```
        ServiceRegistrar[] regs = ev.getRegistrars();
        for (int i = 0; i < regs.length; i++)
            registrars.remove(regs[i]);
        notifyAll(); // notify waiters that the list has changed
    }
```

Each invocation of `discovered` represents one or more newly discovered lookup services. Our implementation gets the array of `ServiceRegistrar` objects (the lookup service's primary interface) and adds each to the list of known registrars. When it is complete, it invokes `notifyAll` in case `searchDiscovered` is blocked waiting for the list to have some elements. Our `discarded` implementation removes elements from the list.

The `searchDiscovered` method invoked by `execute` loops checking out members of that list until it finds a matching service or until `MAX_WAIT` milliseconds have passed:

```
    private List registrars = new LinkedList();

    private final static int MAX_WAIT = 5000;   // five seconds

    private synchronized void searchDiscovered()
        throws Exception
    {
        ServiceTemplate serviceTmpl = buildTmpl(typeArgs);

        // Loop searching in discovered lookup services
        long end = System.currentTimeMillis() + MAX_WAIT;
        for (;;) {
            // wait until a lookup is discovered or time expires
            long timeLeft = end - System.currentTimeMillis();
            while (timeLeft > 0 && registrars.isEmpty()) {
                wait(timeLeft);
                timeLeft = end - System.currentTimeMillis();
            }
            if (timeLeft <= 0)
                break;

            // Check out the next lookup service
            ServiceRegistrar reg =
                (ServiceRegistrar)registrars.remove(0);
            try {
                MessageStream stream =
```

```
                (MessageStream)reg.lookup(serviceTmpl);
            if (stream != null) {
                readStream(stream);
                return;
            }
        } catch (RemoteException e) {
            continue;               // skip on to next
        }
    }
    System.err.println("No service found");
    System.exit(1);          // nothing happened in time
}
```

First the method uses the command line arguments to build up a template. It then starts looping. Each time through the loop the list of registrars is checked. If it is empty, we wait until either the remaining time expires or the list ceases to be empty. During the invocation of `wait` the `discovered` method can be invoked by `LookupDiscovery` in its thread, adding registrars to the list. When registrars are added, the `notifyAll` in the `discovered` method will allow the `wait` in `searchDiscovered` to return. The code in `searchDiscovered` then takes the first element from the list and asks it to look up a service that matches our template. If it finds one, it asks `readStream` to try and read messages from the stream (you will see `readStream` shortly).

If `readStream` executes successfully, `searchDiscovered` will return, which signals successful execution. If `searchDiscovered` does not find a readable stream within the allotted time, it prints out an error message and exits with a non-zero status, indicating failure of the command.

The `buildTmpl` method creates the `net.jini.lookup.ServiceTemplate` object that is passed to the lookup service's `lookup` method. Let's look at how the template is built:

```
private ServiceTemplate buildTmpl(String[] typeNames)
    throws ClassNotFoundException, IllegalAccessException,
           InstantiationException, NoSuchMethodException,
           InvocationTargetException
{
    Set typeSet = new HashSet();     // service types
    Set attrSet = new HashSet();     // attribute objects

    // MessageStream class is always required
    typeSet.add(MessageStream.class);
```

```
        for (int i = 0; i < typeNames.length; i++) {
            // break the type name up into name and argument
            StringTokenizer tokens =    // breaks up string
                new StringTokenizer(typeNames[i], ":");
            String typeName = tokens.nextToken();
            String arg = null;          // string argument
            if (tokens.hasMoreTokens())
                arg = tokens.nextToken();
            Class cl = Class.forName(typeName);

            // test if it is a type of Entry (an attribute)
            if (Entry.class.isAssignableFrom(cl))
                attrSet.add(attribute(cl, arg));
            else
                typeSet.add(cl);
        }

        // create the arrays from the sets
        Entry[] attrs = (Entry[])
            attrSet.toArray(new Entry[attrSet.size()]);
        Class[] types = (Class[])
            typeSet.toArray(new Class[typeSet.size()]);

        return new ServiceTemplate(null, types, attrs);
    }
```

The `buildTmpl` method loops through the type arguments given on the command line. The arguments can be either a type name or, in the case of attributes, a type name followed by a `String` argument to pass to the constructor, of the form *`type`*`(`*`arg`*`)`. The first part of the loop takes the name and checks to see whether it has an open parenthesis. If it does, it strips any closing parenthesis and remembers the argument in the variable `arg`, which is otherwise `null`. Once any argument has been stripped off from the class name in `cName`, we translate the name into a `Class` object for the type. If the type is assignable to `Entry` it is an attribute, and so an object is created of that attribute type, using `arg` if it was present—the method `attribute` (not shown) does this work. If it is not assignable to `Entry`, it must be a service type, and so we add its type to the types the service must support. When the loop is finished, `typeSet` contains all the required service types and `attrSet` contains all the required attribute templates. We then create appropriate arrays from the contents of these sets and pass the arrays to the

ServiceTemplate constructor (the first null argument would be the service ID if we needed to match on a specific one).

As you have seen, when searchDiscovered finds a matching service, it tries to read the stream by invoking the readStream method:

```
private final static int MAX_RETRIES = 5;

public void readStream(MessageStream stream)
    throws RemoteException
{
    int errorCount = 0;      // # of errors seen this message
    int msgNum = 0;          // # of messages
    while (msgNum < count) {
        try {
            Object msg = stream.nextMessage();
            printMessage(msgNum, msg);
            msgNum++;                // successful read
            errorCount = 0;          // clear error count
        } catch (EOFException e) {
            System.out.println("---EOF---");
            break;
        } catch (RemoteException e) {
            e.printStackTrace();
            if (++errorCount > MAX_RETRIES) {
                if (msgNum == 0)     // got no messages
                    throw e;
                else {
                    System.err.println("too many errors");
                    System.exit(1);
                }
            }
            try {
                Thread.sleep(1000); // wait 1 second, retry
            } catch (InterruptedException ie) {
                System.err.println("---Interrupted---");
                System.exit(1);
            }
        }
    }
}
```

```
public void printMessage(int msgNum, Object msg) {
    if (msgNum > 0) // print separator
        System.out.println("---");
    System.out.println(msg);
}
```

The `readStream` method will try to read the number of messages desired. If `readStream` gets a `RemoteException`, it retries up to `MAX_RETRIES` times, waiting one second (1,000 milliseconds) between each try. If it fails to read even a single message it throws `RemoteException`, letting the loop in `searchDiscovered` continue looking for a usable stream. If it reads at least one message, it prints out its failure and exits, so that the user will not see some messages from one stream and a few more from the next one should a failure occur before the desired number of messages are read.

2.3 In Conclusion

Let us revisit the example execution of `StreamReader` from page 21. If you use that command line, the client will look for a `fortune.FortuneStream` service (an interface that we will define in the next section) with an attribute that is of type `fortune.FortuneTheme` created with the string `"General"`. This search will be conducted in lookup services that manage the public group. If any such lookups are found, the `LookupDiscovery` utility object we created in `execute` will invoke our `discovered` method, which adds it to the list of known lookup services. The `searchDiscovered` method looks in each discovered lookup service for a matching stream, and invokes `readStream` to read one message from a stream and print it out. When all this is complete, you should (assuming there is an available matching fortune cookie service) have a fortune cookie message on your screen.

Again, notice that this client can work with any `MessageStream` service. The user specifies which particular service to use by the service's type and any desired attributes. Each message stream service implementation provides a proxy that works properly for the service's needs. The `StreamReader` client you have seen will print messages from any implementation of a message stream, using the proxy as an adaptor from the service definition (`MessageStream`) to the particular service that was matched (`FortuneStream`, `ChatStream`, or whatever). You will next see how to write two different message stream services that can be used by `StreamReader` or any other `MessageStream` client.

3 Writing a Service

Dare to be naïve.
—R. Buckminster Fuller

THE `MessageStream` interface is designed to work for many purposes. We will now show you two example implementations of a message stream service. The first will be a `FortuneStream` subinterface that returns randomly selected "fortune cookie" messages. The second will provide a chat stream that records a history of a conversation among several speakers. First, though, we must talk about what it means to be a Jini service.

A service differs from a client in that a service registers a proxy object with a lookup service, thereby advertising its services—the interfaces and classes that make up its type. A client finds one or more services in a lookup service that it wants to use. Of course, a service might rely on other services and therefore be both a service and a client of those other services.

3.1 Good Lookup Citizenship

To be a usable service, the service implementation must register with appropriate lookup services. In other words, it must be a good *lookup citizen,* which means:

- When starting, discovering lookup services of appropriate groups and registering with any that reply
- When running, listening for lookup service "here I am" messages and, after filtering by group, registering with any new ones
- Remembering its join configuration—the list of groups it should join and the lookup locators for specific lookup services
- Remembering all attributes stamped on it and informing all lookups of changes in those attributes
- Maintaining all leases in lookup services for as long as the service is available

- Remembering the service ID assigned to the service by the first lookup service, so that all registrations of the same service, no matter when made, will be under the same service ID

3.1.1 The JoinManager Utility

Although the work for these tasks is not a vast amount of labor, it is also more than trivial. Services may provide these behaviors in a number of ways. The utility class com.sun.jini.lookup.JoinManager (part of the first release of the Jini Technology Software Kit) handles most of these tasks on a service's behalf, except for the management of storage for attributes and service IDs which the service implementation must provide.

Our example service implementations use JoinManager to manage lookup membership. You are not required to do so—you might find other mechanisms more to your liking, or you might want or need to invent your own.

3.2 The FortuneStream Service

Our first example service will extend MessageStream to provide a "fortune cookie" service, which returns a randomly selected message from a set of messages. Typically, such messages are intended to be amusing, informative, or inspiring. The collections are often broken up into various themes. The most general theme is to be amusing, but collections drawn from particular television shows, movie types, comic strips, or inspirational speakers also exist. Our FortuneStream interface looks like this:

```
package fortune;

interface FortuneStream extends MessageStream, Remote {
    String getTheme() throws RemoteException;
}
```

As with all the classes defined in this example, this interface is in the fortune package. The FortuneStream interface extends the MessageStream interface because it is a particular kind of message stream. FortuneStream extends the interface Remote, which indicates to RMI that objects implementing the FortuneStream interface are accessible remotely using RMI.

The getTheme method returns the theme of the particular stream. As you will see, the theme is primarily reflected as an attribute on the service so that a user can

select a FortuneStream with a theme to their liking. The getTheme method is added here to allow queries after a stream has been selected.

Each fortune stream's theme is represented both in the interface via the getTheme method and as an attribute in the lookup service to help users find a stream that gives the types of fortunes they want:

```
public class FortuneTheme extends AbstractEntry
    implements ServiceControlled
{
    public String theme;

    public FortuneTheme() { }

    public FortuneTheme(String theme) {
        this.theme = theme;
    }
}
```

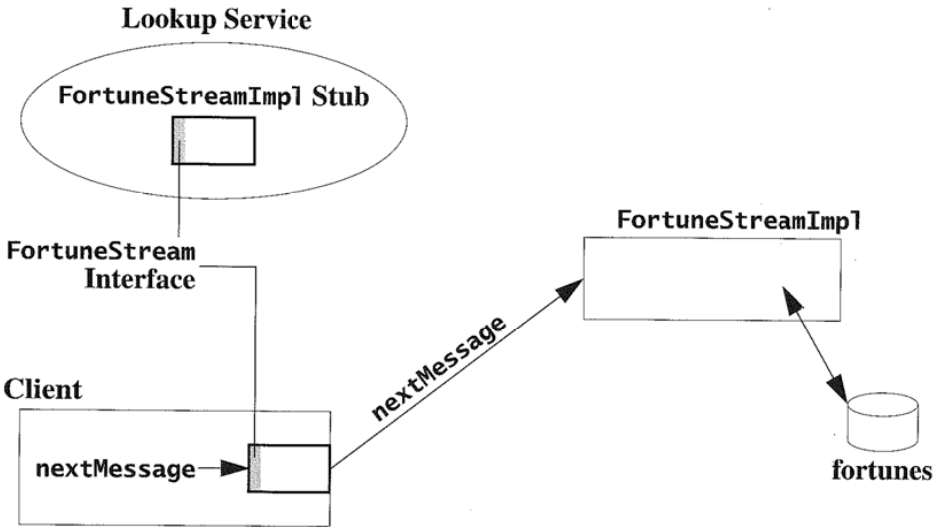
The FortuneTheme attribute is part of the service definition, and is independent of our particular implementation of FortuneStream—a different implementation of FortuneStream would use the same attribute type.

The FortuneTheme attribute fits the requirements for all entries: It has public object-typed fields and a public no-arg constructor. It adds another constructor for convenience. Each FortuneStream service expresses its theme as both a FortuneTheme attribute and a value returned by the FortuneStream class's getTheme method. This redundancy has a purpose—it allows a client of a fortune stream to be written independently of the code that finds the service. For example, it would be possible for a fortune stream client to display the theme of a stream it obtained without using a FortuneTheme attribute.

FortuneTheme extends net.jini.entry.AbstractEntry, which implements Entry and provides useful semantics for entry classes, specifically in defining semantics for the equals, hashCode, and toString methods. Using AbstractEntry is optional—we use it for convenience. FortuneTheme also implements ServiceControlled, which marks the attribute as one that is controlled by the service itself, as opposed to one placed on the service by an administrator. Any tools that let administrators modify attributes should not let ServiceControlled attributes be changed. Only attributes that are exclusively controlled by the service itself should be marked with this interface.

3.2.1 The Implementation Design

The overall fortune service implementation looks like this:



The running service is composed of three parts:

- A database of fortunes, consisting of the collection of fortunes and position offsets for the start of each fortune. The position information is built by reading the fortune collection.
- A server that runs on the same system that contains the database. This server reads the database, choosing a fortune at random each time it needs to return the next message.
- A proxy for the service. This proxy is the object installed in the lookup service to represent the fortune stream service in the Jini system. In this particular case, the proxy is simply a Java RMI stub that passes method invocations directly to the remote server.

3.2.2 Creating the Service

Our `FortuneStream` implementation is provided by the `FortuneStreamImpl` class, which is a Java RMI remote object. Requests for the next message in the

stream will be sent directly to this remote object that will return a random fortune selected from its database.

The fortune database lives in a particular directory, which is set up by a separate `FortuneAdmin` program that creates the database of fortunes from the raw data. The `FortuneAdmin` program is run before the service is created to set up the database a running `FortuneStream` service will use. When the database is ready, you will run `FortuneStreamImpl` to get the service going.

The `FortuneStreamAdmin` command line looks like this:

```
java [java-options] fortune.FortuneAdmin database-dir
```

The *`database-dir`* parameter is the directory in which the database lives. This directory must initially contain a file named `fortunes`, which contains fortunes separated by lines that start with %%, as in:

```
"As an adolescent I aspired to lasting fame, I craved
factual certainty, and I thirsted for a meaningful vision
of human life -- so I became a scientist.  This is like
becoming an archbishop so you can meet girls."
                -- Matt Cartmill
%%
As far as the laws of mathematics refer to reality, they
are not certain, and as far as they are certain, they do
not refer to reality.
                -- Albert Einstein
%%
As far as we know, our computer has never had an undetected
error.
```

The `FortuneAdmin` program creates the position database in that directory if it does not already exist or if it is older than the fortune database file. The position database is stored in a file named `pos`. A typical invocation might look like this:

```
java fortune.FortuneAdmin /files/fortunes/general
```

`FortuneAdmin` will look in the directory `/files/fortunes/general` for a `fortunes` file and will read it to create a `/files/fortunes/general/pos` file.[1] The source to `FortuneAdmin` just manipulates files, so we will not describe it here.

[1] On a Windows system it would be something like `C:\files\fortunes\general`; on a MacOS system it would be more like `Hard Disk:fortunes:general`. We use POSIX-style paths in this book.

3.2.3 The Running Service

The fortune service is started by the `main` method of `FortuneStreamImpl`. The command line looks like this:

```
java [java-options] fortune.FortuneStreamImpl database-dir
     groups|lookup-url theme
```

The *java-options* must include a security policy file and the RMI server codebase URL. The *database-dir* should be the directory given to `FortuneAdmin`. The running service will join lookup services with the given groups or the specified lookup service, with a `FortuneTheme` attribute with the given name. A typical invocation might look like this:

```
java -Djava.security.policy=/file/policies/policy
     -Djava.rmi.server.codebase=http://server/fortune-dl.jar
     fortune.FortuneStreamImpl /files/fortunes/general ""
     General
```

Our implementation of the fortune stream service executes in the virtual machine this command creates, and therefore lives only as long as that virtual machine is running. Later you will see how to write services that live longer than the life of a single virtual machine.

Here is the code that starts the service running:

```
public class FortuneStreamImpl implements FortuneStream {
    private String[] groups = new String[0];
    private String lookupURL;
    private String dir;
    private String theme;
    private Random random = new Random();
    private long[] positions;
    private RandomAccessFile fortunes;
    private JoinManager joinMgr;

    public static void main(String[] args) throws Exception
    {
        FortuneStreamImpl f = new FortuneStreamImpl(args);
        f.execute();
    }

    // ...
}
```

The main method creates a FortuneStreamImpl object, whose constructor initializes the groups, lookupURL, dir, theme, and initialAttrs fields from the command line arguments. The rest of the work is done in the object's execute method:

```
private void execute() throws IOException {
    System.setSecurityManager(new RMISecurityManager());
    UnicastRemoteObject.exportObject(this);

    // Set up the fortune database
    setupFortunes();

    // set our FortuneTheme attribute
    FortuneTheme themeAttr = new FortuneTheme(theme);
    Entry[] initialAttrs = new Entry[] { themeAttr };

    LookupLocator[] locators = null;
    if (lookupURL != null) {
        LookupLocator loc = new LookupLocator(lookupURL);
        locators = new LookupLocator[] { loc };
    }
    joinMgr = new JoinManager(this, initialAttrs,
        groups, locators, null, null);
}
```

First execute sets a security manager, as you saw done in the client. Next we export the FortuneStreamImpl object as an RMI object. Specifically, we export the object as a UnicastRemoteObject, which means that as long as this virtual machine is running, the object will be usable remotely. When the virtual machine dies, the remote object that it represents dies too. RMI provides a mechanism for activatable servers that will be restarted when necessary; most Jini software services are actually best written as activatable services. You will see an activatable service in the next example.

We then call setupFortunes to initialize this server's use of its fortune database. We do not show the code for that here because it is not relevant to the example; setupFortunes sets the positions and fortunes fields that are used by the implementation of nextMessage.

The next two lines create the service-owned FortuneTheme attribute that will identify the theme of this fortune stream in the lookup service. Then we create the JoinManager, which manages all the interactions with lookup services in the net-

work. To do so, you must tell the JoinManager several things. The constructor used by execute (there are others) takes the following parameters:

- The proxy object for the service. We use this because RMI will convert this to the remote stub for the FortuneStreamImpl object, which is what we want in this case. (FortuneStreamImpl implements a Remote interface—FortuneStream extends Remote—so when a FortuneStreamImpl object is marshalled, it gets replaced by its stub.)
- An Entry array that is the initial set of attributes to be associated with the service. Here we provide an array that contains only our FortuneTheme.
- A String array that is the initial set of lookup groups. In our case this will be taken from the command line and be either an array of the groups specified or an empty array if a URL was specified instead.
- A net.jini.discovery.LookupLocator array. LookupLocator is a class that locates lookup services by URL. The array has a LookupLocator for the URL specified, or null if groups were specified instead.
- A com.sun.jini.lookup.ServiceIDListener object. The interface ServiceIDListener provides a method to be called when the service's ID is assigned. This is a hook that lets the service store its ID persistently if it needs to. Since our particular service does not outlive its virtual machine there is no need to store the ID. We therefore pass null, meaning the service will not be notified. (The next example will show this feature in action.)
- A com.sun.jini.lease.LeaseRenewalManager object to manage renewing the leases returned by lookup services. We use null, which tells the JoinManager to create and use its own LeaseRenewalManager. In another situation (for example, exporting multiple services in the same virtual machine) you might want to specify this parameter (in our example, by using the same object in each service's JoinManager to reduce the number of lease manager objects).

When execute is finished we have a service ready to receive messages and, by virtue of its JoinManager, the service registers with all appropriate lookup services and will continue to register appropriately so as long as the service is running. In other words, at this point we have a running Jini service. When execute returns, so does main. RMI will keep the virtual machine running in another thread, waiting to receive requests.

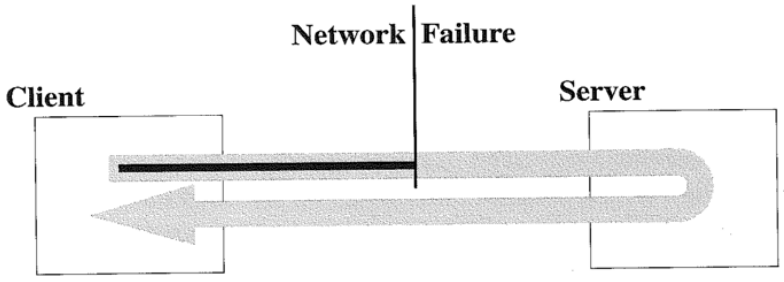
The rest of the code implements nextMessage by picking a random fortune and getTheme by returning the theme field. Again, since these parts show no Jini service code, we leave them to Appendix B.

3.3 The `ChatStream` Service

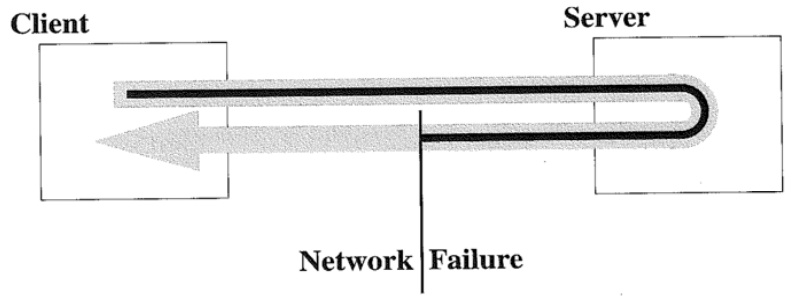
For a more involved example, we provide a message stream whose messages are the utterances of people in a conversation, such as in a chat room. In this case there must be an order to the messages. The fortune stream was picking a message at random, so any message was as good as any other. For a conversation clients will want the messages in the order in which they were spoken.

Consider what happens when `nextMessage` is invoked and a network failure occurs. Either of two interesting situations may have occurred:

- The network failure prevented the request from getting to the remove server:



- The request made it to the remote server, but the network failure blocked the response:



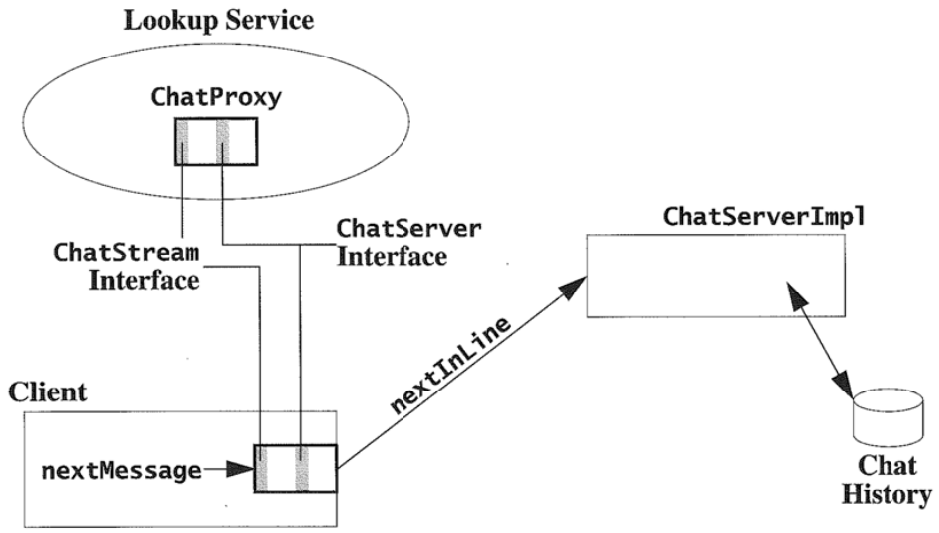
These are very different situations, but the client has no possible way to distinguish between the two cases. If the current position in the stream for each client was stored at the server, the next call to `nextMessage` by the client could return either message 29 (in the first case, in which the server never got the original,

failed request) or message 30 (in the second case, in which the server thought it had returned message 29 but it didn't get to the client).

The `nextMessage` method of `MessageStream` is documented to be *idempotent*, that is, it can be re-invoked after an error to get the same result that would have come had there been no error. For `FortuneStream` idempotency was easy—the fortune was picked at random, so the next message will be equally random, no matter which of the failure situations actually happened.

But for `ChatStream`, this is not good enough. If the proxy was designed naïvely, an utterance might be skipped, and the utterance skipped could be the most important one of the discussion. If a call to `nextMessage` throws an exception because of a communication failure, the next time the client invokes `nextMessage` it should get the same message from the list that it would have gotten on the previous call had there been no failure. Suppose, for example, that we used the same strategy for a `ChatStream` proxy that we did for the `FortuneStreamImpl` proxy—an RMI stub. Then, after getting message number 28 from the server, a network exception is thrown when trying to get message number 29.

So the proxy object registered with lookup services for a `ChatStream` cannot be a simple RMI stub. It must contain enough state to help the service return the right message even in the face of a network failure. To accomplish this, the proxy object will implement the `ChatStream` interface for the client to use, but the server will have an implementation-specific interface that the proxy uses to tell the server which message should be next. It will look like this:



The proxy will use its internal stored state (the number of the last message successfully retrieved) as an argument to the `nextInLine` method of the `ChatServer` interface. That method is hidden from the client, and different implementations of the `ChatStream` service are welcome to use a different mechanism so long as they maintain the idempotency of `nextMessage`.

The `ChatStream` interface—the public service interface that the clients use—inherits `nextMessage` from the `MessageStream` interfaces, and adds a few methods of its own:

```
package chat;

public interface ChatStream extends MessageStream {
    public void add(String speaker, String[] message)
        throws RemoteException;
    public String getSubject() throws RemoteException;
    public String[] getSpeakers() throws RemoteException;
}
```

Like all the code in this example this class is part of the `chat` package. The `add` method lets people add new messages to the discussion. The `speaker` parameter is the name of the speaker; `message` is what they say. You can ask a `ChatStream` what the subject of the chat is, and for the names of the people who have spoken. These last two things are also stored as attributes of the service so they can be used to look up streams.

When a message is read, it will be a `ChatMessage` object:

```
public class ChatMessage implements Serializable {
    private String speaker;
    private String[] content;

    public ChatMessage(String speaker, String[] content) {
        this.speaker = speaker;
        this.content = content;
    }

    public String getSpeaker() { return speaker; }

    public String[] getContent() { return content; }

    public String toString() {
        StringBuffer buf = new StringBuffer(speaker);
        buf.append(": ");
```

```
            for (int i = 0; i < content.length; i++)
                buf.append(content[i]).append('\n');
            buf.setLength(buf.length() - 1); // strip newline
            return buf.toString();
        }
    }
```

`ChatMessage` has methods to pick out the pieces of the message—its speaker and the content—and its `toString` method prints out a reasonable default representation of the message.

When looking for a `ChatStream`, a user might want to choose the subject, so we define a `ChatSubject` attribute type:

```
public class ChatSubject extends AbstractEntry
    implements ServiceControlled
{
    public String subject;

    public ChatSubject() { }

    public ChatSubject(String subject) {
        this.subject = subject;
    }
}
```

A `ChatStream` service should mark itself as being on a certain subject—the same subject that `getSubject` would return. A user might also want to search for chats that had particular speakers, so a stream should also mark itself with a `ChatSpeaker` attribute for each speaker:

```
public class ChatSpeaker extends AbstractEntry
    implements ServiceControlled
{
    public String speaker;

    public ChatSpeaker() { }

    public ChatSpeaker(String speaker) {
        this.speaker = speaker;
    }
}
```

(Remember that we have chosen to use string-based attributes to simplify the examples in this text. Fields in attributes can be any serializable type, so when you design your own attributes, don't use the string-based nature of our examples with a requirement of attributes in general. Use the types you need, not just strings.)

3.3.1 "Service" versus "Server"

At this point it is important to discuss the difference between the word "service" and the word "server." A *service* is a logical notion that has at least one object—the object registered in the lookup service. It usually has other parts as well. Often at least one of those parts will be a *server*—a process running on a machine in the network.

Our fortune service is made up of a proxy object (the RMI stub), a fortune server (the `FortuneStreamImpl` object running on some host), and the underlying storage. A service may use one or more servers to provide its service. In both the fortune and chat examples, each service uses exactly one remote object, which in turn uses an underlying store. Other services might talk to no remote servers (doing all computation locally in the proxy) or several (combining the information from more than one server).

3.3.2 Creating the Service

As we stated before, the chat service's proxy (which runs on the client) needs to hold some state so that it can tell the server which message was last returned successfully. The communication between the proxy and the server must include this information. The `nextMessage` method has no way to impart that data, so the proxy will need a different way to talk to the server in order to pass it along. For this purpose the implementation of our service adds an internal, package-accessible interface:

```
interface ChatServer extends Remote {
    ChatMessage nextInLine(int lastIndex)
        throws EOFException, RemoteException;
    void add(String speaker, String[] msg)
        throws RemoteException;
    String getSubject() throws RemoteException;
    String[] getSpeakers() throws RemoteException;
}
```

The proxy will use the `nextInLine` method to get the message following the last successful one, which it represents by index. The message is returned to the client by the proxy's `nextMessage` method, and the new index is remembered for the

next invocation. The other methods do not require any different treatment from those in the ChatStream interface, and so they are declared identically.

The proxy implementation is pretty simple: The proxy object contains an RMI reference to the server that implements ChatServer and the index of the last successfully returned message:

```
class ChatProxy implements ChatStream, Serializable {
    private final ChatServer server;
    private int lastIndex = -1;
    private transient String subject;

    ChatProxy(ChatServer server) {
        this.server = server;
    }

    public synchronized Object nextMessage()
        throws RemoteException, EOFException
    {
        ChatMessage msg = server.nextInLine(lastIndex);
        lastIndex++;
        return msg;
    }

    public void add(String speaker, String[] msg)
        throws RemoteException
    {
        server.add(speaker, msg);
    }

    public synchronized String getSubject()
        throws RemoteException
    {
        if (subject == null)
            subject = server.getSubject();
        return subject;
    }

    public String[] getSpeakers() throws RemoteException {
        return server.getSpeakers();
    }
}
```

When the client invokes `nextMessage`, the proxy invokes the remote server's `nextInLine` method, passing in the `lastIndex` field. If `nextInLine` returns successfully, it increments its notion of the last message index and then returns the message. If instead `nextInLine` throws an exception, the code following the invocation will not be executed, leaving the value of `lastIndex` unchanged. So in our example, even if a network failure happens after the request reaches the server, the client will get an exception and so the next invocation of `nextMessage` by the client will cause a `nextInLine` to be sent that gets the same message again.[2]

The proxy's `add` and `getSpeakers` methods simply forward the request along to the remote server. The proxy's `getSubject` method uses the fact that the subject of a single `ChatStream` never changes—once the proxy gets the subject it can be remembered to avoid a round trip to the server to get it again. Here again the proxy adds value.

3.3.3 The Chat Server

Now let us look at the server side. Our chat server implementation is decidedly simple to keep the example focused on the Jini service. We will allow an administrator to create a new chat service, which means creating a remotely accessible `ChatServerImpl` object that implements the `ChatServer` interface. This object registers a `ChatProxy` object with the lookup service, giving it the appropriate `ChatSubject` attribute and (initially) no `ChatSpeaker` attributes. The `ChatProxy` object contains a reference to its `ChatServerImpl` object.

The `ChatServerImpl` object will be *activatable,* that is, it will use the RMI activation mechanism to ensure that it is always available, even if the system it is running on crashes and reboots. The fortune service you saw before lives only as long as its virtual machine. Should the machine on which it runs die, it will die too. This may be acceptable for some services, but not others. Many Jini services will need to be activatable, or use some other mechanism to outlast reboots.

This service will be activatable, but this is not the place for a full tutorial on writing activatable services. We will give an overview, point out the places in the code where activation is visible, and provide the full code in Appendix B.

Activation works by having an *activation system* that starts virtual machines for remotely accessible objects when needed. Each activatable object is part of an *activation group*—remotely accessible objects that are part of the same group will

[2] Note that the proxy's implementation of `nextMessage` is synchronized. This ensures that two threads in the same virtual machine invoking `nextMessage` at the same time on the same proxy object will not both use or modify `lastIndex` inconsistently.

always be activated in the same virtual machine, while objects that are in different groups will always be in different virtual machines.

An activatable object is created by registering it with the activation system, telling the system which group the object belongs to, providing a storage key that can be used by the object when it is activated to find its persistent state, and optionally a "keep active" flag. This registration returns a remote reference to a newly available remote object. The reference can be sent around the network like any other remote reference.

If the "keep active" flag is `true`, the activation system will always keep the object active when it can. For example, when a system is rebooted, the activation system will activate each "keep active" object. If the flag is `false`, the activation system will wait until it gets the first message for the object and then activate it. In our example we will set the "keep active" flag to be `true` so the active service can register with the lookup service and maintain its lease. Otherwise the service would be inactive, unable to renew its leases, and so would never be found by anyone looking for a chat stream.

Activation of an object is done via its *activation constructor*—a constructor with the following signature:

```
public ActivatableClass(ActivationID id,
                        MarshalledObject state)
{
    // ...
}
```

During activation the activation system first either creates a virtual machine to manage the group, or finds the existing virtual machine that is already doing so. It then has that virtual machine create a new local object of the correct class using its activation constructor.

An activatable class must extend `java.rmi.activation.Activatable`—in which case the activation constructor must invoke `super(id)`—or invoke the static method `java.rmi.activation.ActivatableObject.exportObject`. Either of these actions lets the activation system know that the object is ready to receive incoming messages.

Once the activation constructor returns, the activation system will tell clients of the remote object to talk directly to the running server object. This means that at most the first message from a client to an activatable object requires talking to the activation system (unless there is an intervening server crash). All subsequent requests go directly to the running service.

In our example we will provide a `ChatServerImpl` class that provides a `ChatStream` service by registration with the activation system. You create a new server with the following command:

```
java [java-options] chat.ChatServerAdmin directory subject
     [groups|lookup-url classpath codebase policy-file]
```

`ChatServerAdmin` is a class that creates an activatable `ChatServerImpl` object for the server. The *`java-options`* typically include the security policy file used during creation. The *`directory`* will define an activation group. If the directory does not exist it will be created; a new activation group will also be created and its information written into a file in that directory. If the directory does exist and contains such a file, that information will be used to place the new chat stream into the same activation group. A typical chat stream will not significantly occupy a single virtual machine, so grouping multiple activatable `ChatServerImpl` objects for different subjects into the same virtual machine will keep overall overhead low.

If you want to create a new activation group for the stream, you must give the last four parameters: the *`groups`* or *`lookup-url`* to specify the lookup services you want the chat registered with, and the *`classpath`*, *`codebase`*, and *`policy-file`* for the activated virtual machine. The classpath will be the one for the running server, the codebase will be where clients will download the remote parts of the service from, and the policy file will be the one used by the running server. This is different from the policy file provided in the *`java-options`*, which is the policy file used only during creation. The *`policy-file`* parameter defines the policy file that will be used by the activated virtual machine.

So a typical invocation to create a new chat stream in a new group would look like this:

```
java -Djava.security.policy=/policies/creation
     chat.ChatServerAdmin /files/chats/technical "Cats" ""
     /jars/chat.jar http://server/chat-dl.jar
     /policies/runtime
```

This invocation would create the `/files/chats/technical` directory (if necessary), create a new activation group, store the group information in it, and put the storage for the `"Cats"` chat in that directory. The service would register with the public group, `""`. The server would run using classes from `/jars/chat.jar`, clients would download code from the codebase `http://server/chat-dl.jar`, and the server's security policy file would be `/policies/runtime`. The subsequent command

```
java -Djava.security.policy=/policies/creation
     chat.ChatServerAdmin /files/chats/technical "Dogs"
```

would create a "Dogs" chat stream in the same activation group as the stream for the subject "Cats", and therefore with the same lookup group, classpath, codebase, and security policy because these are defined by the activation group—all objects sharing an activation group will, by virtue of sharing a single virtual machine, have the same lookup registration, classpath, codebase, and security policy.

Let us look at ChatServerAdmin.main:

```
public static void main(String[] args) throws Exception
{
    if (args.length != 2 && args.length != 6) {
        usage();            // print usage message
        System.exit(1);
    }

    File dir = new File(args[0]);
    String subject = args[1];

    ActivationGroupID group = null;
    if (args.length == 2)
        group = getGroup(dir);
    else {
        String[] groups = ParseUtil.parseGroups(args[2]);
        String lookupURL =
            (args[2].indexOf(':') > 0 ? args[2] : null);
        String classpath = args[3];
        String codebase = args[4];
        String policy = args[5];
        group = createGroup(dir, groups, lookupURL,
            classpath, codebase, policy);
    }

    File data = new File(dir, subject);
    MarshalledObject state = new MarshalledObject(data);
    ActivationDesc desc =
        new ActivationDesc(group, "chat.ChatServerImpl",
                           null, state, true);
    Remote newObj = Activatable.register(desc);
    ChatServer server = (ChatServer)newObj;
```

```
        String s = server.getSubject(); // force server up
        System.out.println("server created for " + s);
    }
```

The `main` method first figures out whether it is using an existing group or creating a new group, and gets the group accordingly. It then creates a `MarshalledObject` that contains the directory and subject; this `MarshalledObject` will be the one that is passed in to the activation constructor when each stream is activated, allowing it to recover its state, as you will see shortly.[3] With the group and startup information in hand, we can tell the activation system to register this new object. The `true` in the registration call is the "keep active" flag. We then invoke the `getSubject` method to force the chat stream to be active for the first time. Until this first call, the chat stream object will be inactive. Once `getSubject` forces the server to be active, it will start its discovery and registration.

This process of creation and subsequent activating is shown in Figure 3–1. When `main` invokes `createGroup`, the activation system remembers the group setup options. After `register`, the activation system has a record of a new object in that activation group. When `main` invokes `getSubject` on the newly registered stream, the activation system (1) starts up a new virtual machine using the settings given when the group was created; and then (2) tells the virtual machine (via a piece of its own code running in it) to create a new `ChatStreamImpl` object using its activation constructor, passing the persistent state `MarshalledObject` given to it when the object was registered. When the constructor invokes `exportObject`, the activation system views the object as ready for incoming messages. In the future, when the activation system starts up it will start up the object in the same way, but without requiring any method invocation to get things going.

The figure shows all this work being handled internally by the client's `ChatServerImpl` stub. A stub for an activatable object contains a direct reference to the remote service. When the stub is first used, it sets this reference by asking the activation system for a direct reference to the remote server. The activation system either activates the service to get a direct reference and then returns it or, if it is already active, simply returns the direct reference. The actual messages are sent directly to the service. Once the stub has a direct reference, it sends all future messages directly to the remote server without contacting the activation system.

The `createGroup` method creates the activation group, setting up the command line that will start the virtual machine to use the correct classpath, codebase,

[3] A `java.rmi.MarshalledObject` stores an object in the same way as it would be marshalled to be passed as an argument in an RMI method call. Its `get` method returns the unmarshalled object. The activation system uses a `MarshalledObject` for the persistence parameter because it does not use the object—it just holds on to it and passes it back—so it has no need to download any required code for the persistence parameter.

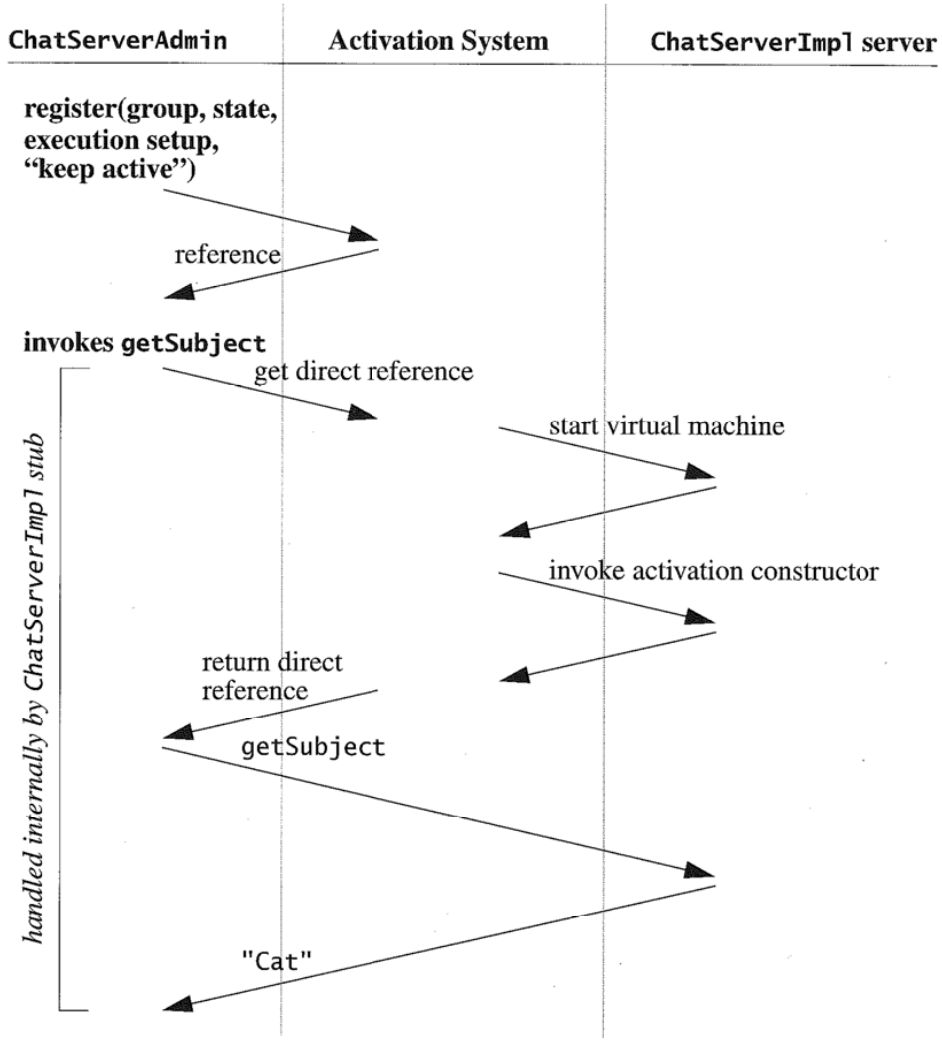


FIGURE 3–1: ***Registration and Activation in ChatAdmin***

and policy file. It then serializes the group descriptor into a file so that future creations that want to share it can find it, adding the lookup groups and URL to the file for the server to use. The `getGroup` method finds an existing group by opening up the directory's group description file and returning the deserialized `ActivationGroupID`. The details of this activation and file work are in the full code in Appendix B.

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When ChatServerAdmin.main invokes getSubject or when the activation system restarts, the ChatServerImpl class's activation constructor gets invoked to create the local object in the activated virtual machine:

```
public ChatServerImpl(ActivationID actID,
                      MarshalledObject state)
    throws IOException, ClassNotFoundException
{
    File dir = (File) state.get();
    store = new ChatStore(dir);
    ChatProxy proxy = new ChatProxy(this);

    LookupLocator[] locators = null;
    if (lookupURL != null) {
        LookupLocator loc = new LookupLocator(lookupURL);
        locators = new LookupLocator[] { loc };
    }
    joinMgr = new JoinManager(proxy, getAttrs(), groups,
        locators, store, renewer);
    Activatable.exportObject(this, actID, 0);
}
```

The activation constructor uses the state object stored by ChatServerAdmin to find the directory in which the chat record is stored and to find its record within the directory (by the subject name).

The ChatStore object manages the server's persistent storage. When the server is first activated, the Jini service ID has not yet been assigned, so we want to know when the ID gets assigned. The JoinManager constructor allows us to provide a com.sun.jini.lookup.ServiceIDListener object that will be told when the identifier is assigned. The ChatStore class is an inner class of ChatServerImpl that implements this interface, adding the ID to the persistent store for future use. The relevant part of ChatStore looks like this:

```
class ChatStore extends LogHandler
    implements ServiceIDListener
{
    //...
    public void serviceIDNotify(ServiceID serviceID) {
        try {
            log.update(serviceID);
        } catch (IOException e) {
            unexpectedException(e);
```

```
            }
            ChatServerImpl.this.serviceID = serviceID;
        }
    }
```

The `serviceIDNotify` method is invoked by the join manager when the service ID is first allocated. Our implementation stores it in the file system for future use. The `log` field and the `LogHandler` interface are part of a "reliable log" subsystem from the `com.sun.jini.reliableLog` package in the release of the Jini technology; the details are left for the full source in Appendix B.

3.3.4 Implementing `nextInLine`

The `nextInLine` method of the chat server takes the incoming message number, looks up the message associated with it, and returns it:

```
public synchronized ChatMessage nextInLine(int index) {
    try {
        int nextIndex = index + 1;
        while (nextIndex >= messages.size())
            wait();
        return (ChatMessage)messages.get(nextIndex);
    } catch (InterruptedException e) {
        unexpectedException(e);
        return null; // keeps the compiler happy
    }
}
```

If the next message isn't available yet, `nextInLine` waits until someone has put one in using `add`:

```
public synchronized void add(String speaker, String[] lines)
{
    ChatMessage msg = new ChatMessage(speaker, lines);
    store.add(msg);
    addSpeaker(speaker);
    messages.add(msg);
    notifyAll();
}

private synchronized void addSpeaker(String speaker) {
    if (speakers.contains(speaker))
```

```
            return;
        speakers.add(speaker);
        Entry speakerAttr = new ChatSpeaker(speaker);
        attrs.add(speakerAttr);
        joinMgr.addAttributes(new Entry[] { speakerAttr });
    }
```

When a new message is added, we create the `ChatMessage` object for the message and then store it in the log. We then add the speaker (`addSpeaker` ignores already known speakers), add the message to our in-memory list of messages, and notify any waiting `nextInLine` method that there is a new message to return.

If the speaker is a new one, `addSpeaker` creates a new `ChatSpeaker` attribute object and stamps it on itself by using the join manager's `addAttributes` method. The join manager will add this attribute to all current and future lookup service registrations.

We have not shown the `store.add` method because it consists only of file-system and data structure management, not Jini service implementation. The full code in Appendix B, of course, shows its implementation.

3.3.5 Notes on Improving `ChatServerImpl`

As shown `ChatServerImpl` works, but it does not scale to large systems well. Each client uses up a thread in the server virtual machine when `nextInLine` blocks waiting for a future message. If there are hundreds of observers of a discussion, the number of threads blocked in the server will also be hundreds as each client waits for its invocation of `nextInLine` to return. There are many possible solutions to this problem. The most interesting is to rewrite the proxy/server interaction to use event notification as described in the distributed event specification. The design would look something like this:

- The `nextInLine` method takes a `RemoteEventListener` object. When `nextInLine` has no message to return, it returns an event registration instead of a message.
- When a new message is added, all registered listeners are notified.
- A proxy that gets an event registration will renew the registration's lease until it receives notification from the server that a new message is available. It will then resume asking for the `nextInLine` until it is blocked again.

We leave an actual implementation of this as an exercise to the reader, as well as other things that could be done to improve the service, such as:

- Making add idempotent.
- Handling the results of system crashes that result in partial creation of the service. The activation constructor should detect such corrupt data and unregister itself.
- A way to mark a chat as being completed so that people can see a record of it without adding to it. This might require adding a new method or two in `ChatStream`.
- Administrative interfaces to allow users and administrators to add their own attributes to the service and to configure a running service as to which lookup groups and lookup URLs it will join. As examples, see the interface `net.jini.admin.JoinAdmin`.

Other improvements could be made as well. You might find it useful to get the existing source compiled and running, and then try adding one or more improvements to it to get a better feel for Jini service implementation.

3.3.6 The Clients

When a chat stream service is created, we will have a service that can be used anywhere in the network that can reach the relevant lookup services. The generic `StreamReader` client can read a chat discussion stream from the beginning. A more specialized client would let users add messages to the chat stream. The generic client has more limited functionality but can work across a broader array of services. A specialized chat client uses the extended features of a `ChatStream`. Both use the same service in different ways.

As an example of a specialized client, here is a `Chatter` client that will use a command line to provide access to a `ChatStream`:

```
package chatter;

public class Chatter extends StreamReader {
    public static void main(String[] args) throws Exception
    {
        String[] fullargs = new String[args.length + 3];
        fullargs[0] = "-c";
        fullargs[1] = String.valueOf(Integer.MAX_VALUE);
        System.arraycopy(args, 0, fullargs, 2, args.length);
        fullargs[fullargs.length - 1] = "chat.ChatStream";
        Chatter chatter = new Chatter(fullargs);
        chatter.execute();
```

```
    }

    private Chatter(String[] args) {
        super(args);
    }

    public void readStream(MessageStream msgStream)
        throws RemoteException
    {
        ChatStream stream = (ChatStream)msgStream;
        new ChatterThread(stream).start();
        super.readStream(stream);
    }

    public void printMessage(int msgNum, Object msg) {
        if (!(msg instanceof ChatMessage))
            super.printMessage(msgNum, msg);
        else {
            ChatMessage cmsg = (ChatMessage)msg;
            System.out.println(cmsg.getSpeaker() + ":");
            String[] lines = cmsg.getContent();
            for (int i = 0; i < lines.length; i++) {
                System.out.print("    ");
                System.out.println(lines[i]);
            }
        }
    }
}
```

All the client code in this section is in the `chatter` package. `Chatter` extends `StreamReader` (the generic client described in Section 2) to force an effectively infinite count of messages to read, and to require that the stream found be at least a `ChatStream`, not simply a `MessageStream`. It overrides `readStream` so that when the stream is found, a new thread will be created to read the user's input. The `printMessage` method is overridden to take advantage of the knowledge that the message object is a `ChatMessage`.

`ChatterThread` uses the stream's `add` method when the user types something:

```
class ChatterThread extends Thread {
    private ChatStream stream;
```

```
ChatterThread(ChatStream stream) {
    this.stream = stream;
}

public void run() {
    BufferedReader in = new BufferedReader(
        new InputStreamReader(System.in));
    String user = System.getProperty("user.name");
    List msg = new ArrayList();
    String[] msgArray = new String[0];
    for (;;) {
        try {
            String line = in.readLine();
            if (line == null)
                System.exit(0);

            boolean more = line.endsWith("\\");
            if (more) {     // strip trailing backslash
                int stripped = line.length() - 1;
                line = line.substring(0, stripped);
            }
            msg.add(line);
            if (!more) {
                msgArray = (String[])
                    msg.toArray(new String[msg.size()]);
                stream.add(user, msgArray);
                msg.clear();
            }
        } catch (RemoteException e) {
            System.out.println("RemoteException:retry");
            for (;;) {
                try {
                    Thread.sleep(1000);
                    stream.add(user, msgArray);
                    msg.clear();
                    break;
                } catch (RemoteException re) {
                    continue;       // try again
                } catch (InterruptedException ie) {
                    System.exit(1);
                }
```

```
                }
            } catch (IOException e) {
                System.exit(1);
            }
        }
    }
}
```

The `run` method will be invoked by the virtual machine when the thread is started. It reads lines from the user to build up messages and uses `add` to add each message to the chat. Lines that end in \ (backslash) mean that the message continues on the next line. When the user types a line that doesn't end in backslash that line is put together with any preceding lines to create the message. The value defined in the `user.name` property (provided by the virtual machine) will be user's name in the chat. If `add` throws a `RemoteException` we retry adding the message until we succeed or until the user kills the application.

When the end of input has been reached, `readLine` returns `null`, and this thread will invoke `System.exit` to bring down the entire virtual machine, including the thread that is reading other speakers' messages.

4 The Rest of This Book

A good question is never answered.
It is not a bolt to be tightened into place but a seed to be planted
and to bear more seed toward the hope of greening the landscape of idea.
—John Ciardi

By now you should have an overview of how the Jini technology works and what it takes to write a client and service. The rest of this book contains the specification of the Jini architecture. Each subpart of the specification is prefaced by a short paragraph describing where it fits into the architecture. After the specification you will find a glossary that defines terms used in the specifications. Appendix A is a reprint of "A Note on Distributed Computing," whose thinking undergirds the Jini architecture. You can follow the Jini architecture and related technical discussions at `http://jini.org`. Appendix B contains the full code for the examples.

Each specification has a two-letter code. For example, the Jini Architecture Specification has the code "AR." This provides a common name for each part of the specification (for example AR.2.1) no matter what order the parts are placed in. For example, in this book we have placed the parts in a reasonable reading order. In another book it might be best to publish only relevant parts of the specification, or publish the parts in a different order. The common names let you talk with others about specification sections using the same section names no matter where each of you read the work. The two letter codes are shown at the beginning of each specification part, in the section and figure numbers within that part, and on the black thumb tabs at the edge of the right-hand pages.

This book is the first in a series that will come "...from the source"— from those who design, implement, and document the Jini system. These books will all be written either by the originators of the work in question or by people who work closely with them to document the designs and technologies. Other good books and web sites will, we expect, also follow from other sources. We hope that the Jini system and its designs prove useful to you both as user and as developer. At our series' web site `http://java.sun.com/docs/books/jini/` you will find

related resources including a downloadable version of the source in the series' books (including this book's source), errata, and other series-related information.

THE JINI ARCHITECTURE SPECIFICATION defines the top-level view of the Jini architecture, its components, and the systems on which the Jini architecture is layered. This will give you a high-level view of the architecture that will be filled out in the following specifications.

AR

The Jini Architecture Specification

AR.1 Introduction

THIS document describes the high-level architecture of a Jini software system, defines the different components that make up the system, characterizes the use of those components, discusses some of the component interactions, and gives an example. This document identifies those parts of the system that are necessary infrastructure, those that are part of the programming model, and those that are optional services that can live within the system.

AR.1.1 Goals of the System

A Jini system is a distributed system based on the idea of federating groups of users and the resources required by those users. The overall goal is to turn the network into a flexible, easily administered tool with which resources can be found by human and computational clients. Resources can be implemented as either hardware devices, software programs, or a combination of the two. The focus of the system is to make the network a more dynamic entity that better reflects the dynamic nature of the workgroup by enabling the ability to add and delete services flexibly.

A Jini system consists of the following parts:

- A set of components that provides an infrastructure for federating services in a distributed system

- A programming model that supports and encourages the production of reliable distributed services
- Services that can be made part of a federated Jini system and that offer functionality to any other member of the federation

Although these pieces are separable and distinct, they are interrelated, which can blur the distinction in practice. The components that make up the Jini technology infrastructure make use of the Jini programming model; services that reside within the infrastructure also use that model; and the programming model is well supported by components in the infrastructure.

The end goals of the system span a number of different audiences; these goals include the following:

- Enabling users to share services and resources over a network
- Providing users easy access to resources anywhere on the network while allowing the network location of the user to change
- Simplifying the task of building, maintaining, and altering a network of devices, software, and users

The Jini system extends the Java application environment from a single virtual machine to a network of machines. The Java application environment provides a good computing platform for distributed computing because both code and data can move from machine to machine. The environment has built-in security that allows the confidence to run code downloaded from another machine. Strong typing in the Java application environment enables identifying the class of an object to be run on a virtual machine even when the object did not originate on that machine. The result is a system in which the network supports a fluid configuration of objects that can move from place to place as needed and can call any part of the network to perform operations.

The Jini architecture exploits these characteristics of the Java application environment to simplify the construction of a distributed system. The Jini architecture adds mechanisms that allow fluidity of all components in a distributed system, extending the easy movement of objects to the entire networked system.

The Jini technology infrastructure provides mechanisms for devices, services, and users to join and detach from a network. Joining and leaving a Jini system are easy and natural, often automatic, occurrences. Jini systems are far more dynamic than is currently possible in networked groups where configuring a network is a centralized function done by hand.

AR.1.2 Environmental Assumptions

The Jini system federates computers and computing devices into what appears to the user as a single system. It relies on the existence of a network of reasonable speed connecting those computers and devices. Some devices require much higher bandwidth and others can do with much less—displays and printers are examples of extreme points. We assume that the latency of the network is reasonable.

We assume that each Jini technology-enabled device has some memory and processing power. Devices without processing power or memory may be connected to a Jini system, but those devices are controlled by another piece of hardware and/or software, called a *proxy*, that presents the device to the Jini system and itself contains both processing power and memory. The architecture for devices not equipped with a Java virtual machine (JVM) is discussed more fully in a separate document.

The Jini system is Java technology centered. The Jini architecture gains much of its simplicity from assuming that the Java programming language is the implementation language for components. The ability to dynamically download and run code is central to a number of the features of the Jini architecture. However, the Java technology-centered nature of the Jini architecture depends on the Java application environment rather than on the Java programming language. Any programming language can be supported by a Jini system if it has a compiler that produces compliant bytecodes for the Java programming language.

AR.2 System Overview

AR.2.1 Key Concepts

THE purpose of the Jini architecture is to *federate* groups of devices and software components into a single, dynamic distributed system. The resulting federation provides the simplicity of access, ease of administration, and support for sharing that are provided by a large monolithic system while retaining the flexibility, uniform response, and control provided by a personal computer or workstation.

The architecture of a single Jini system is targeted to the workgroup. Members of the federation are assumed to agree on basic notions of trust, administration, identification, and policy. It is possible to federate Jini systems themselves for larger organizations.

AR.2.1.1 Services

The most important concept within the Jini architecture is that of a *service*. A service is an entity that can be used by a person, a program, or another service. A service may be a computation, storage, a communication channel to another user, a software filter, a hardware device, or another user. Two examples of services are printing a document and translating from one word-processor format to some other.

Members of a Jini system federate to share access to services. A Jini system should not be thought of as sets of clients and servers, users and programs, or even programs and files. Instead, a Jini system consists of services that can be collected together for the performance of a particular task. Services may make use of other services, and a client of one service may itself be a service with clients of its own. The dynamic nature of a Jini system enables services to be added or withdrawn from a federation at any time according to demand, need, or the changing requirements of the workgroup using the system.

Jini systems provide mechanisms for service construction, lookup, communication, and use in a distributed system. Examples of services include: devices such