Oracle Berkeley DB, Java Edition

Getting Started with Transaction Processing

11g Release 2

Library Version 11.2.5.0

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Published 4/21/2014

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Preface

This document describes how to use transactions with your Berkeley DB, Java Edition applications. It is intended to describe how to transaction protect your application's data. The APIs used to perform this task are described here, as are the environment infrastructure and administrative tasks required by a transactional application. This book also describes multi-threaded JE applications and the requirements they have for deadlock detection.

This book describes Berkeley DB, Java Edition version 11*g* Release 2

This book is aimed at the software engineer responsible for writing a transactional JE application.

This book assumes that you have already read and understood the concepts contained in the *Getting Started with Berkeley DB, Java Edition* guide.

Conventions Used in this Book

The following typographical conventions are used within in this manual:

Class names are represented in `monospaced font`, as are `method names`. For example: "The `Environment.openDatabase()` method returns a `Database` class object."

Variable or non-literal text is presented in *italics*. For example: "Go to your *JE_HOME* directory."

Program examples are displayed in a `monospaced font` on a shaded background. For example:

```
import com.sleepycat.je.Environment;

...

// Open the environment. Allow it to be created if it does not already
// exist.
Environment myDbEnv;
```

In some situations, programming examples are updated from one chapter to the next. When this occurs, the new code is presented in **`monospaced bold`** font. For example:

```
import com.sleepycat.je.Environment;
import com.sleepycat.je.EnvironmentConfig;
import java.io.File;

...

// Open the environment. Allow it to be created if it does not already
// exist.
Environment myDbEnv;
EnvironmentConfig envConfig = new EnvironmentConfig();
envConfig.setAllowCreate(true);
```

```
myDbEnv = new Environment(new File("/export/dbEnv"), envConfig);
```

Note

Finally, notes of special interest are represented using a note block such as this.

For More Information

Beyond this manual, you may also find the following sources of information useful when building a transactional JE application:

- Getting Started with Berkeley DB, Java Edition
- Berkeley DB, Java Edition Javadoc
- Berkeley DB, Java Edition Collections Tutorial
- Berkeley DB, Java Edition Getting Started with High Availability Applications

To download the latest Berkeley DB Java Edition documentation along with white papers and other collateral, visit http://www.oracle.com/technetwork/indexes/documentation/index.html.

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Chapter 1. Introduction

This book provides a thorough introduction and discussion on transactions as used with Berkeley DB, Java Edition (JE). Both the base API as well as the Direct Persistence Layer API is used in this manual. It begins by offering a general overview to transactions, the guarantees they provide, and the general application infrastructure required to obtain full transactional protection for your data.

This book also provides detailed examples on how to write a transactional application. Both single threaded and multi-threaded are discussed. A detailed description of various backup and recovery strategies is included in this manual, as is a discussion on performance considerations for your transactional application.

You should understand the concepts from the *Getting Started with Berkeley DB, Java Edition* guide before reading this book.

Transaction Benefits

Transactions offer your application's data protection from application or system failures. That is, JE transactions offer your application full ACID support:

- **A**tomicity

  Multiple database operations are treated as a single unit of work. Once committed, all write operations performed under the protection of the transaction are saved to your databases. Further, in the event that you abort a transaction, all write operations performed during the transaction are discarded. In this event, your database is left in the state it was in before the transaction began, regardless of the number or type of write operations you may have performed during the course of the transaction.

  Note that JE transactions can span one or more database handles.

- **C**onsistency

  Your databases will never see a partially completed transaction. This is true even if your application fails while there are in-progress transactions. If the application or system fails, then either all of the database changes appear when the application next runs, or none of them appear.

  In other words, whatever consistency requirements your application has will never be violated by JE. If, for example, your application requires every record to include an employee ID, and your code faithfully adds that ID to its database records, then JE will never violate that consistency requirement. The ID will remain in the database records until such a time as your application chooses to delete it.

- **I**solation

  While a transaction is in progress, your databases will appear to the transaction as if there are no other operations occurring outside of the transaction. That is, operations wrapped inside a transaction will always have a clean and consistent view of your databases. They never have to see updates currently in progress under the protection of another transaction. Note, however, that isolation guarantees can be increased and relaxed from the default setting. See Isolation (page 32) for more information.

- **D**urability

  Once committed to your databases, your modifications will persist even in the event of an application or system failure. Note that like isolation, your durability guarantee can be relaxed. See Non-Durable Transactions (page 13) for more information.

A Note on System Failure

From time to time this manual mentions that transactions protect your data against 'system or application failure.' This is true up to a certain extent. However, not all failures are created equal and no data protection mechanism can protect you against every conceivable way a computing system can find to die.

Generally, when this book talks about protection against failures, it means that transactions offer protection against the likeliest culprits for system and application crashes. So long as your data modifications have been committed to disk, those modifications should persist even if your application or OS subsequently fails. And, even if the application or OS fails in the middle of a transaction commit (or abort), the data on disk should be either in a consistent state, or there should be enough data available to bring your databases into a consistent state (via a recovery procedure, for example). You may, however, lose whatever data you were committing at the time of the failure, but your databases will be otherwise unaffected.

Note

Be aware that many disks have a disk write cache and on some systems it is enabled by default. This means that a transaction can have committed, and to your application the data may appear to reside on disk, but the data may in fact reside only in the write cache at that time. This means that if the disk write cache is enabled and there is no battery backup for it, data can be lost after an OS crash even when maximum durability mode is in use. For maximum durability, disable the disk write cache or use a disk write cache with a battery backup.

Of course, if your *disk* fails, then the transactional benefits described in this book are only as good as the backups you have taken.

Finally, by following the programming examples shown in this book, you can write your code so as to protect your data in the event that your code crashes. However, no programming API can protect you against logic failures in your own code; transactions cannot protect you from simply writing the wrong thing to your databases.

Application Requirements

In order to use transactions, your application has certain requirements beyond what is required of non-transactional protected applications. They are:

- Transaction subsystem.

In order to use transactions, you must explicitly enable the transactional subsystem for your application, and this must be done at the time that your environment is first created.

- Transaction handles.

  In order to obtain the atomicity guarantee offered by the transactional subsystem (that is, combine multiple operations in a single unit of work), your application must use transaction handles. These handles are obtained from your Environment objects. They should normally be short-lived, and their usage is reasonably simple. To complete a transaction and save the work it performed, you call its `commit()` method. To complete a transaction and discard its work, you call its `abort()` method.

  In addition, it is possible to use auto commit if you want to transactional protect a single write operation. Auto commit allows a transaction to be used without obtaining an explicit transaction handle. See Auto Commit (page 16) for information on how to use auto commit.

- Entity Store

  If you are using the DPL, then you must configure your entity stores for transactional support before opening them (that is, before obtaining a primary index from them for the first time).

- Database open requirements.

  Your application must transaction protect the database opens, and any secondary index associations, if subsequent operations on the databases are to be transaction protected. The database open and secondary index association are commonly transaction protected using auto commit.

- Deadlock detection.

  Typically transactional applications use multiple threads of control when accessing the database. Any time multiple threads are used on a single resource, the potential for lock contention arises. In turn, lock contention can lead to deadlocks. See Locks, Blocks, and Deadlocks (page 24) for more information.

  Therefore, transactional applications must frequently include code for detecting and responding to deadlocks. Note that this requirement is not *specific* to transactions – you can certainly write concurrent non-transactional JE applications. Further, not every transactional application uses concurrency and so not every transactional application must manage deadlocks. Still, deadlock management is so frequently a characteristic of transactional applications that we discuss it in this book. See Concurrency (page 23) for more information.

Multi-threaded Applications

JE is designed to support multi-threaded applications, but their usage means you must pay careful attention to issues of concurrency. Transactions help your application's concurrency by providing various levels of isolation for your threads of control. In addition, JE provides mechanisms that allow you to detect and respond to deadlocks.

Isolation means that database modifications made by one transaction will not normally be seen by readers from another transaction until the first commits its changes. Different threads use different transaction handles, so this mechanism is normally used to provide isolation between database operations performed by different threads.

Note that JE supports different isolation levels. For example, you can configure your application to see uncommitted reads, which means that one transaction can see data that has been modified but not yet committed by another transaction. Doing this might mean your transaction reads data "dirtied" by another transaction, but which subsequently might change before that other transaction commits its changes. On the other hand, lowering your isolation requirements means that your application can experience improved throughput due to reduced lock contention.

For more information on concurrency, on managing isolation levels, and on deadlock detection, see Concurrency (page 23).

Recoverability

An important part of JE's transactional guarantees is durability. *Durability* means that once a transaction has been committed, the database modifications performed under its protection will not be lost due to system failure.

JE supports a normal recovery that runs against a subset of your log files. This is a routine procedure used whenever your environment is first opened upon application startup, and it is intended to ensure that your database is in a consistent state. JE also supports archival backup and recovery in the case of catastrophic failure, such as the loss of a physical disk drive.

This book describes several different backup procedures you can use to protect your on-disk data. These procedures range from simple offline backup strategies to hot failovers. Hot failovers provide not only a backup mechanism, but also a way to recover from a fatal hardware failure.

This book also describes the recovery procedures you should use for each of the backup strategies that you might employ.

For a detailed description of backup and restore procedures, see the *Getting Started with Berkeley DB, Java Edition* guide.

Performance Tuning

From a performance perspective, the use of transactions is not free. Depending on how you configure them, transaction commits usually require your application to perform disk I/O that a non-transactional application does not perform. Also, for multi-threaded applications, the use of transactions can result in increased lock contention due to extra locking requirements driven by transactional isolation guarantees.

There is therefore a performance tuning component to transactional applications that is not applicable for non-transactional applications (although some tuning considerations do exist whether or not your application uses transactions). Where appropriate, these tuning considerations are introduced in the following chapters.

Chapter 2. Enabling Transactions

In order to use transactions with your application, you must turn them on. To do this you must:

- Turn on transactions for your environment. You do this by using the `EnvironmentConfig.setTransactional()` method, or by using the `je.env.isTransactional` `je.properties` parameter.
- If you are using the DPL, transaction-enable your stores. You do this by using the `StoreConfig.setTransactional() method.`
- Transaction-enable your databases. If you are using the base API, transaction-enable your databases. You do this by using the `DatabaseConfig.setTransactional()` method, and then opening the database from within a transaction. Note that the common practice is for auto commit to be used to transaction-protect the database open. To use auto-commit, you must still enable transactions as described here, but you do not have to explicitly use a transaction when you open your database. An example of this is given in the next section.

Opening a Transactional Environment and Store or Database

To enable transactions for your environment, you must initialize the transactional subsystem. For example, do this with the DPL:

```
package persist.txn;

import com.sleepycat.je.DatabaseException;
import com.sleepycat.je.Environment;
import com.sleepycat.je.EnvironmentConfig;

import com.sleepycat.persist.EntityStore;
import com.sleepycat.persist.StoreConfig;

import java.io.File;

...

Environment myEnv = null;
EntityStore myStore = null;
try {
    EnvironmentConfig myEnvConfig = new EnvironmentConfig();
    StoreConfig storeConfig = new StoreConfig();

    myEnvConfig.setTransactional(true);
    storeConfig.setTransactional(true);

    myEnv = new Environment(new File("/my/env/home"),
                              myEnvConfig);
    myStore = new EntityStore(myEnv, "EntityStore", storeConfig);
} catch (DatabaseException de) {
    // Exception handling goes here
}
```

And when using the base API:

```
package je.txn;

import com.sleepycat.je.DatabaseException;
import com.sleepycat.je.Environment;
import com.sleepycat.je.EnvironmentConfig;

import java.io.File;

...

Environment myEnv = null;
try {
    EnvironmentConfig myEnvConfig = new EnvironmentConfig();
    myEnvConfig.setTransactional(true);

    myEnv = new Environment(new File("/my/env/home"),
                              myEnvConfig);

} catch (DatabaseException de) {
    // Exception handling goes here
}
```

You then create and open your database(s) as you would for a non-transactional system. The only difference is that you must set `DatabaseConfig.setTransactional()` to `true`. Note that your database open must be transactional-protected. However, if you do not give the `openDatabase()` method a transaction handle, then the open is automatically protected using auto commit. Typically auto commit is used for this purpose. For example:

```
package je.txn;

import com.sleepycat.je.Database;
import com.sleepycat.je.DatabaseConfig;
import com.sleepycat.je.DatabaseException;
import com.sleepycat.je.Environment;
import com.sleepycat.je.EnvironmentConfig;

import java.io.File;

...

Database myDatabase = null;
Environment myEnv = null;
try {
    EnvironmentConfig myEnvConfig = new EnvironmentConfig();
    myEnvConfig.setTransactional(true);
    myEnv = new Environment(new File("/my/env/home"),
                              myEnvConfig);

    // Open the database. Create it if it does not already exist.
    DatabaseConfig dbConfig = new DatabaseConfig();
    dbConfig.setTransactional(true);
    myDatabase = myEnv.openDatabase(null,
                                    "sampleDatabase",
                                    dbConfig);

} catch (DatabaseException de) {
    // Exception handling goes here
}
```

Note

Never close a database or store that has active transactions. Make sure all transactions are resolved (either committed or aborted) before closing the database.

Chapter 3. Transaction Basics

Once you have enabled transactions for your environment and your databases, you can use them to protect your database operations. You do this by acquiring a transaction handle and then using that handle for any database operation that you want to participate in that transaction.

You obtain a transaction handle using the `Environment.beginTransaction()` method.

Once you have completed all of the operations that you want to include in the transaction, you must commit the transaction using the `Transaction.commit()` method.

If, for any reason, you want to abandon the transaction, you abort it using `Transaction.abort()`.

Any transaction handle that has been committed or aborted can no longer be used by your application.

Finally, you must make sure that all transaction handles are either committed or aborted before closing your databases and environment.

Note

If you only want to transaction protect a single database write operation, you can use auto commit to perform the transaction administration. When you use auto commit, you do not need an explicit transaction handle. See Auto Commit (page 16) for more information.

For example, the following example opens a transactional-enabled environment and store, obtains a transaction handle, and then performs a write operation under its protection. In the event of any failure in the write operation, the transaction is aborted and the store is left in a state as if no operations had ever been attempted in the first place.

```
package persist.txn;

import com.sleepycat.je.DatabaseException;
import com.sleepycat.je.Environment;
import com.sleepycat.je.EnvironmentConfig;
import com.sleepycat.je.Transaction;

import com.sleepycat.persist.EntityStore;
import com.sleepycat.persist.StoreConfig;

import java.io.File;

...

Environment myEnv = null;
EntityStore store = null;

// Our convenience data accessor class, used for easy access to
// EntityClass indexes.
DataAccessor da;

try {
    EnvironmentConfig myEnvConfig = new EnvironmentConfig();
    myEnvConfig.setTransactional(true);
    myEnv = new Environment(new File("/my/env/home"),
                              myEnvConfig);

    StoreConfig storeConfig = new StoreConfig();
    storeConfig.setTransactional(true);

    EntityStore store = new EntityStore(myEnv,
                             "EntityStore", storeConfig);

    da = new DataAccessor(store);

    // Assume that Inventory is an entity class.
    Inventory theInventory = new Inventory();
    theInventory.setItemName("Waffles");
    theInventory.setItemSku("waf23rbni");

    Transaction txn = myEnv.beginTransaction(null, null);

    try {
        // Put the object to the store using the transaction handle.
        da.inventoryBySku.put(txn, theInventory);

        // Commit the transaction. The data is now safely written to the
        // store.
        txn.commit();
    // If there is a problem, abort the transaction
    } catch (Exception e) {
        if (txn != null) {
            txn.abort();
            txn = null;
        }
    }

} catch (DatabaseException de) {
    // Exception handling goes here
}
```

The same thing can be done with the base API; the database in use is left unchanged if the write operation fails:

```
package je.txn;

import com.sleepycat.je.Database;
import com.sleepycat.je.DatabaseConfig;
import com.sleepycat.je.DatabaseEntry;
import com.sleepycat.je.DatabaseException;
import com.sleepycat.je.Environment;
import com.sleepycat.je.EnvironmentConfig;
import com.sleepycat.je.Transaction;

import java.io.File;

...

Database myDatabase = null;
Environment myEnv = null;
try {
    EnvironmentConfig myEnvConfig = new EnvironmentConfig();
    myEnvConfig.setTransactional(true);
    myEnv = new Environment(new File("/my/env/home"),
                              myEnvConfig);

    // Open the database. Create it if it does not already exist.
    DatabaseConfig dbConfig = new DatabaseConfig();
    dbConfig.setTransactional(true);
    myDatabase = myEnv.openDatabase(null,
                                    "sampleDatabase",
                                    dbConfig);

    String keyString = "thekey";
    String dataString = "thedata";
    DatabaseEntry key =
        new DatabaseEntry(keyString.getBytes("UTF-8"));
    DatabaseEntry data =
        new DatabaseEntry(dataString.getBytes("UTF-8"));

    Transaction txn = myEnv.beginTransaction(null, null);

    try {
        myDatabase.put(txn, key, data);
        txn.commit();
    } catch (Exception e) {
        if (txn != null) {
            txn.abort();
            txn = null;
        }
    }

} catch (DatabaseException de) {
    // Exception handling goes here
}
```

Committing a Transaction

In order to fully understand what is happening when you commit a transaction, you must first understand a little about what JE is doing with its log files. Logging causes all database or store write operations to be identified in log files (remember that in JE, your log files *are* your database files; there is no difference between the two). Enough information is written to restore your entire BTree in the event of a system or application failure, so by performing logging, JE ensures the integrity of your data.

Remember that all write activity made to your database or store is identified in JE's logs as the writes are performed by your application. However, JE maintains logs in memory. Eventually this information is written to disk, but especially in the case of a transactional application this data may be held in memory until the transaction is committed, or JE runs out of buffer space for the logging information.

When you commit a transaction, the following occurs:

- A commit record is written to the log. This indicates that the modifications made by the transaction are now permanent. By default, this write is performed synchronously to disk so the commit record arrives in the log files before any other actions are taken.
- Any log information held in memory is (by default) synchronously written to disk. Note that this requirement can be relaxed, depending on the type of commit you perform. See Non-Durable Transactions (page 13) for more information.

  Note that a transaction commit only writes the BTree's leaf nodes to JE's log files. All other internal BTree structures are left unwritten.
- All locks held by the transaction are released. This means that read operations performed by other transactions or threads of control can now see the modifications without resorting to uncommitted reads (see Reading Uncommitted Data (page 33) for more information).

To commit a transaction, you simply call `Transaction.commit()`.

Remember that transaction commit causes only the BTree leaf nodes to be written to JE's log files. Any other modifications made to the the BTree as a result of the transaction's activities are not written to the log file. This means that over time JE's normal recovery time can greatly increase (remember that JE always runs normal recovery when it opens an environment).

For this reason, JE by default runs the checkpointer thread. This background thread runs a checkpoint on a periodic interval so as to ensure that the amount of data that needs to be recovered upon environment open is minimized. In addition, you can also run a checkpoint manually. For more information, see Checkpoints (page 48).

Note that once you have committed a transaction, the transaction handle that you used for the transaction is no longer valid. To perform database activities under the control of a new transaction, you must obtain a fresh transaction handle.

Non-Durable Transactions

As previously noted, by default transaction commits are durable because they cause the modifications performed under the transaction to be synchronously recorded in your on-disk log files. However, it is possible to use non-durable transactions.

You may want non-durable transactions for performance reasons. For example, you might be using transactions simply for the isolation guarantee. In this case, you might want to relax the synchronized write to disk that JE normally performs as part of a transaction commit. Doing so means that your data will still make it to disk; however, your application will not necessarily have to wait for the disk I/O to complete before it can perform another database operation. This can greatly improve throughput for some workloads.

To relax the durability guarantee for your transactions, you use the `Durability` class to define the durability policy that you want to use. The `Durability` class constructor takes three arguments, only one of which is interesting for a standalone transactional application:

- The synchronization policy for the local machine.
- The synchronization policy for Replicas. Used only for JE HA applications.
- The acknowledgement policy. Again, this is required only for JE HA applications.

We describe JE High Availability Applications in the *Berkeley DB, Java Edition Getting Started with High Availability Applications* guide.

The synchronization policy that you give the `Durability` class constructor can be one of the following:

- `Durability.SyncPolicy.SYNC`

  Write and synchronously flush the log to disk upon transaction commit. This offers the most durable transaction configuration because the commit operation will not return until all of the disk I/O is complete. But, conversely, this offers the worse possible write performance because disk I/O is an expensive and time-consuming operation.

  This is the default synchronization policy. A transaction that uses this policy is considered to be *durable*.

- `Durability.SyncPolicy.NO_SYNC`

  This causes JE to not synchronously force any data to disk upon transaction commit. That is, the modifications are held entirely inside the JVM and the modifications are not forced to the file system for long-term storage. Note, however, that the data will eventually make it to the filesystem (assuming no application or OS crashes) as a part of JE's management of its logging buffers and/or cache.

  This form of a commit provides a weak durability guarantee because data loss can occur due to an application, JVM, or OS crash. In fact, this represents the least durable configuration that you can provide for your transactions. But it also offers much better write performance than the other options.

- `Durability.SyncPolicy.WRITE_NO_SYNC`

  This causes data to be synchronously written to the OS's file system buffers upon transaction commit. The data will eventually be written to disk, but this occurs when the operating system chooses to schedule the activity; the transaction commit can complete successfully before this disk I/O is performed by the OS.

- This form of commit protects you against application and JVM crashes, but not against OS crashes. This method offers less room for the possibility of data loss than does NO_SYNC.

You can specify your durability policy on an environment-wide basis by creating a `Durability` class and then giving it to `EnvironmentConfig.setDurability()`. You can also override the environment default durability policy on a transaction-by-transaction basis by providing a `Durability` class to the `TransactionConfig` object you use to configure your transaction using the `TransactionConfig.setDurability()` method.

For example:

```
package je.txn;

import com.sleepycat.je.Database;
import com.sleepycat.je.DatabaseConfig;
import com.sleepycat.je.DatabaseEntry;
import com.sleepycat.je.DatabaseException;
import com.sleepycat.je.Durability;
import com.sleepycat.je.Environment;
import com.sleepycat.je.EnvironmentConfig;
import com.sleepycat.je.Transaction;
import com.sleepycat.je.TransactionConfig;

import java.io.File;

...

Database myDatabase = null;
Environment myEnv = null;
try {
    Durability defaultDurability =
        new Durability(Durability.SyncPolicy.NO_SYNC,
                       null,    // unused by non-HA applications.
                       null);   // unused by non-HA applications.

    EnvironmentConfig myEnvConfig = new EnvironmentConfig();
    myEnvConfig.setTransactional(true);
    myEnvConfig.setDurability(defaultDurability);
    myEnv = new Environment(new File("/my/env/home"),
                              myEnvConfig);

    // Open the database. Create it if it does not already exist.
    DatabaseConfig dbConfig = new DatabaseConfig();
    dbConfig.setTransactional(true);
    myDatabase = myEnv.openDatabase(null,
                                    "sampleDatabase",
                                    dbConfig);

    String keyString = "thekey";
    String dataString = "thedata";
    DatabaseEntry key =
        new DatabaseEntry(keyString.getBytes("UTF-8"));
    DatabaseEntry data =
        new DatabaseEntry(dataString.getBytes("UTF-8"));

    Durability newDurability =
        new Durability(Durability.SyncPolicy.WRITE_NO_SYNC,
                       null,    // unused by non-HA applications.
                       null);   // unused by non-HA applications.

    TransactionConfig tc = new TransactionConfig();
    tc.setDurability(newDurability);
    Transaction txn = myEnv.beginTransaction(null, tc);

    try {
        myDatabase.put(txn, key, data);
        txn.commit();
    } catch (Exception e) {
        if (txn != null) {
            txn.abort();
            txn = null;
        }
    }

} catch (DatabaseException de) {
    // Exception handling goes here
}
```

Aborting a Transaction

When you abort a transaction, all database or store modifications performed under the protection of the transaction are discarded, and all locks currently held by the transaction are released. In this event, your data is simply left in the state that it was in before the transaction began performing data modifications.

Once you have aborted a transaction, the transaction handle that you used for the transaction is no longer valid. To perform database activities under the control of a new transaction, you must obtain a fresh transactional handle.

To abort a transaction, call `Transaction.abort()`.

Auto Commit

While transactions are frequently used to provide atomicity to multiple database or store operations, it is sometimes necessary to perform a single database or store operation under the control of a transaction. Rather than force you to obtain a transaction, perform the single write operation, and then either commit or abort the transaction, you can automatically group this sequence of events using *auto commit*.

To use auto commit:

1. Open your environment and your databases or store so that they support transactions. See Enabling Transactions (page 6) for details.

2. Do not provide a transactional handle to the method that is performing the database or store write operation.

Note that auto commit is not available for cursors. You must always open your cursor using a transaction if you want the cursor's operations to be transactional protected. See Transactional Cursors (page 17) for details on using transactional cursors.

Note

Never have more than one active transaction in your thread at a time. This is especially a problem if you mix an explicit transaction with another operation that uses auto commit. Doing so can result in undetectable deadlocks.

For example, the following uses auto commit to perform the database write operation:

```
package je.txn;

import com.sleepycat.je.Database;
import com.sleepycat.je.DatabaseConfig;
import com.sleepycat.je.DatabaseEntry;
import com.sleepycat.je.DatabaseException;
import com.sleepycat.je.Environment;
import com.sleepycat.je.EnvironmentConfig;

import java.io.File;

...

Database myDatabase = null;
Environment myEnv = null;
try {
    EnvironmentConfig myEnvConfig = new EnvironmentConfig();
    myEnvConfig.setTransactional(true);
    myEnv = new Environment(new File("/my/env/home"),
                              myEnvConfig);

    // Open the database. Create it if it does not already exist.
    DatabaseConfig dbConfig = new DatabaseConfig();
    dbConfig.setTransactional(true);
    myDatabase = myEnv.openDatabase(null,
                                "sampleDatabase",
                                dbConfig);

    String keyString = "thekey";
    String dataString = "thedata";
    DatabaseEntry key =
        new DatabaseEntry(keyString.getBytes("UTF-8"));
    DatabaseEntry data =
        new DatabaseEntry(dataString.getBytes("UTF-8"));

    // Perform the write. Because the database was opened to
    // support transactions, this write is performed using auto commit.
    myDatabase.put(null, key, data);

} catch (DatabaseException de) {
    // Exception handling goes here
}
```

Transactional Cursors

You can transaction-protect your cursor operations by specifying a transaction handle at the time that you create your cursor. Beyond that, you do not ever provide a transaction handle directly to a cursor method.

Note that if you transaction-protect a cursor, then you must make sure that the cursor is closed before you either commit or abort the transaction. For example:

```
package je.txn;

import com.sleepycat.je.Cursor;
import com.sleepycat.je.Database;
import com.sleepycat.je.DatabaseConfig;
import com.sleepycat.je.DatabaseEntry;
import com.sleepycat.je.DatabaseException;
import com.sleepycat.je.Environment;
import com.sleepycat.je.EnvironmentConfig;
import com.sleepycat.je.LockMode;
import com.sleepycat.je.OperationStatus;
import com.sleepycat.je.Transaction;

import java.io.File;

...

Database myDatabase = null;
Environment myEnv = null;
try {
    // Database and environment opens omitted

    String replacementData = "new data";

    Transaction txn = myEnv.beginTransaction(null, null);
    Cursor cursor = null;
    try {
        // Use the transaction handle here
        cursor = db.openCursor(txn, null);
        DatabaseEntry key, data;

        DatabaseEntry key, data;
        while(cursor.getNext(key, data, LockMode.DEFAULT) ==
           OperationStatus.SUCCESS) {

            data.setData(replacementData.getBytes("UTF-8"));
            // No transaction handle is used on the cursor read or write
            // methods.
            cursor.putCurrent(data);
        }

        cursor.close();
        cursor = null;
        txn.commit();
    } catch (Exception e) {
        if (cursor != null) {
            cursor.close();
        }
        if (txn != null) {
            txn.abort();
            txn = null;
        }
    }

} catch (DatabaseException de) {
    // Exception handling goes here
}
```

Using Transactional DPL Cursors

When using the DPL, you create the cursor using the entity class's primary or secondary index (see the *Getting Started with Berkeley DB, Java Edition* guide for details). At the time that you create the cursor, you pass a transaction handle to the `entities()` method, and this causes all subsequent operations performed using that cursor to be performed within the scope of the transaction.

Note that if you are using a transaction-enabled store, then you must provide a transaction handle when you open your cursor.

For example:

```
package persist.txn;

import com.sleepycat.je.Environment;
import com.sleepycat.je.EnvironmentConfig;
import com.sleepycat.je.Transaction;

import com.sleepycat.persist.EntityCursor;
import com.sleepycat.persist.EntityStore;
import com.sleepycat.persist.PrimaryIndex;

import java.io.File;

...

Environment myEnv = null;
EntityStore store = null;

...


    // Store and environment open omitted, as is the DataAccessor
    // instantiation.

...

    Transaction txn = myEnv.beginTransaction(null, null);
    PrimaryIndex<String,Inventory> pi =
        store.getPrimaryIndex(String.class, Inventory.class);
    EntityCursor<Inventory> pi_cursor = pi.entities(txn, null);

    try {
        for (Inventory ii : pi_cursor) {
            // do something with each object "ii"
            // A transactional handle is not required for any write
            // operations. All operations performed using this cursor
            // will be done within the scope of the transaction, txn.
        }
        pi_cursor.close();
        pi_cursor = null;
        txn.commit();
        txn = null;
    // Always make sure the cursor is closed when we are done with it.
    } catch (Exception e) {
        if (pi_cursor != null) {
            pi_cursor.close();
        }
        if (txn != null) {
            txn.abort();
```

```
                txn = null;
            }
        }
```

Secondary Indices with Transaction Applications

You can use transactions with your secondary indices so long as you open the secondary index so that it is transactional.

All other aspects of using secondary indices with transactions are identical to using secondary indices without transactions. In addition, transaction-protecting secondary cursors is performed just as you protect normal cursors — you simply have to make sure the cursor is opened using a transaction handle, and that the cursor is closed before the handle is either either committed or aborted. See Transactional Cursors (page 17) for details.

Note that when you use transactions to protect your database writes, your secondary indices are protected from corruption because updates to the primary and the secondaries are performed in a single atomic transaction.

Note

If you are using the DPL, then be aware that you never have to provide a transactional handle when opening an index, be it a primary or a secondary. However, if transactions are enabled for your store, then all of the indexes that you open will be enabled for transactional usage. Moreover, any write operation performed using that index will be done using a transaction, regardless of whether you explicitly provide a transactional handle to the write operation.

If you do not explicitly provide a transaction handle to DPL write operations performed on a transactional store, then auto commit is silently used for that operation.

For example:

```
package je.txn;

import com.sleepycat.bind.tuple.TupleBinding;
import com.sleepycat.je.Database;
import com.sleepycat.je.DatabaseType;
import com.sleepycat.je.DatabaseConfig;
import com.sleepycat.je.DatabaseException;
import com.sleepycat.je.Environment;
import com.sleepycat.je.EnvironmentConfig;
import com.sleepycat.je.SecondaryDatabase;
import com.sleepycat.je.SecondaryConfig;

import java.io.FileNotFoundException;

...
```

```
// Environment and primary database opens omitted.

SecondaryConfig mySecConfig = new SecondaryConfig();
mySecConfig.setAllowCreate(true);
mySecConfig.setTransactional(true);

SecondaryDatabase mySecDb = null;
try {
    // A fake tuple binding that is not actually implemented anywhere.
    // The tuple binding is dependent on the data in use.
    // See the Getting Started Guide for details
    TupleBinding myTupleBinding = new MyTupleBinding();

    // Open the secondary. FullNameKeyCreator is not actually implemented
    // anywhere. See the Getting Started Guide for details.
    FullNameKeyCreator keyCreator =
        new FullNameKeyCreator(myTupleBinding);

    // Set the key creator on the secondary config object.
    mySecConfig.setKeyCreator(keyCreator);

    // Perform the actual open. Because this database is configured to be
    // transactional, the open is automatically wrapped in a transaction.
    //      - myEnv is the environment handle.
    //      - myDb is the primary database handle.
    String secDbName = "mySecondaryDatabase";
    mySecDb = myEnv.openSecondary(null, secDbName, null, myDb,
                                  mySecConfig);
} catch (DatabaseException de) {
    // Exception handling goes here ...
}
```

Configuring the Transaction Subsystem

When you configure your transaction subsystem, you need to consider your transaction timeout value. This value represents the longest period of time a transaction can be active. Note, however, that transaction timeouts are checked only when JE examines its lock tables for blocked locks (see Locks, Blocks, and Deadlocks (page 24) for more information). Therefore, a transaction's timeout can have expired, but the application will not be notified until JE has a reason to examine its lock tables.

Be aware that some transactions may be inappropriately timed out before the transaction has a chance to complete. You should therefore use this mechanism only if you know your application might have unacceptably long transactions and you want to make sure your application will not stall during their execution. (This might happen if, for example, your transaction blocks or requests too much data.)

Note that by default transaction timeouts are set to 0 seconds, which means that they never time out.

To set the maximum timeout value for your transactions, use the `EnvironmentConfig.setTxnTimeout()` method. This method configures the entire environment; not just the handle used to set the configuration. Further, this value may be set at any time during the application's lifetime.

This value can also be set using the `je.txn.timeout` property in your JE properties file.

For example:

```
package je.txn;

import com.sleepycat.je.Environment;
import com.sleepycat.je.EnvironmentConfig;

import java.io.File;

...

Environment myEnv = null;
try {
    EnvironmentConfig myEnvConfig = new EnvironmentConfig();
    myEnvConfig.setTransactional(true);

    // Configure a maximum transaction timeout of 1 second.
    myEnvConfig.setTxnTimeout(1000000);

    myEnv = new Environment(new File("/my/env/home"),
                              myEnvConfig);

    // From here, you open your databases (or store), proceed with your
    // database or store operations, and respond to deadlocks as is
    // normal (omitted for brevity).

    ...
```

Chapter 4. Concurrency

JE offers a great deal of support for multi-threaded applications even when transactions are not in use. Many of JE's handles are thread-safe and JE provides a flexible locking subsystem for managing databases in a concurrent application. Further, JE provides a robust mechanism for detecting and responding to lock conflicts. All of these concepts are explored in this chapter.

Before continuing, it is useful to define a few terms that will appear throughout this chapter:

- *Thread of control*

  Refers to a thread that is performing work in your application. Typically, in this book that thread will be performing JE operations.

- *Locking*

  When a thread of control obtains access to a shared resource, it is said to be *locking* that resource. Note that JE supports both exclusive and non-exclusive locks. See Locks (page 25) for more information.

- *Free-threaded*

  Data structures and objects are free-threaded if they can be shared across threads of control without any explicit locking on the part of the application. Some books, libraries, and programming languages may use the term *thread-safe* for data structures or objects that have this characteristic. The two terms mean the same thing.

  For a description of free-threaded JE objects, see Which JE Handles are Free-Threaded (page 24).

- *Blocked*

  When a thread cannot obtain a lock because some other thread already holds a lock on that object, the lock attempt is said to be *blocked*. See Blocks (page 26) for more information.

- *Deadlock*

  Occurs when two or more threads of control attempt to access conflicting resource in such a way as none of the threads can any longer make further progress.

  For example, if Thread A is blocked waiting for a resource held by Thread B, while at the same time Thread B is blocked waiting for a resource held by Thread A, then neither thread can make any forward progress. In this situation, Thread A and Thread B are said to be *deadlocked*.

  For more information, see Deadlocks (page 29).

- Lock Conflict

  In JE, a lock conflict simply means that a thread of control attempted to obtain a lock, but was unable to get it before the lock timeout period expired. This may have happened because a deadlock has occurred, or it might have happened because another thread is taking too long to complete a long-running database operation. Either way, you do the same things in response to a lock conflict as you do for a true deadlock. See JE Lock Management (page 30) for more information.

Which JE Handles are Free-Threaded

The following describes to what extent and under what conditions individual handles are free-threaded.

- `Environment` and the DPL `EntityStore`

  This class is free-threaded.

- `Database` and the DPL `PrimaryIndex`

  These classes are free-threaded.

- `SecondaryDatabase` and DPL `SecondaryIndex`

  These classes are free-threaded.

- `Cursor` and the DPL `EntityCursor`

  If the cursor is a transactional cursor, it can be used by multiple threads of control so long as the application serializes access to the handle. If the cursor is not a transactional cursor, it can not be shared across multiple threads of control at all.

- `SecondaryCursor`

  Same conditions apply as for `Cursor` handles.

- `Transaction`

  This class is free-threaded.

Note

All other classes found in the DPL (`com.sleepycat.persist.*`) and not mentioned above are free-threaded.

All classes found in the bind APIs (`com.sleepycat.bind.*`) are free-threaded.

Locks, Blocks, and Deadlocks

It is important to understand how locking works in a concurrent application before continuing with a description of the concurrency mechanisms JE makes available to you. Blocking and deadlocking have important performance implications for your application. Consequently, this section provides a fundamental description of these concepts, and how they affect JE operations.

Locks

When one thread of control wants to obtain access to an object, it requests a *lock* for that object. This lock is what allows JE to provide your application with its transactional isolation guarantees by ensuring that:

- no other thread of control can read that object (in the case of an exclusive lock), and
- no other thread of control can modify that object (in the case of an exclusive or non-exclusive lock).

Lock Resources

When locking occurs, there are conceptually three resources in use:

1. The locker.

   This is the thing that holds the lock. In a transactional application, the locker is a transaction handle. For non-transactional operations, the locker is the current thread.

2. The lock.

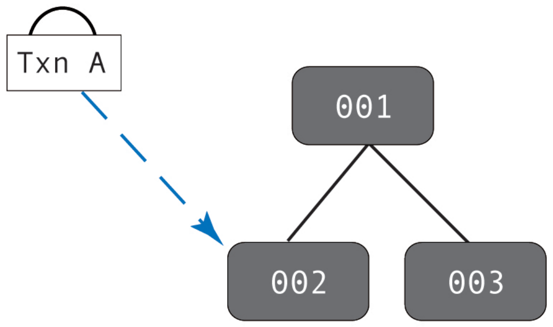
   This is the actual data structure that locks the object. In JE, a locked object structure in the lock manager is representative of the object that is locked.

3. The locked object.

   The thing that your application actually wants to lock. In a JE application, the locked object is usually a database record.

JE has not set a limit for the maximum number of these resources you can use. Instead, you are only limited by the amount of memory available to your application.

The following figure shows a transaction handle, `Txn A`, that is holding a lock on database record `002`. In this graphic, `Txn A` is the locker, and the locked object is record `002`. Only a single lock is in use in this operation.



Types of Locks

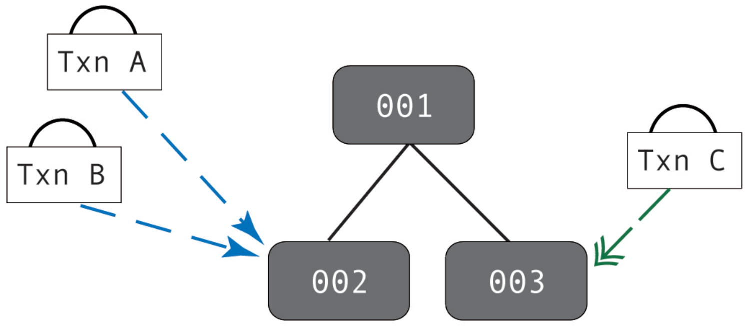
JE applications support both exclusive and non-exclusive locks. *Exclusive locks* are granted when a locker wants to write to an object. For this reason, exclusive locks are also sometimes called *write locks*.

An exclusive lock prevents any other locker from obtaining any sort of a lock on the object. This provides isolation by ensuring that no other locker can observe or modify an exclusively locked object until the locker is done writing to that object.

Non-exclusive locks are granted for read-only access. For this reason, non-exclusive locks are also sometimes called *read locks*. Since multiple lockers can simultaneously hold read locks on the same object, read locks are also sometimes called *shared locks*.

A non-exclusive lock prevents any other locker from modifying the locked object while the locker is still reading the object. This is how transactional cursors are able to achieve repeatable reads; by default, the cursor's transaction holds a read lock on any object that the cursor has examined until such a time as the transaction is committed or aborted.

In the following figure, `Txn A` and `Txn B` are both holding read locks on record `002`, while `Txn C` is holding a write lock on record `003`:



Lock Lifetime

A locker holds its locks until such a time as it does not need the lock any more. What this means is:

1. A transaction holds any locks that it obtains until the transaction is committed or aborted.

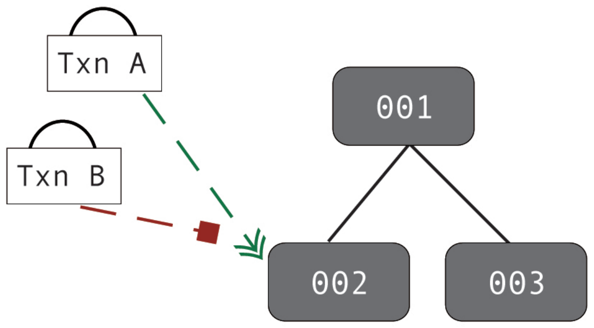
2. All non-transaction operations hold locks until such a time as the operation is completed. For cursor operations, the lock is held until the cursor is moved to a new position or closed.

Blocks

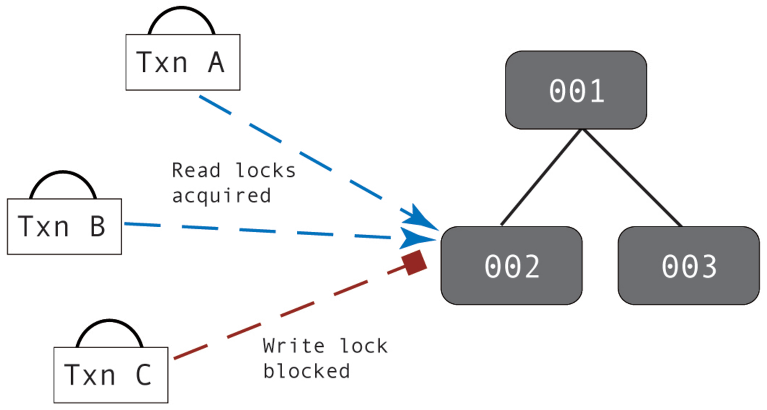
Simply put, a thread of control is blocked when it attempts to obtain a lock, but that attempt is denied because some other thread of control holds a conflicting lock. Once blocked, the thread of control is temporarily unable to make any forward progress until the requested lock is obtained or the operation requesting the lock is abandoned.

Be aware that when we talk about blocking, strictly speaking the thread is not what is attempting to obtain the lock. Rather, some object within the thread (such as a cursor) is attempting to obtain the lock. However, once a locker attempts to obtain a lock, the entire thread of control must pause until the lock request is in some way resolved.

For example, if `Txn A` holds a write lock (an exclusive lock) on record 002, then if `Txn B` tries to obtain a read *or* write lock on that record, the thread of control in which `Txn B` is running is blocked:



However, if `Txn A` only holds a read lock (a shared lock) on record `002`, then only those handles that attempt to obtain a write lock on that record will block.



Blocking and Application Performance

Multi-threaded applications typically perform better than simple single-threaded applications because the application can perform one part of its workload (updating a database record, for example) while it is waiting for some other lengthy operation to complete (performing disk or network I/O, for example). This performance improvement is particularly noticeable if you use hardware that offers multiple CPUs, because the threads can run simultaneously.

That said, concurrent applications can see reduced workload throughput if their threads of control are seeing a large amount of lock contention. That is, if threads are blocking on lock requests, then that represents a performance penalty for your application.

Consider once again the previous diagram of a blocked write lock request. In that diagram, `Txn C` cannot obtain its requested write lock because `Txn A` and `Txn B` are both already holding read locks on the requested record. In this case, the thread in which `Txn C` is running will pause until such a time as `Txn C` either obtains its write lock, or the operation that is requesting the lock is abandoned. The fact that `Txn C`'s thread has temporarily halted all forward progress represents a performance penalty for your application.

Moreover, any read locks that are requested while `Txn C` is waiting for its write lock will also block until such a time as `Txn C` has obtained and subsequently released its write lock.

Avoiding Blocks

Reducing lock contention is an important part of performance tuning your concurrent JE application. Applications that have multiple threads of control obtaining exclusive (write) locks are prone to contention issues. Moreover, as you increase the numbers of lockers and as you increase the time that a lock is held, you increase the chances of your application seeing lock contention.

As you are designing your application, try to do the following in order to reduce lock contention:

- Reduce the length of time your application holds locks.

  Shorter lived transactions will result in shorter lock lifetimes, which will in turn help to reduce lock contention.

  In addition, by default transactional cursors hold read locks until such a time as the transaction is completed. For this reason, try to minimize the time you keep transactional cursors opened, or reduce your isolation levels – see below.

- If possible, access heavily accessed (read or write) items toward the end of the transaction. This reduces the amount of time that a heavily used record is locked by the transaction.

- Reduce your application's isolation guarantees.

  By reducing your isolation guarantees, you reduce the situations in which a lock can block another lock. Try using uncommitted reads for your read operations in order to prevent a read lock being blocked by a write lock.

  In addition, for cursors you can use degree 2 (read committed) isolation, which causes the cursor to release its read locks as soon as it is done reading the record (as opposed to holding its read locks until the transaction ends).

  Be aware that reducing your isolation guarantees can have adverse consequences for your application. Before deciding to reduce your isolation, take care to examine your application's isolation requirements. For information on isolation levels, see Isolation (page 32).

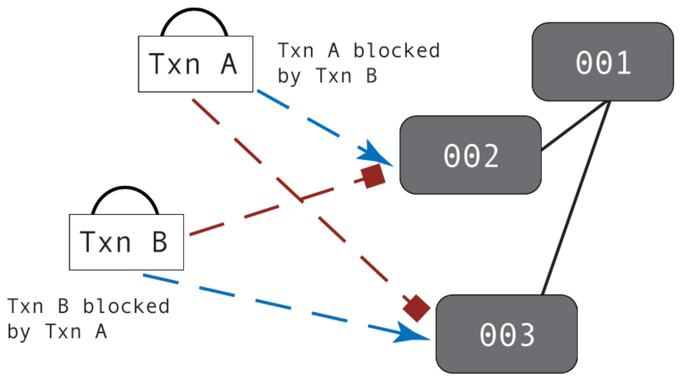
- Consider your data access patterns.

  Depending on the nature of your application, this may be something that you can not do anything about. However, if it is possible to create your threads such that they operate only on non-overlapping portions of your database, then you can reduce lock contention because your threads will rarely (if ever) block on one another's locks.

Deadlocks

A deadlock occurs when two or more threads of control are blocked, each waiting on a resource held by the other thread. When this happens, there is no possibility of the threads ever making forward progress unless some outside agent takes action to break the deadlock.

For example, if `Txn A` is blocked by `Txn B` at the same time `Txn B` is blocked by `Txn A` then the threads of control containing `Txn A` and `Txn B` are deadlocked; neither thread can make any forward progress because neither thread will ever release the lock that is blocking the other thread.



Txn A and Txn B are deadlocked

When two threads of control deadlock, the only solution is to have a mechanism external to the two threads capable of recognizing the deadlock and notifying at least one thread that it is in a deadlock situation. Once notified, a thread of control must abandon the attempted operation in order to resolve the deadlock. JE is capable of notifying your application when it detects a deadlock. (For JE, this is handled in the same way as any lock conflict that a JE application might encounter.) See Managing Deadlocks and other Lock Conflicts (page 31) for more information.

Note that when one locker in a thread of control is blocked waiting on a lock held by another locker in that same thread of the control, the thread is said to be *self-deadlocked*.

Note that in JE, a self-deadlock can occur only if two or more transactions (lockers) are used in the same thread. A self-deadlock cannot occur for non-transactional usage, because the thread is the locker. However, even if you have only one locker per thread, there is still the possibility of a deadlock occurring with another thread of control (it just will not be a self-deadlock), so you still must write code that defends against deadlocks.

Deadlock Avoidance

The things that you do to avoid lock contention also help to reduce deadlocks (see Avoiding Blocks (page 28)). Beyond that, you should also make sure all threads access data in the same order as all other threads. So long as threads lock records in the same basic order, there is no possibility of a deadlock (threads can still block, however).

Be aware that if you are using secondary databases (indexes), then locking order is different for reading and writing. For this reason, if you are writing a concurrent application and you are using secondary databases, you should expect deadlocks.

JE Lock Management

To manage locks in JE, you must do two things:

1. Manage lock timeouts.
2. Detect and respond to lock conflicts. Conceptually, these are deadlocks. But from a coding point of view there is no difference between what you do if a lock times out, and what you do if you encounter a deadlock. In fact, in JE, you cannot tell the difference based on the exceptions that are thrown.

Managing JE Lock Timeouts

Like transaction timeouts (see Configuring the Transaction Subsystem (page 21)), JE allows you to identify the longest period of time that it is allowed to hold a lock. This value plays an important part in performing deadlock detection, because the only way JE can identify a deadlock is if a lock is held past its timeout value.

However, unlike transaction timeouts, lock timeouts are on a true timer. Transaction timeouts are only identified when JE is has a reason to examine its lock table; that is, when it is attempting to acquire a lock. If no such activity is occurring in your application, a transaction can exist for a long time past its expiration timeout. Conversely, lock timeouts are managed by a timer maintained by the JVM. Once this timer has expired, your application will be notified of the event (see the next section on deadlock detection for more information).

You can set the lock timeout on a transaction by transaction basis, or for the entire environment. To set it on a transaction basis, use `Transaction.setLockTimeout()`. To set it for your entire environment, use `EnvironmentConfig.setLockTimeout()` or use the `je.lock.timeout` parameter in the `je.properties` file.

The value that you specify for the lock timeout is in microseconds. `500000` is used by default.

Note that changing this value can have an affect on your application's performance. If you set it too low, locks may expire and be considered deadlocked even though the thread is in fact making forward progress. This will cause your application to abort and retry transactions unnecessarily, which can ultimately harm application throughput. If you set it too high, threads may deadlock for too long before your application receives notification and is able to take corrective action. Again, this can harm application throughput.

Note that for applications in which you will have extremely long-lived locks, you may want to set this value to `0`. Doing so disables lock timeouts entirely. Be aware that disabling lock timeouts can be dangerous because then your application will never be notified of deadlocks. So, alternatively, you might want to set this value to a very large timeout (such as ten minutes) if your application is using extremely long-lived locks.

Managing Deadlocks and other Lock Conflicts

A deadlock is the result of a lock conflict that cannot be resolved by the underlying JE code before the lock times out. Generically, we consider this situation a *lock conflict* because there is no way to tell if the lock timed out because of a true deadlock, or if it timed out because a long-running operation simply held the lock for too long a period of time.

When a lock conflict occurs in JE, the thread of control holding that lock is notified of the event using a `LockConflictException` exception. Note that this exception is actual a common base class for several exception classes that might be able to give you more of a hint as to what the actual problem is. However, the response that you make for any of these exceptions is probably going to be the same, so the best thing to do is simply catch and manage `LockConflictException`.

When a `LockConflictException` is thrown, the thread must:

1. Cease all read and write operations.
2. Close all open cursors.
3. Abort the transaction.
4. Optionally retry the operation. If your application retries operations that are aborted due to a lock conflict, the new attempt must be made using a new transaction.

Note

If a thread has encountered a lock conflict, it may not make any additional database calls using the transaction handle that has experienced the lock conflict.

For example:

```
// retry_count is a counter used to identify how many times
// we've retried this operation. To avoid the potential for
// endless looping, we won't retry more than MAX_DEADLOCK_RETRIES
// times.

// txn is a transaction handle.
// key and data are DatabaseEntry handles. Their usage is not shown here.
while (retry_count < MAX_DEADLOCK_RETRIES) {
    try {
        txn = myEnv.beginTransaction(null, null);
        myDatabase.put(txn, key, data);
        txn.commit();
        return 0;
    } catch (LockConflictException le) {
        try {
            // Abort the transaction and increment the
            // retry counter
            if (txn != null) {
                txn.abort();
            }
```

```
                retry_count++;
                if (retry_count >= MAX_DEADLOCK_RETRIES) {
                    System.err.println("Exceeded retry limit. Giving up.");
                    return -1;
                }
            } catch (DatabaseException ae) {
                System.err.println("txn abort failed: " + ae.toString());
                return -1;
            }
        } catch (DatabaseException e) {
            // If we catch a generic DatabaseException instead of
            // a LockConflictException, we simply abort and give
            // up -- we don't retry the operation.
            try {
                // Abort the transaction.
                if (txn != null) {
                    txn.abort();
                }
            } catch (DatabaseException ae) {
                System.err.println("txn abort failed: " + ae.toString());
            }
            return -1;
        }
}
```

Isolation

Isolation guarantees are an important aspect of transactional protection. Transactions ensure the data your transaction is working with will not be changed by some other transaction. Moreover, the modifications made by a transaction will never be viewable outside of that transaction until the changes have been committed.

That said, there are different degrees of isolation, and you can choose to relax your isolation guarantees to one degree or another depending on your application's requirements. The primary reason why you might want to do this is because of performance; the more isolation you ask your transactions to provide, the more locking that your application must do. With more locking comes a greater chance of blocking, which in turn causes your threads to pause while waiting for a lock. Therefore, by relaxing your isolation guarantees, you can *potentially* improve your application's throughput. Whether you actually see any improvement depends, of course, on the nature of your application's data and transactions.

Supported Degrees of Isolation

JE supports the following levels of isolation:

Degree	ANSI Term	Definition
1	READ UNCOMMITTED	Uncommitted reads means that one transaction will never overwrite another transaction's dirty data. Dirty data is data that a transaction has modified but not yet committed to the underlying

Degree	ANSI Term	Definition
		data store. However, uncommitted reads allows a transaction to see data dirtied by another transaction. In addition, a transaction may read data dirtied by another transaction, but which subsequently is aborted by that other transaction. In this latter case, the reading transaction may be reading data that never really existed in the database.
2	READ COMMITTED	Committed read isolation means that degree 1 is observed, except that dirty data is never read. In addition, this isolation level guarantees that data will never change so long as it is addressed by the cursor, but the data may change before the reading cursor is closed. In the case of a transaction, data at the current cursor position will not change, but once the cursor moves, the previous referenced data can change. This means that readers release read locks before the cursor is closed, and therefore, before the transaction completes. Note that this level of isolation causes the cursor to operate in exactly the same way as it does in the absence of a transaction.
(undefined)	REPEATABLE READ	Committed read is observed, plus the data read by a transaction, T, will never be dirtied by another transaction before T completes. This means that both read and write locks are not released until the transaction completes. This is JE's default isolation level.
3	SERIALIZABLE	Committed read is observed, plus no transactions will see phantoms. Phantoms are records returned as a result of a search, but which were not seen by the same transaction when the identical search criteria was previously used.

By default, JE transactions and transactional cursors offer repeatable read isolation. You can optionally reduce your isolation level by configuring JE to use uncommitted read isolation. See Reading Uncommitted Data (page 33) for more information. You can also configure JE to use committed read isolation. See Committed Reads (page 37) for more information. Finally, you can configure your transactions and transactional cursors to use serializable isolation. See Configuring Serializable Isolation (page 41) for more information.

Reading Uncommitted Data

Berkeley DB allows you to configure your application to read data that has been modified but not yet committed by another transaction; that is, dirty data. When you do this, you may see a performance benefit by allowing your application to not have to block waiting for write locks. On the other hand, the data that your application is reading may change before the transaction has completed.

When used with transactions, uncommitted reads means that one transaction can see data modified but not yet committed by another transaction. When used with transactional cursors, uncommitted reads means that any database reader can see data modified by the cursor before the cursor's transaction has committed.

Because of this, uncommitted reads allow a transaction to read data that may subsequently be aborted by another transaction. In this case, the reading transaction will have read data that never really existed in the database.

To configure your application to read uncommitted data, specify that you want to use uncommitted reads when you create a transaction or open the cursor. To do this, you use the `setReadUncommitted()` method on the relevant configuration object (`TransactionConfig` or `CursorConfig`).

For example:

```
package je.txn;

import com.sleepycat.je.Database;
import com.sleepycat.je.DatabaseConfig;
import com.sleepycat.je.DatabaseEntry;
import com.sleepycat.je.DatabaseException;
import com.sleepycat.je.Environment;
import com.sleepycat.je.EnvironmentConfig;
import com.sleepycat.je.Transaction;
import com.sleepycat.je.TransactionConfig;

import java.io.File;

...

Database myDatabase = null;
Environment myEnv = null;
try {
    EnvironmentConfig myEnvConfig = new EnvironmentConfig();
    myEnvConfig.setTransactional(true);

    myEnv = new Environment(new File("/my/env/home"),
                              myEnvConfig);

    // Open the database.
    DatabaseConfig dbConfig = new DatabaseConfig();
    dbConfig.setTransactional(true);
    myDatabase = myEnv.openDatabase(null, "sampleDatabase", dbConfig);

    TransactionConfig txnConfig = new TransactionConfig();
    txnConfig.setReadUncommitted(true);          // Use uncommitted reads
                                                 // for this transaction.
    Transaction txn = myEnv.beginTransaction(null, txnConfig);

    // From here, you perform your database reads and writes as normal,
    // committing and aborting the transactions as is necessary, and
    // testing for deadlock exceptions as normal (omitted for brevity).

    ...
```

If you are using the DPL:

```
package persist.txn;

import com.sleepycat.je.DatabaseConfig;
import com.sleepycat.je.DatabaseEntry;
import com.sleepycat.je.DatabaseException;
import com.sleepycat.je.Environment;
import com.sleepycat.je.EnvironmentConfig;
import com.sleepycat.je.Transaction;
import com.sleepycat.je.TransactionConfig;

import com.sleepycat.persist.EntityStore;
import com.sleepycat.persist.StoreConfig;

import java.io.File;

...

 myDatabase = null;
Environment myEnv = null;
try {
    EnvironmentConfig myEnvConfig = new EnvironmentConfig();
    myEnvConfig.setTransactional(true);

    myEnv = new Environment(new File("/my/env/home"),
                              myEnvConfig);

    // Open the store.
    StoreConfig myStoreConfig = new StoreConfig();
    myStoreConfig.setAllowCreate(true);
    myStoreConfig.setTransactional(true);

    myStore = new EntityStore(myEnv, "store_name", myStoreConfig);

    TransactionConfig txnConfig = new TransactionConfig();
    txnConfig.setReadUncommitted(true);          // Use uncommitted reads
                                                 // for this transaction.
    Transaction txn = myEnv.beginTransaction(null, txnConfig);
    // From here, you perform your store reads and writes as normal,
    // committing and aborting the transactions as is necessary, and
    // testing for deadlock exceptions as normal (omitted for brevity).

    ...
```

You can also configure uncommitted read isolation on a read-by-read basis by specifying `LockMode.READ_UNCOMMITTED`:

```
package je.txn;

import com.sleepycat.je.Database;
import com.sleepycat.je.DatabaseEntry;
import com.sleepycat.je.Environment;
import com.sleepycat.je.LockMode;
import com.sleepycat.je.Transaction;

...

Database myDb = null;
Environment myEnv = null;
Transaction txn = null;

try {

    // Environment and database open omitted

    ...

    txn = myEnv.beginTransaction(null, null);

    DatabaseEntry theKey =
        new DatabaseEntry((new String("theKey")).getBytes("UTF-8"));
    DatabaseEntry theData = new DatabaseEntry();

    myDb.get(txn, theKey, theData, LockMode.READ_UNCOMMITTED);
} catch (Exception e) {
    // Exception handling goes here
}
```

Using the DPL:

```
package persist.txn;

import com.sleepycat.je.Environment;
import com.sleepycat.je.LockMode;
import com.sleepycat.je.Transaction;

import com.sleepycat.persist.PrimaryIndex;

...
```

```
Environment myEnv = null;
Transaction txn = null;

try {

    // Environment and store open omitted

    ...

    txn = myEnv.beginTransaction(null, null);

    AnEntityClass aec = aPrimaryIndex.get(txn, "pKeya",
                            LockMode.READ_UNCOMMITTED);
} catch (Exception e) {
    // Exception handling goes here
}
```

Committed Reads

You can configure your transaction so that the data being read by a transactional cursor is consistent so long as it is being addressed by the cursor. However, once the cursor is done reading the record or object, the cursor releases its lock on that record or object. This means that the data the cursor has read and released may change before the cursor's transaction has completed.

For example, suppose you have two transactions, `Ta` and `Tb`. Suppose further that `Ta` has a cursor that reads `record R`, but does not modify it. Normally, `Tb` would then be unable to write `record R` because `Ta` would be holding a read lock on it. But when you configure your transaction for committed reads, `Tb` *can* modify `record R` before `Ta` completes, so long as the reading cursor is no longer addressing the record or object.

When you configure your application for this level of isolation, you may see better performance throughput because there are fewer read locks being held by your transactions. Read committed isolation is most useful when you have a cursor that is reading and/or writing records in a single direction, and that does not ever have to go back to re-read those same records. In this case, you can allow JE to release read locks as it goes, rather than hold them for the life of the transaction.

To configure your application to use committed reads, do one of the following:

- Create your transaction such that it allows committed reads. You do this by specifying `true` to `TransactionConfig.setReadCommitted()`.
- Specify `true` to `CursorConfig.setReadCommitted()`.

For example, the following creates a transaction that allows committed reads:

```
package je.txn;

```

```
import com.sleepycat.je.Database;
import com.sleepycat.je.DatabaseConfig;
import com.sleepycat.je.DatabaseEntry;
import com.sleepycat.je.DatabaseException;
import com.sleepycat.je.Environment;
import com.sleepycat.je.EnvironmentConfig;
import com.sleepycat.je.Transaction;
import com.sleepycat.je.TransactionConfig;

import java.io.File;

...

Database myDatabase = null;
Environment myEnv = null;
try {
    EnvironmentConfig myEnvConfig = new EnvironmentConfig();
    myEnvConfig.setTransactional(true);

    myEnv = new Environment(new File("/my/env/home"),
                              myEnvConfig);

    // Open the database.
    DatabaseConfig dbConfig = new DatabaseConfig();
    dbConfig.setTransactional(true);
    myDatabase = myEnv.openDatabase(null, "sampleDatabase", dbConfig);

    // Open the transaction and enable committed reads. All cursors open
    // with this transaction handle will use read committed isolation.
    TransactionConfig txnConfig = new TransactionConfig();
    txnConfig.setReadCommitted(true);          // Use committed reads
                                               // for this transaction.
    Transaction txn = myEnv.beginTransaction(null, txnConfig);

    // From here, you perform your database reads and writes as normal,
    // committing and aborting the transactions as is necessary, and
    // testing for deadlock exceptions as normal (omitted for brevity).

    ...
```

Using the DPL:

```
package persist.txn;

import com.sleepycat.je.Environment;
import com.sleepycat.je.EnvironmentConfig;
import com.sleepycat.je.Transaction;
import com.sleepycat.je.TransactionConfig;

import com.sleepycat.persist.EntityStore;
import com.sleepycat.persist.StoreConfig;

import java.io.File;

...

EntityStore myStore = null;
Environment myEnv = null;
try {
    EnvironmentConfig myEnvConfig = new EnvironmentConfig();
    myEnvConfig.setTransactional(true);

    myEnv = new Environment(new File("/my/env/home"),
                              myEnvConfig);


    // Instantiate the store.
    StoreConfig myStoreConfig = new StoreConfig();
    myStoreConfig.setAllowCreate(true);
    myStoreConfig.setTransactional(true);

    // Open the transaction and enable committed reads. All cursors open
    // with this transaction handle will use read committed isolation.
    TransactionConfig txnConfig = new TransactionConfig();
    txnConfig.setReadCommitted(true);          // Use committed reads
                                               // for this transaction.
    Transaction txn = myEnv.beginTransaction(null, txnConfig);

    // From here, you perform your store reads and writes as normal,
    // committing and aborting the transactions as is necessary, and
    // testing for deadlock exceptions as normal (omitted for brevity).

    ...
```

You can also configure read committed isolation on a read-by-read basis by specifying `LockMode.READ_COMMITTED`:

```
package je.txn;

import com.sleepycat.je.Database;
import com.sleepycat.je.DatabaseEntry;
import com.sleepycat.je.Environment;
import com.sleepycat.je.LockMode;
import com.sleepycat.je.Transaction;

...

Database myDb = null;
Environment myEnv = null;
Transaction txn = null;
```

```
try {

    // Environment and database open omitted

    ...

    txn = myEnv.beginTransaction(null, null);

    DatabaseEntry theKey =
        new DatabaseEntry((new String("theKey")).getBytes("UTF-8"));
    DatabaseEntry theData = new DatabaseEntry();

    myDb.get(txn, theKey, theData, LockMode.READ_COMMITTED);
} catch (Exception e) {
    // Exception handling goes here
}
```

Using the DPL:

```
package persist.txn;

import com.sleepycat.je.Environment;
import com.sleepycat.je.LockMode;
import com.sleepycat.je.Transaction;

import com.sleepycat.persist.PrimaryIndex;

...

Environment myEnv = null;
Transaction txn = null;

try {

    // Environment and store open omitted

    ...

    txn = myEnv.beginTransaction(null, null);

    // Primary index creation omitted
    ...

    AnEntityClass aec = aPrimaryIndex.get(txn, "pKeya",
                            LockMode.READ_COMMITTED);
} catch (Exception e) {
    // Exception handling goes here
}
```

Configuring Serializable Isolation

You can configure JE to use serializable isolation. Serializable isolation prevents transactions from seeing *phantoms*. Phantoms occur when a transaction obtains inconsistent results when performing a given query.

Suppose a transaction performs a search, S, and as a result of that search NOTFOUND is returned. If you are using only repeatable read isolation (the default isolation level), it is possible for the same transaction to perform S at a later point in time and return SUCCESS instead of NOTFOUND. This can occur if another thread of control modified the database in such a way as to cause S to successfully locate data, where before no data was found. When this situation occurs, the results returned by S are said to be a *phantom*.

To prevent phantoms, you can use serializable isolation. Note that this causes JE to perform additional locking in order to prevent keys from being inserted until the transaction ends. However, this additional locking can also result in reduced concurrency for your application, which means that your database access can be slowed.

You configure serializable isolation for all transactions in your environment by using `EnvironmentConfig.setTxnSerializableIsolation()`:

```
package je.txn;

import com.sleepycat.je.Database;
import com.sleepycat.je.DatabaseEntry;
import com.sleepycat.je.Environment;
import com.sleepycat.je.EnvironmentConfig;
import com.sleepycat.je.Transaction;
import com.sleepycat.je.LockMode;

...

Database myDb = null;
Environment myEnv = null;
Transaction txn = null;

try {

    // Open an environment
    EnvironmentConfig envConfig = new EnvironmentConfig();
    envConfig.setAllowCreate(true);
    envConfig.setTransactional(true);

    // Use serializable isolation
    envConfig.setTxnSerializableIsolation(true);

    myEnv = new Environment(myHomeDirectory, envConfig);

    // Database open omitted
    ...

    txn = myEnv.beginTransaction(null, null);

    DatabaseEntry theKey =
        new DatabaseEntry((new String("theKey")).getBytes("UTF-8"));
    DatabaseEntry theData = new DatabaseEntry();

    myDb.get(txn, theKey, theData, LockMode.DEFAULT);
} catch (Exception e) {
    // Exception handling goes here
}
```

If you do not configure serializable isolation for all transactions, you can configure serializable isolation for a specific transaction using `TransactionConfig.setSerializableIsolation()`:

```
package persist.txn;

import com.sleepycat.je.Environment;
import com.sleepycat.je.LockMode;
import com.sleepycat.je.Transaction;
import com.sleepycat.je.TransactionConfig;

import com.sleepycat.persist.PrimaryIndex;

...

Database myDb = null;
Environment myEnv = null;
Transaction txn = null;

try {

    // Environment and store open omitted

    ...

    TransactionConfig tc = new TransactionConfig();
    tc.setSerializableIsolation(true); // Use serializable isolation
    txn = myEnv.beginTransaction(null, tc);

    // Primary index creation omitted
    ...

    AnEntityClass aec = aPrimaryIndex.get(txn, "pKeya",
                            LockMode.DEFAULT);
} catch (Exception e) {
    // Exception handling goes here
}
```

Transactional Cursors and Concurrent Applications

When you use transactional cursors with a concurrent application, remember that in the event of a deadlock you must make sure that you close your cursor before you abort and retry your transaction. This is true of both base API and DPL cursors.

Also, remember that when you are using the default isolation level, every time your cursor reads a record it locks that record until the encompassing transaction is resolved. This means that walking your database with a transactional cursor increases the chance of lock contention.

For this reason, if you must routinely walk your database with a transactional cursor, consider using a reduced isolation level such as read committed. This is true of both base API and DPL cursors.

Using Cursors with Uncommitted Data

As described in Reading Uncommitted Data (page 33) above, it is possible to relax your transaction's isolation level such that it can read data modified but not yet committed by another transaction. You can configure this when you create your transaction handle, and when you do so then all cursors opened inside that transaction will automatically use uncommitted reads.

You can also do this when you create a cursor handle from within a serializable transaction. When you do this, only those cursors configured for uncommitted reads uses uncommitted reads.

The following example shows how to configure an individual cursor handle to read uncommitted data from within a serializable (full isolation) transaction. For an example of configuring a transaction to perform uncommitted reads in general, see Reading Uncommitted Data (page 33).

```
package je.txn;

import com.sleepycat.je.Cursor;
import com.sleepycat.je.CursorConfig;
import com.sleepycat.je.Database;
import com.sleepycat.je.DatabaseConfig;
import com.sleepycat.je.Environment;
import com.sleepycat.je.EnvironmentConfig;

import java.io.File;

...

Database myDatabase = null;
Environment myEnv = null;
try {

    EnvironmentConfig myEnvConfig = new EnvironmentConfig();
    myEnvConfig.setTransactional(true);

    myEnv = new Environment(new File("/my/env/home"),
                              myEnvConfig);

    // Open the database.
    DatabaseConfig dbConfig = new DatabaseConfig();
    dbConfig.setTransactional(true);
    myDatabase = myEnv.openDatabase(null,              // txn handle
                                    "sampleDatabase",  // db file name
                                    dbConfig);

    // Open the transaction. Note that this is a repeatable
    // read transaction.
    Transaction txn = myEnv.beginTransaction(null, null);
    Cursor cursor = null;
    try {
        // Use the transaction handle here
        // Get our cursor. Note that we pass the transaction
        // handle here. Note also that we cause the cursor
        // to perform uncommitted reads.
        CursorConfig cconfig = new CursorConfig();
        cconfig.setReadUncommitted(true);
        cursor = db.openCursor(txn, cconfig);

        // From here, you perform your cursor reads and writes
        // as normal, committing and aborting the transactions as
        // is necessary, and testing for deadlock exceptions as
        // normal (omitted for brevity).

        ...
```

If you are using the DPL:

```
package persist.txn;

import com.sleepycat.je.CursorConfig;
import com.sleepycat.je.Environment;
import com.sleepycat.je.EnvironmentConfig;

import com.sleepycat.persist.EntityCursor;
import com.sleepycat.persist.EntityStore;
import com.sleepycat.persist.PrimaryIndex;
import com.sleepycat.persist.StoreConfig;

import java.util.Iterator;

import java.io.File;

...
```

```
EntityStore myStore = null;
Environment myEnv = null;
PrimaryIndex<String,AnEntityClass> pKey;
try {

    EnvironmentConfig myEnvConfig = new EnvironmentConfig();
    myEnvConfig.setTransactional(true);

    myEnv = new Environment(new File("/my/env/home"),
                              myEnvConfig);

    // Set up the entity store
    StoreConfig myStoreConfig = new StoreConfig();
    myStoreConfig.setAllowCreate(true);
    myStoreConfig.setTransactional(true);

    // Instantiate the store
    myStore = new EntityStore(myEnv, storeName, myStoreConfig);

    // Open the transaction. Note that this is a repeatable
    // read transaction.
    Transaction txn = myEnv.beginTransaction(null, null);

    //Configure our cursor for uncommitted reads.
    CursorConfig cconfig = new CursorConfig();
    cconfig.setReadUncommitted(true);

    // Get our cursor. Note that we pass the transaction
    // handle here. Note also that we cause the cursor
    // to perform uncommitted reads.
    EntityCursor<AnEntityClass> cursor = pKey.entities(txn, cconfig);

    try {
        // From here, you perform your cursor reads and writes
        // as normal, committing and aborting the transactions as
        // is necessary, and testing for deadlock exceptions as
        // normal (omitted for brevity).

        ...
```

Read/Modify/Write

If you are retrieving a record from the database or a class from the store for the purpose of modifying or deleting it, you should declare a read-modify-write cycle at the time that you read the record. Doing so causes JE to obtain write locks (instead of a read locks) at the time of the read. This helps to prevent deadlocks by preventing another transaction from acquiring a read lock on the same record while the read-modify-write cycle is in progress.

Note that declaring a read-modify-write cycle may actually increase the amount of blocking that your application sees, because readers immediately obtain write locks and write locks cannot be shared. For this reason, you should use read-modify-write cycles only if you are seeing a large amount of deadlocking occurring in your application.

In order to declare a read/modify/write cycle when you perform a read operation, specify `com.sleepycat.je.LockMode.RMW` to the database, cursor, `PrimaryIndex`, or `SecondaryIndex` get method.

For example:

```
// Begin the deadlock retry loop as is normal.
while (retry_count < MAX_DEADLOCK_RETRIES) {
    try {
        txn = myEnv.beginTransaction(null, null);

        ...
        // key and data are DatabaseEntry objects.
        // Their usage is omitted for brevity.
        ...

        // Read the data. Declare the read/modify/write cycle here
        myDatabase.get(txn, key, data, LockMode.RMW);


        // Put the data. Note that you do not have to provide any
        // additional flags here due to the read/modify/write
        // cycle. Simply put the data and perform your deadlock
        // detection as normal.
        myDatabase.put(txn, key, data);
        txn.commit();
        return 0;
    } catch (DeadlockException de) {
        // Deadlock detection and exception handling omitted
        // for brevity
        ...
```

Or, with the DPL:

```
// Begin the deadlock retry loop as is normal
        while (retry_count < MAX_DEADLOCK_RETRIES) {
    try {
        txn = myEnv.beginTransaction(null, null);

        ...
        // 'store' is an EntityStore and 'Inventory' is an entity class
        // Their usage and implementation is omitted for brevity.
        ...

        // Read the data, using the PrimaryIndex for the entity object
        PrimaryIndex<String,Inventory> pi =
                store.getPrimaryIndex(String.class, Inventory.class);
        Inventory iv = pi.get(txn, "somekey", LockMode.RMW);

        // Do something to the retreived object


        // Put the object. Note that you do not have to provide any
        // additional flags here due to the read/modify/write
        // cycle. Simply put the data and perform your deadlock
        // detection as normal.

        pi.put(txn, iv);
        txn.commit();
        return 0;

    } catch (DeadlockException de) {
        // Deadlock detection and exception handling omitted
        // for brevity
        ...
```

Chapter 5. Backing up and Restoring Berkeley DB, Java Edition Applications

Fundamentally, you backup your databases by copying JE log files off to a safe storage location. To restore your database from a backup, you copy those files to an appropriate directory on disk and restart your JE application.

Note that if you are using subdirectories to store your JE log files, then your backup and restore process must maintain the relationship between each log file and the subdirectory in which JE intially placed it. That is, if JE placed log file number 17 in the subdirectory named `data003`, then when you perform a recovery log file number 17 must be placed inside subdirectory `data003`.

Beyond these simple activities, there are some differing backup strategies that you may want to consider. These topics are described in this chapter.

Before continuing, before you review the information on log files and background threads in the *Getting Started with Berkeley DB, Java Edition* guide. Those topics contain important information that is basic to the following discussion on backups and restores.

Normal Recovery

Remember that internally JE databases are organized in a BTree, and that in order to operate JE requires the complete BTree be available to it.

When database records are created, modified, or deleted, the modifications are represented in the BTree's leaf nodes. Beyond leaf node changes, database record modifications can also cause changes to other BTree nodes and structures.

Now, if your writes are transaction-protected, then every time a transaction is committed the leaf nodes (and *only* the leaf nodes) modified by that transaction are written to the JE log files on disk. Also, remember that the durability of the write (whether a flush or fsync is performed) depends on the type of commit that is requested. See Non-Durable Transactions (page 13) for more information.

Normal recovery, then, is the process of recreating the entire BTree from the information available in the leaf nodes. You do not have to do anything special to cause normal recovery to be run; this occurs every time a JE environment is opened.

Checkpoints

Running normal recovery can become expensive if over time all that is ever written to disk is BTree leaf nodes. So in order to limit the time required for normal recovery, JE runs checkpoints. Checkpoints write to your log files all the internal BTree nodes and structures modified as a part of write operations. This means that your log files contain a complete BTree up to the moment in time when the checkpoint was run. The result is that normal recovery only needs to recreate the portion of the BTree that has been modified since the time of the last checkpoint.

Checkpoints typically write more information to disk than do transaction commits, and so they are more expensive from a disk I/O perspective. You will therefore need to consider how frequently to run checkpoints as a part of your performance tuning activities. When you do this, balance the cost of the checkpoints against the time it will take your application to restart due to the cost of running normal recovery.

Checkpoints are normally performed by the checkpointer background thread, which is always running. Like all background threads, it is managed using the `je.properties` file. Currently, the only checkpointer property that you may want to manage is `je.checkpointer.bytesInterval`. This property identifies how much JE's log files can grow before a checkpoint is run. Its value is specified in bytes. Decreasing this value causes the checkpointer thread to run checkpoints more frequently. This will improve the time that it takes to run recovery, but it also increases the system resources (notably, I/O) required by JE.

Note that checkpoints are also always performed when the environment is closed normally. Therefore, normal recovery only has work to do if the application crashes or otherwise ends abnormally without calling `Environment.close()`.

Performing Backups

This section describes how to backup your JE database(s) such that catastrophic recovery is possible.

To backup your database, you can either take a hot backup or an offline backup. A hot backup is performed while database write operations are in progress.

Do not confuse offline and hot backups with the concept of a full and incremental backup. Both an offline and a hot backup are full backups – you back up the entire database. The only difference between them is how much of the contents of the in-memory cache are contained in them. On the other hand, an incremental backup is a backup of just those log files modified or created since the time of the last backup. Most backup software is capable of performing both full and incremental backups for you.

Performing a Hot Backup

To perform a hot backup of your JE databases, copy all log files (`*.jdb` files) from your environment directory to your archival location or backup media. The files must be copied in alphabetical order (numerical in effect). You do not have to stop any database operations in order to do this.

Note

If you are using subdirectories to store your log files, then you must backup the subdirectories, making sure to keep log files in the subdirectory in which JE placed them. For information on using subdirectories to store your log files, see the *Getting Started with Berkeley DB, Java Edition* guide.

To make this process a bit easier, you may want to make use of the `DbBackup` helper class. See Using the DbBackup Helper Class (page 50) for details.

Performing an Offline Backup

An offline backup guarantees that you have captured the database in its entirety, including all contents of your in-memory cache, at the moment that the backup was taken. To do this, you must make sure that no write operations are in progress and all database modifications have been written to your log files on disk. To obtain an offline backup:

1. Stop writing your databases.

2. Make sure all your in-memory changes have been flushed to disk. How you do this depends on the type of transactions that you are using:

   - If you are using transactions that writes all dirty data to disk on commit (this is the default behavior), you simply need to make sure all on-going transactions are committed or aborted.

   - If you are using transactions that do not synchronously write on commit, you must run a checkpoint. Remember that closing your environment causes a checkpoint to be run, so if your application is shutting down completely before taking the backup, you have met this requirement.

     For information on changing the transactional sync behavior, see Non-Durable Transactions (page 13). For information on running a checkpoint, see Checkpoints (page 48).

3. If you are using durable transactions, then optionally run a checkpoint. Doing this can shorten the time required to restore your database from this back up.

4. Copy all log files (`*.jdb`) from your environment directory to your archival location or backup media. To make this process a bit easier, you may want to make use of the `DbBackup` helper class. See the next section for details.

   ### Note

   If you are using subdirectories to store your log files, then you must backup the subdirectories, making sure to keep log files in the subdirectory in which JE placed them. For information on using subdirectories to store your log files, see the *Getting Started with Berkeley DB, Java Edition* guide.

You can now resume normal database operations.

Using the DbBackup Helper Class

In order to simplify backup operations, JE provides the `DbBackup` helper class. This class stops and restarts JE background activity in an open environment. It also lets the application create a backup which can support restoring the environment to a specific point in time.

Because you do not have to stop JE write activity in order to take a backup, it is usually necessary to examine your log files twice before you decide that your backup is complete. This is because JE may create a new log file while you are running your backup. A second pass over your log files allows you to ensure that no new files have been created and so you can declare your backup complete.

For example:

```
 time    files in                    activity
         environment

  t0     000000001.jdb     Backup starts copying file 1
         000000003.jdb
         000000004.jdb

  t1     000000001.jdb     JE log cleaner migrates portion of file 3 to
         000000004.jdb     newly created file 5 and deletes file 3.
         000000005.jdb     Backup finishes file 1, starts copying file 4.
                           Backup MUST include file 5 for a consistent
                           backup!

  t2     000000001.jdb     Backup finishes copying file 4, starts and
         000000004.jdb     finishes file 5, has caught up. Backup ends.
         000000005.jdb
```

`DbBackup` works around this problem by defining the set of files that must be copied for each backup operation, and freezes all changes to those files. The application can copy that defined set of files and finish operation without checking for the ongoing creation of new files. Also, there will be no need to check for a newer version of the last file on the next backup.

In the example above, if `DbBackup` was used at t0, the application would only have to copy files 1, 3 and 4 to back up. On a subsequent backup, the application could start its copying at file 5. There would be no need to check for a newer version of file 4.

The following code fragment illustrates this class' usage. See the `DbBackup` javadoc for additional examples and more information on incremental backups.

```
package je.gettingStarted;

...
import com.sleepycat.je.util.DbBackup;
...

    // Find the file number of the last file in the previous backup
    // persistently, by either checking the backup archive, or saving
    // state in a persistent file.
    long lastFileCopiedInPrevBackup =  ...

    Environment env = new Environment(...);
    DbBackup backupHelper = new DbBackup(env, lastFileCopiedInPrevBackup);

    // Start backup, find out what needs to be copied.
    // If multiple environment subdirectories are in use,
    // the getLogFilesInBackupSet returns the log file
    // name prefixed with the dataNNN/ directory in which
    // it resides.
    backupHelper.startBackup();
    try {
        String[] filesForBackup = backupHelper.getLogFilesInBackupSet();

        // Copy the files to archival storage.
        myApplicationCopyMethod(filesForBackup)
        // Update our knowlege of the last file saved in the backup set,
        // so we can copy less on the next backup
        lastFileCopiedInPrevBackup = backupHelper.getLastFileInBackupSet();
        myApplicationSaveLastFile(lastFileCopiedInBackupSet);
    }
    finally {
        // Remember to exit backup mode, or all log files won't be cleaned
        // and disk usage will bloat.
       backupHelper.endBackup();
   }
```

Performing Catastrophic Recovery

Catastrophic recovery is necessary whenever your environment and/or database have been lost or corrupted due to a media failure (disk failure, for example). Catastrophic recovery is also required if normal recovery fails for any reason.

In order to perform catastrophic recovery, you must have a full backup of your databases. You will use this backup to restore your database. See the previous section for information on running back ups.

To perform catastrophic recovery:

1. Shut down your application.

2. Delete the contents of your environment home directory (the one that experienced a catastrophic failure), if there is anything there.

3. Copy your most recent full backup into your environment home directory. If you are using subdirectories to store your log files, be sure to place the recovered log files back into the subdirectory from which they were originally backed up.

4. If you are using a backup utility that runs incremental backups of your environment directory, copy any log files generated since the time of your last full backup. Be sure to restore all log files in the order that they were written. The order is important because it is possible the same log file appears in multiple archives, and you want to run recovery using the most recent version of each log file.

5. Open the environment as normal. JE's normal recovery will run, which will bring your database to a consistent state relative to the changed data found in your log files.

You are now done restoring your database.

Hot Failover

As a final backup/recovery strategy, you can create a hot failover. Note that using hot failovers requires your application to be able to specify its environment home directory at application startup time. Most application developers allow the environment home directory to be identified using a command line option or a configuration or properties file. If your application has its environment home hard-coded into it, you cannot use hot failovers.

You create a hot failover by periodically backing up your database to an alternative location on disk. Usually this alternative location is on a separate physical drive from where you normally keep your database, but if multiple drives are not available then you should at least put the hot failover on a separate disk partition.

You failover by causing your application to reopen its environment using the failover location.

Note that a hot failover should not be used as a substitute for backing up and archiving your data to a safe location physically remote from your computing environment. Even if your data is spread across multiple physical disks, a truly serious catastrophe (fires, malevolent software viruses, faulty disk controllers, and so forth) can still cause you to lose your data.

To create and maintain a hot failover:

1. Copy all log files (`*.jdb`) from your environment directory to the location where you want to keep your failover. Either an offline or a hot backup can be used for this purpose, but typically a hot failoveris initially created by taking an offline backup of your database. This ensures that you have captured the contents of your in-memory cache.

   ### Note

   If you are using subdirectories to store your log files, then you must backup the subdirectories, making sure to keep log files in the subdirectory in which JE placed them. For information on using subdirectories to store your log files, see the *Getting Started with Berkeley DB, Java Edition* guide.

2. Periodically copy to your failover directory any log files that were changed or created since the time of your last copy. Most backup software is capable of performing this kind of an incremental backup for you.

   Note that the frequency of your incremental copies determines the amount of data that is at risk due to catastrophic failures. For example, if you perform the incremental copy once an hour then at most your hot failover is an hour behind your production database, and so you are risking at most an hours worth of database changes.

3. Remove any `*.jdb` files from the hot failover directory that have been removed or renamed to `.del` files in the primary directory. This is not necessary for consistency, but will help to reduce disk space consumed by the hot failover.

Chapter 6. Summary and Examples

Throughout this manual we have presented the concepts and mechanisms that you need to provide transactional protection for your application. In this chapter, we summarize these mechanisms, and we provide a complete example of a multi-threaded transactional JE application.

Anatomy of a Transactional Application

Transactional applications are characterized by performing the following activities:

1. Create your environment handle.
2. Open your environment, specifying that the transactional subsystem is to be used.
3. If you are using the base API, open your database handles, indicating that they are to support transactions. Otherwise, open your store such that it is configured for transactions.
4. Spawn off worker threads. How many of these you need and how they split their JE workload is entirely up to your application's requirements. However, any worker threads that perform write operations will do the following:
    a. Begin a transaction.
    b. Perform one or more read and write operations.
    c. Commit the transaction if all goes well.
    d. Abort and retry the operation if a deadlock is detected.
    e. Abort the transaction for most other errors.
5. On application shutdown:
    a. Make sure there are no opened cursors.
    b. Make sure there are no active transactions. Either abort or commit all transactions before shutting down.
    c. Close your databases.
    d. Close your environment.

Note

Robust JE applications should monitor their worker threads to make sure they have not died unexpectedly. If a thread does terminate abnormally, you must shutdown all your worker threads and then run normal recovery (you will have to reopen your environment to do this). This is the only way to clear any resources (such as a lock or a mutex) that the abnormally exiting worker thread might have been holding at the time that it died.

Failure to perform this recovery can cause your still-functioning worker threads to eventually block forever while waiting for a lock that will never be released.

In addition to these activities, which are entirely handled by code within your application, you also need to periodically back up your log files. This is required in order to obtain the durability guarantee made by JE's transaction ACID support. See Backing up and Restoring Berkeley DB, Java Edition Applications (page 48) for more information.

Base API Transaction Example

The following Java code provides a fully functional example of a multi-threaded transactional JE application. The example opens an environment and database, and then creates 5 threads, each of which writes 500 records to the database. The keys used for these writes are pre-determined strings, while the data is a class that contains randomly generated data. This means that the actual data is arbitrary and therefore uninteresting; we picked it only because it requires minimum code to implement and therefore will stay out of the way of the main points of this example.

Each thread writes 10 records under a single transaction before committing and writing another 10 (this is repeated 50 times). At the end of each transaction, but before committing, each thread calls a function that uses a cursor to read every record in the database. We do this in order to make some points about database reads in a transactional environment.

Of course, each writer thread performs deadlock detection as described in this manual. In addition, normal recovery is performed when the environment is opened.

To implement this example, we need three classes:

- `TxnGuide.java`

  This is the main class for the application. It performs environment and database management, spawns threads, and creates the data that is placed in the database. See TxnGuide.java (page 55) for implementation details.

- `DBWriter.java`

  This class extends `java.lang.Thread`, and as such it is our thread implementation. It is responsible for actually reading and writing to the database. It also performs all of our transaction management. See DBWriter.java (page 60) for implementation details.

- `PayloadData.java`

  This is a data class used to encapsulate several data fields. It is fairly uninteresting, except that the usage of a class means that we have to use the bind APIs to serialize it for storage in the database. See PayloadData.java (page 59) for implementation details.

TxnGuide.java

The main class in our example application is used to open and close our environment and database. It also spawns all the threads that we need. We start with the normal series of Java package and import statements, followed by our class declaration:

```
// File TxnGuide.java

package je.txn;

import com.sleepycat.bind.serial.StoredClassCatalog;

import com.sleepycat.je.Database;
import com.sleepycat.je.DatabaseConfig;
import com.sleepycat.je.DatabaseException;

import com.sleepycat.je.Environment;
import com.sleepycat.je.EnvironmentConfig;

import java.io.File;
import java.io.FileNotFoundException;

public class TxnGuide {
```

Next we declare our class' private data members. Mostly these are used for constants such as the name of the database that we are opening and the number of threads that we are spawning. However, we also declare our environment and database handles here.

```
    private static String myEnvPath = "./";
    private static String dbName = "mydb.db";
    private static String cdbName = "myclassdb.db";

    // DB handles
    private static Database myDb = null;
    private static Database myClassDb = null;
    private static Environment myEnv = null;

    private static final int NUMTHREADS = 5;
```

Next, we implement our `usage()` method. This application optionally accepts a single command line argument which is used to identify the environment home directory.

```
    private static void usage() {
        System.out.println("TxnGuide [-h <env directory>]");
        System.exit(-1);
    }
```

Now we implement our `main()` method. This method simply calls the methods to parse the command line arguments and open the environment and database. It also creates the stored class catalog that we use for serializing the data that we want to store in our database. Finally, it creates and then joins the database writer threads.

```
    public static void main(String args[]) {
        try {
            // Parse the arguments list
            parseArgs(args);
            // Open the environment and databases
            openEnv();
            // Get our class catalog (used to serialize objects)
            StoredClassCatalog classCatalog =
                new StoredClassCatalog(myClassDb);

            // Start the threads
            DBWriter[] threadArray;
            threadArray = new DBWriter[NUMTHREADS];
            for (int i = 0; i < NUMTHREADS; i++) {
                threadArray[i] = new DBWriter(myEnv, myDb, classCatalog);
                threadArray[i].start();
            }

            // Join the threads. That is, wait for each thread to
            // complete before exiting the application.
            for (int i = 0; i < NUMTHREADS; i++) {
                threadArray[i].join();
            }
        } catch (Exception e) {
            System.err.println("TxnGuide: " + e.toString());
            e.printStackTrace();
        } finally {
            closeEnv();
        }
        System.out.println("All done.");
    }
```

Next we implement `openEnv()`. This method is used to open the environment and then a database in that environment. Along the way, we make sure that the transactional subsystem is correctly initialized.

For the database open, notice that we open the database such that it supports duplicate records. This is required purely by the data that we are writing to the database, and it is only necessary if you run the application more than once without first deleting the environment.

```
    private static void openEnv() throws DatabaseException {
        System.out.println("opening env");

        // Set up the environment.
        EnvironmentConfig myEnvConfig = new EnvironmentConfig();
        myEnvConfig.setAllowCreate(true);
        myEnvConfig.setTransactional(true);
        // Environment handles are free-threaded by default in JE,
        // so we do not have to do anything to cause the
        // environment handle to be free-threaded.

        // Set up the database
        DatabaseConfig myDbConfig = new DatabaseConfig();
        myDbConfig.setAllowCreate(true);
        myDbConfig.setTransactional(true);
        myDbConfig.setSortedDuplicates(true);

        // Open the environment
        myEnv = new Environment(new File(myEnvPath),    // Env home
                                myEnvConfig);

        // Open the database. Do not provide a txn handle. This open
        // is auto committed because DatabaseConfig.setTransactional()
        // is true.
        myDb = myEnv.openDatabase(null,     // txn handle
                                  dbName,   // Database file name
                                  myDbConfig);

        // Used by the bind API for serializing objects
        // Class database must not support duplicates
        myDbConfig.setSortedDuplicates(false);
        myClassDb = myEnv.openDatabase(null,     // txn handle
                                       cdbName,  // Database file name
                                       myDbConfig);
    }
```

Finally, we implement the methods used to close our environment and databases, parse the command line arguments, and provide our class constructor. This is fairly standard code and it is mostly uninteresting from the perspective of this manual. We include it here purely for the purpose of completeness.

```
    private static void closeEnv() {
        System.out.println("Closing env and databases");
        if (myDb != null ) {
            try {
                myDb.close();
            } catch (DatabaseException e) {
                System.err.println("closeEnv: myDb: " +
                    e.toString());
                e.printStackTrace();
            }
        }

        if (myClassDb != null ) {
            try {
                myClassDb.close();
            } catch (DatabaseException e) {
                System.err.println("closeEnv: myClassDb: " +
                    e.toString());
                e.printStackTrace();
            }
        }

        if (myEnv != null ) {
            try {
                myEnv.close();
            } catch (DatabaseException e) {
                System.err.println("closeEnv: " + e.toString());
                e.printStackTrace();
            }
        }
    }

    private TxnGuide() {}

    private static void parseArgs(String args[]) {
        for(int i = 0; i < args.length; ++i) {
            if (args[i].startsWith("-")) {
                switch(args[i].charAt(1)) {
                    case 'h':
                        myEnvPath = new String(args[++i]);
                        break;
                    default:
                        usage();
                }
            }
        }
    }
}
```

PayloadData.java

Before we show the implementation of the database writer thread, we need to show the class that we will be placing into the database. This class is fairly minimal. It simply allows you to store and retrieve an `int`, a `String`, and a `double`. We will be using the JE bind API from within the writer thread to serialize instances of this class and place them into our database.

```
package je.txn;

import java.io.Serializable;

public class PayloadData implements Serializable {
    private int oID;
    private String threadName;
    private double doubleData;

    PayloadData(int id, String name, double data) {
        oID = id;
        threadName = name;
        doubleData = data;
    }

    public double getDoubleData() { return doubleData; }
    public int getID() { return oID; }
    public String getThreadName() { return threadName; }
}
```

DBWriter.java

`DBWriter.java` provides the implementation for our database writer thread. It is responsible for:

- All transaction management.
- Responding to deadlock exceptions.
- Providing data to be stored into the database.
- Serializing and then writing the data to the database.

In order to show off some of the ACID properties provided by JE's transactional support, `DBWriter.java` does some things in a less efficient way than you would probably decide to use in a true production application. First, it groups 10 database writes together in a single transaction when you could just as easily perform one write for each transaction. If you did this, you could use auto commit for the individual database writes, which means your code would be slightly simpler and you would run a *much* smaller chance of encountering blocked and deadlocked operations. However, by doing things this way, we are able to show transactional atomicity, as well as deadlock handling.

At the end of each transaction, `DBWriter.java` runs a cursor over the entire database by way of counting the number of records currently existing in the database. There are better ways to discover this information, but in this case we want to make some points regarding cursors, transactional applications, and deadlocking (we get into this in more detail later in this section).

To begin, we provide the usual package and import statements, and we declare our class:

```
package je.txn;

import com.sleepycat.bind.EntryBinding;
import com.sleepycat.bind.serial.StoredClassCatalog;
import com.sleepycat.bind.serial.SerialBinding;
import com.sleepycat.bind.tuple.StringBinding;

import com.sleepycat.je.Cursor;
import com.sleepycat.je.CursorConfig;
import com.sleepycat.je.Database;
import com.sleepycat.je.DatabaseEntry;
import com.sleepycat.je.DatabaseException;
import com.sleepycat.je.Environment;
import com.sleepycat.je.LockMode;
import com.sleepycat.je.LockConflictException;
import com.sleepycat.je.OperationStatus;
import com.sleepycat.je.Transaction;

import java.io.UnsupportedEncodingException;
import java.util.Random;

public class DBWriter extends Thread
{
```

Next we declare our private data members. Notice that we get handles for the environment and the database. We also obtain a handle for an `EntryBinding`. We will use this to serialize `PayloadData` class instances (see PayloadData.java (page 59)) for storage in the database. The random number generator that we instantiate is used to generate unique data for storage in the database. The `MAX_RETRY` variable is used to define how many times we will retry a transaction in the face of a deadlock. And, finally, `keys` is a `String` array that holds the keys used for our database entries.

```
    private Database myDb = null;
    private Environment myEnv = null;
    private EntryBinding dataBinding = null;
    private Random generator = new Random();


    private static final int MAX_RETRY = 20;

    private static String[] keys = {"key 1", "key 2", "key 3",
                                    "key 4", "key 5", "key 6",
                                    "key 7", "key 8", "key 9",
                                    "key 10"};
```

Next we implement our class constructor. The most interesting thing we do here is instantiate a serial binding for serializing `PayloadData` instances.

```
    // Constructor. Get our DB handles from here
    DBWriter(Environment env, Database db, StoredClassCatalog scc)
        throws DatabaseException {
        myDb = db;
        myEnv = env;
        dataBinding = new SerialBinding(scc, PayloadData.class);
    }
```

Now we implement our thread's `run()` method. This is the method that is run when `DBWriter` threads are started in the main program (see TxnGuide.java (page 55)).

```
    // Thread method that writes a series of records
    // to the database using transaction protection.
    // Deadlock handling is demonstrated here.
    public void run () {
```

The first thing we do is get a `null` transaction handle before going into our main loop. We also begin the top transaction loop here that causes our application to perform 50 transactions.

```
        Transaction txn = null;

        // Perform 50 transactions
        for (int i=0; i<50; i++) {
```

Next we declare a `retry` variable. This is used to determine whether a deadlock should result in our retrying the operation. We also declare a `retry_count` variable that is used to make sure we do not retry a transaction forever in the unlikely event that the thread is unable to ever get a necessary lock. (The only thing that might cause this is if some other thread dies while holding an important lock. This is the only code that we have to guard against that because the simplicity of this application makes it highly unlikely that it will ever occur.)

```
            boolean retry = true;
            int retry_count = 0;
            // while loop is used for deadlock retries
            while (retry) {
```

Now we go into the `try` block that we use for deadlock detection. We also begin our transaction here.

```
                 // try block used for deadlock detection and
                 // general db exception handling
                 try {

                     // Get a transaction
                     txn = myEnv.beginTransaction(null, null);
```

Now we write 10 records under the transaction that we have just begun. By combining multiple writes together under a single transaction, we increase the likelihood that a deadlock will occur. Normally, you want to reduce the potential for a deadlock and in this case the way to do that is to perform a single write per transaction. In other words, we *should* be using auto commit to write to our database for this workload.

However, we want to show deadlock handling and by performing multiple writes per transaction we can actually observe deadlocks occurring. We also want to underscore the idea that you can combing multiple database operations together in a single atomic unit of work. So for our example, we do the (slightly) wrong thing.

Further, notice that we store our key into a `DatabaseEntry` using `com.sleepycat.bind.tuple.StringBinding` to perform the serialization. Also, when we instantiate the `PayloadData` object, we call `getName()` which gives us the string representation of this thread's name, as well as `Random.nextDouble()` which gives us a random double value. This latter value is used so as to avoid duplicate records in the database.

```

                     // Write 10 records to the db
                     // for each transaction
                     for (int j = 0; j < 10; j++) {
                         // Get the key
                         DatabaseEntry key = new DatabaseEntry();
                         StringBinding.stringToEntry(keys[j], key);

                         // Get the data
                         PayloadData pd = new PayloadData(i+j, getName(),
                             generator.nextDouble());
```

```
                        DatabaseEntry data = new DatabaseEntry();
                        dataBinding.objectToEntry(pd, data);

                        // Do the put
                        myDb.put(txn, key, data);
                    }
```

Having completed the inner database write loop, we could simply commit the transaction and continue on to the next block of 10 writes. However, we want to first illustrate a few points about transactional processing so instead we call our `countRecords()` method before calling the transaction commit. `countRecords()` uses a cursor to read every record in the database and return a count of the number of records that it found.

Because `countRecords()` reads every record in the database, if used incorrectly the thread will self-deadlock. The writer thread has just written 500 records to the database, but because the transaction used for that write has not yet been committed, each of those 500 records are still locked by the thread's transaction. If we then simply run a non-transactional cursor over the database from within the same thread that has locked those 500 records, the cursor will block when it tries to read one of those transactional protected records. The thread immediately stops operation at that point while the cursor waits for the read lock it has requested. Because that read lock will never be released (the thread can never make any forward progress), this represents a self-deadlock for the thread.

There are three ways to prevent this self-deadlock:

1. We can move the call to `countRecords()` to a point after the thread's transaction has committed.

2. We can allow `countRecords()` to operate under the same transaction as all of the writes were performed.

3. We can reduce our isolation guarantee for the application by allowing uncommitted reads.

For this example, we choose to use option 3 (uncommitted reads) to avoid the deadlock. This means that we have to open our cursor handle so that it knows to perform uncommitted reads.

```
                    // commit
                    System.out.println(getName() + " : committing txn : "
                        + i);

                    // Using uncommitted reads to avoid the deadlock, so
                    // null is passed for the transaction here.
                    System.out.println(getName() + " : Found " +
                        countRecords(null) + " records in the database.");
```

Having performed this somewhat inelegant counting of the records in the database, we can now commit the transaction.

```
                    try {
                        txn.commit();
                        txn = null;
                    } catch (DatabaseException e) {
                        System.err.println("Error on txn commit: " +
                            e.toString());
                    }
                    retry = false;
```

If all goes well with the commit, we are done and we can move on to the next batch of 10 records to add to the database. However, in the event of an error, we must handle our exceptions correctly. The first of these is a deadlock exception. In the event of a deadlock, we want to abort and retry the transaction, provided that we have not already exceeded our retry limit for this transaction.

```
            } catch (LockConflictException le) {
                System.out.println("################# " + getName() +
                    " : caught deadlock");
                // retry if necessary
                if (retry_count < MAX_RETRY) {
                    System.err.println(getName() +
                        " : Retrying operation.");
                    retry = true;
                    retry_count++;
                } else {
                    System.err.println(getName() +
                        " : out of retries. Giving up.");
                    retry = false;
                }
```

In the event of a standard, non-specific database exception, we simply log the exception and then give up (the transaction is not retried).

```
            } catch (DatabaseException e) {
                // abort and don't retry
                retry = false;
                System.err.println(getName() +
                    " : caught exception: " + e.toString());
                e.printStackTrace();
```

And, finally, we always abort the transaction if the transaction handle is not null. Note that immediately after committing our transaction, we set the transaction handle to null to guard against aborting a transaction that has already been committed.

```
            } finally {
                if (txn != null) {
                    try {
                        txn.abort();
                    } catch (Exception e) {
                        System.err.println("Error aborting txn: " +
                            e.toString());
                        e.printStackTrace();
                    }
                    }
                }
            }
        }
    }
```

The final piece of our `DBWriter` class is the `countRecords()` implementation. Notice how in this example we open the cursor such that it performs uncommitted reads:

```
    // A method that counts every record in the database.

    // Note that this method exists only for illustrative purposes.
    // A more straight-forward way to count the number of records in
    // a database is to use the Database.getStats() method.
    private int countRecords(Transaction txn)  throws DatabaseException {
        DatabaseEntry key = new DatabaseEntry();
        DatabaseEntry data = new DatabaseEntry();
        int count = 0;
        Cursor cursor = null;

        try {
            // Get the cursor
            CursorConfig cc = new CursorConfig();
            cc.setReadUncommitted(true);
            cursor = myDb.openCursor(txn, cc);
            while (cursor.getNext(key, data, LockMode.DEFAULT) ==
                    OperationStatus.SUCCESS) {

                    count++;
            }
        } finally {
            if (cursor != null) {
                cursor.close();
            }
        }

        return count;

    }
}
```

This completes our transactional example. If you would like to experiment with this code, you can find the example in the following location in your JE distribution:

```
JE_HOME/examples/je/txn
```

DPL Transaction Example

The following Java code provides a fully functional example of a multi-threaded transactional JE application using the DPL. This example is nearly identical to the example provided in the previous section, except that it uses an entity class and entity store to manage its data.

As is the case with the previous examples, this example opens an environment and then an entity store. It then creates 5 threads, each of which writes 500 records to the database. The primary key for these writes are based on pre-determined integers, while the data is randomly generated data. This means that the actual data is arbitrary and therefore uninteresting; we picked it only because it requires minimum code to implement and therefore will stay out of the way of the main points of this example.

Each thread writes 10 records under a single transaction before committing and writing another 10 (this is repeated 50 times). At the end of each transaction, but before committing, each thread calls a function that uses a cursor to read every record in the database. We do this in order to make some points about database reads in a transactional environment.

Of course, each writer thread performs deadlock detection as described in this manual. In addition, normal recovery is performed when the environment is opened.

To implement this example, we need three classes:

- `TxnGuide.java`

  This is the main class for the application. It performs environment and store management, spawns threads, and creates the data that is placed in the database. See TxnGuide.java (page 66) for implementation details.

- `StoreWriter.java`

  This class extends `java.lang.Thread`, and as such it is our thread implementation. It is responsible for actually reading and writing store. It also performs all of our transaction management. See StoreWriter.java (page 70) for implementation details.

- `PayloadDataEntity.java`

  This is an entity class used to encapsulate several data fields. See PayloadDataEntity.java (page 69) for implementation details.

TxnGuide.java

The main class in our example application is used to open and close our environment and store. It also spawns all the threads that we need. We start with the normal series of Java package and import statements, followed by our class declaration:

```
// File TxnGuideDPL.java

package persist.txn;

import com.sleepycat.je.DatabaseConfig;
import com.sleepycat.je.DatabaseException;

import com.sleepycat.je.Environment;
import com.sleepycat.je.EnvironmentConfig;

import com.sleepycat.persist.EntityStore;
import com.sleepycat.persist.StoreConfig;

import java.io.File;

public class TxnGuideDPL {
```

Next we declare our class' private data members. Mostly these are used for constants such as the name of the database that we are opening and the number of threads that we are spawning. However, we also declare our environment and database handles here.

```
    private static String myEnvPath = "./";
    private static String storeName = "exampleStore";

    // Handles
    private static EntityStore myStore = null;
    private static Environment myEnv = null;
    private static final int NUMTHREADS = 5;
```

Next, we implement our `usage()` method. This application optionally accepts a single command line argument which is used to identify the environment home directory.

```
    private static void usage() {
        System.out.println("TxnGuideDPL [-h <env directory>]");
        System.exit(-1);
    }
```

Now we implement our `main()` method. This method simply calls the methods to parse the command line arguments and open the environment and store. It also creates and then joins the store writer threads.

```
    public static void main(String args[]) {
        try {
            // Parse the arguments list
            parseArgs(args);
            // Open the environment and store
            openEnv();

            // Start the threads
            StoreWriter[] threadArray;
            threadArray = new StoreWriter[NUMTHREADS];
            for (int i = 0; i < NUMTHREADS; i++) {
                threadArray[i] = new StoreWriter(myEnv, myStore);
                threadArray[i].start();
            }

            for (int i = 0; i < NUMTHREADS; i++) {
                threadArray[i].join();
            }
        } catch (Exception e) {
            System.err.println("TxnGuideDPL: " + e.toString());
            e.printStackTrace();
        } finally {
            closeEnv();
        }
        System.out.println("All done.");
    }
```

Next we implement `openEnv()`. This method is used to open the environment and then an entity store in that environment. Along the way, we make sure that the transactional subsystem is correctly initialized.

```
    private static void openEnv() throws DatabaseException {
        System.out.println("opening env and store");

        // Set up the environment.
        EnvironmentConfig myEnvConfig = new EnvironmentConfig();
        myEnvConfig.setAllowCreate(true);
        myEnvConfig.setTransactional(true);
        //  Environment handles are free-threaded by default in JE,
        // so we do not have to do anything to cause the
        // environment handle to be free-threaded.

        // Set up the entity store
        StoreConfig myStoreConfig = new StoreConfig();
        myStoreConfig.setAllowCreate(true);
        myStoreConfig.setTransactional(true);

        // Open the environment
        myEnv = new Environment(new File(myEnvPath),    // Env home
                                    myEnvConfig);

        // Open the store
        myStore = new EntityStore(myEnv, storeName, myStoreConfig);
    }
```

Finally, we implement the methods used to close our environment and databases, parse the command line arguments, and provide our class constructor. This is fairly standard code and it is mostly uninteresting from the perspective of this manual. We include it here purely for the purpose of completeness.

```
    private static void closeEnv() {
        System.out.println("Closing env and store");
        if (myStore != null ) {
            try {
                myStore.close();
            } catch (DatabaseException e) {
                System.err.println("closeEnv: myStore: " +
                    e.toString());
                e.printStackTrace();
            }
        }
        if (myEnv != null ) {
            try {
                myEnv.close();
            } catch (DatabaseException e) {
                System.err.println("closeEnv: " + e.toString());
                e.printStackTrace();
            }
        }
    }

    private TxnGuideDPL() {}

    private static void parseArgs(String args[]) {
        int nArgs = args.length;
        for(int i = 0; i < args.length; ++i) {
            if (args[i].startsWith("-")) {
                switch(args[i].charAt(1)) {
                    case 'h':
                        if (i < nArgs - 1) {
                            myEnvPath = new String(args[++i]);
                        }
                    break;
                    default:
                        usage();
                }
            }
        }
    }
}
```

PayloadDataEntity.java

Before we show the implementation of the store writer thread, we need to show the class that we will be placing into the store. This class is fairly minimal. It simply allows you to store and retrieve an `int`, a `String`, and a `double`. The `int` is our primary key.

```
package persist.txn;
import com.sleepycat.persist.model.Entity;
import com.sleepycat.persist.model.PrimaryKey;
import static com.sleepycat.persist.model.Relationship.*;

@Entity
public class PayloadDataEntity {
    @PrimaryKey
    private int oID;

    private String threadName;

    private double doubleData;
    PayloadDataEntity() {}

    public double getDoubleData() { return doubleData; }
    public int getID() { return oID; }
    public String getThreadName() { return threadName; }

    public void setDoubleData(double dd) { doubleData = dd; }
    public void setID(int id) { oID = id; }
    public void setThreadName(String tn) { threadName = tn; }

}
```

StoreWriter.java

`StoreWriter.java` provides the implementation for our entity store writer thread. It is responsible for:

- All transaction management.
- Responding to deadlock exceptions.
- Providing data to be stored in the entity store.
- Writing the data to the store.

In order to show off some of the ACID properties provided by JE's transactional support, `StoreWriter.java` does some things in a less efficient way than you would probably decide to use in a true production application. First, it groups 10 database writes together in a single transaction when you could just as easily perform one write for each transaction. If you did this, you could use auto commit for the individual database writes, which means your code would be slightly simpler and you would run a *much* smaller chance of encountering blocked and deadlocked operations. However, by doing things this way, we are able to show transactional atomicity, as well as deadlock handling.

To begin, we provide the usual package and import statements, and we declare our class:

```
package persist.txn;

import com.sleepycat.je.CursorConfig;
import com.sleepycat.je.DatabaseException;
import com.sleepycat.je.DeadlockException;
import com.sleepycat.je.Environment;
import com.sleepycat.je.Transaction;

import com.sleepycat.persist.EntityCursor;
import com.sleepycat.persist.EntityStore;
import com.sleepycat.persist.PrimaryIndex;

import java.util.Iterator;
import java.util.Random;
import java.io.UnsupportedEncodingException;
```

```
public class StoreWriter extends Thread
{
```

Next we declare our private data members. Notice that we get handles for the environment and the entity store. The random number generator that we instantiate is used to generate unique data for storage in the database. Finally, the `MAX_RETRY` variable is used to define how many times we will retry a transaction in the face of a deadlock.

```
    private EntityStore myStore = null;
    private Environment myEnv = null;
    private PrimaryIndex<Integer,PayloadDataEntity> pdKey;
    private Random generator = new Random();
    private boolean passTxn = false;

    private static final int MAX_RETRY = 20;
```

Next we implement our class constructor. The most interesting thing about our constructor is that we use it to obtain our entity class's primary index.

```
    // Constructor. Get our handles from here
    StoreWriter(Environment env, EntityStore store)

        throws DatabaseException {
        myStore = store;
        myEnv = env;

        // Open the data accessor. This is used to store persistent
        // objects.
        pdKey = myStore.getPrimaryIndex(Integer.class,
                    PayloadDataEntity.class);
    }
```

Now we implement our thread's `run()` method. This is the method that is run when `StoreWriter` threads are started in the main program (see TxnGuide.java (page 66)).

```
    // Thread method that writes a series of records
    // to the database using transaction protection.
    // Deadlock handling is demonstrated here.
    public void run () {
```

The first thing we do is get a `null` transaction handle before going into our main loop. We also begin the top transaction loop here that causes our application to perform 50 transactions.

```
        Transaction txn = null;

        // Perform 50 transactions
        for (int i=0; i<50; i++) {
```

Next we declare a `retry` variable. This is used to determine whether a deadlock should result in our retrying the operation. We also declare a `retry_count` variable that is used to make sure we do not retry a transaction forever in the unlikely event that the thread is unable to ever get a necessary lock. (The only thing that might cause this is if some other thread dies while holding an important lock. This is the only code that we have to guard against that because the simplicity of this application makes it highly unlikely that it will ever occur.)

```
            boolean retry = true;
            int retry_count = 0;
            // while loop is used for deadlock retries
            while (retry) {
```

Now we go into the `try` block that we use for deadlock detection. We also begin our transaction here.

```
                 // try block used for deadlock detection and
                 // general exception handling
                 try {

                     // Get a transaction
                     txn = myEnv.beginTransaction(null, null);
```

Now we write 10 objects under the transaction that we have just begun. By combining multiple writes together under a single transaction, we increase the likelihood that a deadlock will occur. Normally, you want to reduce the potential for a deadlock and in this case the way to do that is to perform a single write per transaction. In other words, we *should* be using auto commit to write to our database for this workload.

However, we want to show deadlock handling and by performing multiple writes per transaction we can actually observe deadlocks occurring. We also want to underscore the idea that you can combing multiple database operations together in a single atomic unit of work. So for our example, we do the (slightly) wrong thing.

```


                     // Write 10 PayloadDataEntity objects to the
                     // store for each transaction
                     for (int j = 0; j < 10; j++) {
                         // Instantiate an object
                         PayloadDataEntity pd = new PayloadDataEntity();

                         // Set the Object ID. This is used as the
                         // primary key.
                         pd.setID(i + j);

                         // The thread name is used as a secondary key, and
                         // it is retrieved by this class's getName()
                         // method.
                         pd.setThreadName(getName());

                         // The last bit of data that we use is a double
                         // that we generate randomly. This data is not
                         // indexed.
                         pd.setDoubleData(generator.nextDouble());
```

```
                    // Do the put
                    pdKey.put(txn, pd);
                }
```

Having completed the inner database write loop, we could simply commit the transaction and continue on to the next block of 10 writes. However, we want to first illustrate a few points about transactional processing so instead we call our `countObjects()` method before calling the transaction commit. `countObjects()` uses a cursor to read every object in the entity store and return a count of the number of objects that it found.

Because `countObjects()` reads every object in the store, if used incorrectly the thread will self-deadlock. The writer thread has just written 500 objects to the database, but because the transaction used for that write has not yet been committed, each of those 500 objects are still locked by the thread's transaction. If we then simply run a non-transactional cursor over the store from within the same thread that has locked those 500 objects, the cursor will block when it tries to read one of those transactional protected records. The thread immediately stops operation at that point while the cursor waits for the read lock it has requested. Because that read lock will never be released (the thread can never make any forward progress), this represents a self-deadlock for the thread.

There are three ways to prevent this self-deadlock:

1. We can move the call to `countObjects()` to a point after the thread's transaction has committed.
2. We can allow `countObjects()` to operate under the same transaction as all of the writes were performed.
3. We can reduce our isolation guarantee for the application by allowing uncommitted reads.

For this example, we choose to use option 3 (uncommitted reads) to avoid the deadlock. This means that we have to open our cursor handle so that it knows to perform uncommitted reads.

```
                // commit
                System.out.println(getName() + " : committing txn : "
                                   + i);
                System.out.println(getName() + " : Found " +
                    countObjects(txn) + " objects in the store.");
```

Having performed this somewhat inelegant counting of the objects in the database, we can now commit the transaction.

```
                try {
                    txn.commit();
                    txn = null;
                } catch (DatabaseException e) {
                    System.err.println("Error on txn commit: " +
                        e.toString());
                }
```

```
                     retry = false;
```

If all goes well with the commit, we are done and we can move on to the next batch of 10 objects to add to the store. However, in the event of an error, we must handle our exceptions correctly. The first of these is a deadlock exception. In the event of a deadlock, we want to abort and retry the transaction, provided that we have not already exceeded our retry limit for this transaction.

```
                 } catch (DeadlockException de) {
                     System.out.println("################# " + getName() +
                         " : caught deadlock");
                     // retry if necessary
                     if (retry_count < MAX_RETRY) {
                         System.err.println(getName() +
                             " : Retrying operation.");
                         retry = true;
                         retry_count++;
                     } else {
                         System.err.println(getName() +
                             " : out of retries. Giving up.");
                         retry = false;
                     }
```

In the event of a standard, non-specific database exception, we simply log the exception and then give up (the transaction is not retried).

```
                 } catch (DatabaseException e) {
                     // abort and don't retry
                     retry = false;
                     System.err.println(getName() +
                         " : caught exception: " + e.toString());
                     e.printStackTrace();
```

And, finally, we always abort the transaction if the transaction handle is not null. Note that immediately after committing our transaction, we set the transaction handle to null to guard against aborting a transaction that has already been committed.

```
                 } finally {
                     if (txn != null) {
                         try {
                             txn.abort();
                         } catch (Exception e) {
                             System.err.println("Error aborting txn: " +
                                 e.toString());
                             e.printStackTrace();
                         }
                     }
                 }
             }
         }
     }
```

The final piece of our `StoreWriter` class is the `countObjects()` implementation. Notice how in this example we open the cursor such that it performs uncommitted reads:

```
    // A method that counts every object in the store.

    private int countObjects(Transaction txn)  throws DatabaseException {
        int count = 0;

        CursorConfig cc = new CursorConfig();
        // This is ignored if the store is not opened with uncommitted read
        // support.
        cc.setReadUncommitted(true);
        EntityCursor<PayloadDataEntity> cursor = pdKey.entities(txn, cc);

        try {
            for (PayloadDataEntity pdi : cursor) {
                    count++;
            }
        } finally {
            if (cursor != null) {
                cursor.close();
            }
        }

        return count;

    }
}
```

This completes our transactional example. If you would like to experiment with this code, you can find the example in the following location in your JE distribution:

```
JE_HOME/examples/persist/txn
```