Ignoring the difference between the performance of local and remote invocations can lead to designs whose implementations are virtually assured of having performance problems because the design requires a large amount of communication between components that are in different address spaces and on different machines. Ignoring the difference in the time it takes to make a remote object invocation and the time it takes to make a local object invocation is to ignore one of the major design areas of an application. A properly designed application will require determining, by understanding the application being designed, what objects can be made remote and what objects must be clustered together.

The vision outlined earlier, however, has an answer to this objection. The answer is two-pronged. The first prong is to rely on the steadily increasing speed of the underlying hardware to make the difference in latency irrelevant. This, it is often argued, is what has happened to efficiency concerns having to do with everything from high level languages to virtual memory. Designing at the cutting edge has always required that the hardware catch up before the design is efficient enough for the real world. Arguments from efficiency seem to have gone out of style in software engineering, since in the past such concerns have always been answered by speed increases in the underlying hardware.

The second prong of the reply is to admit to the need for tools that will allow one to see what the pattern of communication is between the objects that make up an application. Once such tools are available, it will be a matter of tuning to bring objects that are in constant contact to the same address space, while moving those that are in relatively infrequent contact to wherever is most convenient. Since the vision allows all objects to communicate using the same underlying mechanism, such tuning will be possible by simply altering the implementation details (such as object location) of the relevant objects. However, it is important to get the application correct first, and after that one can worry about efficiency.

Whether or not it will ever become possible to mask the efficiency difference between a local object invocation and a distributed object invocation is not answerable *a priori.* Fully masking the distinction would require not only advances in the technology underlying remote object invocation, but would also require changes to the general programming model used by developers.

If the only difference between local and distributed object invocations was the difference in the amount of time it took to make the call, one could strive for a future in which the two kinds of calls would be conceptually indistinguishable. Whether the technology of distributed computing has moved far enough along to allow one to plan products based on such technology would be a matter of judgement, and rational people could disagree as to the wisdom of such an approach.

However, the difference in latency between the two kinds of calls is only the most obvious difference. Indeed, this difference is not really the fundamental difference between the two kinds of calls, and that even if it were possible to develop

the technology of distributed calls to an extent that the difference in latency between the two sorts of calls was minimal, it would be unwise to construct a programming paradigm that treated the two calls as essentially similar. In fact, the difference in latency between local and remote calls, because it is so obvious, has been the only difference most see between the two, and has tended to mask the more irreconcilable differences.

A.4.2 Memory Access

A more fundamental (but still obvious) difference between local and remote computing concerns the access to memory in the two cases—specifically in the use of pointers. Simply put, pointers in a local address space are not valid in another (remote) address space. The system can paper over this difference, but for such an approach to be successful, the transparency must be complete. Two choices exist: either all memory access must be controlled by the underlying system, or the programmer must be aware of the different types of access—local and remote. There is no inbetween.

If the desire is to completely unify the programming model—to make remote accesses behave as if they were in fact local—the underlying mechanism must totally control all memory access. Providing distributed shared memory is one way of completely relieving the programmer from worrying about remote memory access (or the difference between local and remote). Using the object-oriented paradigm to the fullest, and requiring the programmer to build an application with "objects all the way down," (that is, only object references or values are passed as method arguments) is another way to eliminate the boundary between local and remote computing. The layer underneath can exploit this approach by marshalling and unmarshalling method arguments and return values for intra-address space transmission.

But adding a layer that allows the replacement of all pointers to objects with object references only *permits* the developer to adopt a unified model of object interaction. Such a unified model cannot be *enforced* unless one also removes the ability to get address-space-relative pointers from the language used by the developer. Such an approach erects a barrier to programmers who want to start writing distributed applications, in that it requires that those programmers learn a new style of programming which does not use address-space-relative pointers. In requiring that programmers learn such a language, moreover, one gives up the complete transparency between local and distributed computing.[A]

Even if one were to provide a language that did not allow obtaining address-space-relative pointers to objects (or returned an object reference whenever such a pointer was requested), one would need to provide an equivalent way of making

cross-address space reference to entities other than objects. Most programmers use pointers as references for many different kinds of entities. These pointers must either be replaced with something that can be used in cross-address space calls or the programmer will need to be aware of the difference between such calls (which will either not allow pointers to such entities, or do something special with those pointers) and local calls. Again, while this could be done, it does violate the doctrine of complete unity between local and remote calls. Because of memory access constraints, the two *have* to differ.

The danger lies in promoting the myth that "remote access and local access are exactly the same" and not enforcing the myth. An underlying mechanism that does not unify all memory accesses while still promoting this myth is both misleading and prone to error. Programmers buying into the myth may believe that they do not have to change the way they think about programming. The programmer is therefore quite likely to make the mistake of using a pointer in the wrong context, producing incorrect results. "Remote is just like local," such programmers think, "so we have just one unified programming model." Seemingly, programmers need not change their style of programming. In an incomplete implementation of the underlying mechanism, or one that allows an implementation language that in turn allows direct access to local memory, the system does not take care of all memory accesses, and errors are bound to occur. These errors occur because the programmer is not aware of the difference between local and remote access and what is actually happening "under the covers."

The alternative is to explain the difference between local and remote access, making the programmer aware that remote address space access is very different from local access. Even if some of the pain is taken away by using an interface definition language like that specified in [1] and having it generate an intelligent language mapping for operation invocation on distributed objects, the programmer aware of the difference will not make the mistake of using pointers for cross-address space access. The programmer will know it is incorrect. By not masking the difference, the programmer is able to learn when to use one method of access and when to use the other.

Just as with latency, it is logically possible that the difference between local and remote memory access could be completely papered over and a single model of both presented to the programmer. When we turn to the problems introduced to distributed computing by partial failure and concurrency, however, it is not clear that such a unification is even conceptually possible.

A.5 Partial Failure and Concurrency

While unlikely, it is at least logically possible that the differences in latency and memory access between local computing and distributed computing could be masked. It is not clear that such a masking could be done in such a way that the local computing paradigm could be used to produce distributed applications, but it might still be possible to allow some new programming technique to be used for both activities. Such a masking does not even seem to be logically possible, however, in the case of partial failure and concurrency. These aspects appear to be different in kind in the case of distributed and local computing.[2]

Partial failure is a central reality of distributed computing. Both the local and the distributed world contain components that are subject to periodic failure. In the case of local computing, such failures are either total, affecting all of the entities that are working together in an application, or detectable by some central resource allocator (such as the operating system on the local machine).

This is not the case in distributed computing, where one component (machine, network link) can fail while the others continue. Not only is the failure of the distributed components independent, but there is no common agent that is able to determine what component has failed and inform the other components of that failure, no global state that can be examined that allows determination of exactly what error has occurred. In a distributed system, the failure of a network link is indistinguishable from the failure of a processor on the other side of that link.

These sorts of failures are not the same as mere exception raising or the inability to complete a task, which can occur in the case of local computing. This type of failure is caused when a machine crashes during the execution of an object invocation or a network link goes down, occurrences that cause the target object to simply disappear rather than return control to the caller. A central problem in distributed computing is insuring that the state of the whole system is consistent after such a failure; this is a problem that simply does not occur in local computing.

The reality of partial failure has a profound effect on how one designs interfaces and on the semantics of the operations in an interface. Partial failure requires that programs deal with indeterminacy. When a local component fails, it is possible to know the state of the system that caused the failure and the state of the system after the failure. No such determination can be made in the case of a distributed system. Instead, the interfaces that are used for the communication must be designed in such a way that it is possible for the objects to react in a consistent way to possible partial failures.

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[2] In fact, authors such as Schroeder[12] and Hadzilacos and Toueg[13] take partial failure and concurrency to be the defining problems of distributed computing.

Being robust in the face of partial failure requires some expression at the interface level. Merely improving the implementation of one component is not sufficient. The interfaces that connect the components must be able to state whenever possible the cause of failure, and there must be interfaces that allow reconstruction of a reasonable state when failure occurs and the cause cannot be determined.

If an object is co-resident in an address space with its caller, partial failure is not possible. A function may not complete normally, but it always completes. There is no indeterminism about how much of the computation completed. Partial completion can occur only as a result of circumstances that will cause the other components to fail.

The addition of partial failure as a possibility in the case of distributed computing does not mean that a single object model cannot be used for both distributed computing and local computing. The question is not "can you make remote method invocation look like local method invocation?" but rather "what is the price of making remote method invocation identical to local method invocation?" One of two paths must be chosen if one is going to have a unified model.

The first path is to treat all objects as if they were local and design all interfaces as if the objects calling them, and being called by them, were local. The result of choosing this path is that the resulting model, when used to produce distributed systems, is essentially indeterministic in the face of partial failure and consequently fragile and non-robust. This path essentially requires ignoring the extra failure modes of distributed computing. Since one can't get rid of those failures, the price of adopting the model is to require that such failures are unhandled and catastrophic.

The other path is to design all interfaces as if they were remote. That is, the semantics and operations are all designed to be deterministic in the face of failure, both total and partial. However, this introduces unnecessary guarantees and semantics for objects that are never intended to be used remotely. Like the approach to memory access that attempts to require that all access is through system-defined references instead of pointers, this approach must also either rely on the discipline of the programmers using the system or change the implementation language so that all of the forms of distributed indeterminacy are forced to be dealt with on all object invocations.

This approach would also defeat the overall purpose of unifying the object models. The real reason for attempting such a unification is to make distributed computing more like local computing and thus make distributed computing easier. This second approach to unifying the models makes local computing as complex as distributed computing. Rather than encouraging the production of distributed applications, such a model will discourage its own adoption by making all object-based computing more difficult.

Similar arguments hold for concurrency. Distributed objects by their nature must handle concurrent method invocations. The same dichotomy applies if one insists on a unified programming model. Either all objects must bear the weight of concurrency semantics, or all objects must ignore the problem and hope for the best when distributed. Again, this is an interface issue and not solely an implementation issue, since dealing with concurrency can take place only by passing information from one object to another through the agency of the interface. So either the overall programming model must ignore significant modes of failure, resulting in a fragile system; or the overall programming model must assume a worst-case complexity model for all objects within a program, making the production of any program, distributed or not, more difficult.

One might argue that a multi-threaded application needs to deal with these same issues. However, there is a subtle difference. In a multi-threaded application, there is no real source of indeterminacy of invocations of operations. The application programmer has complete control over invocation order when desired. A distributed system by its nature introduces truly asynchronous operation invocations. Further, a non-distributed system, even when multi-threaded, is layered on top of a single operating system that can aid the communication between objects and can be used to determine and aid in synchronization and in the recovery of failure. A distributed system, on the other hand, has no single point of resource allocation, synchronization, or failure recovery, and thus is conceptually very different.

A.6 The Myth of "Quality of Service"

One could take the position that the way an object deals with latency, memory access, partial failure, and concurrency control is really an aspect of the implementation of that object, and is best described as part of the "quality of service" provided by that implementation. Different implementations of an interface may provide different levels of reliability, scalability, or performance. If one wants to build a more reliable system, one merely needs to choose more reliable implementations of the interfaces making up the system.

On the surface, this seems quite reasonable. If I want a more robust system, I go to my catalog of component vendors. I quiz them about their test methods. I see if they have ISO9000 certification, and I buy my components from the one I trust the most. The components all comply with the defined interfaces, so I can plug them right in; my system is robust and reliable, and I'm happy.

Let us imagine that I build an application that uses the (mythical) queue interface to enqueue work for some component. My application dutifully enqueues records that represent work to be done. Another application dutifully dequeues them and performs the work. After a while, I notice that my application crashes

due to time-outs. I find this extremely annoying, but realize that it's my fault. My application just isn't robust enough. It gives up too easily on a time-out. So I change my application to retry the operation until it succeeds. Now I'm happy. I almost never see a time-out. Unfortunately, I now have another problem. Some of the requests seem to get processed two, three, four, or more times. How can this be? The component I bought which implements the queue has allegedly been rigorously tested. It shouldn't be doing this. I'm angry. I call the vendor and yell at him. After much fingerpointing and research, the culprit is found. The problem turns out to be the way I'm using the queue. Because of my handling of partial failures (which in my naivete, I had thought to be total), I have been enqueuing work requests multiple times.

Well, I yell at the vendor that it is still their fault. Their queue should be detecting the duplicate entry and removing it. I'm not going to continue using this software unless this is fixed. But, since the entities being enqueued are just values, there is no way to do duplicate elimination. The only way to fix this is to change the protocol to add request IDs. But since this is a standardized interface, there is no way to do this.

The moral of this tale is that robustness is not simply a function of the implementations of the interfaces that make up the system. While robustness of the individual components has some effect on the robustness of the overall systems, it is not the sole factor determining system robustness. Many aspects of robustness can be reflected only at the protocol/interface level.

Similar situations can be found throughout the standard set of interfaces. Suppose I want to reliably remove a name from a context. I would be tempted to write code that looks like:

```
while (true) {
    try {
        context->remove(name);
        break;
    }
    catch (NotFoundInContext) {
        break;
    }
    catch (NetworkServerFaliure) {
        continue;
    }
}
```

That is, I keep trying the operation until it succeeds (or until I crash). The problem is that my connection to the name server may have gone down, but another client's may have stayed up. I may have, in fact, successfully removed the name but not

discovered it because of a network disconnection. The other client then adds the same name, which I then remove. Unless the naming interface includes an operation to lock a naming context, there is no way that I can make this operation completely robust. Again, we see that robustness/reliability needs to be expressed at the interface level. In the design of any operation, the question has to be asked: What happens if the client chooses to repeat this operation with the exact same parameters as previously? What mechanisms are needed to ensure that they get the desired semantics? These are things that can be expressed only at the interface level. These are issues that can't be answered by supplying a "more robust implementation" because the lack of robustness is inherent in the interface and not something that can be changed by altering the implementation.

Similar arguments can be made about performance. Suppose an interface describes an object which maintains sets of other objects. A defining property of sets is that there are no duplicates. Thus, the implementation of this object needs to do duplicate elimination. If the interfaces in the system do not provide a way of testing equality of reference, the objects in the set must be queried to determine equality. Thus, duplicate elimination can be done only by interacting with the objects in the set. It doesn't matter how fast the objects in the set implement the equality operation. The overall performance of eliminating duplicates is going to be governed by the latency in communicating over the slowest communications link involved. There is no change in the set implementations that can overcome this. An interface design issue has put an upper bound on the performance of this operation.

A.7 Lessons From NFS

We do not need to look far to see the consequences of ignoring the distinction between local and distributed computing at the interface level. NFS®, Sun's distributed computing file system[14,15] is an example of a non-distributed application programer interface (API) (open, read, write, close, etc.) re-implemented in a distributed way.

Before NFS and other network file systems, an error status returned from one of these calls indicated something rare: a full disk, or a catastrophe such as a disk crash. Most failures simply crashed the application along with the file system. Further, these errors generally reflected a situation that was either catastrophic for the program receiving the error or one that the user running the program could do something about.

NFS opened the door to partial failure within a file system. It has essentially two modes for dealing with an inaccessible file server: soft mounting and hard mounting. But since the designers of NFS were unwilling (for easily understand-

able reasons) to change the interface to the file system to reflect the new, distributed nature of file access, neither option is particularly robust.

Soft mounts expose network or server failure to the client program. Read and write operations return a failure status much more often than in the single-system case, and programs written with no allowance for these failures can easily corrupt the files used by the program. In the early days of NFS, system administrators tried to tune various parameters (time-out length, number of retries) to avoid these problems. These efforts failed. Today, soft mounts are seldom used, and when they are used, their use is generally restricted to read-only file systems or special applications.

Hard mounts mean that the application hangs until the server comes back up. This generally prevents a client program from seeing partial failure, but it leads to a malady familiar to users of workstation networks: one server crashes, and many workstations—even those apparently having nothing to do with that server—freeze. Figuring out the chain of causality is very difficult, and even when the cause of the failure can be determined, the individual user can rarely do anything about it but wait. This kind of brittleness can be reduced only with strong policies and network administration aimed at reducing interdependencies. Nonetheless, hard mounts are now almost universal.

Note that because the NFS protocol is stateless, it assumes clients contain no state of interest with respect to the protocol; in other words, the server doesn't care what happens to the client. NFS is also a "pure" client-server protocol, which means that failure can be limited to three parties: the client, the server, or the network. This combination of features means that failure modes are simpler than in the more general case of peer-to-peer distributed object-oriented applications where no such limitation on shared state can be made and where servers are themselves clients of other servers. Such peer-to-peer distributed applications can and will fail in far more intricate ways than are currently possible with NFS.

The limitations on the reliability and robustness of NFS have nothing to do with the implementation of the parts of that system. There is no "quality of service" that can be improved to eliminate the need for hard mounting NFS volumes. The problem can be traced to the interface upon which NFS is built, an interface that was designed for non-distributed computing where partial failure was not possible. The reliability of NFS cannot be changed without a change to that interface, a change that will reflect the distributed nature of the application.

This is not to say that NFS has not been successful. In fact, NFS is arguably the most successful distributed application that has been produced. But the limitations on the robustness have set a limitation on the scalability of NFS. Because of the intrinsic unreliability of the NFS protocol, use of NFS is limited to fairly small numbers of machines, geographically co-located and centrally administered. The way NFS has dealt with partial failure has been to informally require a centralized

resource manager (a system administrator) who can detect system failure, initiate resource reclamation and insure system consistency. But by introducing this central resource manager, one could argue that NFS is no longer a genuinely distributed application.

A.8 Taking the Difference Seriously

Differences in latency, memory access, partial failure, and concurrency make merging of the computational models of local and distributed computing both unwise to attempt and unable to succeed. Merging the models by making local computing follow the model of distributed computing would require major changes in implementation languages (or in how those languages are used) and make local computing far more complex than is otherwise necessary. Merging the models by attempting to make distributed computing follow the model of local computing requires ignoring the different failure modes and basic indeterminacy inherent in distributed computing, leading to systems that are unreliable and incapable of scaling beyond small groups of machines that are geographically colocated and centrally administered.

A better approach is to accept that there are irreconcilable differences between local and distributed computing, and to be conscious of those differences at all stages of the design and implementation of distributed applications. Rather than trying to merge local and remote objects, engineers need to be constantly reminded of the differences between the two, and know when it is appropriate to use each kind of object.

Accepting the fundamental difference between local and remote objects does not mean that either sort of object will require its interface to be defined differently. An interface definition language such as IDL[B] can still be used to specify the set of interfaces that define objects. However, an additional part of the definition of a class of objects will be the specification of whether those objects are meant to be used locally or remotely. This decision will need to consider what the anticipated message frequency is for the object, and whether clients of the object can accept the indeterminacy implied by remote access. The decision will be reflected in the interface to the object indirectly, in that the interface for objects that are meant to be accessed remotely will contain operations that allow reliability in the face of partial failure.

It is entirely possible that a given object will often need to be accessed by some objects in ways that cannot allow indeterminacy, and by other objects relatively rarely and in a way that does allow indeterminacy. Such cases should be split into two objects (which might share an implementation) with one having an

interface that is best for local access and the other having an interface that is best for remote access.

A compiler for the interface definition language used to specify classes of objects will need to alter its output based on whether the class definition being compiled is for a class to be used locally or a class being used remotely. For interfaces meant for distributed objects, the code produced might be very much like that generated by RPC stub compilers today. Code for a local interface, however, could be much simpler, probably requiring little more than a class definition in the target language.

While writing code, engineers will have to know whether they are sending messages to local or remote objects, and access those objects differently. While this might seem to add to the programming difficulty, it will in fact aid the programmer by providing a framework under which he or she can learn what to expect from the different kinds of calls. To program completely in the local environment, according to this model, will not require any changes from the programmer's point of view. The discipline of defining classes of objects using an interface definition language will insure the desired separation of interface from implementation, but the actual process of implementing an interface will be no different than what is done today in an object-oriented language.

Programming a distributed application will require the use of different techniques than those used for non-distributed applications. Programming a distributed application will require thinking about the problem in a different way than before it was thought about when the solution was a non-distributed application. But that is only to be expected. Distributed objects are different from local objects, and keeping that difference visible will keep the programmer from forgetting the difference and making mistakes. Knowing that an object is outside of the local address space, and perhaps on a different machine, will remind the programmer that he or she needs to program in a way that reflects the kinds of failures, indeterminacy, and concurrency constraints inherent in the use of such objects. Making the difference visible will aid in making the difference part of the design of the system.

Accepting that local and distributed computing are different in an irreconcilable way will also allow an organization to allocate its research and engineering resources more wisely. Rather than using those resources in attempts to paper over the differences between the two kinds of computing, resources can be directed at improving the performance and reliability of each.

One consequence of the view espoused here is that it is a mistake to attempt to construct a system that is "objects all the way down" if one understands the goal as a distributed system constructed of the *same kind* of objects all the way down. There will be a line where the object model changes; on one side of the line will be distributed objects, and on the other side of the line there will (perhaps) be

local objects. On either side of the line, entities on the other side of the line will be opaque; thus one distributed object will not know (or care) if the implementation of another distributed object with which it communicates is made up of objects or is implemented in some other way. Objects on different sides of the line will differ in kind and not just in degree; in particular, the objects will differ in the kinds of failure modes with which they must deal.

A.9 A Middle Ground

As noted in Section A.2, the distinction between local and distributed objects as we are using the terms is not exhaustive. In particular, there is a third category of objects made up of those that are in different address spaces but are guaranteed to be on the same machine. These are the sorts of objects, for example, that appear to be the basis of systems such as Spring[16] or Clouds[4]. These objects have some of the characteristics of distributed objects, such as increased latency in comparison to local objects and the need for a different model of memory access. However, these objects also share characteristics of local objects, including sharing underlying resource management and failure modes that are more nearly deterministic.

It is possible to make the programming model for such "local-remote" objects more similar to the programming model for local objects than can be done for the general case of distributed objects. Even though the objects are in different address spaces, they are managed by a single resource manager. Because of this, partial failure and the indeterminacy that it brings can be avoided. The programming model for such objects will still differ from that used for objects in the same address space with respect to latency, but the added latency can be reduced to generally acceptable levels. The programming models will still necessarily differ on methods of memory access and concurrency, but these do not have as great an effect on the construction of interfaces as additional failure modes.

The other reason for treating this class of objects separately from either local objects or generally distributed objects is that a compiler for an interface definition language can be significantly optimized for such cases. Parameter and result passing can be done via shared memory if it is known that the objects communicating are on the same machine. At the very least, marshalling of parameters and the unmarshalling of results can be avoided.

The class of locally distributed objects also forms a group that can lead to significant gains in software modularity. Applications made up of collections of such objects would have the advantage of forced and guaranteed separation between the interface to an object and the implementation of that object, and would allow the replacement of one implementation with another without affecting other parts of the system. Because of this, it might be advantageous to investigate the uses of

such a system. However, this activity should not be confused with the unification of local objects with the kinds of distributed objects we have been discussing.

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A.11 Observations for this Reprinting

[A] When this note was written, the major system programming languages (C, C++, Modula3, etc.) all allowed direct access, to a greater or lesser degree, to pointers to internal memory. This paragraph points out that adding indirect references to such languages would allow two kinds of reference, one of which was distribution transparent while the other was not. Java, of course, does not have direct access to pointers. Because of the Java use of references within the language, it does provide a platform in which address-space-relative pointers are missing. Thus Java not only permits a unified addressing scheme, it enforces that scheme.

[B] There are actually a number of interface definition languages that are referred to by the initials IDL. When this note was originally written, we were referring to the CORBA interface definition language. However, the other languages that use this name share the characteristics discussed here, so the argument presented would apply equally to them.

APPENDIX B

The Example Code

The first rule of magic is simple:
Don't waste your time waving your hands and hoping
when a rock or a club will do.
—McCloctnik the Lucid

THE following pages contain the complete code for the examples used in the introductory chapters of this book. The sources are listed in alphabetical order by the full name, including the package name. For your convenience, here is a mapping from the simple class name to its fully-qualified class name:

You can also find the code at `http://java.sun.com/docs/books/jini/`

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chat.ChatMessage

```
package chat;

import java.io.Serializable;

/**
 * A single message in the <CODE>ChatStream</CODE>.  This is the
 * type of <CODE>Object</CODE> returned by <CODE>ChatStream.nextMessage</CODE>.
 *
 * @see ChatStream
 */
public class ChatMessage implements Serializable {
    /**
     * The speaker of the message.
     * @serial
     */
    private String speaker;

    /**
     * The contents of the message.
     * @serial
     */
    private String[] content;

    /**
     * The serial version UID.  Stating it explicitly is good.
     *
     * @see fortune.FortuneTheme#serialVersionUID
     */
    static final long serialVersionUID =
                            -1852351967189107571L;

    /**
     * Create a new <CODE>ChatMessage</CODE> with the given
     * <CODE>speaker</CODE> and <CODE>content</CODE>.
     */
    public ChatMessage(String speaker, String[] content) {
        this.speaker = speaker;
        this.content = content;
    }

    /**
     * Return the speaker of the message.
     */
    public String getSpeaker() { return speaker; }

    /**
     * Return the content of the message.  Each string in the array
     * represents a single line of content.
```

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

    // inherit doc comment from superclass
    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();
    }
}
```

330
chat.ChatProxy

```
    package chat;

import java.io.EOFException;
import java.io.Serializable;
import java.rmi.RemoteException;

/**
 * The client-side proxy for a <CODE>ChatServer</CODE>-based
 * <CODE>ChatStream</CODE> service.  This forwards most requests to the
 * server, remembering the last successfuly retrieved message index.
 */
class ChatProxy implements ChatStream, Serializable {
    /**
     * Reference to the remote server.
     * @serial
     */
    private final ChatServer server;

    /**
     * The index of the last entry successfully received.
     * @serial
     */
    private int lastIndex = -1;

    /**
     * Cache of the subject of the chat.
     */
    private transient String subject;

    /**
     * Create a new proxy that will talk to the given server object.
     */
    ChatProxy(ChatServer server) {
        this.server = server;
    }

    // inherit doc comment from ChatStream
    public synchronized Object nextMessage()
        throws RemoteException, EOFException
    {
        ChatMessage msg = server.nextInLine(lastIndex);
        lastIndex++;
        return msg;
    }

    // inherit doc comment from ChatStream
    public void add(String speaker, String[] msg)
        throws RemoteException
```

```
    {
        server.add(speaker, msg);
    }

    // inherit doc comment from ChatStream
    public synchronized String getSubject()
        throws RemoteException
    {
        if (subject == null)
            subject = server.getSubject();
        return subject;
    }

    // inherit doc comment from ChatStream
    public String[] getSpeakers() throws RemoteException {
        return server.getSpeakers();
    }
}
```

```
package chat;

import util.ParseUtil;

import java.io.BufferedInputStream;
import java.io.BufferedOutputStream;
import java.io.File;
import java.io.FileInputStream;
import java.io.FileOutputStream;
import java.io.IOException;
import java.io.ObjectInputStream;
import java.io.ObjectOutputStream;
import java.rmi.activation.Activatable;
import java.rmi.activation.ActivationDesc;
import java.rmi.activation.ActivationException;
import java.rmi.activation.ActivationGroup;
import java.rmi.activation.ActivationGroupDesc.CommandEnvironment;
import java.rmi.activation.ActivationGroupDesc;
import java.rmi.activation.ActivationGroupID;
import java.rmi.activation.ActivationSystem;
import java.rmi.MarshalledObject;
import java.rmi.Remote;
import java.rmi.RemoteException;
import java.util.Properties;

/**
 * The administrative program that creates a new <CODE>ChatServerImpl</CODE>
 * chat stream service.  It's invocation is:
 * <pre>
 *      java [<i>java-options</i>] chat.ChatServerAdmin <i>dir subject</i>
 *              [<i>groups|lookupURL classpath codebase policy-file</i>]
 * </pre>
 * Where the options are:
 * <dl>
 * <dt><i><CODE>java-options</CODE></i>
 * <dd>Options to the Java VM that will run the admin program.  Typically
 * this includes a security policy property.
 * <p>
 * <dt><i><CODE>dir</CODE></i>
 * <dd>The directory in which all the chats in the same group will live.
 * <p>
 * <dt><i><CODE>subject</CODE></i>
 * <dd>The subject of the chat.  This must be unique within the group.
 * <p>
 * <dt><i><CODE>groups</CODE></i>|<i><CODE>lookupURL</CODE></i>
 * <dd>Either a comma-separated list of groups in which all the services
 * in the group will be regsitered or a URL to a specific lookup service.
 * <p>
```

```
 * <dt><i><CODE>classpath</CODE></i>
 * <dd>The classpath for the activated service (<CODE>ChatServerImpl</CODE>
 * will be loaded from this).
 * <p>
 * <dt><i><CODE>codebase</CODE></i>
 * <dd>The codebase for users of the service (<CODE>ChatProxy</CODE> will
 * be loaded from this).
 * <p>
 * <dt><i><CODE>policy-file</CODE></i>
 * <dd>The policy file for the activated service's virtual machine.
 * </dl>
 * <p>The last four parameters imply creation of a new group.  If any
 * are specified they must all be specified.  If none are specified the
 * new chat stream will be in the same activation group as the others
 * who use the same storage directory, and so will use the same values
 * for the last four parameters.
 */
public class ChatServerAdmin {
    /**
     * The main program for <CODE>ChatServerAdmin</CODE>.
     */
    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);
    }

    /**
     * Print a usage message for the user.
     */
    private static void usage() {
        System.out.println("usage: java [java-options] " +
            ChatServerAdmin.class + " dir subject " +
            " [groups|lookupURL classpath codebase policy-file]\n");
    }

    /**
     * Create a new group with the given parameters.
     */
    private static ActivationGroupID
        createGroup(File dir, String[] groups, String lookupURL,
                    String classpath, String codebase,
                    String policy)
        throws IOException, ActivationException
    {
        if (!dir.isDirectory())
            dir.mkdirs();

        Properties props = new Properties();
        props.put("java.rmi.server.codebase", codebase);
        props.put("java.security.policy", policy);
        String[] argv = new String[] { "-cp", classpath };
        CommandEnvironment cmd =
            new CommandEnvironment("java", argv);
        ActivationSystem actSys = ActivationGroup.getSystem();
        ActivationGroupDesc groupDesc =
            new ActivationGroupDesc(props, cmd);
        ActivationGroupID id = actSys.registerGroup(groupDesc);

        FileOutputStream fout =
            new FileOutputStream(groupFile(dir));
        ObjectOutputStream out = new ObjectOutputStream(
            new BufferedOutputStream(fout));
        out.writeObject(id);
        out.writeObject(groups);
        out.writeObject(lookupURL);
        out.flush();            // force bits out of buffer
```

```
            fout.getFD().sync();    // force bits to the disk
            out.close();

            return id;
        }

        /**
         * Return a <CODE>File</CODE> object contains the group description.
         * This assumes that nobody will create a group with the subject
         * <CODE>"grpdesc"</CODE>.  This is probably a bad assumption -- a
         * fully robust implementation should either check this and forbid it
         * or figure out a way to store this someplace that does not conflict
         * with subject names.
         */
        static File groupFile(File dir) {
            return new File(dir, "grpdesc");
        }

        /**
         * Get the ActivationGroupID for the existing group in the given
         * directory.
         */
        private static ActivationGroupID getGroup(File dir)
            throws IOException, ClassNotFoundException
        {
            ObjectInputStream in = null;
            try {
                in = new ObjectInputStream(new BufferedInputStream(
                    new FileInputStream(groupFile(dir))));
                return (ActivationGroupID)in.readObject();
            } finally {
                if (in != null)
                    in.close();
            }
        }
    }
```

```
package chat;

import net.jini.core.discovery.LookupLocator;
import net.jini.core.entry.Entry;
import net.jini.core.lookup.ServiceID;

import com.sun.jini.lease.LeaseRenewalManager;
import com.sun.jini.lookup.JoinManager;
import com.sun.jini.lookup.ServiceIDListener;
import com.sun.jini.reliableLog.LogHandler;
import com.sun.jini.reliableLog.ReliableLog;

import java.io.File;
import java.io.FileInputStream;
import java.io.InputStream;
import java.io.IOException;
import java.io.ObjectInputStream;
import java.io.ObjectOutputStream;
import java.io.OutputStream;
import java.rmi.activation.Activatable;
import java.rmi.activation.ActivationID;
import java.rmi.MarshalledObject;
import java.util.ArrayList;
import java.util.HashSet;
import java.util.List;
import java.util.Set;

/**
 * The implementation of <CODE>ChatServer</CODE>.  This runs inside an
 * activation group defined by the persistent state from the activation
 * service.
 */
public class ChatServerImpl implements ChatServer {
    /**
     * The join manager we're using.
     */
    private JoinManager joinMgr;

    /**
     * Our subject of discussion.
     */
    private String subject;

    /**
     * The set of known speakers.
     */
    private Set speakers = new HashSet();
```

```
    /**
     * The list of messages.
     */
    private List messages = new ArrayList();

    /**
     * The list of service attributes.
     */
    private List attrs;

    /**
     * The service ID (or <CODE>null</CODE>).
     */
    private ServiceID serviceID;

    /**
     * Our persistent storage.
     */
    private ChatStore store;

    /**
     * Groups to register with (or an empty array).
     */
    private String[] groups = new String[0];

    /**
     * URL to specific join manager (or <CODE>null</CODE>).
     */
    private String lookupURL;

    /**
     * The lease renewal manager for all servers in our group.
     * We share it because this gives it more leases it might be
     * able to compress into single renewal messages.
     */
    private static LeaseRenewalManager renewer;

    /**
     * The storage for a <CODE>ChatServerImpl</CODE>.
     */
    class ChatStore extends LogHandler
        implements ServiceIDListener
    {
        /**
         * The reliable log in which we store our state.
         */
        private ReliableLog log;
```

```
/**
 * Create a new <CODE>ChatStore</CODE> object for the given
 * directory.  The directory is the full path for the specific
 * storage for this chat on the subject.  The parent directory
 * is the one for the group.
 */
ChatStore(File dir) throws IOException {
    // If the directory exists, recover from it.  Otherwise
    // create it as a a new subject.
    if (dir.exists()) {
        log = new ReliableLog(dir.toString(), this);
        log.recover();
    } else {
        subject = dir.getName();
        log = new ReliableLog(dir.toString(), this);
        attrs = new ArrayList();
        attrs.add(new ChatSubject(subject));
        log.snapshot();
    }

    // Read in the lookup groups and lookupURL for our service
    ObjectInputStream in = null;
    try {
        in = new ObjectInputStream(
            new FileInputStream(
                ChatServerAdmin.groupFile(dir.getParentFile())));
        in.readObject();        // skip over the group ID
        groups = (String[])in.readObject();
        lookupURL = (String)in.readObject();
    } catch (ClassNotFoundException e) {
        unexpectedException(e);
    } catch (IOException e) {
        unexpectedException(e);
    } finally {
        if (in != null)
            in.close();
    }
}

/**
 * Stores the current information in storage.  In our case only
 * the start state is snapshoted -- everything else is added
 * incrementally anyway and so the log of changes is the
 * state.  Part of <CODE>ReliableLogHandler</CODE>.
 */
public void snapshot(OutputStream out) throws Exception {
    ObjectOutputStream oo = new ObjectOutputStream(out);
    oo.writeObject(subject);
```

```
        oo.writeObject(attrs);
    }

    /**
     * Recovers the information from storage.  Part of
     * <CODE>ReliableLogHandler</CODE>.
     *
     * @see #snapshot
     */
    public void recover(InputStream in) throws Exception {
        ObjectInputStream oi = new ObjectInputStream(in);
        subject = (String)oi.readObject();
        attrs = (List)oi.readObject();
    }

    /**
     * Apply an update from the log during recovery.  The types
     * of data we add happen to all be distinct so we know exactly
     * what something is based on its type alone (lucky us).  Part
     * of <CODE>ReliableLogHandler</CODE>.
     */
    public void applyUpdate(Object update) throws Exception {
        if (update instanceof ChatMessage) {
            messages.add(update);
            addSpeaker(((ChatMessage)update).getSpeaker());
        } else if (update instanceof Entry) {
            attrs.add(update);
        } else if (update instanceof ServiceID) {
            serviceID = (ServiceID)update;
        } else {
            throw new IllegalArgumentException(
                "Internal error: update type " +
                update.getClass().getName() + ", " + update);
        }
    }

    /**
     * Invoked when the serviceID is first assigned to the service.
     * Part of <CODE>ServiceIDListener</CODE>.
     */
    public void serviceIDNotify(ServiceID serviceID) {
        try {
            log.update(serviceID);
        } catch (IOException e) {
            unexpectedException(e);
        }
        ChatServerImpl.this.serviceID = serviceID;
    }
```

```
    /**
     * Add a new speaker to the persistent storage log.
     */
    synchronized void add(ChatMessage msg) {
        try {
            log.update(msg, true);
        } catch (IOException e) {
            unexpectedException(e);
        }
    }
}

/**
 * The activation constructor for <CODE>ChatServerImpl</CODE>.  The
 * <CODE>state</CODE> object contains the directory which is our
 * reliable log directory.
 */
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);
}

/**
 * Return the attributes as an array for use in JoinManager.
 */
private Entry[] getAttrs() {
    return (Entry[])attrs.toArray(new Entry[attrs.size()]);
}

// inherit doc comment from ChatServer
public String getSubject() {
    return subject;
}
```

```
    // inherit doc comment from ChatServer
    public String[] getSpeakers() {
        return (String[])speakers.toArray(new String[speakers.size()]);
    }

    // inherit doc comment from ChatServer
    public synchronized void add(String speaker, String[] lines)
    {
        ChatMessage msg = new ChatMessage(speaker, lines);
        store.add(msg);
        addSpeaker(speaker);
        messages.add(msg);
        notifyAll();
    }

    /**
     * Add a speaker to the known list.  If the speaker is already
     * known, this does nothing.
     */
    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 });
    }

    // inherit doc comment from ChatServer
    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
        }
    }

    /**
     * Turn any unexpected exception into a runtime exception reflected
     * back to the client.  These are both unexpected and unrecoverable
     * exception (such as "file system full").
     */
    private static void unexpectedException(Throwable e) {
```

```
            throw new RuntimeException("unexpected exception: " + e);
        }
    }
```

```
package chat;

import net.jini.entry.AbstractEntry;
import net.jini.lookup.entry.ServiceControlled;

/**
 * An attribute for the <CODE>ChatStream</CODE> service that marks a
 * speaker as being present in a particular stream.
 *
 * @see ChatStream
 */
public class ChatSpeaker extends AbstractEntry
    implements ServiceControlled
{
    /**
     * The serial version UID.  Stating it explicitly is good.
     *
     * @see fortune.FortuneTheme#serialVersionUID
     */
    static final long serialVersionUID =
                            6748592884814857788L;

    /**
     * The speaker's name.
     * @serial
     */
    public String speaker;

    /**
     * Public no-arg constructor.  Required for all <CODE>Entry</CODE>
     * objects.
     */
    public ChatSpeaker() { }

    /**
     * Create a new <CODE>ChatSpeaker</CODE> with the given speaker.
     */
    public ChatSpeaker(String speaker) {
        this.speaker = speaker;
    }
}
```

```
package chat;

import message.MessageStream;

import java.rmi.RemoteException;

/**
 * A type of <CODE>MessageStream</CODE> whose contents are a chat
 * session.  The <CODE>nextMessage</CODE> method blocks if there is
 * as yet no next message in the stream.  The messages in the stream
 * are ordered, so <CODE>nextMessage</CODE> must be idempotent -- should
 * the client receive a <CODE>RemoteException</CODE>, the next invocation
 * must return the next message that the client has not yet seen.
 * <p>
 * Each message returned by <CODE>nextMessage</CODE> is a
 * <CODE>ChatMessage</CODE> object that has a speaker and what they
 * said.
 *
 * @see ChatMessage
 * @see ChatSpeaker
 * @see ChatSubject
 */
public interface ChatStream extends MessageStream {
    /**
     * Add a new message to the stream.  If the speaker is previously
     * unknown in the stream, a <CODE>ChatSpeaker</CODE> attribute
     * will be added to the service.
     *
     * @see ChatSpeaker
     */
    public void add(String speaker, String[] message)
        throws RemoteException;

    /**
     * Return the subject of the chat.  This does not change during the
     * lifetime of the service.  This subject will also exist as a
     * <CODE>ChatSubject</CODE> attribute on the service.
     *
     * @see ChatSubject
     */
    public String getSubject() throws RemoteException;

    /**
     * Return the list of speakers currently known in the stream.
     * The order is not significant.
     *
     * @see ChatSpeaker
```

```
         */
        public String[] getSpeakers() throws RemoteException;
    }
```

```
    package chat;

import net.jini.entry.AbstractEntry;
import net.jini.lookup.entry.ServiceControlled;

/**
 * An attribute for the <CODE>ChatStream</CODE> service that marks the
 * subject of discussion.
 *
 * @see ChatStream
 */
public class ChatSubject extends AbstractEntry
    implements ServiceControlled
{
    /**
     * The serial version UID.  Stating it explicitly is good.
     *
     * @see fortune.FortuneTheme#serialVersionUID
     */
    static final long serialVersionUID =
                            -4036337828321897774L;

    /**
     * The subject of the discussion.
     * @serial
     */
    public String subject;

    /**
     * Public no-arg constructor.  Required for all <CODE>Entry</CODE>
     * objects.
     */
    public ChatSubject() { }

    /**
     * Create a new <CODE>ChatSubject</CODE> with the given subject.
     */
    public ChatSubject(String subject) {
        this.subject = subject;
    }
}
```

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chatter.Chatter

```
package chatter;

import chat.ChatStream;
import chat.ChatMessage;
import client.StreamReader;
import message.MessageStream;

import java.rmi.RemoteException;

/**
 * A client that talks to a <CODE>ChatStream</CODE>, allowing the user
 * to add messages as well as read them.  The user's login name is used
 * as their name in the chat.  The usage is:
 * <pre>
 *      java [java-options] chatter.Chatter args...
 * </pre>
 * The arguments are the same as those for <CODE>client.StreamReader</CODE>
 * except that you cannot specify the <CODE>-c</CODE> option.  The stream
 * used will be at least a <CODE>chat.ChatStream</CODE> service.
 *
 * @see client.StreamReader
 * @see ChatterThread
 */
public class Chatter extends StreamReader {
    /**
     * Start up the service.
     */
    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();
    }

    /**
     * Create a new <CODE>Chatter</CODE>.  The <CODE>args</CODE> are
     * passed to the superclass.
     */
    private Chatter(String[] args) {
        super(args);
    }

    /**
     * Overrides <CODE>readStream</CODE> to start up a
```

```
     * <CODE>ChatterThread</CODE> when the stream is found.  The
     * <CODE>ChatterThread</CODE> lets the user type messages, while this
     * thread continually reads them.
     */
    public void readStream(MessageStream msgStream)
        throws RemoteException
    {
        ChatStream stream = (ChatStream)msgStream;
        new ChatterThread(stream).start();
        super.readStream(stream);
    }

    /**
     * Print out a message, marking the speaker for easy reading.
     */
    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]);
            }
        }
    }
}
```

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chatter.ChatterThread

```
package chatter;

import chat.ChatStream;

import java.io.BufferedReader;
import java.io.InputStreamReader;
import java.io.IOException;
import java.rmi.RemoteException;
import java.util.ArrayList;
import java.util.List;

/**
 * The thread that <CODE>Chatter</CODE> uses to let the user type
 * new messages.
 */
class ChatterThread extends Thread {
    /**
     * The stream to which we're adding.
     */
    private ChatStream stream;

    /**
     * Create a new <CODE>ChatterThread</CODE> to write to the given stream.
     */
    ChatterThread(ChatStream stream) {
        this.stream = stream;
    }

    /**
     * The thread's workhorse.  Read what the user types and put it into
     * the stream as messages from the user.  The user's name is read from
     * the <CODE>user.name</CODE> property.  A message consists of a series
     * of lines ending in backslash until one that doesn't.
     */
    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);
        }
    }
}
}
```

```
package client;

import net.jini.core.discovery.LookupLocator;
import net.jini.core.entry.Entry;
import net.jini.core.lookup.ServiceRegistrar;
import net.jini.core.lookup.ServiceTemplate;
import net.jini.discovery.DiscoveryEvent;
import net.jini.discovery.DiscoveryListener;
import net.jini.discovery.LookupDiscovery;

import message.MessageStream;

import java.io.BufferedReader;
import java.io.EOFException;
import java.io.InputStreamReader;
import java.io.Reader;
import java.lang.reflect.Constructor;
import java.lang.reflect.InvocationTargetException;
import java.rmi.RemoteException;
import java.rmi.RMISecurityManager;
import java.util.HashSet;
import java.util.LinkedList;
import java.util.List;
import java.util.Set;
import java.util.StringTokenizer;

/**
 * This class provides a client that reads messages from a
 * <code>MessageStream</code> service.  It's use is:
 * <pre>
 *      java [<i>java-options</i>] client.StreamReader [-c <i>count</i>]
 *               <i>groups|lookupURL</i>
 *               [<i>service-type</i>|<i>attribute</i> ...]
 * </pre>
 * Where the options are:
 * <dl>
 * <dt><i><CODE>java-options</CODE></i>
 * <dd>Options to the Java VM that will run the admin program.  Typically
 * this includes a security policy property.
 * <p>
 * <dt><i><CODE>-c <i>count</i></CODE></i>
 * <dd>The number of messages to print.
 * <p>
 * <dt><i><CODE>groups</CODE></i>|<i><CODE>lookupURL</CODE></i>
 * <dd>Either a comma-separated list of groups in which all the services
 * in the group will be regsitered or a URL to a specific lookup service.
 * <p>
 * <dt><i><CODE>service-type</CODE></i>|<i><CODE>attribute</CODE></i>
```

```
 * <dd>A combination (in any order) of service types and attribute definitions.
 * Service types are specfied as types that the service must be an instance of.
 * Attribute definitions are either <CODE>Entry</CODE> type names,
 * which declare that the service must have an attribute of that type,
 * or <CODE>Entry</CODE> type names with a single <CODE>String</CODE>
 * parameter for the constructor, as in
 * <CODE><i>AttributeType</i>:<i>stringArg</i></CODE>.
 * </dl>
 * <p>The lookups are searched for a <CODE>MessageStream</CODE> that
 * supports any additional service types specfied and that matches all
 * specified attributes.  If one is found, then <CODE><i>count</i></CODE>
 * messages are printed from it.  If a <CODE>RemoteException</CODE>
 * occurs the <CODE>nextMessage</CODE> invocation is retried up to
 * a maximum number of times.
 * <P>
 * This class is designed to be subclassed.  As an example, see
 * <CODE>chatter.Chatter</CODE>.
 *
 * @see message.MessageStream
 * @see chatter.Chatter
 */
public class StreamReader implements DiscoveryListener {
    /**
     * The number of messages to print.
     */
    private int count;

    /**
     * The lookup groups (or an empty array).
     */
    private String[] groups = new String[0];

    /**
     * The lookup URL (or <code>null</code>).
     */
    private String lookupURL;

    /**
     * The stream and attribute types.
     */
    private String[] typeArgs;

    /**
     * The list of unexamined registrars.
     */
    private List registrars = new LinkedList();

    /**
```

```
     * How long to wait for matches before giving up.
     */
    private final static int MAX_WAIT = 5000;   // five seconds

    /**
     * Maximum number of retries of <code>nextMessage</code>.
     */
    private final static int MAX_RETRIES = 5;

    /**
     * Run the program.
     *
     * @param args      The command-line arguments
     *
     * @see #StreamReader
     */
    public static void main(String[] args) throws Exception
    {
        StreamReader reader = new StreamReader(args);
        reader.execute();
    }

    /**
     * Create a new <code>StreamReader</code> object from the
     * given command line arguments.
     */
    public StreamReader(String[] args) {
        // parse command into the fields count, groups,
        // lookupURL, and typesArgs...
        if (args.length == 0) {
            usage();
            throw new IllegalArgumentException();
        }

        int start;
        if (!args[0].equals("-c")) {
            count = 1;
            start = 0;
        } else {
            count = Integer.parseInt(args[1]);
            start = 2;
        }

        if (args[start].indexOf(':') < 0)
            groups = util.ParseUtil.parseGroups(args[start]);
        else
            lookupURL = args[start];
        typeArgs = new String[args.length - start - 1];
```

```
        System.arraycopy(args, start + 1, typeArgs, 0, typeArgs.length);
    }

    /**
     * Print out a usage message.
     */
    private void usage() {
        System.err.println("usage: java [java-options] " + StreamReader.class +
            " [-c count] groups|lookupURL [service-type|attribute ...]");
    }

    /**
     * Execute the program by consuming messages.
     */
    public void execute() throws Exception {
        if (System.getSecurityManager() == null)
            System.setSecurityManager(new RMISecurityManager());

        // Create lookup discovery object and have it notify us
        LookupDiscovery ld = new LookupDiscovery(groups);
        ld.addDiscoveryListener(this);

        searchDiscovered(); // search discovered lookup services
    }

    /**
     * Search through an discovered lookup services.
     */
    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
    }

    /**
     * Build up a <code>ServiceTemplate</code> object for
     * matching based on the types listed on the command line.
     */
    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);
    }

    /**
     * Create an attribute from the class name and optional argument.
     */
    private Object attribute(Class cl, String arg)
        throws IllegalAccessException, InstantiationException,
               NoSuchMethodException, InvocationTargetException
    {
        if (arg == null)
            return cl.newInstance();
        else {
            Class[] argTypes = new Class[] { String.class };
            Constructor ctor = cl.getConstructor(argTypes);
            Object[] args = new Object[] { arg };
            return ctor.newInstance(args);
        }
    }


    /**
     * Notified by <code>LookupDiscovery</code> code when it finds one
     * or more registries.  This implementation adds it to the list of
     * known registries and notifies any waiting thread.
     */
    public synchronized void discovered(DiscoveryEvent ev) {
        ServiceRegistrar[] regs = ev.getRegistrars();
        for (int i = 0; i < regs.length; i++)
            registrars.add(regs[i]);
        notifyAll(); // notify waiters that the list has changed
    }

    /**
     * Notified by <code>LookupDiscovery</code> code when one or more
     * found registries vanishes.  This implementation removes it from
     * the list of known registries.  No notification is necessary
     * since the only waiting threads are waiting for additions, not
     * subtractions.
     */
    public synchronized void discarded(DiscoveryEvent ev) {
        ServiceRegistrar[] regs = ev.getRegistrars();
        for (int i = 0; i < regs.length; i++)
```

```
            registrars.remove(regs[i]);
        notifyAll(); // notify waiters that the list has changed
    }

    /**
     * Read the required number of messages from the given stream.
     */
    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);
                }
            }
        }
    }

    /**
     * Print out the message in a reasonable format.
     */
    public void printMessage(int msgNum, Object msg) {
        if (msgNum > 0) // print separator
            System.out.println("---");
```

```
            System.out.println(msg);
        }
    }
```

```
package fortune;

import message.MessageStream;

import java.io.DataOutputStream;
import java.io.File;
import java.io.FileOutputStream;
import java.io.IOException;
import java.io.RandomAccessFile;
import java.util.ArrayList;
import java.util.List;

import java.rmi.activation.ActivationException;

/**
 * Administer a <code>FortuneStreamImpl</code>.
 * <pre>
 *      java [<i>java options</i>] fortune.FortuneAdmin <i>database-dir</i>
 * </pre>
 * The database is initialized from the fortune set in the directory's
 * <code>fortunes</code> file, creating a file named <code>pos</code> that
 * contains each fortune's starting position.  The <code>fortunes</code>
 * file must be present.  The <code>pos</code> file, if it exists, will
 * be overwritten.
 *
 * @see FortuneStreamImpl
 */
public class FortuneAdmin {
    /**
     * Run the FortuneAdmin utility.  The class comment describes the
     * possibilities.
     *
     * @param args
     *          The arguments passed on the command line
     *
     * @see FortuneAdmin
     */
    public static void main(String[] args) throws Exception {
        if (args.length != 1)
            usage();
        else
            setup(args[0]);
    }

    /**
     * Set up a directory, reading its <code>fortunes</code> file and
     * creating a correct <code>pos</code> file.
     *
```

```
     * @param dir
     *          The fortune database directory.
     * @throws java.io.IOException
     *          Some error accessing the database files.
     */
    private static void setup(String dir) throws IOException {
        File fortuneFile = new File(dir, "fortunes");
        File posFile = new File(dir, "pos");
        if (posFile.lastModified() > fortuneFile.lastModified()) {
            System.out.println("positions up to date");
            return;
        }

        System.out.print("positions out of date, updating");
        // Open the fortunes file
        RandomAccessFile fortunes =
            new RandomAccessFile(new File(dir, "fortunes"), "r");

        // Remember the start of each fortune
        List positions = new ArrayList();
        positions.add(new Long(0));
        String line;
        while ((line = fortunes.readLine()) != null)
            if (line.startsWith("%%"))
                positions.add(new Long(fortunes.getFilePointer()));
        fortunes.close();

        // Write the pos file
        DataOutputStream pos =
            new DataOutputStream(new FileOutputStream(new File(dir, "pos")));
        int size = positions.size();
        pos.writeLong(size);
        for (int i = 0; i < size; i++)
            pos.writeLong(((Long) positions.get(i)).longValue());
        pos.close();
        System.out.println();
    }

    /**
     * Print out a usage message.
     */
    private static void usage() {
        System.out.println("usage: java [java-options] " + FortuneAdmin.class +
            " database-dir");
    }
}
```

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fortune.FortuneStream

```
package fortune;

import message.MessageStream;

import java.rmi.Remote;
import java.rmi.RemoteException;

/**
 * A <CODE>FortuneStream</CODE> is a <CODE>MessageStream</CODE> whose
 * <CODE>nextMessage</CODE> method returns a random saying on some theme.
 * The theme is returned by the <CODE>getTheme</CODE> method.
 *
 * @see FortuneTheme
 */
interface FortuneStream extends MessageStream, Remote {
    /**
     * Return the theme of the stream.  This is also represented in the
     * lookup service as a <CODE>FortuneTheme</CODE> object.
     */
    String getTheme() throws RemoteException;
}
```

```
package fortune;

import message.MessageStream;
import util.ParseUtil;

import net.jini.core.discovery.LookupLocator;
import net.jini.core.entry.Entry;
import net.jini.core.lookup.ServiceID;

import com.sun.jini.lease.LeaseRenewalManager;
import com.sun.jini.lookup.JoinManager;

import java.io.BufferedInputStream;
import java.io.DataInputStream;
import java.io.DataOutputStream;
import java.io.EOFException;
import java.io.File;
import java.io.FileInputStream;
import java.io.IOException;
import java.io.RandomAccessFile;
import java.rmi.Remote;
import java.rmi.RMISecurityManager;
import java.rmi.server.UnicastRemoteObject;
import java.util.Random;

/**
 * Implement a <code>MessageStream</code> whose
 * <code>nextMessage</code> method returns ``fortune cookie'' selected
 * at random.  The stream is an activatable remote object.  It requires
 * no special proxy because there is no client-side state or smarts --
 * the simple RMI stub works perfectly for this use.
 *
 * <code>FortuneStreamImpl</code> objects are created using the
 * <code>create</code>.  It's only public constructor is designed for
 * use by the activation system itself.  The class
 * <code>FortuneAdmin</code> provides a program that will invoke
 * <code>create</code>.
 *
 * @see FortuneAdmin
 */
public class FortuneStreamImpl implements FortuneStream {
    /**
     * Groups to register with (or an empty array).
     */
    private String[] groups = new String[0];

    /**
     * URL to specific join manager (or <CODE>null</CODE>).
```

```
     */
    private String lookupURL;

    /**
     * The directory we work in.
     */
    private String dir;

    /**
     * The theme of this stream.
     */
    private String theme;

    /**
     * The random number generator we use.
     */
    private Random random = new Random();

    /**
     * The positions of the start of each fortune in the file.
     */
    private long[] positions;

    /**
     * The file that contains the fortunes.
     */
    private RandomAccessFile fortunes;

    /**
     * The join manager does most work required of services in Jini systems.
     */
    private JoinManager joinMgr;

    /**
     * @param args      The command line arguments.
     */
    public static void main(String[] args) throws Exception
    {
        FortuneStreamImpl f = new FortuneStreamImpl(args);
        f.execute();
    }

    /**
     * Create a stream that reads from the given directory.
     *
     * @param dir       The directory name.
     */
    private FortuneStreamImpl(String args[])
```

```
        throws IOException
    {
        // Set the groups, lookupURL, dir, and theme
        // fields...
        if (args.length != 3) {
            usage();
            throw new IllegalArgumentException();
        }
        if (args[0].indexOf(':') < 0)
            groups = util.ParseUtil.parseGroups(args[0]);
        else
            lookupURL = args[0];
        dir = args[1];
        theme = args[2];
    }

    /**
     * Print out a usage message.
     */
    private void usage() {
        System.err.println("usage: java " + FortuneStreamImpl.class +
            " groups|lookupURL database-dir theme");
    }

    /**
     * Export this service as a UnicastRemoteObject for debugging purposes.
     *
     * @see #main
     */
    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);
    }
```

```
/**
 * Called when the database needs to be set up.  This can be called
 * multiple times, for example if the database has been modified while
 * the service is running.
 *
 * @throws java.io.IOException
 *         Some problem occurred accessing the database files.
 */
private synchronized void setupFortunes() throws IOException {
    // Read in the position of each fortune
    File posFile = new File(dir, "pos");
    DataInputStream in = new DataInputStream(
        new BufferedInputStream(new FileInputStream(posFile)));
    int count = (int) in.readLong();
    positions = new long[count];
    for (int i = 0; i < positions.length; i++)
        positions[i] = in.readLong();
    in.close();

    // Close the fortune file if previously opened
    if (fortunes != null)
        fortunes.close();
    // Open up the fortune file
    fortunes = new RandomAccessFile(new File(dir, "fortunes"), "r");
}

/**
 * Return the next message from the stream.  Since messages are
 * selected at random, any message is as good as any other and so
 * this is idempotent by contract: there will be no violation of
 * the contract if the client calls it a second time after getting
 * a <code>RemoteException</code>.  The <CODE>Object</CODE> returned
 * is a <CODE>String</CODE> with embeded newlines, but no trailing
 * newline.
 *
 * @throws java.io.EOFException
 *         The database has been corrupted -- no more messages
 *         from this stream.
 */
public synchronized Object nextMessage() throws EOFException {
    try {
        int which = random.nextInt(positions.length);
        fortunes.seek(positions[which]);
        StringBuffer buf = new StringBuffer();
        String line;
        while ((line = fortunes.readLine()) != null && !line.equals("%%")) {
            if (buf.length() > 0)
```

```
                buf.append('\n');
            buf.append(line);
        }
        return buf.toString();
    } catch (IOException e) {
        throw new EOFException("directory not available:" + e.getMessage());
    }
}

// inherit doc comment from interface
public String getTheme() {
    return theme;
}
}
```

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fortune.FortuneTheme

```
package fortune;

import net.jini.entry.AbstractEntry;
import net.jini.lookup.entry.ServiceControlled;

/**
 * This class is used as an attribute in the lookup system to tell
 * the user what theme of fortunes a stream generates.
 */
public class FortuneTheme extends AbstractEntry
    implements ServiceControlled
{
    /**
     * The serial version UID.  Stating it explicitly allows future
     * evolution with a guaranteed consistency of the UID itself.  It
     * is also more efficient since otherwise the UID must be calculated
     * when the class is serialized.  A good specification should include
     * the serial version UID of each class.
     */
    static final long serialVersionUID =
                            -1696813496901296488L;

    /**
     * The theme of this collection of fortunes.
     *
     * @see fortune.FortuneStream#getTheme
     * @serial
     */
    public String theme;

    /**
     * Public no-arg constructor.  Required for all <CODE>Entry</CODE>
     * objects.
     */
    public FortuneTheme() { }

    /**
     * Create a new <CODE>FortuneTheme</CODE> with the given theme.
     */
    public FortuneTheme(String theme) {
        this.theme = theme;
    }
}
```

```
package message;

import java.io.EOFException;
import java.rmi.RemoteException;

/**
 * This interface defines a message stream service.  Successive
 * invocations of <code>nextMessage</code> return the next message in
 * turn.  Subinterfaces may add methods to rewind the stream or
 * otherwise move around within the stream if appropriate.
 */
public interface MessageStream {
    /**
     * Return the next message in the stream.  Each message is an
     * object whose default method of display is a string returned by
     * its <CODE>toString</CODE> method.  This method is idempotent: if
     * the client receives a <code>RemoteException</code>, the next
     * invocation from the client should return an equivalent message.
     * A service may specify which kinds of messages will be returned.
     *
     * @returns The next message as an <CODE>Object</CODE>.
     * @throws  java.io.EOFException
     *          The end of the stream has been reached.
     * @throws  java.rmi.RemoteException
     *          A remote exception has occurred.
     */
    Object nextMessage()
        throws EOFException, RemoteException;
}
```

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util.ParseUtil

```
package util;

import java.util.HashSet;
import java.util.Set;
import java.util.StringTokenizer;

/**
 * This class holds the static <CODE>parseGroups</CODE> method.
 */
public class ParseUtil {
    /**
     * Break up a comma-separated list of groups into an array of strings.
     *
     * @param groupDesc A comma-separated list of groups.
     * @returns         An array of strings (empty if none were specified).
     */
    public static String[] parseGroups(String groupDesc) {
        if (groupDesc.equals(""))
            return new String[] {""};
        Set groups = new HashSet();
        StringTokenizer strs = new StringTokenizer(groupDesc, ", \t\n");
        while (strs.hasMoreTokens())
            groups.add(strs.nextToken());
        return (String[]) groups.toArray(new String[groups.size()]);
    }
}
```

Index

It's a d–mn poor mind that can only think of one way to spell a word!
—Andrew Jackson

A

D

E

F

G

H

I

J

L

M

N

O

P

Q

R

S

T

Colophon

***Collaboration**, n.:*
A literary partnership based on the false assumption that the other people can spell.

THIS book is set in 11 point Times Roman, with variations of size, angle, and weight for headers, chapter quotes, and diagram labels. All code is set in `Lucida Sans Typewriter` at 83% of the surrounding text size. A few decorations are in Zapf Dingbats.

The text was written using FrameMaker on several Sun workstations and two Macintosh laptop computers.

Code examples in the introductory material and its associated appendix were written and compiled on the Solaris systems and then broken into fragments by a Perl script looking for specially formatted comments. Source fragments and generated output were inserted in the book by another Perl script.

NOTE TO TRANSLATORS

The fonts in this book have been chosen carefully. The font for code, when mixed with body text, has the same "x" height and roughly the same weight and "color." `Code` in text looks even—if you read quickly it can seem like body text, but it is nonetheless easy to tell that `code` text *is* different. Please use the fonts that we have used (we would be happy to help you locate any that you do not have) or choose other code and body fonts that are balanced in the same way.

ABOUT THE AUTHORS

KEN ARNOLD, of Sun Microsystems, Inc., is one of the original architects of the Jini technology and is the lead engineer of Sun's JavaSpaces technology. He is the co-author, with James Gosling, of *The Java Programming Language* and is a leading expert in object-oriented design, C, C++ and distributed computing.

BRYAN O'SULLIVAN, while at Sun Microsystems, Inc., developed the Jini Discovery and Join Protocol. He supports his rock climbing habit by designing and building distributed systems.

ROBERT W. SCHEIFLER is a Senior Staff Engineer and one of the original architects of Jini technology with Sun Microsystems, where he has been responsible for the design and implementation of the lookup service and the associated discovery protocol and attribute schema. Before joining Sun, he spent nine years as Director and then President of the X Consortium, a non-profit organization devoted to the development and evolution of the X Window System. He was chief architect of the X Window System protocol, and created the Consortium originally while a principal research scientist at the MIT Laboratory for Computer Science.

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