the object of a notification may actively desire that the notification be delayed. In systems that allow object activation (such as is allowed by Java Remote Method Invocation (RMI) in the Java Development Kit, version 1.2, commonly called JDK1.2), an object might wish to be able to find out whether an event occurred but not want that notification to cause an activation of the object if it is otherwise quiescent. In such cases, the object receiving the event might wish the notification to be delayed until the object requests notification delivery, or until the object has been activated for some other reason.

Central to the notion of a distributed notification is the ability to place a third-party object between the object that generates the notification and the party that ultimately wishes to receive the notification. Such third parties, which can be strung together in arbitrary ways, allow ways of offloading notifications from objects, implementing various delivery guarantees, storing of notifications until needed or desired by a recipient, and the filtering and rerouting of notifications. In a distributed system in which full applications are made up of components assembled to produce an overall application, the third party may be more than a filter or storage spot for a notification; in such systems it is possible that the third party is the final intended destination of the notification.

EV.1.2 Goals and Requirements

The requirements of this set of interfaces are to:

- Specify an interface that can be used to send a notification of the occurrence of the event
- Specify the information that must be contained in such a notification

In addition, the fact that the interfaces are designed to be used by objects in different virtual machines, perhaps separated by a network, imposes other requirements, including:

- Allowing various degrees of assurance on delivery of a notification
- Support for different policies of scheduling notification
- Explicitly allowing the interposition of objects that will collect, hold, filter, and forward notifications

Notice that there is no requirement for a single interface that can be used to register interest in a particular kind of event. Given the wide variety of kinds of events, the way in which interest in such events can be indicated may vary from object to object. This document will talk about a model that lies behind the system's notion of such a registration, but the interfaces that are used to accomplish such a registration are not open to general description.

EV.1.3 Dependencies

This document relies on the following other specifications:

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

EV.2 The Basic Interfaces

THE basic interfaces you are about to see define a protocol that can be used by one object to register interest in a kind of state change in another object, and to receive a notification of an occurrence of that kind of state change, either directly or through some third-party, that is specified by the object at the time of registration. The protocol is meant to be as simple as possible. No attempt is made to indicate the reliability or the timeliness of the notifications; such guarantees are not part of the protocol but instead are part of the implementation of the various objects involved.

In particular, the purpose of these interfaces is:

- To show the information needed in any method that allows registration of interest in the occurrence of a kind of event in an object
- To provide an example of an interface that allows the registration of interest in such events
- To specify an interface that can be used to send a notification of the occurrence of the event

Implicit in the event registration and notification is the idea that events can be classified into *kinds*. Registration of interest indicates the kind of event that is of interest, while a notification indicates that an instance of that kind of event has occurred.

EV.2.1 Entities Involved

An *event* is something that happens in an object, corresponding to some change in the abstract state of the object. Events are abstract occurrences that are not directly observed outside of an object, and might not correspond to a change in the *actual* state of the object that advertises the ability to register interest in the event. However, an object may choose to export an identification of a kind of event and allow other objects to indicate interest in the occurrence of events of that kind; this indicates that the *abstract* state of the object includes the notion of this state changing. The information concerning what kinds of events occur within an object can be exported in a number of ways, including identifiers for the various events or methods allowing registration of interest in that kind of event.

An object is responsible for identifying the kinds of events that can occur within that object, allowing other objects to register interest in the occurrence of such events, and generating `RemoteEvent` objects that are sent as notifications to the objects that have registered interest when such events occur.

Registration of interest is not temporally open ended but is limited to a given duration using the notion of a lease. Full specification of the way in which leasing is used is contained in the *Jini Distributed Leasing Specification.*

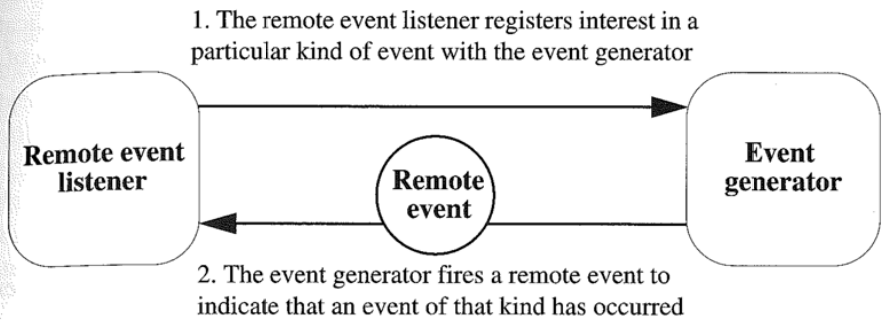
The basic, concrete objects involved in a distributed event system are:

- The object that registers interest in an event
- The object in which an event occurs (referred to as the event generator)
- The recipient of event notifications (referred to as a remote event listener)

An *event generator* is an object that has some kinds of abstract state changes that might be of interest to other objects and allows other objects to register interest in those events. This is the object that will generate notifications when events of this kind occur, sending those notifications to the event listeners that were indicated as targets in the calls that registered interest in that kind of event.

A *remote event listener* is an object that is interested in the occurrence of some kinds of events in some other object. The major function of a remote event listener is to receive notifications of the occurrence of an event in some other object (or set of objects).

A *remote event* is an object that is passed from an event generator to a remote event listener to indicate that an event of a particular kind has occurred. At a minimum, a remote event contains information about the kind of event that has occurred, a reference to the object in which the event occurred, and a sequence number allowing identification of the particular instance of the event. A notification will also include an object that was supplied by the object that registered interest in the kind of event as part of the registration call.



EV.2.2 Overview of the Interfaces and Classes

The event and notification interfaces introduced here define a single basic type of entity, a set of requirements on the information that needs to be handed to that entity, and some supporting interfaces and classes. All of the classes and interfaces defined in this specification are in the `net.jini.core.event` package.

The basic type is defined by the interface `RemoteEventListener`. This interface requires certain information to be passed in during the registration of interest in the kind of event that the notification is indicating. There is no single interface that defines how to register interest in such events, but the ways in which such information could be communicated will be discussed.

The supporting interfaces and classes define a `RemoteEvent` object, an `EventRegistration` object used as an identifier for registration, and a set of exceptions that can be generated.

The `RemoteEventListener` is the receiver of `RemoteEvents`, which signals that a particular kind of event has occurred. A `RemoteEventListener` is defined by an interface that contains a single method, `notify`, which informs interested listeners that an event has occurred. This method returns no value, and has parameters that contain enough information to allow the method call to be idempotent. In addition, this method will return information that was passed in during the registration of interest in the event, allowing the *registrant,* the object that registered interest with the event generator, to associate arbitrary information or actions with the notification.

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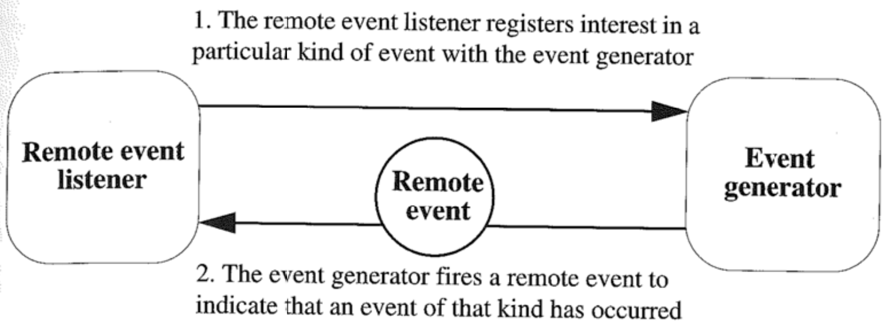

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The `RemoteEventListener` interface extends from the `Remote` interface, so the methods defined in `RemoteEventListener` are remote methods and objects supporting these interfaces will be passed by RMI, by reference. Other objects defined by the system will be local objects, passed by value in the remote calls.

The first of these supporting classes is `RemoteEvent`, which is sent to indicate that an event of interest has occurred in the event generator. The basic form of a `RemoteEvent` contains:

- An identifier for the kind of event in which interest has been registered
- A reference to the object in which the event occurred
- A sequence number identifying the instance of the event type
- An object that was passed in, as part of the registration of interest in the event by the registrant

These `RemoteEvent` notification objects are passed to a `RemoteEventListener` as a parameter to the `RemoteEventListener` `notify` method.

The `EventRegistration` class defines an object that returns the information needed by the registrant and is intended to be the return value of remote event registration calls. Instances of the `EventRegistration` class contain an identifier for the kind of event, the current sequence number of the kind of event, and a `Lease` object for the registration of interest.

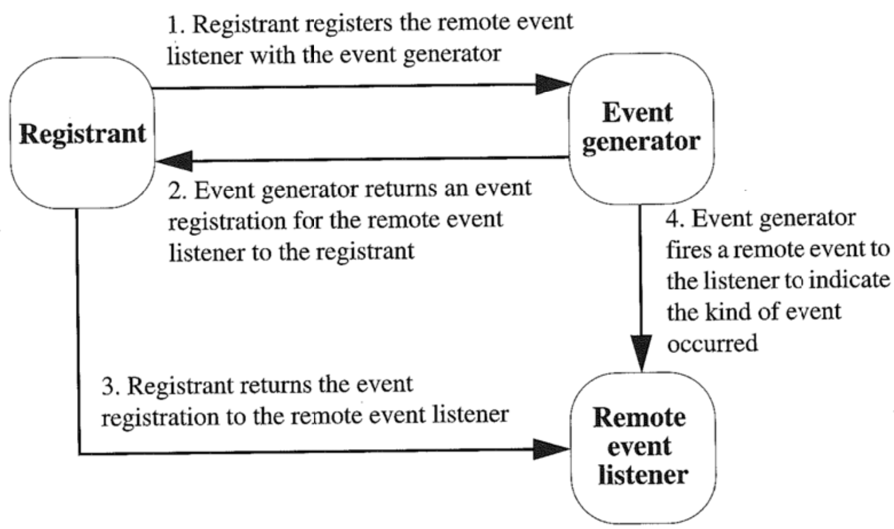
Although there is no single interface that allows for the registration of event notifications, there are a number of requirements that would be put on any such interface if it wished to conform with the remote event registration model. In particular, any such interface should reflect:

- Event registrations are bounded in time in a way that allows those registrations to be renewed when necessary. This can easily be reflected by returning, as part of an event registration, a lease for that registration.
- Notifications need not be delivered to the entity that originally registered interest in the event. The ability to have third-party filters greatly enhances the functionality of the system. The easiest way to allow such functionality is to allow the specification of the `RemoteEventListener` to receive the notification as part of the original registration call.
- Notifications can contain a `MarshalledObject` supplied by the original registrant, allowing the passing of arbitrary information (including a closure that is to be run on notification) as part of the event notification, so the registration call should include a `MarshalledObject` that is to be passed as part of the `RemoteEvent`.

EV.2.3 Details of the Interfaces and Classes

EV.2.3.1 The `RemoteEventListener` Interface

The `RemoteEventListener` interface needs to be implemented by any object that wants to receive a notification of a `RemoteEvent` from some other object. The object supporting the `RemoteEventListener` interface does not have to be the object that originally registered interest in the occurrence of an event. To allow the notification of an event's occurrence to be sent to an entity other than the one that registered with the event generator, the registration call needs to accept a destination parameter that indicates the object to which the notification should be sent. This destination must be an object that implements the `RemoteEventListener` interface.



The `RemoteEventListener` interface extends the `Remote` interface (indicating that it is an interface to a `Remote` object) and the `java.util.EventListener` interface. This latter interface is used in the Java Abstract Window Toolkit (AWT) and JavaBeans™ components to indicate that an interface is the recipient of event notifications. The `RemoteEventListener` interface consists of a single method, `notify`:

```
public interface RemoteEventListener extends Remote,
    java.util.EventListener
{
    void notify(RemoteEvent theEvent)
        throws UnknownEventException, RemoteException;
}
```

The `notify` method has a single parameter of type `RemoteEvent` that encapsulates the information passed as part of a notification. The `RemoteEvent` base class extends the class `java.util.EventObject` that is used in both JavaBeans components and AWT components to propagate event information. The `notify` method returns nothing but can throw exceptions.

EV.2.3.2 The `RemoteEvent` Class

The public part of the `RemoteEvent` class is defined as:

```
public class RemoteEvent extends java.util.EventObject {
    public RemoteEvent(Object source,long eventID,
                       long seqNum, MarshalledObject handback)
    public Object getSource () {...}
    public long getID() {...}
    public long getSequenceNumber() {...}
    public MarshalledObject getRegistrationObject() {...}
}
```

The abstract state contained in a `RemoteEvent` object includes: a reference to the object in which the event occurred, a `long` that identifies the kind of event relative to the object in which the event occurred, a `long` that indicates the sequence number of this instance of the event kind, and a `MarshalledObject` that is to be handed back when the notification occurs.

The combination of the event identifier and the object reference of the event generator obtained from the `RemoteEvent` object should uniquely identify the event type. If this type is not one in which the `RemoteEventListener` has registered interest (or in which someone else has registered interest on behalf of the `RemoteEventListener` object), an `UnknownEventException` may be generated as a return from the remote event listener's `notify` method.[1]

On receipt of an `UnknownEventException`, the caller of the `notify` method is allowed to cancel the lease for the combination of the `RemoteEventListener` instance and the kind of event that was contained in the `notify` call.

The sequence number obtained from the `RemoteEvent` object is an increasing value that can act as a hint to the number of occurrences of this event relative to some earlier sequence number. Any object that generates a `RemoteEvent` is required to ensure that for any two `RemoteEvent` objects with the same event identifier, the sequence number of those events differ if and only if the `RemoteEvent` objects are a response to different events. This guarantee is required to allow notification calls to be idempotent. A further guarantee is that if two `RemoteEvents`, *x* and *y*, come from the same source and have the same event identifier, then *x* occurred before *y* if and only if the sequence number of *x* is lower than the sequence number of *y*.

A stronger guarantee is possible for those generators of `RemoteEvents` that choose support it. This guarantee states that not only do sequence numbers increase, but they are not skipped. In such a case, if `RemoteEvent` *x* and *y* have the same source and the same event identifier, and *x* has sequence number *m* and *y* has sequence number *n*, then if $m < n$ there were exactly $n–m–1$ events of the same event type between the event that triggered *x* and the event that triggered *y*. Such sequence numbers are said to be "fully ordered."

There are interactions between the generation of sequence numbers for a `RemoteEvent` object and the ability to see events that occur within the scope of a transaction. Those interactions are discussed in Section EV.2.4 on page 169.

The common intent of a call to the `notify` method is to allow the recipient to find out that an occurrence of a kind of event has taken place. The call to the `notify` method is synchronous to allow the party making the call to know whether the call succeeded. However, it is not part of the semantics of the call that the notification return can be delayed while the recipient of the call reacts to the occurrence of the event. Simply put, the best strategy on the part of the recipient is to note the occurrence in some way and then return from the `notify` method as quickly as possible.

EV.2.3.3 The `UnknownEventException`

The `UnknownEventException` is thrown when the recipient of a `RemoteEvent` does not recognize the combination of the event identified and the source of the

[1] There are cases in which the `UnknownEventException` may not be appropriate, even when the notification is for a combination of an event and a source that is not expected by the recipient. Objects that act as event mailboxes for other objects, for example, may be willing to accept any sort of notification from a particular source until explicitly told otherwise.

event as something in which it is interested. Throwing this exception has the effect of asking the sender to not send further notifications of this kind of event from this source in the future. This exception is defined as:

```
public class UnknownEventException extends Exception {
    public UnknownEventException() {
        super();
    }
    public UnknownEventException(String reason){
        super(reason);
    }
}
```

EV.2.3.4 An Example `EventGenerator` Interface

Registering interest in an event can take place in a number of ways, depending on how the event generator identifies its internal events. There is no single way of identifying the events that are reasonable for all objects and all kinds of events, and so there is no single way of registering interest in events. Because of this, there is no single interface for registration of interest.

However, the interaction between the event generator and the remote event listener does require that some initial information be passed from the registrant to the object that will make the call to its `notify` method.

The `EventGenerator` interface is an example of the kind of interface that could be used for registration of interest in events that can (logically) occur within an object. This is a remote interface that contains one method:

```
public interface EventGenerator extends Remote {
    public EventRegistration register(long evId,
                    MarshalledObject handback,
                    RemoteEventListener toInform,
                    long leaseLength
        throws UnknownEventException, RemoteException;
}
```

The one method, `register`, allows registration of interest in the occurrence of an event inside the object. The method takes an `evID` that is used to identify the class of events, an object that is handed back as part of the notification, a reference to an `RemoteEventListener` object, and a `long` integer indicating the leasing period for the interest registration.

The `evID` is a `long` that is obtained by a means that is not specified here. It may be returned by other interfaces or methods, or be defined by constants associated with the class or some interface implemented by the class. If an evID is supplied to this call that is not recognized by the EventGenerator object, an UnknownEventException is thrown. The use of a long to identify kinds of events is used only for illustrative purposes—objects may identify events by any number of mechanisms, including identifiers, using separate methods to allow registration in different events, or allowing various sorts of pattern matching to determine what events are of interest.

The second argument of the register method is a MarshalledObject that is to be handed back as part of the notification generated when an event of the appropriate type occurs. This object is known to the remote event listener and should contain any information that is needed by the listener to identify the event and to react to the occurrence of that event. This object will be passed back as part of the event object that is passed as an argument to the notify method. By passing a MarshalledObject into the register method, the re-creation of the object is postponed until the object is needed.

The ability to pass a MarshalledObject as part of the event registration should be common to all event registration methods. While there is no single method for identifying events in an object, the use of the pattern in which the remote event listener passes in an object that is passed back as part of the notification is central to the model of remote events presented here.

The third argument of the EventGenerator interface's register method is a RemoteEventListener implementation that is to receive event notifications. The listener may be the object that is registering interest, or it may be some other RemoteEventListener, such as a third-party event handler or notification "mailbox." The ability to specify some third-party object to handle the notification is also central to this model of event notification, and the capability of specifying the recipient of the notification is also common to all event registration interfaces.

The final argument to the register method is a long indicating the requested duration of the registration. This period is a request, and the period of interest actually granted by the event generator may be different. The actual duration of the registration lease is returned as part of the Lease object included in the EventRegistration object.

The return value of the register method is an object of the EventRegistration class. This object contains a long identifying the kind of event in which interest was registered (relative to the object granting the registration), a reference to the object granting the registration, and a Lease object.

EV.2.3.5 The EventRegistration Class

Objects of the class EventRegistration are meant to encapsulate the information the client needs to identify a notification as a response to a registration request and to maintain that registration request. It is not necessary for a method that allows event interest registration to return an object of type EventRegistration. However, the class does show the kind of information that needs to be returned in the event model.

The public parts of this class look like

```
public class EventRegistration implements java.io.Serializable
{
    public EventRegistration(long eventID,
                             Object eventSource,
                             Lease eventLease,
                             long seqNum) {...}
    public long getID() {...}
    public Object getSource() {...}
    public Lease getLease() {...}
    public long getSequenceNumber() {...}
}
```

The getID method returns the identifier of the event in which interest was registered. This, combined with the return value returned by getSource, will uniquely identify the kind of event. This information is needed to hand off to third-party repositories to allow them to recognize the event and route it correctly if they are to receive notifications of those events.

The result of the EventRegistration.getID method should be the same as the result of the RemoteEvent.getID method, and the result of the EventRegistration.getSource method should be the same as the RemoteEvent.getSource method.

The getSource method returns a reference to the event generator, which is used in combination with the result of the getID method to uniquely identify an event.

The getLease returns the Lease object for this registration. It is used in lease maintenance.

The getSequenceNumber method returns the value of the sequence number on the event kind that was current when the registration was granted, allowing comparison with the sequence number in any subsequent notifications.

EV.2.4 Sequence Numbers, Leasing and Transactions

There are cases in which event registrations are allowed within the scope of a transaction, in such a way that the notifications of these events can occur within the scope of the transaction. This means that other participants in the transaction may see some events whose visibility is hidden by the transaction from entities outside of the transaction. This has an effect on the generation of sequence numbers and the duration of an event registration lease.

An event registration that occurs within a transaction is considered to be scoped by that transaction. This means that any occurrence of the kind of event of interest that happens as part of the transaction will cause a notification to be sent to the recipients indicated by the registration that occurred in the transaction. Such events must have a separate event identification number (the `long` returned in the `RemoteEvent getID` method) to allow third-party store-and-forward entities to distinguish between an event that happens within a transaction and those that happen outside of the transaction. Notifications of these events will not be sent to entities that registered interest in this kind of event outside the scope of the transaction until and unless the transaction is committed.

Because of this isolation requirement of transactions, notifications sent from inside a transaction will have a different sequence number than the notifications of the same events would have outside of the transaction. Within a transaction, all `RemoteEvent` objects for a given kind of event are given a sequence number relative to the transaction, even if the event that triggered the `RemoteEvent` occurs outside of the scope of the transaction (but is visible within the transaction). One counter-intuitive effect of this is that an object could register for notification of some event *E* both outside a transaction and within a transaction, and receive two distinct `RemoteEvent` objects with different sequence numbers for the same event. One of the `RemoteEvent` objects would contain the event with a sequence number relative to the transaction, while the other would contain the event with a sequence number relative to the source object.

The other effect of transactions on event registrations is to limit the duration of a lease. A registration of interest in some kind of event that occurs within the scope of a transaction should be leased in the same way as other event interest registrations. However, the duration of the registration is the minimum of the length of the lease and the duration of the transaction. Simply put, when the transaction ends (either because of a commit or a rollback), the interest registration also ends. This is true even if the lease for the event registration has not expired and no call has been made to `cancel` the lease.

It is still reasonable to lease event interest registrations, even in the scope of a transaction, because the requested lease may be shorter than the transaction in question. However, no such interest registration will survive the transaction in which it occurs.

EV.2.5 Serialized Forms

Class	serialVersionUID	Serialized Fields
RemoteEvent	1777278867291906446L	Object source long eventID long seqNum MarshalledObject handback
UnknownEventException	5563758083292687048L	*none*
EventRegistration	4055207527458053347L	Object source long eventID Lease lease long seqNum

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EV.3 Third-Party Objects

ONE of the basic reasons for the event design is to allow the production of third-party objects, or "agents," that can be used to enhance a system built using distributed events and notifications. Now we will look at three examples of such agents, which allow various forms of enhanced functionality without changing the basic interfaces. Each of these agents may be thought of as *distributed event adapters*.

The first example we will look at is a *store-and-forward agent*. The purpose of this object is to act on behalf of the event generator, allowing the event generator to send the notification to one entity (the store-and-forward agent) that will forward the notification to all of the event listeners, perhaps with a particular policy that allows a failed delivery attempt to be retried at some later date.

The second example, which we will call a *notification filter*, is an object that may be local to either the event generator or the event listener. This agent gets the notification and spawns a thread that will respond, using a method supplied by the object that originally registered interest in events of that kind.

The final object is a *notification mailbox*. This mailbox will store notifications for another object (a remote event listener) until that object requests that the notifications be delivered. This design allows the listener object that registered interest in the event type to select the times at which a notification can be delivered without losing any notifications that would have otherwise have been delivered.

EV.3.1 Store-and-Forward Agents

A store-and-forward agent enables the object generating a notification to hand off the actual notification of those who have registered interest to a separate object.

This agent can implement various policies for reliability. For example, the agent could try to deliver the notification once (or a small number of times) and, if that call fails, not try again. Or the agent could try and, on notification failure, try again at a preset or computed interval of time for some known period of time. Either way, the object in which the event occurred could avoid worrying about the delivery of notifications, needing to notify only the store-and-forward agent (which might be on the same machine and hence more reliably available).

From the point of view of the remote event listener, there is no difference between the notification delivered by a store-and-forward agent and one delivered directly from the object in which the event that generated the original notification occurred. This transparency allows the decision to use a store-and-forward agent to be made by the object generating the notification, independent of the object receiving the notification. There is no need for distributed agreement; all that is required is that the object using the agent know about the agent.

A store-and-forward agent is used by an object that generates notifications. When an object registers interest in receiving notifications of a particular event type, the object receiving that registration will pass the registration along to the store-and-forward agent. This agent will keep track of which objects need to be notified of events that occur in the original object.

When an event of interest occurs in the original object, it need send only a single notification to the store-and-forward agent. This notification can return immediately, with processing further happening inside the store-and-forward agent. The object in which the event of interest occurred will now be freed from informing those that registered interest in the event.

Notification is taken over by the store-and-forward agent. This agent will now consult the list of entities that have registered interest in the occurrence of an event and send a notification to those entities. Note that these might not be the same as the objects that registered interest in the event; the object that should receive the event notification is specified during the event interest registration.

The store-and-forward agent might be able to make use of network-level multicast (assuming that the `RemoteEvent` object to be returned is identical for multiple recipients of the `notify` call), or might send a separate notification to each of the entities that have registered interest. Different store-and-forward agents could implement different levels of service, from a simple agent that sends a notification and doesn't care whether the notification is actually delivered (for example, one that simply caught `RemoteExceptions` and discards them) to agents that will repeatedly try to send the notification, perhaps using different fallback strategies, until the notification is known to be successful or some number of tries have been attempted.

The store-and-forward agent does not need to know anything about the kinds of events that are triggering the notifications that it stores and forwards. All that is needed is that the agent implement the `RemoteEventListener` interface and some interface that allows the object producing the initial notification to register with the agent. This combination of interfaces allows such a service to be offered to any number of different objects without having to know anything about the possible changes in abstract state that might be of interest in those objects.

Note that the interface used by the object generating the original notifications to register with the store-and-forward agent does not need to be standard. Different qualities of service concerning the delivery of notifications may require different registration protocols. Whether or not the relationship between the notification originator and the store-and-forward agent is leased or not is also up to the implementation of the agent. If the relationship is leased, lease renewal requests would need to be forwarded to the agent.

In fact, an expected pattern of implementation would be to place a store-and-forward agent on every machine on which objects were running that could produce events. This agent, which could be running in a separate JVM (on hardware that supported multiple processes) could offload the notification-generating objects from the need to send those notifications to all objects that had registered interest. It would also allow for consistent handling of delivery guarantees across all objects on a particular machine. Since the store-and-forward agent is on the same machine as the objects using the agent, the possibilities of partial failure brought about by network problems (which wouldn't affect communication between objects on the same machine) and server machine failure (which would induce total, rather than partial, failure in this case) are limited. This allows the reliability of notifications to be offloaded to these agents instead of being a problem that needs to be solved by all of the objects using the notification interfaces.

A store-and-forward agent does require an interface that allows the agent to know what notifications it is supposed to send, the destinations of those notifications, and on whose behalf those notifications are being sent. Since it is the store-and-forward agent that is directing notification calls to the individual recipients, the agent will also need to hold the `Object` (if any) that was passed in during interest registration to be returned as part of the `RemoteEvent` object.

In addition, the store-and-forward agent could be the issuer of `Lease` objects to the object registering interest in some event. This could offload any lease renewal calls from the original recipient of the registration call, which would need to know only when there were no more interest registrations of a particular event kind remaining in the store-and-forward agent.

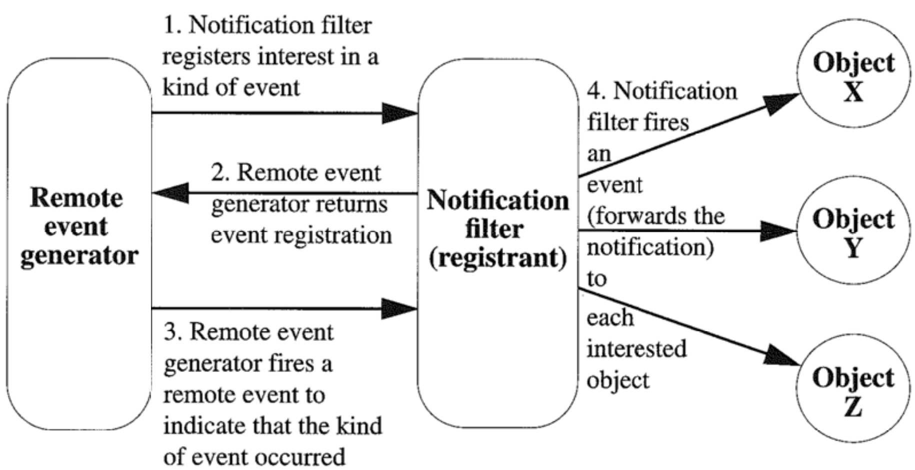
EV.3.2 Notification Filters

Similar to a store-and-forward agent is a notification filter, which can be used by either the generator of a notification or the recipient to intercept notification calls, do processing on those calls, and act in accord with that processing (perhaps forwarding the notification, or even generating new notifications).

Again, such filters are made possible because of the uniform signature of the method used to send all notifications and because of the ability of an object to indicate the recipient of a notification when registering for a notification. This uniformity and indirection allow the composition of third-party entities. A filter could receive events from a store-and-forward agent without the client of the original registration knowing about the store-and-forward agent or the server in which the notifications are generated knowing about the filter. This composition can be extended further; store-and-forward agents could use other store-and-forward agents, and filters can themselves receive notifications from other filters.

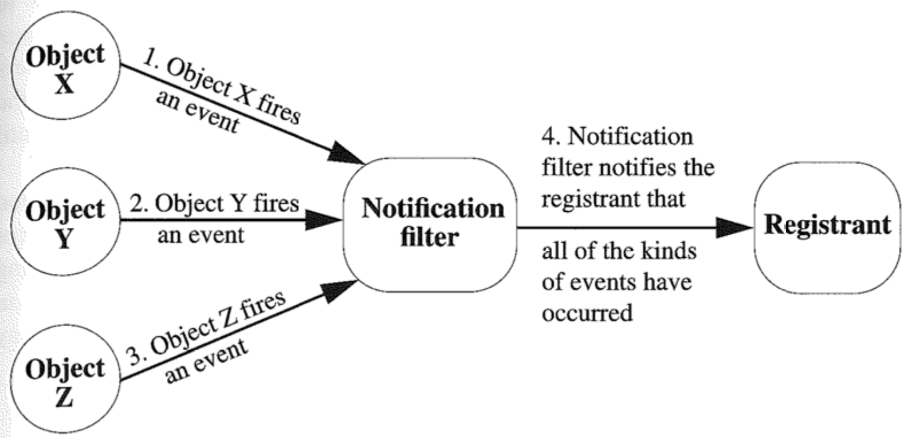
EV.3.2.1 Notification Multiplexing

One example of such a filter is one that can be used to concentrate notifications in a way to help minimize network traffic. If a number of different objects on a single machine are all interested in some particular kind of event, it could make sense to create a notification filter that would register interest in the event. When a notification was received by the filter, it would forward the notification to each of the (machine local) objects that had expressed interest.



EV.3.2.2 Notification Demultiplexing

Another example of such a filter is an object that generates an event in response to a series of events that it has received. There might be an object that is interested only in some particular sequence of events in some other object or group of objects. This object could register interest in all of the different kinds of events, asking that the notifications be sent to a filter. The purpose of the filter is to receive the notifications and, when the notifications fit the desired pattern (as determined by some class passed in from the object that has asked the notifications be sent to the filter), generate some new notification that is delivered to the client object.



EV.3.3 Notification Mailboxes

The purpose of a notification mailbox is to store the notifications sent to an object until such time as the object for which the notifications were intended desires delivery.

Such delivery can be in a single batch, with the mailbox storing any notifications received after the last request for delivery until the next request is received. Alternatively, a notification mailbox can be viewed as a faucet, with notifications turned on (delivering any that have arrived since the notifications were last turned off) and then delivering any subsequent notifications to an object immediately, until told by that object to hold the notifications.

The ability to have notification mailboxes is important in a system that allows objects to be deactivated (for example, to be saved to stable storage in such a way that they are no longer taking up any computing resource) and re-activated. The usual mechanism for activating an object is a method call. Such activation can be expensive in both time and computing resources; it is often too expensive to be justified for the receipt of what would otherwise be an asynchronous event notification. An event mailbox can be used to ensure that an object will not be activated merely to handle an event notification.

Use of a mailbox is simple; the object registering interest in receiving an event notification simply gives the mailbox as the place to send the notifications. The mailbox can be made responsible for renewing leases while an object is inactive, and for storing all (or the most recent, or the most recent and the count of other) notifications for each type of event of interest to the object. When the object indicates that it wishes to receive any notifications from the mailbox, those notifications can be delivered. Delivery can continue until the object requests storage to occur again, or storage can resume automatically.

Such a mailbox is a type of filter. In this case, however, the mailbox filters over time rather than over events. A pure mailbox need not be concerned with the kinds of notifications that it stores. It simply holds the `RemoteEvent` objects until they are wanted.

It is because of mailboxes and other client-side filters that the information returned from an event registration needs to include a way of identifying the event and the source of the event. Such client-side agents need a way of distinguishing between the events they are expected to receive and those that should generate an exception to the sender. This distinction cannot be made without some simple way of identifying the event and the object of origin.

EV.3.4 Compositionality

All of the above third-party entities work because of two simple features of the `RemoteEventListener` interface:

- There is a single method, `notify`, that passes a single type of object, `RemoteEvent` (or a subtype of that object) for all notifications
- There is a level of indirection in delivery allowed by the separate specification of a recipient in the registration method that allows the client of that call to specify a third-party object to contact for notifications

The first of these features allows the composition of notification handlers to be chained, beginning with the object that generates the notification. Since the ultimate recipient of the event is known to be expecting the event through a call to the single `notify` method, other entities can be composed and interposed in the call chain as long as they produce this call with the right `RemoteEvent` object (which will include a field indicating the object at which the notification originated). Because there is a single method call for all notifications, third-party handlers can be produced to accept notifications of events without having to know the kind of event that has occurred or any other detail of the event.

Compositionality in the other direction (driven by the recipient of the notification) is enabled by allowing the object registering interest to indicate the first in an arbitrary chain of third parties to receive the notification. Thus the recipient can build a chain of filters, mailboxes, and forwarding agents to allow any sort of delivery policy that object desires, and then register interest with an indication that all notifications should be delivered to the beginning of that chain. From the point of view of the object in which the notification originates, the series of objects the notification then goes through is unknown and irrelevant.

EV.4 Integration with JavaBeans Components

As we noted previously, distributed notification differs from local notification (such as the notification used in user interface programming) in a number of ways. In particular, a distributed notification may be delayed, dropped, or otherwise fail between the object in which the event occurred and the object that is the ultimate recipient of the notification of that event. Additionally, a distributed event notification may require handling by a number of third-party objects between the object that is interested in the notification and the object that generates the notification. These third-party objects need to be able to handle arbitrary events, and so from the point of view of the type system, all of the events must be delivered in the same fashion.

Although this model differs from the event model used for user interface tools such as the AWT or Java Foundation Classes (JFC), such a difference in model is to be expected. The event model for such user interface toolkits was never meant to allow the components that communicate using these local event notifications to be distributed across virtual or physical machines; indeed, such systems assume that the event delivery will be fast, reliable, and not open to the kinds of partial failures or delays that are common in the distributed case.

In between the requirements of a local event model and the distributed event model presented here is the event model used by software components to communicate changes in state. The delegation event model, which is the event model for JavaBeans components, written in the Java programming language, is built as an extension of the event model used for AWT and JFC. This is completely appropriate, as most JavaBeans components will be located in a single address space and can assume that the communication of events between components will meet the reliability and promptness requirements of that model.

However, it is also possible that JavaBeans components will be distributed across virtual, and even physical, machines. The assumption that the event propagation will be either fast or reliable can lead to subtle program errors that will not be found until the components are deployed (perhaps on a slow or unreliable network). In such case, an event and notification model such as that found in this specification is more appropriate.

One approach would be to add a second event model to the JavaBeans component specification that dealt only with distributed events. While this would have the advantage of exporting the difference between local and remote components to the component builder, it would also complicate the JavaBeans component model unnecessarily.

We will show how the current distributed event model can be fit into the existing Java platform's event model. While the mapping is not perfect (nor can it be, since there are essential differences between the two models), it will allow the current tools used to assemble JavaBeans components to be used when those components are distributed.

EV.4.1 Differences with the JavaBeans Component Event Model

The JavaBeans component event model is derived from the event model used in the AWT in JDK 1.2. The model is characterized by:

- Propagation of event notifications from sources to listeners by Java technology method invocations on the target listener objects
- Identification of the kind of event notification by using a different method in the listener being called for each kind of event
- Encapsulation of any state associated with an event notification in an object that inherits from `java.util.EventObject` and that is passed as the sole argument of the notification method
- Identification of event sources by the convention of those sources defining registration methods, one for each kind of event in which interest can be registered, that follow a particular design pattern

The distributed event and notification model that we have defined is similar in a number of ways:

- Distributed event propagation is accomplished by the use of `Remote` methods.
- State passed as part of the notification is encapsulated in an object that is derived from `java.util.EventObject` and is passed as the sole argument of the notification method.
- The `RemoteEventListener` interface extends the more basic interface `java.util.EventListener`.

However, there are also differences between the JavaBeans component event model and the distributed event model proposed here:

- Identification of the kind of event is accomplished by passing an identifier from the source of the notification to the listener; the combination of the object in which the event occurred and the identifier uniquely identifies the kind of event.
- Notifications are accomplished through a single method, `notify`, defined in the `RemoteEventListener` interface rather than by a different method for each kind of event.
- Registration of interest in a kind of event is for a (perhaps renewable) period of time, rather than being for a period of time bound by the active cancellation of interest.
- Objects registering interest in an event can, as part of that registration, include an object that will be passed back to the recipient of the notification when an event of the appropriate type occurs.

Most of these differences in the two models can be directly traced to the distributed nature of the events and notifications defined in this specification.

For example, as you have seen, reliability and recovery of the distributed notification model is based on the ability to create third-party objects that can provide those guarantees. However, for those third-party objects to be able to work in general cases, the signature for a notification must be the same for all of the event notifications that are to be handled by that third party. If we were to follow the JavaBeans component model of having a different method for each kind of event notification, third party objects would need to support every possible notification method, including those that had not yet been defined when the third-party object was implemented. This is clearly impossible.

Note that this is not a weakness in the JavaBeans component event model, merely a difference required by the different environments in which the event models are assumed to be used. The JavaBeans component event model, like the AWT model on which it is based, assumes that the event notification is being passed between objects in the same address space. Such notifications do not need various delivery and reliability guarantees—delivery can be considered to be (virtually) instantaneous and can be assumed to be fully reliable.

Being able to send event notifications through a single `Remote` method also requires that the events be identified in some way other than the signature of the notification delivery method. This leads to the inclusion of an event identifier in the event object. Since the generation of these event identifiers cannot be guaranteed to be globally unique across all of the objects in a distributed system, they must be made relative to the object in which they are generated, thus requiring the combination of the object of origin and the event identifier to completely identify the kind of event.

The sequence number being included in the event object is also an outgrowth of the distributed nature of the interfaces. Since no distributed mechanism can guarantee reliability, there is always the possibility that a particular notification will not be delivered, or could be delivered more than once by some notification agent. This is not a problem in the single-address-space environment of AWT and JavaBeans components, but requires the inclusion of a sequence number in the distributed case.

EV.4.2 Converting Distributed Events to JavaBeans Events

Translating between the event models is fairly straightforward. All that is required is:

- Allow an event listener to map from a distributed event listener to the appropriate call to a notification method
- Allow creation of a `RemoteEvent` from the event object passed in the JavaBeans component event notification method
- Allow creation of a JavaBeans component event object from a `RemoteEvent` object without loss of information

Each of these is fairly straightforward and can be accomplished in a number of ways.

More complex matings of the two systems could be undertaken, including third-party objects that keep track of the interest registrations made by remote objects and implement the corresponding JavaBeans component event notification methods by making the remote calls to the `RemoteEventListener notify` method with properly constructed `RemoteEvent` objects. Such objects would need to keep track of the event sequence numbers and would need to deal with the additional failure modes that are inherent in distributed calls. However, their implementation would be fairly straightforward and would fit into the JavaBeans component model of event adapters.

THE JINI TRANSACTION SPECIFICATION defines the lightweight distributed transaction mechanism for the Jini architecture. The purpose is to allow any set of participants to cooperate with the transaction's manager to provide transactional behavior. The participant services need not know about each other—the client, simply by using the same transaction with multiple services, can use the transaction's manager to drive them all to completion or, if necessary, abort all the operations. The specification covers both the general transaction mechanism and the specific ones that implement the standard Jini transactions with their associated semantics. The lookup service does not use transactions, but a shared transaction mechanism for Jini services is important enough to put this specification into the core of Jini specifications.

TX

The Jini Transaction Specification

Transactions (TX)

TX.1 Introduction

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 ensure 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 those objects can use 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 backward). 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 ensure 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.

TX.1.1 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 needs to know only 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.

As shown in Figure TX.1.1, 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 interface `TransactionParticipant`. Particular operations associated with a given transaction are said to be *performed under* that transaction. The client that created the transaction might or might not be a participant in the transaction.

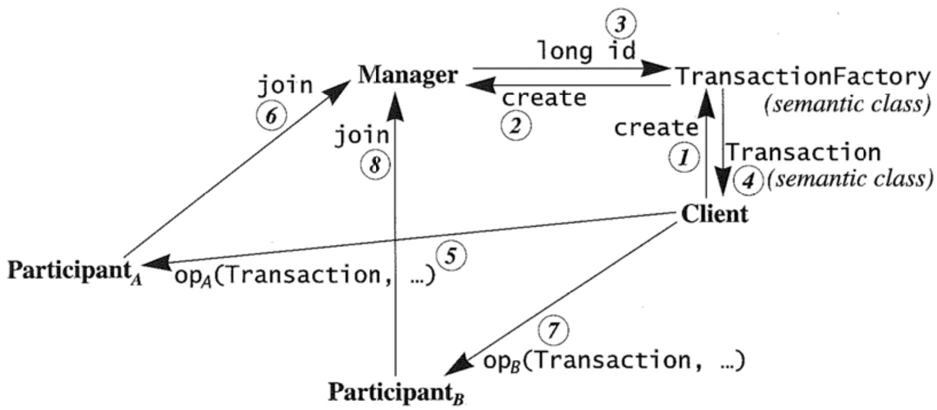


FIGURE TX.1.1: ***Transaction Creation and Use***

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.

TX.1.2 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 whether 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 see only 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 ensure that the ACID properties are met and go to considerable trouble to ensure that no participant can violate any of the properties.

This approach differs for both philosophical and practical reasons. The philosophical reason is centered on a 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 that can still make use of the two-phase commit protocol. A group of transient objects might 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 only part of the changes made under the transaction. 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 be prevented only by coordination with the transaction manager or the client that committed the transaction. Coordination between clients is outside the scope of this specification.

TX.1.3 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.

TX.1.4 Dependencies

This document relies upon the following other specifications:

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

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TX.2 The Two-Phase Commit Protocol

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.

The following types are imported from other packages and are referenced in unqualified form in the rest of this specification:

```
java.rmi.Remote
java.rmi.RemoteException
java.rmi.NoSuchObjectException
java.io.Serializable
net.jini.core.lease.LeaseDeniedException
net.jini.core.lease.Lease
```

All the methods defined to throw `RemoteException` will do so in the circumstances described by the RMI specification.

Each type is defined where it is first described. Each method is described where it occurs in the lifecycle of the two-phase commit protocol. 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, using the § abbreviation for the word "section."

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

TX.2.2 Starting a Nested Transaction

The `TransactionManager.create` method returns a new *top-level* transaction. Managers that implement just the `TransactionManager` interface support only 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) // §TX.2.2
        throws UnknownTransactionException,
                CannotJoinException, LeaseDeniedException,
                RemoteException;
    void promote(long id, TransactionParticipant[] parts,
                  long[] crashCounts,
                  TransactionParticipant drop)
        throws UnknownTransactionException,
                CannotJoinException, CrashCountException,
                RemoteException; // §TX.2.7
}
```

The `create` method takes a *parent* transaction—represented by the manager for the parent transaction and the identifier 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` (§TX.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 because 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) {...}
}
```

TX.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 // §TX.2.4
{
    int prepare(TransactionManager mgr, long id) // §TX.2.6
        throws UnknownTransactionException, RemoteException;
    void commit(TransactionManager mgr, long id) // §TX.2.6
        throws UnknownTransactionException, RemoteException;
    void abort(TransactionManager mgr, long id) // §TX.2.6
        throws UnknownTransactionException, RemoteException;
    int prepareAndCommit(TransactionManager mgr, long id)
                                                // §TX.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 (because of a system crash if the storage is volatile, for example) 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
{
```

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```
        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 because 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`.

TX.2.4 Transaction States

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

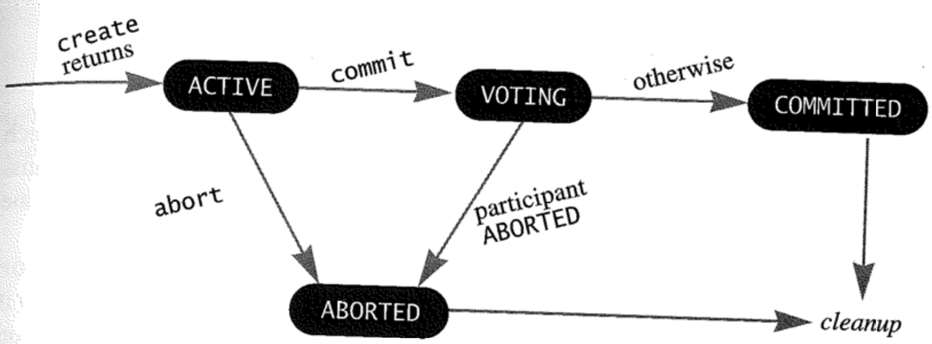
```
package net.jini.core.transaction.server;

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.

TX.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.

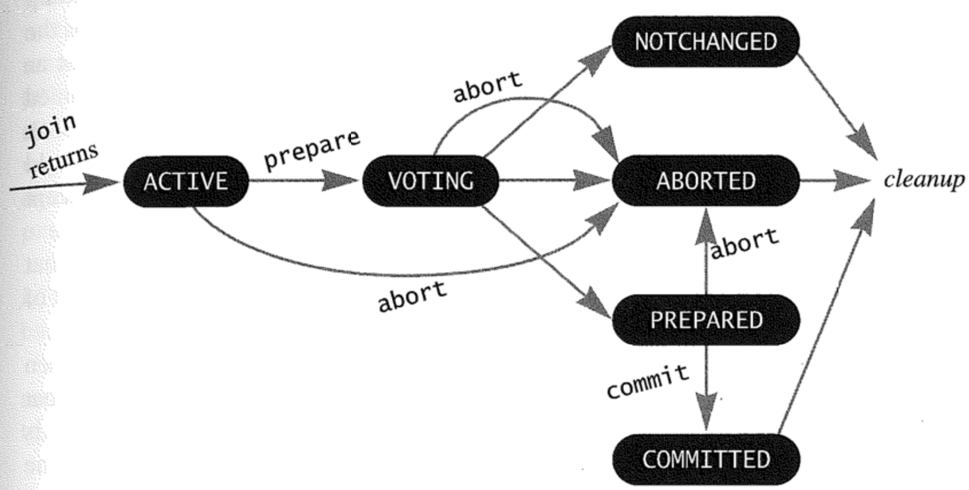
Overloads of the `commit` and `abort` methods take an additional `waitFor` timeout parameter specified in milliseconds that tells the manager to wait until it has successfully notified all participants about the outcome of the transaction before the method returns. If the timeout expires before all participants 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 to `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) {…}
}
```

TX.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 (§TX.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 (§TX.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 (§TX.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 will 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 drop out of a transaction only 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 re-invoke 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.

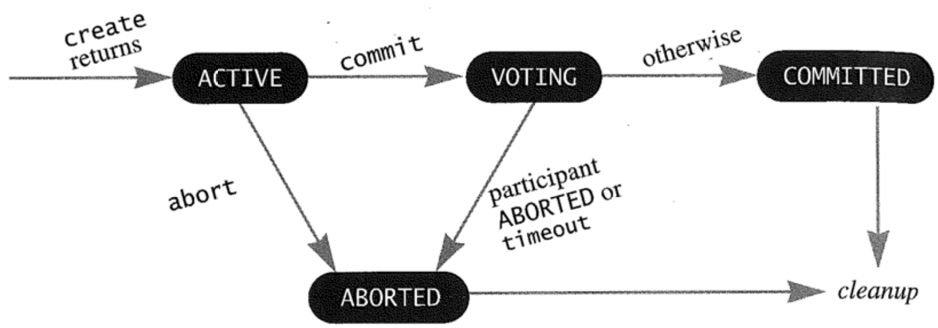
The participant's implementation of prepareAndCommit must be equivalent to the following:

```
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.

TX.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, in which 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*, in which 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 that 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 because the participant called 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 in which 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 that is 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 in which 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.

TX.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 that 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 in which some, but not all, of the participants have rolled forward.

TX.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 if it crashes 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 either an UnknownTransactionException or a NoSuchObjectException: The recovery should move the participant to the ABORTED state.
- getState throws RemoteException: The recovery should repeat the attempt after a pause.

TX.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 be using only one disk. Or a participant may always store its data in memory, expecting to lose it in 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.

TX.3 Default Transaction Semantics

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 §TX.1.2). 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 following definition of semantics for any activities performed under that transaction.

TX.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() // §TX.2.5
            throws UnknownTransactionException,
                   CannotCommitException,
                   RemoteException;
        void commit(long waitFor) // §TX.2.5
            throws UnknownTransactionException,
                   CannotCommitException,
                   TimeoutExpiredException, RemoteException;
        void abort() // §TX.2.5
            throws UnknownTransactionException,
                   CannotAbortException,
                   RemoteException;
        void abort(long waitFor) // §TX.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 §TX.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) // §TX.2.2
        throws UnknownTransactionException,
               CannotJoinException, LeaseDeniedException,
               RemoteException;
    Created create(NestableTransactionManager mgr,
                   long leaseFor) // §TX.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.

TX.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)
                                                    // §TX.2.1
        throws LeaseDeniedException, RemoteException {…}
    public static NestableTransaction.Created
        create(NestableTransactionManager mgr,long leaseFor)
                                                    // §TX.2.2
        throws LeaseDeniedException, RemoteException {…}
}
```

The first `create` method is usually used when nested transactions are not required. However, if the manager that is 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.

TX.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) // §TX.2.3
        throws UnknownTransactionException,
               CannotJoinException, CrashCountException,
               RemoteException {...}
    public int getState() // §TX.2.7
        throws UnknownTransactionException, RemoteException
        {...}
    public boolean isNested() {...} // §TX.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 intended 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 that is 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
    extendsServerTransaction implements NestableTransaction
{
    public final NestableServerTransaction parent;
    public NestableServerTransaction(
           NestableTransactionManager mgr, long id,
           NestableServerTransaction parent) {…}
    public void promote(TransactionParticipant[] parts,
                        long[] crashCounts,
                        TransactionParticipant drop)
                                                    // §TX.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 (§TX.2.2) or null if it is a top-level transaction.

The constructor should not be used directly; it is intended 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)
```