Java™ Object Serialization Specification

Object serialization in the Java™ system is the process of creating a serialized representation of objects or a graph of objects. Object values and types are serialized with sufficient information to insure that the equivalent typed object can be recreated. Deserialization is the symmetric process of recreating the object or graph of objects from the serialized representation. Different versions of a class can write and read compatible streams.

Revision 1.4.1, October 8, 1997

Contents

Change History

July 3, 1997 Updates for JDK 1.2

- Documents the requirements for specifing the serializable persistent state of classes. See Section 1.5, “Specifying Serializable Persistent Fields and Data for a Class”.
- Added the Serializable Fields API to allow classes more flexibility in accessing the serialized fields of a class. The stream protocol is unchanged. See Section 1.7, “Accessing Serializable Fields of a Class, Section 2.2, “The ObjectOutputStream.PutField Class”, Section 3.2, “The ObjectInputStream.GetField Class”.
- Clarified that field descriptors and data are written to and read from the stream in canonical order. See Section 4.1, “The ObjectStreamClass Class”

Sept. 4, 1997 Updates for JDK 1.2

- Separate Replaceable interface into two interfaces, Replaceable and Resolvable. The Replaceable interface allows a class to nominate its own replacement just before serializing the object to the stream. The Resolvable interface allows a class to nominate its own replacement when reading an object from the stream. See Section 1.12, “The Replaceable & Resolvable Interfaces”.
- Updated serialization to use JDK 1.2 security model. Rather than require that a class be loaded by the null classloader, the requirement is that the calling sequences to methods, ObjectInputStream.enableReplace and

ObjectOutputStream.enableResolve, has SerializablePermission “enableSubstitution”. See Section 2.1, “The ObjectOutputStream Class “and Section 3.1, “The ObjectInputStream Class”.

- Updated writeObject’s exception handler to write handled IOExceptions into the stream. See Section 2.1, “The ObjectOutputStream Class”.

System Architecture 1

Topics:

- Overview
- Writing to an Object Stream
- Reading from an Object Stream
- Object Streams as Containers
- Specifying Serializable Persistent Fields and Data for a Class
- Defining Serializable Persistent Fields for a Class
- Accessing Serializable Fields of a Class
- The ObjectOutput Interface
- The ObjectInput Interface
- The Serializable Interface
- The Externalizable Interface
- The Replaceable & Resolvable Interfaces
- Protecting Sensitive Information

1.1 Overview

The capability to store and retrieve Java objects is essential to building all but the most transient applications. The key to storing and retrieving objects in a serialized form is representing the state of objects sufficient to reconstruct the object(s). Objects to be saved in the stream may support either the `Serializable` or the `Externalizable` interface. For Java objects, the serialized form must be able to identify and verify the Java class from which the object's contents were saved and to restore the contents to a new instance. For serializable objects, the stream includes sufficient information to restore the fields in the stream to a compatible version of the class. For Externalizable objects, the class is solely responsible for the external format of its contents.

Objects to be stored and retrieved frequently refer to other objects. Those other objects must be stored and retrieved at the same time to maintain the relationships between the objects. When an object is stored, all of the objects that are reachable from that object are stored as well.

The goals for serializing Java objects are to:

- Have a simple yet extensible mechanism.
- Maintain the Java object type and safety properties in the serialized form.
- Be extensible to support marshaling and unmarshaling as needed for remote objects.
- Be extensible to support simple persistence of Java objects.
- Require per class implementation only for customization.
- Allow the object to define its external format.

1.2 Writing to an Object Stream

Writing objects and primitives to a stream is a straight-forward process. For example:

```
// Serialize today's date to a file.
    FileOutputStream f = new FileOutputStream("tmp");
    ObjectOutput s = new ObjectOutputStream(f);
    s.writeObject("Today");
    s.writeObject(new Date());
    s.flush();
```

First an `OutputStream`, in this case a `FileOutputStream`, is needed to receive the bytes. Then an `ObjectOutputStream` is created that writes to the `FileOutputStream`. Next, the string “Today” and a Date object are written to the stream. More generally, objects are written with the `writeObject` method and primitives are written to the stream with the methods of `DataOutput`.

The `writeObject` method (see Section 2.3, “The writeObject Method) serializes the specified object and traverses its references to other objects in the object graph recursively to create a complete serialized representation of the graph. Within a stream, the first reference to any object results in the object being serialized or externalized and the assignment of a handle for that object. Subsequent references to that object are encoded as the handle. Using object handles preserves sharing and circular references that occur naturally in object graphs. Subsequent references to an object use only the handle allowing a very compact representation.

Special handling is required for objects of type `Class`, `ObjectStreamClass`, strings, and arrays. Other objects must implement either the `Serializable` or the `Externalizable` interface to be saved in or restored from a stream.

Primitive data types are written to the stream with the methods in the `DataOutput` interface, such as `writeInt`, `writeFloat`, or `writeUTF`. Individual bytes and arrays of bytes are written with the methods of `OutputStream`. Primitive data, excluding serializable fields and externalizable data, is written to the stream in block-data records prefixed by a marker and the number of bytes in the record.

`ObjectOutputStream` can be extended to customize the information about classes in the stream or to replace objects to be serialized. Refer to the `annotateClass` and `replaceObject` method descriptions for details.

1.3 Reading from an Object Stream

Reading an object from a stream, like writing, is straight-forward:

```
// Deserialize a string and date from a file.
    FileInputStream in = new FileInputStream(“tmp”);
    ObjectInputStream s = new ObjectInputStream(in);
    String today = (String)s.readObject();
    Date date = (Date)s.readObject();
```

First an `InputStream`, in this case a `FileInputStream`, is needed as the source stream. Then an `ObjectInputStream` is created that reads from the `InputStream`. Next, the string "Today" and a Date object are read from the stream. Generally, objects are read with the `readObject` method and primitives are read from the stream with the methods of `DataInput`.

The `readObject` method deserializes the next object in the stream and traverses its references to other objects recursively to create the complete graph of objects serialized.

Primitive data types are read from the stream with the methods in the `DataInput` interface, such as `readInt`, `readFloat`, or `readUTF`. Individual bytes and arrays of bytes are read with the methods of `InputStream`. Primitive data, excluding serializable fields and externalizable data, is read from block-data records.

ObjectInputStream can be extended to utilize customized information in the stream about classes or to replace objects that have been deserialized. Refer to the `resolveClass` and `resolveObject` method descriptions for details.

1.4 Object Streams as Containers

Object Serialization produces and consumes a stream of bytes that contain one or more primitives and objects. The objects written to the stream, in turn, refer to other objects which are also represented in the stream. Object Serialization produces just one stream format that encodes and stores the contained objects. Object Serialization has been designed to provide a rich set of features for Java classes.

Each object acting as a container implements an interface that allows primitives and objects to be stored in or retrieved from it. These are the `ObjectOutput` and `ObjectInput` interfaces which:

- Provide a stream to write to and read from
- Handle requests to write primitive types and objects to the stream,

Each object which is to be stored in a stream must explicitly allow itself to be stored and must implement the protocols needed to save and restore its state. Object Serialization defines two such protocols. The protocols allow the container to ask the object to write and read its state. To be stored in an Object Stream, each object must implement either the `Serializable` or the `Externalizable` interface.

For a serializable class, Object Serialization can automatically save and restore fields of each class of an object and automatically handle classes that evolve by adding fields or supertypes. A serializable class can declare which of its fields are saved or restored, and write and read optional values and objects. Optional primitive values are written and read from block-data records. Putting the optional data in records allows it to be skipped if necessary.

For an Externalizable class, Object Serialization delegates to the class complete control over its external format and how the state of the supertype(s) is saved and restored.

1.5 Specifying Serializable Persistent Fields and Data for a Class

When objects are declared to be serializable so that they can be written to or read from a stream, the class designer must take care that the information saved for the class is appropriate for persistence and follows serialization's rules for evolution and interoperability. Serialized streams of objects must interoperate over time and across versions of the classes that are written to and read from them. The specification of the classes serializable persistent fields makes it possible for classes to evolve and still be able to communicate with previous and future versions of the class. This is an essential feature and benefit of using serialization for persistence or for communication. "Versioning of Serializable Objects" covers class evolution in greater detail.

For classes that are declared Serializable, the serializable state of the object is defined by fields (by name and type) plus optional data. Optional data may be written to and read from the stream explicitly by the class itself. By default, the non-transient and non-static fields of the class define the set of serializable fields. This default set of fields can be overridden by declaring the set of serializable persistent fields. See Section 1.6, "Defining Serializable Persistent Fields for a Class".

For classes that are declared Externalizable, the persistent state is defined by the data written to the stream by the class itself. It is up to the class to specify the order, types, and meaning of each datum written to the stream. It is up to the class to handle its own evolution so that it can continue to read data written by previous versions and that it writes data that can be read by previous versions. The class must coordinate with the superclass when saving and restoring data. The location of the superclasses data in the stream must be specified.

Regardless of the serialization mechanism chosen, the specification must define the fields as if they were fields of the object using the Java specifications for names and types. Optional data written to the stream must be specified by sequence and type. The meaning associated with persistent fields and data must be defined. For example, a class Window has a field named “background” that refers to a Color object that is to be used to fill the part of the window not otherwise covered. These persistent fields may correspond directly to declarations in the class or may only be accessible via get and set methods described below. Independent of the mechanism used to make the persistent field visible to the client the semantics of the object are expressed in terms of these values. The initial or default value must be specified for each value. Classes may or may not have other fields which are not part of the persistent state of the object.

1.6 Defining Serializable Persistent Fields for a Class

By default, the serializable fields of a class are defined to be the non-transient and non-static fields. These declarations can be overridden by declaring a special field in the class. For example, the declaration below duplicates the default behavior.

```
class List implements Serializable {
    List next;

    public final static ObjectStreamFields[] serialPersistentFields
                = {new ObjectStreamField(“next”, List.class)};
}
```

The `serialPersistentFields` field must be initialized with an array of `ObjectStreamField` objects that list the names and types of the serializable fields. The field must be static and final so it does not change during operation.

When an `ObjectStreamClass` is created for a class it examines the class to determine the serializable fields. It looks for the definition of the `serialPersistentFields` and if it is not found then the list of serializable fields is created from the non-transient and non-static fields of the class.

1.7 Accessing Serializable Fields of a Class

Serialization provides two mechanisms for accessing the serializable fields in a stream. The default mechanism requires no customization while the alternative allows the class to explicitly access the fields by name and type.

The default mechanism is used automatically when reading or writing objects that implement the Serializable interface and do no further customization. The serializable persistent fields are mapped to the corresponding fields of the class and values are written to the stream from those fields or read in and assigned respectively. If the class provides `writeObject` and `readObject` methods the default mechanism can be invoked by calling `defaultWriteObject` and `defaultReadObject`. When implementing these methods the class has an opportunity to modify the data values before they are written or after they are read.

When the default mechanism cannot be used, the serializable class can use the `putFields` of `ObjectOutputStream` to put the values for the serializable fields into the stream. The `writeFields` method of `ObjectOutputStream` puts the values in the in the correct order and writes them to the stream using the existing protocol for serialization. Correspondingly, the `readFields` method of `ObjectInputStream` reads the values from the stream and makes them available to the class by name in any order.

1.8 The ObjectOutput Interface

The `ObjectOutput` interface provides an abstract, stream-based interface to object storage. It extends `DataOutput` so those methods may be used for writing primitive data types. Objects implementing this interface can be used to store primitives and objects.

```
package java.io;

public interface ObjectOutput extends DataOutput
{
    public void writeObject(Object obj) throws IOException;

    public void write(int b) throws IOException;

    public void write(byte b[]) throws IOException;

    public void write(byte b[], int off, int len) throws IOException;
```

```
    public void flush() throws IOException;

    public void close() throws IOException;
}
```

The `writeObject` method is used to write an object. The exceptions thrown reflect errors while accessing the object or its fields, or exceptions that occur in writing to storage. If any exception is thrown, the underlying storage may be corrupted, and you should refer to the object implementing this interface for details.

1.9 The ObjectInput Interface

The `ObjectInput` interface provides an abstract stream based interface to object retrieval. It extends `DataInput` so those methods for reading primitive data types are accessible in this interface.

```
package java.io;

public interface ObjectInput extends DataInput
{
    public Object readObject()
        throws ClassNotFoundException, IOException;

    public int read() throws IOException;

    public int read(byte b[]) throws IOException;

    public int read(byte b[], int off, int len) throws IOException;

    public long skip(long n) throws IOException;

    public int available() throws IOException;

    public void close() throws IOException;
}
```

The `readObject` method is used to read and return an object. The exceptions thrown reflect errors while accessing the objects or its fields or exceptions that occur in reading from the storage. If any exception is thrown, the underlying storage may be corrupted, refer to the object implementing this interface for details.

1.10 The Serializable Interface

Object Serialization produces a stream with information about the Java classes for the objects that are being saved. For serializable objects, sufficient information is kept to restore those objects even if a different (but compatible) version of the class's implementation is present. The interface `Serializable` is defined to identify classes that implement the serializable protocol:

```
package java.io;

public interface Serializable {};
```

A serializable object:

- Must implement the `java.io.Serializable` interface.
- Must mark its fields that are not to be persistent with the transient keyword or use the `serialPersistentFields` to specify the serializable fields.
- Can implement a `writeObject` method to control what information is saved, or to append additional information to the stream.
- Can implement a `readObject` method so it can read the information written by the corresponding `writeObject` method, or to update the state of the object after it has been restored.
- The first non-Serializable superclass must have a public or protected no-arg constructor.

`ObjectOutputStream` and `ObjectInputStream` are designed and implemented to allow the serializable classes they operate on to evolve. Evolve in this context means to allow changes to the classes that are compatible with the earlier versions of the classes. Details of the mechanism to allow compatible changes can be found in Section 5.5, "Compatible Java Type Evolution.

1.11 The Externalizable Interface

For Externalizable objects only the identity of class of the object is saved by the container and it is the responsibility of the class to save and restore the contents. The interface Externalizable is defined as:

```
package java.io;

public interface Externalizable extends Serializable
```

```
{
    public void writeExternal(ObjectOutput out)
        throws IOException;

    public void readExternal(ObjectInput in)
        throws IOException, java.lang.ClassNotFoundException;
}
```

An externalizable object:

- Must implement the `java.io.Externalizable` interface.
- Must implement a `writeExternal` method to save the state of the object. It must explicitly coordinate with its supertype to save its state.
- Must implement a `readExternal` method to read the data written by the `writeExternal` method from the stream and restore the state of the object. It must explicitly coordinate with the supertype to save its state.
- If writing an externally defined format, the `writeExternal` and `readExternal` methods are solely responsible for that format.
- Must have a public or protected no-arg constructor.

Note – The `writeExternal` and `readExternal` methods are public and raise the risk that a client may be able to write or read information in the object other than by using its methods and fields. These methods must be used only when the information held by the object is not sensitive or when exposing it would not present a security risk.

1.12 The Replaceable & Resolvable Interfaces

The Replaceable interface allows an object to nominate its own replacement in the stream before the object is written. The Resolvable interface allows a class to replace/resolve the object read from the stream before it is returned to the caller. The interfaces are defined as:

```
package java.io;

public interface Replaceable extends Serializable {
    public Object writeReplace(Object obj);
}
```

```
public interface Resolvable extends Serializable {
       public Object readResolve(Object obj);
}
```

By implementing the Replaceable interface the class itself can directly control the types and instances of its own instances being serialized. By implementing the Resolvable interface the class itself can directly control the types and instances of its own instances being deserialized

For example, a Symbol class could be created for which only a single instance of each symbol binding existed within a virtual machine. The `readResolve` method would be implemented to determine if that symbol was already defined and substitute the preexisting equivalent Symbol object to maintain the identity constraint. In this way the uniqueness of Symbol objects can be maintained across serialization.

The writeReplace method is called when `ObjectOutputStream` is preparing to write the object to the stream. The `ObjectOutputStream` checks to see if the class implements the `Replaceable` interface. If so, it calls the `writeReplace` method to allow the object to designate its replacement in the stream. The object returned either should be of the same type as the object passed in or an object that when read and resolved will result in an object of a type that is compatible with all references to the object, otherwise a `ClassCastException` will occur when the type mismatch is discovered.

The readResolve method is called when `ObjectInputStream` has read an object from the stream and is preparing to return it to the caller. `ObjectInputStream` checks if the object implements the `Resolvable` interface. If so, it calls the `readResolve` method to allow the object in the stream to designate the object to be returned. The object returned should be of a type that is compatible with all uses or a `ClassCastException` will be thrown when the type mismatch is discovered.

1.13 *Protecting Sensitive Information*

When developing a class that provides controlled access to resources, care must be taken to protect sensitive information and functions. During deserialization, the private state of the object is restored. For example, a file descriptor contains a handle that provides access to an operating system resource. Being able to forge a file descriptor would allow some forms of illegal access, since restoring state is done from a stream. Therefore, the serializing runtime must take the conservative approach and not trust the stream to

contain only valid representations of objects. To avoid compromising a class, the sensitive state of an object must not be restored from the stream, or it must be reverified by the class. Several techniques are available to protect sensitive data in classes.

The easiest technique is to mark fields that contain sensitive data as `private transient`. Transient fields are not persistent and will not be saved by any persistence mechanism. Marking the field will prevent the state from appearing in the stream and from being restored during deserialization. Since writing and reading (of private fields) cannot be superseded outside of the class, the class's transient fields are safe.

Particularly sensitive classes should not be serialized at all. To accomplish this, the object should not implement either the `Serializable` or the `Externalizable` interface.

Some classes may find it beneficial to allow writing and reading but specifically handle and revalidate the state as it is deserialized. The class should implement `writeObject` and `readObject` methods to save and restore only the appropriate state. If access should be denied, throwing a `NotSerializableException` will prevent further access.

Object Output Classes 2

Topics:

- The ObjectOutputStream Class
- The ObjectOutputStream.PutField Class
- The writeObject Method
- The writeExternal Method

2.1 The ObjectOutputStream Class

Class `ObjectOutputStream` implements object serialization. It maintains the state of the stream including the set of objects already serialized. Its methods control the traversal of objects to be serialized to save the specified objects and the objects to which they refer.

```
package java.io;

public class ObjectOutputStream
    extends OutputStream
    implements ObjectOutput, ObjectStreamConstants
{
    public ObjectOutputStream(OutputStream out)
        throws IOException;

    public final void writeObject(Object obj)
        throws IOException;
```

```
public final void defaultWriteObject();
    throws IOException, NotActiveException;
public PutField putFields()
    throws IOException;

public writeFields()
    throws IOException;
    public void reset() throws IOException;

protected void annotateClass(Class cl) throws IOException;

protected Object replaceObject(Object obj) throws IOException;

protected final boolean enableReplaceObject(boolean enable)
    throws SecurityException;

protected void writeStreamHeader() throws IOException;

public void write(int data) throws IOException;

public void write(byte b[]) throws IOException;

public void write(byte b[], int off, int len) throws IOException;

public void flush() throws IOException;

protected void drain() throws IOException;

public void close() throws IOException;

public void writeBoolean(boolean data) throws IOException;

public void writeByte(int data) throws IOException;

public void writeShort(int data)  throws IOException;

public void writeChar(int data)  throws IOException;

public void writeInt(int data)  throws IOException;

public void writeLong(long data)  throws IOException;

public void writeFloat(float data) throws IOException;

public void writeDouble(double data) throws IOException;
```

```
    public void writeBytes(String data) throws IOException;

    public void writeChars(String data) throws IOException;

    public void writeUTF(String data) throws IOException;

    // Inner class to provide access to serializable fields.
    public class PutField
    {
        public void put(String name, boolean value)
            throws IOException, IllegalArgumentException;

        public void put(String name, char data)
            throws IOException, IllegalArgumentException;

        public void put(String name, byte data)
            throws IOException, IllegalArgumentException;

        public void put(String name, short data)
            throws IOException, IllegalArgumentException;

        public void put(String name, int data)
            throws IOException, IllegalArgumentException;

        public void put(String name, long data)
            throws IOException, IllegalArgumentException;

        public void put(String name, float data)
            throws IOException, IllegalArgumentException;

        public void put(String name, double data)
            throws IOException, IllegalArgumentException;

        public void put(String name, Object data)
            throws IOException, IllegalArgumentException;
    }
}


}
```

The `ObjectOutputStream` constructor requires an OutputStream. The constructor calls `writeStreamHeader` to write a magic number and version to the stream, that will be read and verified by the corresponding `readStreamHeader` in the `ObjectInputStream` constructor.

The `writeObject` method is used to serialize an object to the stream. Objects are serialized as follows:

1. If there is data in the block-data buffer, it is written to the stream and the buffer is reset.
2. If the object is null, null is put in the stream and writeObject returns.
3. If the object has already been written to the stream, its handle is written to the stream and writeObject returns. If the object has been already been replaced, the handle for the previously-written replacement object is written to the stream.
4. If the object is a Class, the corresponding ObjectStreamClass is written to the stream, a handle is assigned for the class, and writeObject returns.
5. If the object is an ObjectStreamClass, a descriptor for the class is written to the stream including its name, serialVersionUID, and the list of fields by name and type. A handle is assigned for the descriptor. The annotateClass subclass method is called before `writeObject` returns.
6. If the object is a `java.lang.String`, the string is written in Universal Transfer Format (UTF) format, a handle is assigned to the string, and writeObject returns.
7. If the object is an array, `writeObject` is called recursively to write the `ObjectStreamClass` of the array. The handle for the array is assigned. It is followed by the length of the array. Each element of the array is then written to the stream, after which `writeObject` returns.
8. Process potential substitutions by the class of the object and/or by a subclass of `ObjectInputStream`..
   - If the object implements the `Replaceable` interface, its `writeReplace` method is called and the method can optionally return a substitute object to be serialized.
   - Then if enabled by calling `enableReplaceObject` method, the `replaceObject` method is called to allow subclasses of `ObjectOutputStream` to substitute for the object being serialized.

If the original object was replaced by either one or both steps above, the mapping from the original object to the replacement is recorded for later use in step 3, and steps 2 through 7 are repeated on the new object. If the replacement object is not one of the types covered by steps 2 through 7, processing resumes using the replacement object at step 9.

9. For regular objects, the `ObjectStreamClass` for the object's class is written by recursively calling writeObject. It will appear in the stream only the first time it is referenced. A handle is assigned for this object.

10. The contents of the object is written to the stream.
    - If the object is serializable, the highest serializable class is located. For that class, and each derived class, that class's fields are written. If the class does not have a `writeObject` method, the `defaultWriteObject` method is called to write the serializable fields to the stream. If the class does have a `writeObject` method, it is called. It may call `defaultWriteObject` or `putFields` and `writeFields` to save the state of the object, and then it can write other information to the stream.
    - If the object is externalizable, the writeExternal method of the object is called.
    - If the object is neither serializable or externalizable, the `NotSerializableException` is thrown.

Exceptions may occur during the traversal or may occur in the underlying stream. For any subclass of `IOException`, the exception is written to the stream using the exception protocol and the stream state is discarded. If a second `IOException` is thrown while attempting to write the first exception into the stream, the stream is left in an unknown state and `StreamCorruptedException` is thrown from `writeObject`. For other `exceptions`, the stream is aborted and left in an unknown and unusable state.

The `defaultWriteObject` method implements the default serialization mechanism for the current class. This method may be called only from a class's `writeObject` method. The method writes all of the nonstatic and nontransient fields of the current class to the stream. If called from outside the `writeObject` method, the `NotActiveException` is thrown.

The `putFields` method returns a `PutField` object the caller uses to set the values of the serializable fields in the stream. The fields may be set in any order. After all of the fields have been set, `writeFields` must be called to write the field values in the canonical order to the stream. If a field is not set, the default value appropriate for its type will be written to the stream. This

method may only called from within the `writeObject` method of a serializable class. It may not be called more than once or if `defaultWriteObject` has been called. Only after `writeFields` has been called can other data may be written to the stream.

The `reset` method resets the stream state to be the same as if it had just been constructed. Reset will discard the state of any objects already written to the stream. The current point in the stream is marked as reset, so the corresponding ObjectInputStream will reset at the same point. Objects previously written to the stream will not be remembered as already having been written to the stream. They will be written to the stream again. This is useful when the contents of an object or objects must be sent again. Reset may not be called while objects are being serialized. If called inappropriately, an `IOException` is thrown.

The `annotateClass` method is called while a Class is being serialized, and after the class descriptor has been written to the stream. Subclasses may extend this method and write other information to the stream about the class. This information must be read by the `resolveClass` method in a corresponding `ObjectInputStream` subclass.

An `ObjectOutputStream` subclass can implement the `replaceObject` method to monitor or replace objects during serialization. Replacing objects must be enabled explicitly by calling `enableReplaceObject` before calling `writeObject` with the first object to be replaced. Once enabled, `replaceObject` is called for each object just prior to serializing the object for the first time. Note that the `replaceObject` method is not called for objects of the specially handled classes, `Class`, `ObjectStreamClass`, `String`, and arrays. A subclass's implementation may return a substitute object that will be serialized instead of the original. The substitute object must be serializable. All references in the stream to the original object will be replaced by the substitute object.

When objects are being replaced, the subclass must ensure that the substituted object is compatible with every field where the reference will be stored, or that a complementary substitution will be made during deserialization. Objects, whose type is not a subclass of the type of the field or array element, will later abort the deserialization by raising a `ClassCastException` and the reference will not be stored.

The `enableReplaceObject` method can be called by trusted subclasses of `ObjectOutputStream` to enable the substitution of one object for another during serialization. Replacing objects is disabled until `enableReplaceObject` is called with a `true` value. It may thereafter be disabled by setting it to `false`. The previous setting is returned. The `enableReplaceObject` method checks that the stream requesting the replacement can be trusted. To ensure that the private state of objects is not unintentionally exposed, only trusted stream subclasses may use `replaceObject`. Trusted classes are those classes that belong to a security protection domain with permission to enable Serializable substitution.

If the subclass of `ObjectOutputStream` is not considered part of the system domain, the following line has to be added to the security policy file to provide a subclass of `ObjectOutputStream` permission to call `enableReplaceObject`.

```
permission SerializablePermission "enableSubstitution"
     [, CodeBase "URL"] [, SignedBy "signer_name"];
```

`AccessControlException` is thrown if the protection domain of the subclass of `ObjectInputStream` does not have permission to "enableSubstitution" by calling `enableReplaceObject`. See "The Java Security Architecture(JDK1.2)" document for further details on the security model.

The `writeStreamHeader` method writes the magic number and version to the stream. This information must be read by the `readStreamHeader` method of `ObjectInputStream`. Subclasses may need to implement this method to identify the stream's unique format.

The `flush` method is used to empty any buffers being held by the stream and to forward the flush to the underlying stream. The `drain` method may be used by subclassers to empty only the `ObjectOutputStream`'s buffers without forcing the underlying stream to be flushed.

All of the write methods for primitive types encode their values using a DataOutputStream to put them in the standard stream format. The bytes are buffered into block data records so they can be distinguished from the encoding of objects. This buffering allows primitive data to be skipped if necessary for class versioning. It also allows the stream to be parsed without invoking class-specific methods.

2.2 The ObjectOutputStream.PutField Class

Class `PutField` provides the API for setting values of the serializable fields for a class when the class does not use default serialization. Each method puts the specified named value into the stream. I/O exceptions will be thrown if the underlying stream throws an exception. An IllegalArgumentException is thrown if the name does not match the name of a field declared for this object's ObjectStreamClass or if the type of the value does not match the declared type of the serializable field.

2.3 The writeObject Method

For serializable objects, the `writeObject` method allows a class to control the serialization of its own fields. Here is its signature:

```
private void writeObject(ObjectOutputStream stream)
    throws IOException;
```

Each subclass of a serializable object may define its own `writeObject` method. If a class does not implement the method, the default serialization provided by defaultWriteObject will be used. When implemented, the class is only responsible for having its own fields, not those of its supertypes or subtypes.

The class's `writeObject` method, if implemented, is responsible for saving the state of the class. The `defaultWriteObject` method should be called before writing any optional data that will be needed by the corresponding `readObject` method to restore the state of the object. The responsibility for the format, structure, and versioning of the optional data lies completely with the class.

2.4 The writeExternal Method

Objects implementing `java.io.Externalizable` must implement the `writeExternal` method to save the entire state of the object. It must coordinate with its superclasses to save their state. All of the methods of `ObjectOutput` are available to save the object's primitive typed fields and object fields.

```
public void writeExternal(ObjectOutput stream)
    throws IOException;
```

Object Input Classes 3

Topics:

- The ObjectInputStream Class
- The ObjectInputStream.GetField Class
- The ObjectInputValidation Interface
- The readObject Method
- The readExternal Method

3.1 The ObjectInputStream Class

Class `ObjectInputStream` implements object deserialization. It maintains the state of the stream including the set of objects already deserialized. Its methods allow primitive types and objects to be read from a stream written by ObjectOutputStream. It manages restoration of the object and the objects that it refers to from the stream.

```
package java.io;

public class ObjectInputStream
    extends InputStream
    implements ObjectInput, ObjectStreamConstants
{
    public ObjectInputStream(InputStream in)
        throws StreamCorruptedException, IOException;
```

```
public final Object readObject()
    throws OptionalDataException, ClassNotFoundException,
        IOException;

public final void defaultReadObject()
    throws IOException, ClassNotFoundException,
        NotActiveException;

public GetField readFields()
    throws IOException;

public synchronized void registerValidation(
    ObjectInputValidation obj, int prio)
    throws NotActiveException, InvalidObjectException;

protected Class resolveClass(ObjectStreamClass v)
    throws IOException, ClassNotFoundException;

protected Object resolveObject(Object obj)
    throws IOException;

protected final boolean enableResolveObject(boolean enable)
    throws SecurityException;

protected void readStreamHeader()
    throws IOException, StreamCorruptedException;

public int read() throws IOException;

public int read(byte[] data, int offset, int length)
    throws IOException

public int available() throws IOException;

public void close() throws IOException;

public boolean readBoolean() throws IOException;

public byte readByte() throws IOException;

public int readUnsignedByte()  throws IOException;

public short readShort()  throws IOException;

public int readUnsignedShort() throws IOException;
```

```
public char readChar()  throws IOException;

public int readInt()  throws IOException;

public long readLong()  throws IOException;

public float readFloat() throws IOException;

public double readDouble() throws IOException;

public void readFully(byte[] data) throws IOException;

public void readFully(byte[] data, int offset, int size)
    throws IOException;

public int skipBytes(int len) throws IOException;

public String readLine() throws IOException;

public String readUTF() throws IOException;

// Inner class to provide access to serializable fields.
public class GetField
{
    public getObjectStreamClass();

    public boolean defaulted(String name)
        throws IOException, IllegalArgumentException;

    public char get(String name, char defalt)
        throws IOException, IllegalArgumentException;

    public boolean get(String name, boolean defalt)
        throws IOException, IllegalArgumentException;

    public byte get(String name, byte defalt)
        throws IOException, IllegalArgumentException;

    public short get(String name, short defalt)
        throws IOException, IllegalArgumentException;

    public int get(String name, int defalt)
        throws IOException, IllegalArgumentException;

    public long get(String name, long defalt)
        throws IOException, IllegalArgumentException;
```

```
        public float get(String name, float defalt)
            throws IOException, IllegalArgumentException;

        public double get(String name, double defalt)
            throws IOException, IllegalArgumentException;

        public Object get(String name, Object defalt)
            throws IOException, IllegalArgumentException;
    }
}
```

The `ObjectInputStream` constructor requires an InputStream. The constructor calls `readStreamHeader` to read and verifies the header and version written by the corresponding `ObjectOutputStream.writeStreamHeader` method.

The `readObject` method is used to deserialize an object from the stream. It reads from the stream to reconstruct an object.

1. If a block data record occurs in the stream, throw a BlockDataException with the number of available bytes.
2. If the object in the stream is null, return null.
3. If the object in the stream is a handle to a previous object, return the object.
4. If the object in the stream is a String, read its UTF encoding, add it and its handle to the set of known objects, and return the String.
5. If the object in the stream is a Class, read its ObjectStreamClass descriptor, add it and its handle to the set of known objects, and return the corresponding Class object.
6. If the object in the stream is an ObjectStreamClass, read its name, serialVersionUID, and fields. Add it and its handle to the set of known objects. Call the resolveClass method on the stream to get the local class for this descriptor, and throw an exception if the class cannot be found. Return the ObjectStreamClass object.
7. If the object in the stream is an array, read its ObjectStreamClass and the length of the array. Allocate the array, and add it and its handle in the set of known objects. Read each element using the appropriate method for its type, assign it to the array, and return the array.

8. For all other objects, the ObjectStreamClass of the object is read from the stream. The local class for that ObjectStreamClass is retrieved. The class must be serializable or externalizable.

9. An instance of the class is allocated. The instance and its handle are added to the set of known objects. The contents restored appropriately:
   - For serializable objects, the no-arg constructor for the first non-serializable supertype is run. For serializable classes, the fields are initialized to the default value appropriate for its type. Then each class's fields are restored by calling class-specific `readObject` methods, or if these are not defined, by calling the `defaultReadObject` method. Note that field initializers and constructors are not executed for serializable classes during deserialization. In the normal case, the version of the class that wrote the stream will be the same as the class reading the stream. In this case, all of the supertypes of the object in the stream will match the supertypes in the currently-loaded class. If the version of the class that wrote the stream had different supertypes than the loaded class, the ObjectInputStream must be more careful about restoring or initializing the state of the differing classes. It must step through the classes, matching the available data in the stream with the classes of the object being restored. Data for classes that occur in the stream, but do not occur in the object, is discarded. For classes that occur in the object, but not in the stream, the class fields are set to default values by default serialization.
   - For externalizable objects, the no-arg constructor for the class is run and then the `readExternal` method is called to restore the contents of the object.

10. Process potential substitutions by the class of the object and/or by a subclass of `ObjectInputStream`..
    - If the object implements the `Resolvable` interface, it's `readResolve` method is called to allow the object to replace itself.
    - Then if previously enabled by `enableResolveObject`, the `resolveObject` method is called to allow subclasses of the stream to examine and replace the object. If the previous step did replace the original object, the `resolveObject` method is called with the replacement object.

    If a replacement took place, the table of known objects is updated so the replaced object is associated with the handle. This object is then returned from `readObject`.

All of the methods for reading primitives types only consume bytes from the block data records in the stream. If a read for primitive data occurs when the next item in the stream is an object, the read methods return -1 or the EOFException as appropriate. The value of a primitive type is read by a DataInputStream from the block data record.

The exceptions thrown reflect errors during the traversal or exceptions that occur on the underlying stream. If any exception is thrown, the underlying stream is left in an unknown and unusable state.

When the reset token occurs in the stream, all of the state of the stream is discarded. The set of known objects is cleared.

When the exception token occurs in the stream, the exception is read and a new WriteAbortedException is thrown with the terminating exception as an argument. The stream context is reset as described earlier.

The `defaultReadObject` method is used to read the fields and object from the stream. It uses the class descriptor in the stream to read the fields in the canonical order by name and type from the stream. The values are assigned to the matching fields by name in the current class. Details of the versioning mechanism can be found in Section 5.5, “Compatible Java Type Evolution. Any field of the object that does not appear in the stream is set to its default value. Values that appear in the stream, but not in the object, are discarded. This occurs primarily when a later version of a class has written additional fields that do not occur in the earlier version. This method may only be called from the `readObject` method while restoring the fields of a class. When called at any other time, the NotActiveException is thrown.

The `readFields` method reads the values of the serializable fields from the stream and makes them available via the `GetField` class. The `readFields` method is only callable from within the `readObject` method of a serializable class. It cannot be called more than once or if `defaultReadObject` has been called. The `GetFields` object uses the current object’s `ObjectStreamClass` to verify the fields that can be retrieved for this class. The GetFields object returned by `readFields` is only valid during this call to the classes `readObject` method. The fields may be retrieved in any order. Additional data may only be read directly from stream after readFields has been called.

The `registerValidation` method can be called to request a callback when the entire graph has been restored but before the object is returned to the original caller of `readObject`. The order of validate callbacks can be controlled

using the priority. Callbacks registered with higher values are called before those with lower values. The object to be validated must support the `ObjectInputValidation` interface and implement the `validateObject` method. It is only correct to register validations during a call to a class's `readObject` method. Otherwise, a NotActiveException is thrown. If the callback object supplied to registerValidation is null, an InvalidObjectException is thrown.

The `resolveClass` method is called while a class is being deserialized, and after the class descriptor has been read. Subclasses may extend this method to read other information about the class written by the corresponding subclass of `ObjectOutputStream`. The method must find and return the class with the given name and serialVersionUID. The default implementation locates the class by calling the class loader of the closest caller of `readObject` that has a class loader. If the class cannot be found `ClassNotFoundException` should be thrown.

The `resolveObject` method is used by trusted subclasses to monitor or substitute one object for another during deserialization. Resolving objects must be enabled explicitly by calling `enableResolveObject` before calling `readObject` for the first object to be resolved. Once enabled `resolveObject` is called once for each serializable object just prior to the first time it is being returned from `readObject`. Note that the `resolveObject` method is not called for objects of the specially handled classes, `Class`, `ObjectStreamClass`, `String`, and arrays. A subclass's implementation of `resolveObject` may return a substitute object that will be assigned or returned instead of the original. The object returned must be of a type that is consistent and assignable to every reference of the original object or else a `ClassCastException` will be thrown. All assignments are type-checked. All references in the stream to the original object will be replaced by references to the substitute object.

The `enableResolveObject` method is called by trusted subclasses of `ObjectOutputStream` to enable the monitoring or substitution of one object for another during deserialization. Replacing objects is disabled until `enableResolveObject` is called with a `true` value. It may thereafter be disabled by setting it to `false`. The previous setting is returned. The `enableResolveObject` method checks if the stream has permission to request substitution during serialization. To ensure that the private state of objects is

not unintentionally exposed, only trusted streams may use `resolveObject`. Trusted classes are those classes with a class loader equal to null or belong to a security protection domain that provides permission to enable substitution.

If the subclass of `ObjectInputStream` is not considered part of the system domain, the following line has to be added to the security policy file to provide a subclass of `ObjectInputStream` permission to call `enableResolveObject`.

```
permission SerializablePermission "enableSubstitution"
    [, CodeBase "URL"] [, SignedBy "signer_name"];
```

`AccessControlException` is thrown if the protection domain of the subclass of `ObjectStreamClass` does not have permission to "enableSubstitution" by calling `enableResolveObject`. See "The Java Security Architecture(JDK1.2)" document for further details on the security model.

The `readStreamHeader` method reads and verifies the magic number and version of the stream. If they do not match, the `StreamCorruptedMismatch` is thrown.

3.2 The ObjectInputStream.GetField Class

The class `ObjectInputStream.GetField` provides the API for getting the values of serializable fields. The protocol of the stream is the same as used by `defaultReadObject`. Using `readFields` to access the serializable fields does not change the format of the stream. It only provides an alternate API to access the values which does not require the class to have the corresponding non-transient fields for each named serializable field. The serializable fields are those declared using `serialPersistentFields` or if it is not declared the non-transient and non-static fields of the object. When the stream is read the available serializable fields are those written to the stream when the object was serialized. If the class that wrote the stream is a different version not all fields will correspond to the serializable fields of the current class. The available fields can be retrieved from the ObjectStreamClass of the GetField object.

The `getObjectStreamClass` method returns an ObjectStreamClass object representing the class in the stream. It contains the list of serializable fields.

The `defaulted` method returns true if the field is not present in the stream. An `IllegalArgumentException` is thrown if the requested field is not a serializable field of the current class.

Each `get` method returns the specified serializable field from the stream. I/O exceptions will be thrown if the underlying stream throws an exception. An `IllegalArgumentException` is thrown if the name or type does not match the name and type of an field serializable field of the current class. The default value is returned if the stream does not contain an explicit value for the field.

3.3 The ObjectInputValidation Interface

This interface allows an object to be called when a complete graph of objects has been deserialized. If the object cannot be made valid, it should throw the `ObjectInvalidException`. Any exception that occurs during a call to validateObject will terminate the validation process, and the InvalidObjectException will be thrown.

```
package java.io;

public interface ObjectInputValidation
{
    public void validateObject()
        throws InvalidObjectException;
}
```

3.4 The readObject Method

For serializable objects, the `readObject` method allows a class to control the deserialization of its own fields. Here is its signature:

```
private void readObject(ObjectInputStream stream)
    throws IOException, ClassNotFoundException;
```

Each subclass of a serializable object may define its own readObject method. If a class does not implement the method, the default serialization provided by defaultReadObject will be used. When implemented, the class is only responsible for restoring its own fields, not those of its supertypes or subtypes.

The class's readObject method, if implemented, is responsible for restoring the state of the class. The values of every field of the object whether transient or not, static or not are set to the default value for the fields type. The `defaultReadObject` method should be called before reading any optional data written by the corresponding `writeObject` method. If the classes `readObject` method attempts to read more data than is present in the optional

part of the stream for this class, the stream will throw an EOFException. The responsibility for the format, structure, and versioning of the optional data lies completely with the class.

If the class being restored is not present in the stream being read, its fields are initialized to the appropriate default values.

Reading an object from the ObjectInputStream is analagous to creating a new object. Just as a new object's constructors are invoked in the order from the superclass to the subclass, an object being read from a stream is deserialized from superclass to subclass. The `readObject`, or `defaultReadObject`, method is called instead of the constructor for each Serializable subclass during deserialization.

One last similarity between a constructor and a `readObject` method is that both provide the opportunity to invoke a method on an object that is not fully constructed. Any non-final method called while an object is being constructed can potentially be overridden by a subclass. Methods called during the construction phase of an object are resolved by the actual type of the object, not the type currently being initialized by either its constructor or `readObject` method. This situation results in the overriding method being invoked on an object that is not fully constructed yet.

3.5 The readExternal Method

Objects implementing `java.io.Externalizable` must implement the `readExternal` method to restore the entire state of the object. It must coordinate with its superclasses to restore their state. All of the methods of `ObjectInput` are available to restore the object's primitive typed fields and object fields.

```
public void readExternal(ObjectInput stream)
    throws IOException;
```

Note – The `readExternal` method is public, and it raises the risk of a client being able to overwrite an existing object from a stream. The class may add it own checks to insure that this is only called when appropriate.

Class Descriptors 4

Topics:

- The ObjectStreamClass Class
- The ObjectStreamField Class
- Inspecting Serializable Classes
- Stream Unique Identifiers

4.1 The ObjectStreamClass Class

The `ObjectStreamClass` provides information about classes that are saved in a Serialization stream. The descriptor provides the fully-qualified name of the class and its serialization version UID. A SerialVersionUID identifies the unique original class version for which this class is capable of writing streams and from which it can read.

```
package java.io;

public class ObjectStreamClass
{
    public static ObjectStreamClass lookup(Class cl);

    public String getName();

    public Class forClass();

    public ObjectStreamField[] getFields();
```

```
    public long getSerialVersionUID();

    public String toString();
}
```

The `lookup` method returns the `ObjectStreamClass` descriptor for the specified class in the Java VM. If the class has defined `serialVersionUID` it is retrieved from the class. If not defined by the class it is computed from the class's definition in the Java Virtual Machine. `null` is returned if the specified class is not serializable or externalizable. Only class descriptions for classes that implement either `java.io.Serializable` or `java.io.Externalizable` interfaces can be written to a stream.

The `getName` method returns the fully-qualified name of the class. The class name is saved in the stream and is used when the class must be loaded.

The `forClass` method returns the Class in the local Virtual Machine if one is known. Otherwise, it returns null.

The `getFields` method returns an array of `ObjectStreamField` objects that represent the persistent fields of this class.

The `getSerialVersionUID` method returns the `serialVersionUID` of this class. Refer to Section 4.4, "Stream Unique Identifiers. If not specified by the class, the value returned is a hash computed from the class's name, interfaces, methods, and fields using the Secure Hash Algorithm (SHA) as defined by the National Institute of Standard.

The `toString` method returns a printable representation of the class descriptor including the class's name and serialVersionUID.

When an `ObjectStreamClass` instance is written to the stream it writes the class name and serialVersionUID, flags and the number of fields. Depending on the class additional information may be written:

- For non-serializable classes number of fields is always zero. Neither of the serializable or externalizable flag bits are set.
- For serializable classes,the serializable flag is set, the number of fields counts the number of serializable fields and is followed by a descriptor for each serializable field. The descriptors are written in canonical order. The

descriptors for primitive typed fields are written first sorted by field name followed by descriptors for the object typed fields sorted by field name. The names are sorted using String.compareTo. The protocol describes the format.

- For externalizable classes, flags includes the externalizable flag and the number of fields is always zero.

4.2 The ObjectStreamField Class

ObjectStreamField objects represent serializable fields of serializable classes. The serializable fields of a class can be retrieved from the ObjectStreamClass. An array of ObjectStreamFields is used to override the default of serializable fields.

```
package java.io;

public class ObjectStreamField {

    public ObjectStreamField(String name, Class clazz);

    public String getName();

    public Class getType() throws ClassNotFoundException;

    public String toString();
}
```

The `ObjectStreamField` constructor is used to create a new instance of an ObjectStreamField. The argument is the type of the serializable field. For example, Integer.TYPE or java.lang.Hashtable.class. ObjectStreamField objects are used to specify the serializable fields of a class or to describe the fields present in a stream.

The `getName` method returns the name of the serializable field.

The `getType` method returns the type of the field.

The `toString` method returns a printable representation with name and type.

4.3 Inspecting Serializable Classes

The program `serialver` can be used to find out if a class is serializable and to get its `serialVersionUID`. When invoked with -show it puts up a simple user interface. To find out if a class is serializable and to find out its `serialVersionUID`, enter its full class name and press either the Enter or the Show button. The string printed can be copied and pasted into the evolved class.

When invoked on the command line with one or more class names, serialver prints the serialVersionUID for each class in a form suitable for copying into an evolving class. When invoked with no arguments, it prints a usage line.

4.4 Stream Unique Identifiers

Each versioned class must identify the original class version for which it is capable of writing streams and from which it can read. For example, a versioned class must declare:

```
static final long SerialVersionUID = 3487495895819393L;
```

The stream-unique identifier is a 64-bit hash of the class name, interface class names, methods, and fields. The value must be declared in all versions of a class except the first. It may be declared in the original class but is not required. The value is fixed for all compatible classes. If the SUID is not declared for a class, the value defaults to the hash for that class. Serializable classes do not need to anticipate versioning; however, Externalizable classes do. The initial version of an Externalizable class must output a stream data format that is extensible in the future. The intial version of the method `readExternal` has to be able to read the output format of all future versions of the method `writeExternal`.

The serialVersionUID is computed using the signature of a stream of bytes that reflect the class definition. The National Institute of Standards and Technology (NIST) Secure Hash Algorithm (SHA-1) is used to compute a signature for the

stream. The first two 32-bit quantities are used to form a 64-bit hash. A java.lang.DataOutputStream is used to convert primitive data types to a sequence of bytes. The values input to the stream are defined by the Java virtual machine (VM) specification for classes. The sequence of items in the stream is as follows:

1. The class name written using UTF encoding.
2. The class modifiers written as a 32-bit integer.
3. The name of each interface sorted by name written using UTF encoding.
4. For each field of the class sorted by field name (except private static and private transient fields):
   - The name of the field in UTF encoding.
   - The modifiers of the field written as an 32-bit integer.
   - The descriptor of the field in UTF encoding.
5. For each method including the class initiaizer method and each constructor sorted by method name and signature, except private methods and constructors:
   - The name of the method in UTF encoding.
   - The modifiers of the method written as an 32-bit integer.
   - The descriptor of the method in UTF encoding.
6. The SHA-1 algorithm is executed on the stream of bytes produced by DataOutputStream and produces five 32-bit values sha[0..4].
7. The hash value is assembled from the first and second 32-bit values.
   long hash = sha[1] << 32 + sha[0].

Versioning of Serializable Objects 5

Topics:

- Overview
- Goals
- Assumptions
- Who's Responsible for Versioning of Streams
- Compatible Java Type Evolution
- Type Changes Affecting Serialization

5.1 Overview

When Java objects use serialization to save state in files, or as blobs in databases, the potential arises that the version of a class reading the data is different than the version that wrote the data.

Versioning raises some fundamental questions about the identity of a class, including what constitutes a compatible change. A *compatible change* is a change that does not affect the contract between the class and its callers.

This section describes the goals, assumptions, and a solution that attempts to address this problem by restricting the kinds of changes allowed and by carefully choosing the mechanisms.

The proposed solution provides a mechanism for “automatic” handling of classes that evolve by adding fields and adding classes. Serialization will handle versioning without class-specific methods to be implemented for each version. The stream format can be traversed without invoking class-specific methods.

5.2 Goals

The goals are to:

- Support bidirectional communication between different versions of a class operating in different virtual machines by:
  - Defining a mechanism that allows Java classes to read streams written by older versions of the same class.
  - Defining a mechanism that allows Java classes to write streams intended to be read by older versions of the same class.
- Provide default serialization for persistence and for RMI.
- Perform well and produce compact streams in simple cases, so that RMI can use serialization.
- Be able to identify and load classes that match the exact class used to write the stream.
- Keep the overhead low for nonversioned classes.
- Use a stream format that allows the traversal of the stream without having to invoke methods specific to the objects saved in the stream.

5.3 Assumptions

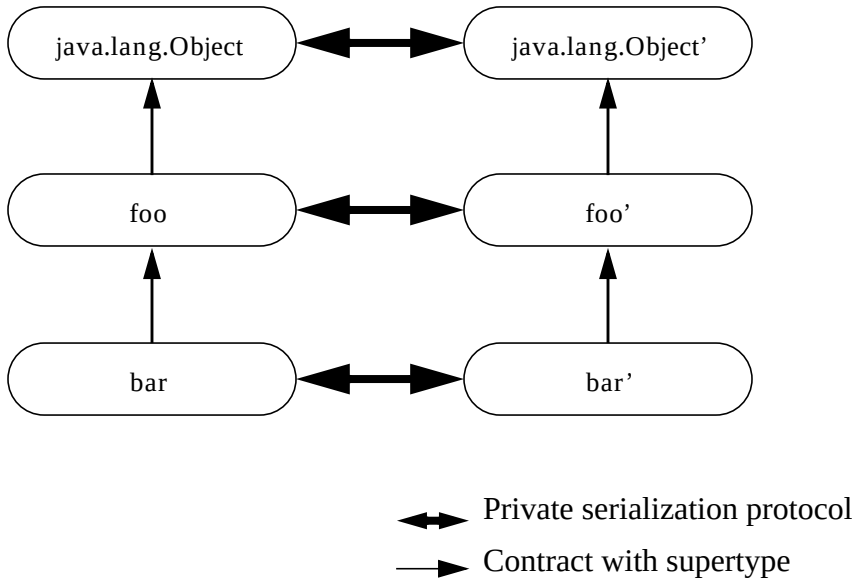
The assumptions are that:

- Versioning will only apply to serializable classes since it must control the stream format to achieve it goals. Externalizable classes will be responsible for their own versioning which is tied to the external format.
- All data and objects must be read from, or skipped in, the stream in the same order as they were written.

- Classes evolve individually as well as in concert with supertypes and subtypes.
- Classes are identified by name. Two classes with the same name may be different versions or completely different classes that can be distinguished only by comparing their interfaces or by comparing hashes of the interfaces.
- Default serialization will not perform any type conversions.
- The stream format only needs to support a linear sequence of type changes, not arbitrary branching of a type.

5.4 *Who's Responsible for Versioning of Streams*

In the evolution of classes, it is the responsibility of the evolved (later version) class to maintain the contract established by the nonevolved class. This takes two forms. First, the evolved class must not break the existing assumptions about the interface provided by the original version, so that the evolved class can be used in place of the original. Secondly, when communicating with the original (or previous) versions, the evolved class must provide sufficient and equivalent information to allow the earlier version to continue to satisfy the nonevolved contract.



For the purposes of the discussion here, each class implements and extends the interface or contract defined by its supertype. New versions of a class, for example foo', must continue to satisfy the contract for foo and may extend the interface or modify its implementation.

Communication between objects via serialization is not part of the contract defined by these interfaces. Serialization is a private protocol between the implementations. It is the responsibility of the implementations to communicate sufficiently to allow each implementation to continue to satisfy the contract expected by its clients.

5.5 *Compatible Java Type Evolution*

In the *Java Language Specification*, Chapter 13 discusses binary compatibility of Java classes as those classes evolve. Most of the flexibility of binary compatibility comes from the use of late binding of symbolic references for the names of classes, interfaces, fields, methods, and so on.

The following are the principle aspects of the design for versioning of serialized object streams.

- The default serialization mechanism will use a symbolic model for binding the fields in the stream to the fields in the corresponding class in the virtual machine.
- Each class referenced in the stream will uniquely identify itself, its supertype, and the types and names of each nonstatic and nontransient field written to the stream. The fields are ordered with the primitive types first sorted by field name, followed by the object fields sorted by field name.
- Two types of data may occur in the stream for each class: required data (corresponding directly to the nonstatic and nontransient fields of the object); and optional data (consisting of an arbitrary sequence of primitives and objects). The stream format defines how the required and optional data occur in the stream so that the whole class, the required, or the optional parts can be skipped if necessary.
  - The required data consists of the fields of the object in the order defined by the class descriptor.
  - The optional data is written to the stream and does not correspond directly to fields of the class. The class itself is responsible for the length, types, and versioning of this optional information.
- If defined for a class, the writeObject / readObject methods supersede the default mechanism to write / read the state of the class. These methods write and read the optional data for a class. The required data is written by calling `defaultWriteObject` and read by calling `defaultReadObject`.
- The stream format of each class is identified by the use of a Stream Unique Identifier (SUID). By default, this is the hash of the class. All later versions of the class must declare the Stream Unique Identifier (SUID) that they are compatible with. This guards against classes with the same name that might inadvertently be identified as being versions of a single class.
- Subtypes of ObjectOutputStream and ObjectInputStream may include their own information identifying the class using the annotateClass method; for example, MarshalOutputStream embeds the URL of the class.

5.6 Type Changes Affecting Serialization

With these concepts, we can now describe how the design will cope with the different cases of an evolving class. The cases are described in terms of a stream written by some version of a class. When the stream is read back by the same version of the class, there is no loss of information or functionality. The stream is the only source of information about the original class. Its class descriptions, while a subset of the original class description, are sufficient to match up the data in the stream with the version of the class being reconstituted.

The descriptions are from the perspective of the stream being read in order to reconstitute either an earlier or later version of the class. In the parlance of RPC systems, this is a “receiver makes right” system. The writer writes its data in the most suitable form and the receiver must interpret that information to extract the parts it needs and to fill in the parts that are not available.

5.6.1 Incompatible Changes

Incompatible changes to classes are those changes for which the guarantee of interoperability cannot be maintained. The incompatible changes that may occur while evolving a class are:

- Deleting fields - If a field is deleted in a class, the stream written will not contain its value. When the stream is read by an earlier class, the value of the field will be set to the default value because no value is available in the stream. However, this default value may adversely impair the ability of the earlier version to fulfill its contract.
- Moving classes up or down the hierarchy - This cannot be allowed since the data in the stream appears in the wrong sequence.
- Changing a nonstatic field to static or a nontransient field to transient - This is equivalent to deleting a field from the class. This version of the class will not write that data to the stream, so it will not be available to be read by earlier versions of the class. As when deleting a field, the field of the earlier version will be initialized to the default value, which can cause the class to fail in unexpected ways.

- Changing the declared type of a primitive field - Each version of the class writes the data with its declared type. Earlier versions of the class attempting to read the field will fail because the type of the data in the stream does not match the type of the field.
- Changing the `writeObject` or `readObject` method so that it no longer writes or reads the default field data or changing it so that it attempts to write it or read it when the previous version did not. The default field data must consistently either appear or not appear in the stream.
- Changing a class from `Serializable` to `Externalizable` or visa-versa is an incompatible change since the stream will contain data that is incompatible with the implementation in the available class.
- Removing either `Serializable` or `Externalizable` is an incompatible change since when written it will not longer supply the fields needed by older versions of the class.
- Adding the `Replaceable` interface to a class is incompatible if the behavior of `writeReplace` would produce an object that is incompatible with any older version of the class.

5.6.2 Compatible Changes

The compatible changes to a class are handled as follows:

- Adding fields - When the class being reconstituted has a field that does not occur in the stream, that field in the object will be initialized to the default value for its type. If class-specific initialization is needed, the class may provide a readObject method that can initialize the field to nondefault values.
- Adding classes - The stream will contain the type hierarchy of each object in the stream. Comparing this hierarchy in the stream with the current class can detect additional classes. Since there is no information in the stream from which to initialize the object, the class's fields will be initialized to the default values.
- Removing classes - Comparing the class hierarchy in the stream with that of the current class can detect that a class has been deleted. In this case, the fields and objects corresponding to that class are read from the stream. Primitive fields are discarded, but the objects referenced by the deleted class are created, since they may be referred to later in the stream. They will be garbage-collected when the stream is garbage-collected or reset.

- Adding writeObject/readObject methods - If the version reading the stream has these methods then readObject is expected, as usual, to read the required data written to the stream by the default serialization. It should call `defaultReadObject` first before reading any optional data. The `writeObject` method is expected as usual to call `defaultWriteObject` to write the required data and then may write optional data.
- Removing writeObject/readObject methods - If the class reading the stream does not have these methods, the required data will be read by default serialization, and the optional data will be discarded.
- Adding `java.io.Serializable` - This is equivalent to adding types. There will be no values in the stream for this class so its fields will be initialized to default values. The support for subclassing nonserializable classes requires that the class's supertype have a no-arg constructor and the class itself will be initialized to default values. If the no-arg constructor is not available, the `InvalidClassException` is thrown.
- Changing the access to a field - The access modifiers public, package, protected, and private have no effect on the ability of serialization to assign values to the fields.
- Changing a field from static to nonstatic or transient to nontransient - This is equivalent to adding a field to the class. The new field will be written to the stream but earlier classes will ignore the value since serialization will not assign values to static or transient fields.

Object Serialization Stream Protocol 6

Topics:

- Overview
- Stream Elements
- Grammar for the Stream Format
- Example

6.1 Overview

The stream format is designed to satisfy the following goals:

- Be compact and structured for efficient reading.
- Allow skipping through the stream using only the knowledge of the structure and format of the stream. Do not require any per class code to be invoked.
- Require only stream access to the data.

6.2 Stream Elements

A basic structure is needed to represent objects in a stream. Each attribute of the object needs to be represented: its classes, its fields, and data written and later read by class-specific methods. The representation of objects in the stream can be described with a grammar. There are special representations for null

objects, new objects, classes, arrays, strings, and back references to any object already in the stream. Each object written to the stream is assigned a handle that is used to refer back to the object. Handles are assigned sequentially starting from 0x7E0000. The handles restart at 0x7E0000 when the stream is reset.

A class object is represented by:

- Its ObjectStreamClass object.

An ObjectStreamClass object is represented by:
- The Stream Unique Identifier (SUID) of compatible classes.
- A flag indicating if the class had writeObject/readObject methods.
- The number of nonstatic and nontransient fields.
- The array of fields of the class that are serialized by the default mechanism. For arrays and object fields, the type of the field is included as a string.
- Optional block-data records or objects written by the annotateClass method.
- The ObjectStreamClass of its supertype (null if the superclass is not serializable).

Strings are represented by their UTF encoding. Note, the current specification and implementation of the modified UTF restricts the total length of the encoded string to 65535 characters.

Arrays are represented by:

- Their ObjectStreamClass object.
- The number of elements.
- The sequence of values. The type of the values is implicit in the type of the array. for example the values of a byte array are of type byte.

New objects in the stream are represented by:

- The most derived class of the object.
- Data for each serializable class of the object, with the highest superclass first. For each class the stream contains:
  - The default serialized fields (those fields not marked static or transient as described in the corresponding ObjectStreamClass).
  - If the class has `writeObject`/`readObject` methods, there may be optional objects and/or block-data records of primitive types written by the `writeObject` method followed by an endBlockData code.

All primitive data written by classes is buffered and wrapped in block-data records whether the data is written to the stream within a `writeObject` method or written directly to the stream from outside a `writeObject` method. This data may only be read by the corresponding `readObject` methods or directly from the stream. Objects written by `writeObject` terminate any previous block-data record and are written as regular objects, or null or back references as appropriate. The block-data records allow error recovery to discard any optional data. When called from within a class, the stream can discard any data or objects until the endBlockData.

6.3 Grammar for the Stream Format

The table below contains the grammar. Nonterminal symbols are shown in italics. Terminal symbols in a fixed width font. Definitions of nonterminals are followed by a ":". The definition is followed by one or more alternatives, each on a separate line. The following table describes the notation:

Notation	Meaning
(datatype)	This token has the data type specified, such as byte.
token[n]	A predefined number of occurrences of the token, that is an array.
`x0001`	A literal value expressed in hexadecimal. The number of hex digits reflects the size of the value.
<xxx>	A value read from the stream used to indicate the length of an array.

6.3.1 Rules of the Grammar

A Serialized stream is represented by any stream satisfying the *stream* rule.

stream:
    magic version contents

contents:
    content
    contents content

content:
    object
    blockdata

object:
    newObject
    newClass
    newArray
    newString
    newClassDesc
    prevObject
    nullReference
    exception
    TC_RESET

newClass:
    TC_CLASS *classDesc newHandle*

classDesc:
    newClassDesc
    nullReference
    (ClassDesc)prevObject *// an object required to be of type ClassDesc*

superClassDesc:
    classDesc

newClassDesc:
    TC_CLASSDESC *className serialVersionUIDnewHandle classDescInfo*

classDescInfo:
    classDescFlags fields classAnnotation superClassDesc

className:
    (utf)

serialVersionUID:
    (long)

classDescFlags:
    (byte) *// Defined in Terminal Symbols and Constants*

fields:
    (short)<count> fieldDesc[count]

fieldDesc:
    primitiveDesc
    objectDesc

primitiveDesc:
    prim_typecode fieldName

objectDesc:
    obj_typecode fieldName className1

fieldName:
    (utf)

className1:
    (String)object *// String containing the field's type*

classAnnotation:
    endBlockData
    contents endBlockData *// contents written by annotateClass*

prim_typecode:
    `'B'` *// byte*
    `'C'` *// char*
    `'D'` *// double*
    `'F'` *// float*
    `'I'` *// integer*
    `'J'` *// long*
    `'S'` *// short*
    `'Z'` *// boolean*

obj_typecode:
    `'['` *// array*
    `'L'` *// object*

newArray:
    `TC_ARRAY` *classDesc newHandle (int)<size> values[size]*

newObject:
    `TC_OBJECT` *classDesc newHandle classdata[]// data for each class*

classdata:
    nowrclass *// SC_WRRD_METHOD & !classDescFlags*
    wrclass objectAnnotation *// SC_WRRD_METHOD & classDescFlags*

nowrclass:
    values *// fields in order of class descriptor*

wrclass:
    nowrclass

objectAnnotation:
    endBlockData
    contents endBlockData *// contents written by writeObject*

blockdata:
    `TC_BLOCKDATA` *(unsigned byte)<size> (byte)[size]*

blockdatalong:
    `TC_BLOCKDATALONG` *(int)<size> (byte)[size]*

endBlockData:
    `TC_ENDBLOCKDATA`

newString:
    `TC_STRING` *(utf)*

prevObject:
    `TC_REFERENCE` *(int)handle*

nullReference:
    `TC_NULL`

exception:
    `TC_EXCEPTION` *reset (Throwable)object reset*

magic:
    `STREAM_MAGIC`

version:
    `STREAM_VERSION`

values: *// The size and types are described by the*
// classDesc for the current object

newHandle: *// The next number in sequence is assigned*
// to the object being serialized or deserialized

reset: *// The set of known objects is discarded*
// so the objects of the exception do not
// overlap with the previously sent objects or
// with objects that may be sent after the
// exception

6.3.2 *Terminal Symbols and Constants*

The following symbols in java.io.ObjectStreamConstants define the terminal and constant values expected in a stream.

```
final static short STREAM_MAGIC = (short)0xaced;
final static short STREAM_VERSION = 5;
final static byte TC_NULL = (byte)0x70;
final static byte TC_REFERENCE = (byte)0x71;
final static byte TC_CLASSDESC = (byte)0x72;
final static byte TC_OBJECT = (byte)0x73;
final static byte TC_STRING = (byte)0x74;
final static byte TC_ARRAY = (byte)0x75;
final static byte TC_CLASS = (byte)0x76;
final static byte TC_BLOCKDATA = (byte)0x77;
final static byte TC_ENDBLOCKDATA = (byte)0x78;
final static byte TC_RESET = (byte)0x79;
final static byte TC_BLOCKDATALONG = (byte)0x7A;
final static byte TC_EXCEPTION = (byte)0x7B;
final static  intbaseWireHandle = 0x7E0000;
```

The flag byte classDescFlags may include values of

```
final static byte SC_WRITE_METHOD = 0x01;
final static byte SC_SERIALIZABLE = 0x02;
final static byte SC_EXTERNALIZABLE = 0x04;
```

The flag SC_WRITE_METHOD is set if the class writing the stream had a writeObject method that may have written additional data to the stream. In this case a TC_ENDBLOCKDATA marker is always expected to terminate the data for that class.

The flag SC_SERIALIZABLE is set if the class that wrote the stream extended `java.io.Serializable` but not `java.io.Externalizable`, the class reading the stream must also extend `java.io.Serializabl` and the default serialization mechanism is to be used.

The flag SC_EXTERNALIZABLE is set if the class that wrote the stream extended `java.io.Externalizable`, the class reading the data must also extend Externalizable and the data will be read using it's writeExternal and readExternal methods.

Example

Consider the case of an original class and two instances in a linked list:

```
class List implements java.io.Serializable {
    int value;
    List next;
    public static void main(String[] args) {
        try {
            List list1 = new List();
            List list2 = new List();
            list1.value = 17;
            list1.next = list2;
            list2.value = 19;
            list2.next = null;

            ByteArrayOutputStream o = new ByteArrayOutputStream();
            ObjectOutputStream out = new ObjectOutputStream(o);
            out.writeObject(list1);
            out.writeObject(list2);
            out.flush();
            ...
        } catch (Exception ex) {
            ex.printStackTrace();
        }
    }
}
```

The resulting stream contains:

```
00: ac ed 00 05 73 72 00 04 4c 69 73 74 69 c8 8a 15 >....sr..Listi...<
10: 40 16 ae 68 02 00 02 49 00 05 76 61 6c 75 65 4c >Z......I..valueL<
20: 00 04 6e 65 78 74 74 00 06 4c 4c 69 73 74 3b 78 >..nextt..LList;x<
30: 70 00 00 00 11 73 71 00 7e 00 00 00 00 00 13 70 >p....sq.~......p<
40: 71 00 7e 00 03                                  >q.~..<
```

Security in Object Serialization A

Topics:

- Overview
- Design Goals
- Using transient to Protect Important System Resources
- Writing Class-Specific Serializing Methods
- Encrypting a Bytestream

A.1 Overview

The object serialization system allows a bytestream to be produced from a graph of objects, sent out of the Java environment (either saved to disk or sent over the network) and then used to recreate an equivalent set of new objects with the same state.

What happens to the state of the objects outside of the environment is outside of the control of the Java system (by definition), and therefore is outside the control of the security provided by the system. The question then arises, once an object has been serialized, can the resulting byte array be examined and changed, perhaps injecting viruses into Java programs? The intent of this section is to address these security concerns.

A.2 Design Goals

The goal for object serialization is to be as simple as possible and yet still be consistent with known security restrictions; the simpler the system is, the more likely it is to be secure. The following points summarize how security in object serialization has been implemented:

- Only objects implementing the java.io.Serializable or java.io.Externalizable interfaces can be serialized. there are mechanisms for not serializing certain fields and certain classes.
- The serialization package cannot be used to recreate the *same* object, and no object is ever overwritten by a deserialize operation. All that can be done with the serialization package is to create *new* objects, initialized in a particular fashion.
- While deserializing an object might cause code for the class of the object to be loaded, that code loading is protected by all of the usual Java code verification and security management guarantees. Classes loaded because of deserialization are no more or less secure than those loaded in any other fashion.
- Externalizable objects expose themselves to being overwritten because the readExternal method is public.

A.3 Using transient to Protect Important System Resources

Direct handles to system resources, such as file handles, are the kind of information that is relative to an address space and should not be written out as part of an object's persistent state. Therefore, fields that contain this kind of information should be declared `transient`, which prevents them from being serialized. Note that this is not a new or overloaded meaning for the `transient` keyword.

If a resource, like a file handle, was not declared `transient`, the object could be altered while in its serialized state, enabling it to have improper access to resources after it is deserialized.

A.4 Writing Class-Specific Serializing Methods

To guarantee that a deserialized object does not have state which violates some set of invariants that need to be guaranteed, a class can define its own serializing and deserializing methods. If there is some set of invariants that need to be maintained between the data members of a class, only the class can know about these invariants, and it is up to the class writer to provide a deserialization method that checks these invariants.

This is important even if you are not worried about security; it is possible that disk files can be corrupted and serialized data be invalid. So checking such invariants is more than just a security measure; it is a validity measure. However, the only place it can be done is in the code for the particular class, since there is no way the serialization package can determine what invariants should be maintained or checked.

A.5 Encrypting a Bytestream

Another way of protecting a bytestream outside the Java virtual machine is to encrypt the stream produced by the serialization package. Encrypting the bytestream prevents the decoding and the reading of a serialized object’s private state.

The implementation allows encryption, both by allowing the classes to have their own special methods for serialization / deserialization and by using the stream abstraction for serialization, so the output can be fed into some other stream or filter.

Exceptions In Object Serialization B

All exceptions thrown by serialization classes are subclasses of `ObjectStreamException` which is a subclass of `IOException`.

Exception	Description
`ObjectStreamException`	Superclass of all serialization exceptions.
`InvalidClassException`	Thrown when a class cannot be used to restore objects for any of these reasons: • The class does not match the serial version of the class in the stream. • The class contains fields with invalid primitive data types. • The class is not public; the class does not have an accessible no-arg constructor.
`NotSerializableException`	Thrown by a `readObject` or `writeObject` method to terminate serialization or deserialization.
`StreamCorruptedException`	Thrown when the stream header is invalid or when control information in the stream is not found or found to be invalid.
`NotActiveException`	Thrown if `registerValidation` is not called during `readObject`.

Exception	Description
`InvalidObjectException`	Thrown when a restored object cannot be made valid.
`OptionalDataException`	Thrown by readObject when there is primitive data in the stream and an object is expected. The length field of the exception indicates the number of bytes that are available in the current block.
`WriteAbortedException`	Thrown when reading a stream terminated by an exception that occurred while the stream was being written.

Example of Serializable Fields C

Topics:

- Example Alternate Implementation of java.lang.File

C.1 Example Alternate Implementation of java.lang.File

Here's a brief example of how an existing class could be specified and implemented to inter-operate with the existing implementation but without requiring the same assumptions about the representation of the file name as a String.

The system class java.lang.File represents a filename and has methods for parsing, manipulating files and directories by name. It has a single private field that contains the current file name. The semantics of the methods that parse paths depend on the current path separator which is held in a static field. This path separator is part of the persistent state of a file so that file name can be adjusted when read.

The persistent state of a File object is defined as the persistent fields and the sequence of data values for the file. In this case there is one of each.

```
Serializable Fields:
    String path;   // path name with embedded separators
Serializable Data:
    char           // path name separator for path name
```

An alternate implementation might be defined as follows:

```
class File implements java.io.Serializable {
    ...
    private String[] pathcomponents;
    ...
    private void writeObject(ObjectOutputStream s)
        throws IOException
    {
        ObjectOutputStream.PutField fields = s.putFields();
        StringBuffer str = new StringBuffer();
        for(int i = 0; i < pathcomponents; i++) {
            str.append(separator);
            str.append(pathcomponents[i]);
        }
        fields.put("path", str.toString());
        s.writeFields();
        s.writeChar(separatorChar); // Add the separator character
    }
    ...
    private void readObject(ObjectInputStream s)
        throws IOException
    {
        ObjectInputStream.GetField fields = s.readFields();
        String path = (String)fields.get("path", null);
        ...
        char sep = s.readChar(); // read the previous separator char

        // parse path into components using the separator
        // and store into pathcomponents array.
    }

    // Define persistent fields with the ObjectStreamClass
    static final ObjectStreamField[] serialPersistentFields = {
            new ObjectStreamField("path", String.class)
    };

}
```