

Networking

28

Objectives

In this chapter you'll:

- Implement Java networking applications by using sockets and datagrams.
- Implement Java clients and servers that communicate with one another.
- Implement network-based collaborative applications.



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Outline

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28.1 Introduction¹

Java provides a number of built-in networking capabilities that make it easy to develop Internet-based and web-based applications. Java can enable programs to search the world for information and to collaborate with programs running on other computers internationally, nationally or just within an organization (subject to security constraints).

Java's fundamental networking capabilities are declared by the classes and interfaces of package **java.net**, through which Java offers **stream-based communications** that enable applications to view networking as streams of data. The classes and interfaces of package **java.net** also offer **packet-based communications** for transmitting individual **packets** of information—commonly used to transmit data images, audio and video over the Internet. In this chapter, we show how to communicate with packets and streams of data.

We focus on both sides of the **client/server relationship**. The **client** *requests* that some action be performed, and the **server** performs the action and *responds* to the client. A common implementation of the *request-response model* is between web browsers and web servers. When a user selects a website to browse through a browser (the client application), a request is sent to the appropriate web server (the server application). The server normally responds to the client by sending an appropriate web page to be rendered by the browser.

We introduce Java's **socket-based communications**, which enable applications to view networking as if it were *file I/O*—a program can read from a **socket** or write to a socket as simply as reading from a file or writing to a file. The socket is simply a software construct that represents one endpoint of a connection. We show how to create and manipulate *stream sockets* and *datagram sockets*. With **stream sockets**, a process establishes a **connection** to another process. While the connection is in place, data flows between the processes in continuous **streams**. Stream sockets are said to provide a **connection-oriented service**. The protocol used for transmission is the popular **TCP (Transmission Control Protocol)**.

With **datagram sockets**, individual **packets** of information are transmitted. The protocol used—**UDP, the User Datagram Protocol**—is a **connectionless service** and does *not* guarantee that packets arrive in any particular *order*. With UDP, packets can even be *lost* or *duplicated*. Significant extra programming is required on your part to deal with these problems (if you choose to do so). UDP is most appropriate for network applications that do not require the error checking and reliability of TCP. Stream sockets and the TCP protocol will be more desirable for the vast majority of Java networking applications.

1. This is a legacy chapter posted as is from the book's 10th edition.

28.2 Reading a File on a Web Server

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**Performance Tip 28.1**

Connectionless services generally offer greater performance but less reliability than connection-oriented services.

**Portability Tip 28.1**

TCP, UDP and related protocols enable heterogeneous computer systems (i.e., those with different processors and different operating systems) to intercommunicate.

For interested readers, we provide at

<http://www.deitel.com/books/jhttp11>

a case study from an older edition of this book. In the case study, we implement a client/server chat application using **multicasting**, in which a server can publish information and *many* clients can *subscribe* to it. When the server publishes information, *all* subscribers receive it.

28.2 Reading a File on a Web Server

The application in Fig. 28.1 uses Swing GUI component **JEditorPane** (from package `javax.swing`) to display the contents of a file on a web server. The user enters a URL in the **JTextField** at the top of the window, and the application displays the corresponding document (if it exists) in the **JEditorPane**. Class **JEditorPane** is able to render both plain text and basic HTML-formatted text, as illustrated in the two screen captures (Fig. 28.2), so this application acts as a simple web browser. The application also demonstrates how to process **HyperlinkEvents** when the user clicks a hyperlink in the HTML document.

```

1 // Fig. 28.1: ReadServerFile.java
2 // Reading a file by opening a connection through a URL.
3 import java.awt.BorderLayout;
4 import java.awt.event.ActionEvent;
5 import java.awt.event.ActionListener;
6 import java.io.IOException;
7 import javax.swing.JEditorPane;
8 import javax.swing.JFrame;
9 import javax.swing.JOptionPane;
10 import javax.swing.JScrollPane;
11 import javax.swing.JTextField;
12 import javax.swing.event.HyperlinkEvent;
13 import javax.swing.event.HyperlinkListener;
14
15 public class ReadServerFile extends JFrame
16 {
17     private JTextField enterField; // JTextField to enter site name
18     private JEditorPane contentsArea; // to display website
19
20     // set up GUI
21     public ReadServerFile()
22     {

```

Fig. 28.1 | Reading a file by opening a connection through a URL. (Part 1 of 2.)

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```

23     super("Simple Web Browser");
24
25     // create enterField and register its listener
26     enterField = new JTextField("Enter file URL here");
27     enterField.addActionListener(
28         new ActionListener()
29     {
30         // get document specified by user
31         public void actionPerformed(ActionEvent event)
32         {
33             getThePage(event.getActionCommand());
34         }
35     });
36 );
37
38 add(enterField, BorderLayout.NORTH);
39
40 contentsArea = new JEditorPane(); // create contentsArea
41 contentsArea.setEditable(false);
42 contentsArea.addHyperlinkListener(
43     new HyperlinkListener()
44     {
45         // if user clicked hyperlink, go to specified page
46         public void hyperlinkUpdate(HyperlinkEvent event)
47         {
48             if (event.getEventType() ==
49                 HyperlinkEvent.EventType.ACTIVATED)
50                 getThePage(event.getURL().toString());
51         }
52     });
53 );
54
55 add(new JScrollPane(contentsArea), BorderLayout.CENTER);
56 setSize(400, 300); // set size of window
57 setVisible(true); // show window
58 }
59
60 // load document
61 private void getThePage(String location)
62 {
63     try // Load document and display location
64     {
65         contentsArea.setPage(location); // set the page
66         enterField.setText(location); // set the text
67     }
68     catch (IOException ioException)
69     {
70         JOptionPane.showMessageDialog(this,
71             "Error retrieving specified URL", "Bad URL",
72             JOptionPane.ERROR_MESSAGE);
73     }
74 }
75 }
```

Fig. 28.1 | Reading a file by opening a connection through a URL. (Part 2 of 2.)

28.2 Reading a File on a Web Server

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```

1 // Fig. 28.2: ReadServerFileTest.java
2 // Create and start a ReadServerFile.
3 import javax.swing.JFrame;
4
5 public class ReadServerFileTest
6 {
7     public static void main(String[] args)
8     {
9         ReadServerFile application = new ReadServerFile();
10        application.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
11    }
12 }
```



Fig. 28.2 | Test class for `ReadServerFile`.

The application class `ReadServerFile` contains `JTextField enterField`, in which the user enters the URL of the file to read and `JEditorPane contentsArea` to display the file's contents. When the user presses the *Enter* key in `enterField`, the application calls method `actionPerformed` (lines 31–34). Line 33 uses `ActionEvent` method `getActionCommand` to get the `String` the user input in the `JTextField` and passes the `String` to utility method `getThePage` (lines 61–74).

Line 65 invokes `JEditorPane` method `setPage` to download the document specified by `location` and display it in the `JEditorPane`. If there's an error downloading the document, method `setPage` throws an `IOException`. Also, if an invalid URL is specified, a `MalformedURLException` (a subclass of `IOException`) occurs. If the document loads successfully, line 66 displays the current location in `enterField`.

Typically, an HTML document contains **hyperlinks** that, when clicked, provide quick access to another document on the web. If a `JEditorPane` contains an HTML document and the user clicks a hyperlink, the `JEditorPane` generates a `HyperlinkEvent` (package `javax.swing.event`) and notifies all registered `HyperlinkListeners` (package `javax.swing.event`) of that event. Lines 42–53 register a `HyperlinkListener` to handle `HyperlinkEvents`. When a `HyperlinkEvent` occurs, the program calls method `hyperlinkUpdate` (lines 46–51). Lines 48–49 use `HyperlinkEvent` method `getEventType` to determine the type of the `HyperlinkEvent`. Class `HyperlinkEvent` contains a public nested class called `EventType` that declares three static `EventType` objects, which represent the hyperlink event types. `ACTIVATED` indicates that the user clicked a hyperlink to change web pages, `ENTERED` indicates that the user moved the mouse over a hyperlink and `EXITED` indicates that the user moved the mouse away from a hyperlink. If a hyperlink was `ACTIVATED`, line 50 uses `HyperlinkEvent` method `getURL` to obtain the URL represented by the hyperlink. Method `toString` converts the returned URL to a `String` that can be passed to utility method `getThePage`.

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Look-and-Feel Observation 28.1



A `JEditorPane` generates `HyperlinkEvents` only if it's uneditable.

28.3 Establishing a Simple Server Using Stream Sockets

The two examples discussed so far use *high-level* Java networking capabilities to communicate between applications. In the examples, it was not your responsibility to establish the connection between a client and a server. The first program relied on the web browser to communicate with a web server. The second program relied on a `JEditorPane` to perform the connection. This section begins our discussion of creating your own applications that can communicate with one another.

Step 1: Create a `ServerSocket`

Establishing a simple server in Java requires five steps. *Step 1* is to create a `ServerSocket` object. A call to the `ServerSocket` constructor, such as

```
ServerSocket server = new ServerSocket(portNumber, queueLength);
```

registers an available TCP **port number** and specifies the maximum number of clients that can wait to connect to the server (i.e., the **queue length**). The port number is used by clients to locate the server application on the server computer. This is often called the **handshake point**. If the queue is full, the server refuses client connections. The constructor establishes the port where the server waits for connections from clients—a process known as **binding the server to the port**. Each client will ask to connect to the server on this **port**. Only one application at a time can be bound to a specific port on the server.

Software Engineering Observation 28.1



Port numbers can be between 0 and 65,535. Most operating systems reserve port numbers below 1024 for system services (e.g., e-mail and World Wide Web servers). Generally, these ports should not be specified as connection ports in user programs. In fact, some operating systems require special access privileges to bind to port numbers below 1024.

Step 2: Wait for a Connection

Programs manage each client connection with a `Socket` object. In *Step 2*, the server listens indefinitely (or **blocks**) for an attempt by a client to connect. To listen for a client connection, the program calls `ServerSocket` method `accept`, as in

```
Socket connection = server.accept();
```

which returns a `Socket` when a connection with a client is established. The `Socket` allows the server to interact with the client. The interactions with the client actually occur at a different server port from the *handshake point*. This allows the port specified in *Step 1* to be used again in a multithreaded server to accept another client connection. We demonstrate this concept in Section 28.7.

Step 3: Get the `Socket`'s I/O Streams

Step 3 is to get the `OutputStream` and `InputStream` objects that enable the server to communicate with the client by sending and receiving bytes. The server sends information to

28.3 Establishing a Simple Server Using Stream Sockets

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the client via an `OutputStream` and receives information from the client via an `InputStream`. The server invokes method `getOutputStream` on the `Socket` to get a reference to the `Socket`'s `OutputStream` and invokes method `getInputStream` on the `Socket` to get a reference to the `Socket`'s `InputStream`.

The stream objects can be used to send or receive individual bytes or sequences of bytes with the `OutputStream`'s method `write` and the `InputStream`'s method `read`, respectively. Often it's useful to send or receive values of primitive types (e.g., `int` and `double`) or `Serializable` objects (e.g., `Strings` or other serializable types) rather than sending bytes. In this case, we can use the techniques discussed in Chapter 15 to wrap other stream types (e.g., `ObjectOutputStream` and `ObjectInputStream`) around the `OutputStream` and `InputStream` associated with the `Socket`. For example,

```
ObjectInputStream input =
    new ObjectInputStream(connection.getInputStream());
ObjectOutputStream output =
    new ObjectOutputStream(connection.getOutputStream());
```

The beauty of establishing these relationships is that whatever the server writes to the `ObjectOutputStream` is sent via the `OutputStream` and is available at the client's `InputStream`, and whatever the client writes to its `OutputStream` (with a corresponding `ObjectOutputStream`) is available via the server's `InputStream`. The transmission of the data over the network is seamless and is handled completely by Java.

Step 4: Perform the Processing

Step 4 is the *processing* phase, in which the server and the client communicate via the `OutputStream` and `InputStream` objects.

Step 5: Close the Connection

In *Step 5*, when the transmission is complete, the server closes the connection by invoking the `close` method on the streams and on the `Socket`.



Software Engineering Observation 28.2

With sockets, network I/O appears to Java programs to be similar to sequential file I/O. Sockets hide much of the complexity of network programming.



Software Engineering Observation 28.3

A multithreaded server can take the `Socket` returned by each call to `accept` and create a new thread that manages network I/O across that `Socket`. Alternatively, a multithreaded server can maintain a pool of threads (a set of already existing threads) ready to manage network I/O across the new `Sockets` as they're created. These techniques enable multithreaded servers to manage many simultaneous client connections.



Performance Tip 28.2

In high-performance systems in which memory is abundant, a multithreaded server can create a pool of threads that can be assigned quickly to handle network I/O for new `Sockets` as they're created. Thus, when the server receives a connection, it need not incur thread-creation overhead. When the connection is closed, the thread is returned to the pool for reuse.

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28.4 Establishing a Simple Client Using Stream Sockets

Establishing a simple client in Java requires four steps.

Step 1: Create a Socket to Connect to the Server

In *Step 1*, we create a `Socket` to connect to the server. The `Socket` constructor establishes the connection. For example, the statement

```
Socket connection = new Socket(serverAddress, port);
```

uses the `Socket` constructor with two arguments—the server's address (`serverAddress`) and the `port` number. If the connection attempt is successful, this statement returns a `Socket`. A connection attempt that fails throws an instance of a subclass of `IOException`, so many programs simply catch `IOException`. An `UnknownHostException` occurs specifically when the system is unable to resolve the server name specified in the call to the `Socket` constructor to a corresponding IP address.

Step 2: Get the Socket's I/O Streams

In *Step 2*, the client uses `Socket` methods `getInputStream` and `getOutputStream` to obtain references to the `Socket`'s `InputStream` and `OutputStream`. As we mentioned in the preceding section, we can use the techniques of Chapter 15 to wrap other stream types around the `InputStream` and `OutputStream` associated with the `Socket`. If the server is sending information in the form of actual types, the client should receive the information in the same format. Thus, if the server sends values with an `ObjectOutputStream`, the client should read those values with an `ObjectInputStream`.

Step 3: Perform the Processing

Step 3 is the processing phase in which the client and the server communicate via the `InputStream` and `OutputStream` objects.

Step 4: Close the Connection

In *Step 4*, the client closes the connection when the transmission is complete by invoking the `close` method on the streams and on the `Socket`. The client must determine when the server is finished sending information so that it can call `close` to close the `Socket` connection. For example, the `InputStream` method `read` returns the value `-1` when it detects end-of-stream (also called EOF—end-of-file). If an `ObjectInputStream` reads information from the server, an `EOFException` occurs when the client attempts to read a value from a stream on which end-of-stream is detected.

28.5 Client/Server Interaction with Stream Socket Connections

Figures 28.3 and 28.5 use stream sockets, `ObjectInputStream` and `ObjectOutputStream` to demonstrate a simple **client/server chat application**. The server waits for a client connection attempt. When a client connects to the server, the server application sends the client a `String` object (recall that `Strings` are `Serializable` objects) indicating that the connection was successful. Then the client displays the message. The client and server applications each provide text fields that allow the user to type a message and send it to the other application. When the client or the server sends the `String` "TERMINATE", the con-

28.5 Client/Server Interaction with Stream Socket Connections

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nection terminates. Then the server waits for the next client to connect. The declaration of class `Server` appears in Fig. 28.3. The declaration of class `Client` appears in Fig. 28.5. The screen captures showing the execution between the client and the server are shown in Fig. 28.6.

Server Class

Server's constructor (Fig. 28.3, lines 30–55) creates the server's GUI, which contains a `JTextField` and a `JTextArea`. Server displays its output in the `JTextArea`. When the `main` method (lines 6–11 of Fig. 28.4) executes, it creates a `Server` object, specifies the window's default close operation and calls method `runServer` (Fig. 28.3, lines 57–86).

```

1 // Fig. 28.3: Server.java
2 // Server portion of a client/server stream-socket connection.
3 import java.io.EOFException;
4 import java.io.IOException;
5 import java.io.ObjectInputStream;
6 import java.io.ObjectOutputStream;
7 import java.net.ServerSocket;
8 import java.net.Socket;
9 import java.awt.BorderLayout;
10 import java.awt.event.ActionEvent;
11 import java.awt.event.ActionListener;
12 import javax.swing.JFrame;
13 import javax.swing.JScrollPane;
14 import javax.swing.JTextArea;
15 import javax.swing.JTextField;
16 import javax.swing.SwingUtilities;
17
18 public class Server extends JFrame
19 {
20     private JTextField enterField; // inputs message from user
21     private JTextArea displayArea; // display information to user
22     private ObjectOutputStream output; // output stream to client
23     private ObjectInputStream input; // input stream from client
24     private ServerSocket server; // server socket
25     private Socket connection; // connection to client
26     private int counter = 1; // counter of number of connections
27
28     // set up GUI
29     public Server()
30     {
31         super("Server");
32
33         enterField = new JTextField(); // create enterField
34         enterField.setEditable(false);
35         enterField.addActionListener(
36             new ActionListener()
37             {
38                 // send message to client
39                 public void actionPerformed(ActionEvent event)
40                 {

```

Fig. 28.3 | Server portion of a client/server stream-socket connection. (Part I of 4.)

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```
41             sendData(event.getActionCommand());
42         }
43     }
44 }
45 );
46
47 add(enterField, BorderLayout.NORTH);
48
49 displayArea = new JTextArea(); // create displayArea
50 add(new JScrollPane(displayArea), BorderLayout.CENTER);
51
52 setSize(300, 150); // set size of window
53 setVisible(true); // show window
54 }
55
56 // set up and run server
57 public void runServer()
58 {
59     try // set up server to receive connections; process connections
60     {
61         server = new ServerSocket(12345, 100); // create ServerSocket
62
63         while (true)
64         {
65             try
66             {
67                 waitForConnection(); // wait for a connection
68                 getStreams(); // get input & output streams
69                 processConnection(); // process connection
70             }
71             catch (EOFException eofException)
72             {
73                 displayMessage("\nServer terminated connection");
74             }
75             finally
76             {
77                 closeConnection(); // close connection
78                 ++counter;
79             }
80         }
81     }
82     catch (IOException ioException)
83     {
84         ioException.printStackTrace();
85     }
86 }
87
88 // wait for connection to arrive, then display connection info
89 private void waitForConnection() throws IOException
90 {
91     displayMessage("Waiting for connection\n");
92     connection = server.accept(); // allow server to accept connection
```

Fig. 28.3 | Server portion of a client/server stream-socket connection. (Part 2 of 4.)

28.5 Client/Server Interaction with Stream Socket Connections

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```

93     displayMessage("Connection " + counter + " received from: " +
94         connection.getInetAddress().getHostName());
95 }
96
97 // get streams to send and receive data
98 private void getStreams() throws IOException
99 {
100     // set up output stream for objects
101     output = new ObjectOutputStream(connection.getOutputStream());
102     output.flush(); // flush output buffer to send header information
103
104     // set up input stream for objects
105     input = new ObjectInputStream(connection.getInputStream());
106
107     displayMessage("\nGot I/O streams\n");
108 }
109
110 // process connection with client
111 private void processConnection() throws IOException
112 {
113     String message = "Connection successful";
114     sendData(message); // send connection successful message
115
116     // enable enterField so server user can send messages
117     setTextFieldEditable(true);
118
119     do // process messages sent from client
120     {
121         try // read message and display it
122         {
123             message = (String) input.readObject(); // read new message
124             displayMessage("\n" + message); // display message
125         }
126         catch (ClassNotFoundException classNotFoundException)
127         {
128             displayMessage("\nUnknown object type received");
129         }
130
131     } while (!message.equals("CLIENT>>> TERMINATE"));
132 }
133
134 // close streams and socket
135 private void closeConnection()
136 {
137     displayMessage("\nTerminating connection\n");
138     setTextFieldEditable(false); // disable enterField
139
140     try
141     {
142         output.close(); // close output stream
143         input.close(); // close input stream
144         connection.close(); // close socket
145     }

```

Fig. 28.3 | Server portion of a client/server stream-socket connection. (Part 3 of 4.)

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```

146     catch (IOException ioException)
147     {
148         ioException.printStackTrace();
149     }
150 }
151
152 // send message to client
153 private void sendData(String message)
154 {
155     try // send object to client
156     {
157         output.writeObject("SERVER>> " + message);
158         output.flush(); // flush output to client
159         displayMessage("\nSERVER>> " + message);
160     }
161     catch (IOException ioException)
162     {
163         displayArea.append("\nError writing object");
164     }
165 }
166
167 // manipulates displayArea in the event-dispatch thread
168 private void displayMessage(final String messageToDisplay)
169 {
170     SwingUtilities.invokeLater(
171         new Runnable()
172         {
173             public void run() // updates displayArea
174             {
175                 displayArea.append(messageToDisplay); // append message
176             }
177         }
178     );
179 }
180
181 // manipulates enterField in the event-dispatch thread
182 private void setTextFieldEditable(final boolean editable)
183 {
184     SwingUtilities.invokeLater(
185         new Runnable()
186         {
187             public void run() // sets enterField's editability
188             {
189                 enterField.setEditable(editable);
190             }
191         }
192     );
193 }
194 }
```

Fig. 28.3 | Server portion of a client/server stream-socket connection. (Part 4 of 4.)

28.5 Client/Server Interaction with Stream Socket Connections

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```

1 // Fig. 28.4: ServerTest.java
2 // Test the Server application.
3 import javax.swing.JFrame;
4
5 public class ServerTest
6 {
7     public static void main(String[] args)
8     {
9         Server application = new Server(); // create server
10        application.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
11        application.runServer(); // run server application
12    }
13 }
```

Fig. 28.4 | Test class for Server.

Method *runServer*

Method *runServer* (Fig. 28.3, lines 57–86) sets up the server to receive a connection and processes one connection at a time. Line 61 creates a *ServerSocket* called *server* to wait for connections. The *ServerSocket* listens for a connection from a client at port 12345. The second argument to the constructor is the number of connections that can wait in a queue to connect to the server (100 in this example). If the queue is full when a client attempts to connect, the server refuses the connection.



Common Programming Error 28.1

Specifying a port that's already in use or specifying an invalid port number when creating a ServerSocket results in a BindException.

Line 67 calls method *waitForConnection* (declared at lines 89–95) to wait for a client connection. After the connection is established, line 68 calls method *getStreams* (declared at lines 98–108) to obtain references to the connection's streams. Line 69 calls method *processConnection* (declared at lines 111–132) to send the initial connection message to the client and to process all messages received from the client. The *finally* block (lines 75–79) terminates the client connection by calling method *closeConnection* (lines 135–150), even if an exception occurs. These methods call *displayMessage* (lines 168–179), which uses the event-dispatch thread to display messages in the application's *JTextArea*. **SwingUtilities** method *invokeLater* receives a *Runnable* object as its argument and places it into the event-dispatch thread for execution. This ensures that we don't modify a GUI component from a thread other than the event-dispatch thread, which is important since *Swing GUI components are not thread safe*. We use a similar technique in method *setTextFieldEditable* (lines 182–193), to set the editability of *enterField*. For more information on interface *Runnable*, see Chapter 23.

Method *waitForConnection*

Method *waitForConnection* (lines 89–95) uses *ServerSocket* method *accept* (line 92) to wait for a connection from a client. When a connection occurs, the resulting *Socket* is assigned to *connection*. Method *accept* blocks until a connection is received (i.e., the thread in which *accept* is called stops executing until a client connects). Lines 93–94 output the host name of the computer that made the connection. *Socket* method *getInet-*

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Address returns an **InetAddress** (package `java.net`) containing information about the client computer. **InetAddress** method `getHostName` returns the host name of the client computer. For example, a special IP address (**127.0.0.1**) and host name (**localhost**) are useful for testing networking applications on your local computer (this is also known as the **loopback address**). If `getHostName` is called on an **InetAddress** containing **127.0.0.1**, the corresponding host name returned by the method will be **localhost**.

Method `getStreams`

Method `getStreams` (lines 98–108) obtains the `Socket`'s streams and uses them to initialize an `ObjectOutputStream` (line 101) and an `ObjectInputStream` (line 105), respectively. Note the call to `ObjectOutputStream` method `flush` at line 102. This statement causes the `ObjectOutputStream` on the server to send a **stream header** to the corresponding client's `ObjectInputStream`. The stream header contains such information as the version of object serialization being used to send objects. This information is required by the `ObjectInputStream` so that it can prepare to receive those objects correctly.



Software Engineering Observation 28.4

When using `ObjectOutputStream` and `ObjectInputStream` to send and receive data over a network connection, always create the `ObjectOutputStream` first and `flush` the stream so that the client's `ObjectInputStream` can prepare to receive the data. This is required for networking applications that communicate using `ObjectOutputStream` and `ObjectInputStream`.



Performance Tip 28.3

A computer's I/O components are typically much slower than its memory. Output buffers are used to increase the efficiency of an application by sending larger amounts of data fewer times, reducing the number of times an application accesses the computer's I/O components.

Method `processConnection`

Line 114 of method `processConnection` (lines 111–132) calls method `sendData` to send "SERVER>>> Connection successful" as a `String` to the client. The loop at lines 119–131 executes until the server receives the message "CLIENT>>> TERMINATE". Line 123 uses `ObjectInputStream` method `readObject` to read a `String` from the client. Line 124 invokes method `displayMessage` to append the message to the `JTextArea`.

Method `closeConnection`

When the transmission is complete, method `processConnection` returns, and the program calls method `closeConnection` (lines 135–150) to close the streams associated with the `Socket` and close the `Socket`. Then the server waits for the next connection attempt from a client by continuing with line 67 at the beginning of the `while` loop.

Server receives a connection, processes it, closes it and waits for the next connection. A more likely scenario would be a Server that receives a connection, sets it up to be processed as a separate thread of execution, then immediately waits for new connections. The separate threads that process existing connections can continue to execute while the Server concentrates on new connection requests. This makes the server more efficient, because multiple client requests can be processed concurrently. We demonstrate a *multi-threaded server* in Section 28.7.

28.5 Client/Server Interaction with Stream Socket Connections

28_15

Processing User Interactions

When the user of the server application enters a `String` in the text field and presses the `Enter` key, the program calls method `actionPerformed` (lines 39–43), which reads the `String` from the text field and calls utility method `sendData` (lines 153–165) to send the `String` to the client. Method `sendData` writes the object, flushes the output buffer and appends the same `String` to the text area in the server window. It's not necessary to invoke `displayMessage` to modify the text area here, because method `sendData` is called from an event handler—thus, `sendData` executes as part of the *event-dispatch thread*.

Client Class

Like class `Server`, class `Client`'s constructor (Fig. 28.5, lines 29–56) creates the GUI of the application (a `JTextField` and a `JTextArea`). `Client` displays its output in the text area. When method `main` (lines 7–19 of Fig. 28.6) executes, it creates an instance of class `Client`, specifies the window's default close operation and calls method `runClient` (Fig. 28.5, lines 59–79). In this example, you can execute the client from any computer on the Internet and specify the IP address or host name of the server computer as a command-line argument to the program. For example, the command

```
java Client 192.168.1.15
```

attempts to connect to the Server on the computer with IP address 192.168.1.15.

```

1 // Fig. 28.5: Client.java
2 // Client portion of a stream-socket connection between client and server.
3 import java.io.EOFException;
4 import java.io.IOException;
5 import java.io.ObjectInputStream;
6 import java.io.ObjectOutputStream;
7 import java.net.InetAddress;
8 import java.net.Socket;
9 import java.awt.BorderLayout;
10 import java.awt.event.ActionEvent;
11 import java.awt.event.ActionListener;
12 import javax.swing.JFrame;
13 import javax.swing.JScrollPane;
14 import javax.swing.JTextArea;
15 import javax.swing.JTextField;
16 import javax.swing.SwingUtilities;
17
18 public class Client extends JFrame
19 {
20     private JTextField enterField; // enters information from user
21     private JTextArea displayArea; // display information to user
22     private ObjectOutputStream output; // output stream to server
23     private ObjectInputStream input; // input stream from server
24     private String message = ""; // message from server
25     private String chatServer; // host server for this application
26     private Socket client; // socket to communicate with server
27 }
```

Fig. 28.5 | Client portion of a stream-socket connection between client and server. (Part 1 of 5.)

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```
28 // initialize chatServer and set up GUI
29 public Client(String host)
30 {
31     super("Client");
32
33     chatServer = host; // set server to which this client connects
34
35     enterField = new JTextField(); // create enterField
36     enterField.setEditable(false);
37     enterField.addActionListener(
38         new ActionListener()
39     {
40         // send message to server
41         public void actionPerformed(ActionEvent event)
42     {
43             sendData(event.getActionCommand());
44             enterField.setText("");
45         }
46     }
47 );
48
49     add(enterField, BorderLayout.NORTH);
50
51     displayArea = new JTextArea(); // create displayArea
52     add(new JScrollPane(displayArea), BorderLayout.CENTER);
53
54     setSize(300, 150); // set size of window
55     setVisible(true); // show window
56 }
57
58 // connect to server and process messages from server
59 public void runClient()
60 {
61     try // connect to server, get streams, process connection
62     {
63         connectToServer(); // create a Socket to make connection
64         getStreams(); // get the input and output streams
65         processConnection(); // process connection
66     }
67     catch (EOFException eofException)
68     {
69         displayMessage("\nClient terminated connection");
70     }
71     catch (IOException ioException)
72     {
73         ioException.printStackTrace();
74     }
75     finally
76     {
77         closeConnection(); // close connection
78     }
79 }
```

Fig. 28.5 | Client portion of a stream-socket connection between client and server. (Part 2 of 5.)

```
80      // connect to server
81  private void connectToServer() throws IOException
82  {
83      displayMessage("Attempting connection\n");
84
85      // create Socket to make connection to server
86      client = new Socket(InetAddress.getByName(chatServer), 12345);
87
88      // display connection information
89      displayMessage("Connected to: " +
90                      client.getInetAddress().getHostName());
91  }
92
93
94      // get streams to send and receive data
95  private void getStreams() throws IOException
96  {
97      // set up output stream for objects
98      output = new ObjectOutputStream(client.getOutputStream());
99      output.flush(); // flush output buffer to send header information
100
101     // set up input stream for objects
102     input = new ObjectInputStream(client.getInputStream());
103
104     displayMessage("\nGot I/O streams\n");
105  }
106
107    // process connection with server
108  private void processConnection() throws IOException
109  {
110      // enable enterField so client user can send messages
111      setTextFieldEditable(true);
112
113      do // process messages sent from server
114      {
115          try // read message and display it
116          {
117              message = (String) input.readObject(); // read new message
118              displayMessage("\n" + message); // display message
119          }
120          catch (ClassNotFoundException classNotFoundException)
121          {
122              displayMessage("\nUnknown object type received");
123          }
124
125      } while (!message.equals("SERVER>> TERMINATE"));
126  }
127
128    // close streams and socket
129  private void closeConnection()
130  {
131      displayMessage("\nClosing connection");
132      setTextFieldEditable(false); // disable enterField
```

Fig. 28.5 | Client portion of a stream-socket connection between client and server. (Part 3 of 5.)

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```

133
134     try
135     {
136         output.close(); // close output stream
137         input.close(); // close input stream 1
138         client.close(); // close socket
139     }
140     catch (IOException ioException)
141     {
142         ioException.printStackTrace();
143     }
144 }
145
146 // send message to server
147 private void sendData(String message)
148 {
149     try // send object to server
150     {
151         output.writeObject("CLIENT>>> " + message);
152         output.flush(); // flush data to output
153         displayMessage("\nCLIENT>>> " + message);
154     }
155     catch (IOException ioException)
156     {
157         displayArea.append("\nError writing object");
158     }
159 }
160
161 // manipulates displayArea in the event-dispatch thread
162 private void displayMessage(final String messageToDisplay)
163 {
164     SwingUtilities.invokeLater(
165         new Runnable()
166         {
167             public void run() // updates displayArea
168             {
169                 displayArea.append(messageToDisplay);
170             }
171         }
172     );
173 }
174
175 // manipulates enterField in the event-dispatch thread
176 private void setTextFieldEditable(final boolean editable)
177 {
178     SwingUtilities.invokeLater(
179         new Runnable()
180         {
181             public void run() // sets enterField's editability
182             {
183                 enterField.setEditable(editable);
184             }
185         }
186     );
187 }

```

Fig. 28.5 | Client portion of a stream-socket connection between client and server. (Part 4 of 5.)

28.5 Client/Server Interaction with Stream Socket Connections

28_19

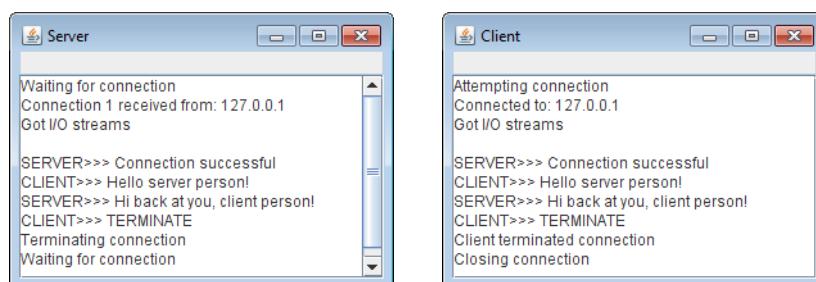
```

186     );
187 }
188 }
```

Fig. 28.5 | Client portion of a stream-socket connection between client and server. (Part 5 of 5.)

```

1 // Fig. 28.6: ClientTest.java
2 // Class that tests the Client.
3 import javax.swing.JFrame;
4
5 public class ClientTest
6 {
7     public static void main(String[] args)
8     {
9         Client application; // declare client application
10
11         // if no command line args
12         if (args.length == 0)
13             application = new Client("127.0.0.1"); // connect to localhost
14         else
15             application = new Client(args[0]); // use args to connect
16
17         application.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
18         application.runClient(); // run client application
19     }
20 }
```

**Fig. 28.6** | Class that tests the Client.***Method runClient***

Client method `runClient` (Fig. 28.5, lines 59–79) sets up the connection to the server, processes messages received from the server and closes the connection when communication is complete. Line 63 calls method `connectToServer` (declared at lines 82–92) to perform the connection. After connecting, line 64 calls method `getStreams` (declared at lines 95–105) to obtain references to the `Socket`'s stream objects. Then line 65 calls method `processConnection` (declared at lines 108–126) to receive and display messages sent from the server. The `finally` block (lines 75–78) calls `closeConnection` (lines 129–144) to close the streams and the `Socket` even if an exception occurred. Method `displayMessage` (lines 162–173) is called from these methods to use the event-dispatch thread to display messages in the application's text area.

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Method connectToServer

Method `connectToServer` (lines 82–92) creates a `Socket` called `client` (line 87) to establish a connection. The arguments to the `Socket` constructor are the IP address of the server computer and the port number (12345) where the server application is awaiting client connections. In the first argument, `InetAddress static method getByName` returns an `InetAddress` object containing the IP address specified as a command-line argument to the application (or 127.0.0.1 if none was specified). Method `getByName` can receive a `String` containing either the actual IP address or the host name of the server. The first argument also could have been written other ways. For the `localhost` address 127.0.0.1, the first argument could be specified with either of the following expressions:

```
InetAddress.getByName("localhost")
InetAddress.getLocalHost()
```

Other versions of the `Socket` constructor receive the IP address or host name as a `String`. The first argument could have been specified as the IP address "127.0.0.1" or the host name "localhost". We chose to demonstrate the client/server relationship by connecting between applications on the same computer (`localhost`). Normally, this first argument would be the IP address of another computer. The `InetAddress` object for another computer can be obtained by specifying the computer's IP address or host name as the argument to `InetAddress` method `getByName`. The `Socket` constructor's second argument is the server port number. This *must* match the port number at which the server is waiting for connections (called the *handshake point*). Once the connection is made, lines 90–91 display a message in the text area indicating the name of the server computer to which the client has connected.

The Client uses an `ObjectOutputStream` to send data to the server and an `ObjectInputStream` to receive data from the server. Method `getStreams` (lines 95–105) creates the `ObjectOutputStream` and `ObjectInputStream` objects that use the streams associated with the `client` socket.

Methods processConnection and closeConnection

Method `processConnection` (lines 108–126) contains a loop that executes until the client receives the message "SERVER>>> TERMINATE". Line 117 reads a `String` object from the server. Line 118 invokes `displayMessage` to append the message to the text area. When the transmission is complete, method `closeConnection` (lines 129–144) closes the streams and the `Socket`.

Processing User Interactions

When the client application user enters a `String` in the text field and presses *Enter*, the program calls method `actionPerformed` (lines 41–45) to read the `String`, then invokes utility method `sendData` (147–159) to send the `String` to the server. Method `sendData` writes the object, flushes the output buffer and appends the same `String` to the client window's `JTextArea`. Once again, it's not necessary to invoke utility method `displayMessage` to modify the text area here, because method `sendData` is called from an event handler.

28.6 Datagrams: Connectionless Client/Server Interaction

We've been discussing connection-oriented, streams-based transmission. Now we consider **connectionless transmission with datagrams**.

28.6 Datagrams: Connectionless Client/Server Interaction

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Connection-oriented transmission is like the telephone system in which you dial and are given a connection to the telephone of the person with whom you wish to communicate. The connection is maintained for your phone call, *even when you're not talking*.

Connectionless transmission with datagrams is more like the way mail is carried via the postal service. If a large message will not fit in one envelope, you break it into separate pieces that you place in sequentially numbered envelopes. All of the letters are then mailed at once. The letters could arrive *in order*, *out of order* or *not at all* (the last case is rare). The person at the receiving end *reassembles* the pieces into sequential order before attempting to make sense of the message.

If your message is small enough to fit in one envelope, you need not worry about the “out-of-sequence” problem, but it’s still possible that your message might not arrive. One advantage of datagrams over postal mail is that duplicates of datagrams can arrive at the receiving computer.

Figures 28.7–28.10 use datagrams to send packets of information via the User Datagram Protocol (UDP) between a client application and a server application. In the Client application (Fig. 28.9), the user types a message into a text field and presses *Enter*. The program converts the message into a byte array and places it in a datagram packet that’s sent to the server. The Server (Figs. 28.7–28.8) receives the packet and displays the information in it, then *echoes* the packet back to the client. Upon receiving the packet, the client displays the information it contains.

Server Class

Class Server (Fig. 28.7) declares two **DatagramPackets** that the server uses to send and receive information and one **DatagramSocket** that sends and receives the packets. The constructor (lines 19–37), which is called from **main** (Fig. 28.8, lines 7–12), creates the GUI in which the packets of information will be displayed. Line 30 creates the **DatagramSocket** in a **try** block. Line 30 in Fig. 28.7 uses the **DatagramSocket** constructor that takes an integer port-number argument (5000 in this example) to bind the server to a port where it can receive packets from clients. Clients sending packets to this Server specify the same port number in the packets they send. A **SocketException** is thrown if the **DatagramSocket** constructor fails to bind the **DatagramSocket** to the specified port.



Common Programming Error 28.2

Specifying a port that's already in use or specifying an invalid port number when creating a **DatagramSocket** results in a **SocketException**.

```

1 // Fig. 28.7: Server.java
2 // Server side of connectionless client/server computing with datagrams.
3 import java.io.IOException;
4 import java.net.DatagramPacket;
5 import java.net.DatagramSocket;
6 import java.net.SocketException;
7 import java.awt.BorderLayout;
8 import javax.swing.JFrame;
9 import javax.swing.JScrollPane;
10 import javax.swing.JTextArea;
```

Fig. 28.7 | Server side of connectionless client/server computing with datagrams. (Part 1 of 3.)

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```

11 import javax.swing.SwingUtilities;
12
13 public class Server extends JFrame
14 {
15     private JTextArea displayArea; // displays packets received
16     private DatagramSocket socket; // socket to connect to client
17
18     // set up GUI and DatagramSocket
19     public Server()
20     {
21         super("Server");
22
23         displayArea = new JTextArea(); // create displayArea
24         add(new JScrollPane(displayArea), BorderLayout.CENTER);
25         setSize(400, 300); // set size of window
26         setVisible(true); // show window
27
28         try // create DatagramSocket for sending and receiving packets
29         {
30             socket = new DatagramSocket(5000);
31         }
32         catch (SocketException socketException)
33         {
34             socketException.printStackTrace();
35             System.exit(1);
36         }
37     }
38
39     // wait for packets to arrive, display data and echo packet to client
40     public void waitForPackets()
41     {
42         while (true)
43         {
44             try // receive packet, display contents, return copy to client
45             {
46                 byte[] data = new byte[100]; // set up packet
47                 DatagramPacket receivePacket =
48                     new DatagramPacket(data, data.length);
49
50                 socket.receive(receivePacket); // wait to receive packet
51
52                 // display information from received packet
53                 displayMessage("\nPacket received:" +
54                     "\nFrom host: " + receivePacket.getAddress() +
55                     "\nHost port: " + receivePacket.getPort() +
56                     "\nLength: " + receivePacket.getLength() +
57                     "\nContaining:\n\t" + new String(receivePacket.getData(),
58                     0, receivePacket.getLength()));
59
60                 sendPacketToClient(receivePacket); // send packet to client
61             }
62             catch (IOException ioException)
63             {

```

Fig. 28.7 | Server side of connectionless client/server computing with datagrams. (Part 2 of 3.)

```

64         displayMessage(ioException + "\n");
65         ioException.printStackTrace();
66     }
67 }
68 }
69
70 // echo packet to client
71 private void sendPacketToClient(DatagramPacket receivePacket)
72 throws IOException
73 {
74     displayMessage("\n\nEcho data to client...");
75
76     // create packet to send
77     DatagramPacket sendPacket = new DatagramPacket(
78         receivePacket.getData(), receivePacket.getLength(),
79         receivePacket.getAddress(), receivePacket.getPort());
80
81     socket.send(sendPacket); // send packet to client
82     displayMessage("Packet sent\n");
83 }
84
85 // manipulates displayArea in the event-dispatch thread
86 private void displayMessage(final String messageToDisplay)
87 {
88     SwingUtilities.invokeLater(
89         new Runnable()
90     {
91         public void run() // updates displayArea
92         {
93             displayArea.append(messageToDisplay); // display message
94         }
95     });
96 }
97 }
98 }
```

Fig. 28.7 | Server side of connectionless client/server computing with datagrams. (Part 3 of 3.)

```

1 // Fig. 28.8: ServerTest.java
2 // Class that tests the Server.
3 import javax.swing.JFrame;
4
5 public class ServerTest
6 {
7     public static void main(String[] args)
8     {
9         Server application = new Server(); // create server
10        application.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
11        application.waitForPackets(); // run server application
12    }
13 }
```

Fig. 28.8 | Class that tests the Server. (Part 1 of 2.)

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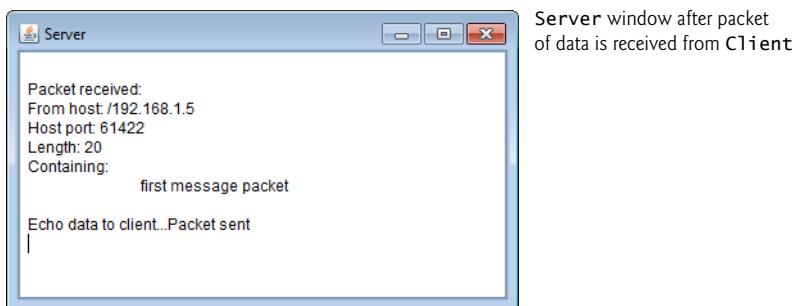


Fig. 28.8 | Class that tests the Server. (Part 2 of 2.)

Method `waitForPackets`

Server method `waitForPackets` (Fig. 28.7, lines 40–68) uses an infinite loop to wait for packets to arrive at the Server. Lines 47–48 create a `DatagramPacket` in which a received packet of information can be stored. The `DatagramPacket` constructor for this purpose receives two arguments—a byte array in which the data will be stored and the length of the array. Line 50 uses `DatagramSocket` method `receive` to wait for a packet to arrive at the Server. Method `receive` blocks until a packet arrives, then stores the packet in its `DatagramPacket` argument. The method throws an `IOException` if an error occurs while receiving a packet.

Method `displayMessage`

When a packet arrives, lines 53–58 call method `displayMessage` (declared at lines 86–97) to append the packet's contents to the text area. `DatagramPacket` method `getAddress` (line 54) returns an `InetAddress` object containing the IP address of the computer from which the packet was sent. Method `getPort` (line 55) returns an integer specifying the port number through which the client computer sent the packet. Method `getLength` (line 56) returns an integer representing the number of bytes of data received. Method `getData` (line 57) returns a byte array containing the data. Lines 57–58 initialize a `String` object using a three-argument constructor that takes a byte array, the offset and the length. This `String` is then appended to the text to display.

Method `sendPacketToClient`

After displaying a packet, line 60 calls method `sendPacketToClient` (declared at lines 71–83) to create a new packet and send it to the client. Lines 77–79 create a `DatagramPacket` and pass four arguments to its constructor. The first argument specifies the byte array to send. The second argument specifies the number of bytes to send. The third argument specifies the client computer's IP address, to which the packet will be sent. The fourth argument specifies the port where the client is waiting to receive packets. Line 81 sends the packet over the network. Method `send` of `DatagramSocket` throws an `IOException` if an error occurs while sending a packet.

Client Class

The `Client` (Figs. 28.9–28.10) works similarly to class `Server`, except that the `Client` sends packets only when the user types a message in a text field and presses the *Enter* key.

When this occurs, the program calls method `actionPerformed` (Fig. 28.9, lines 32–57), which converts the `String` the user entered into a byte array (line 41). Lines 44–45 create a `DatagramPacket` and initialize it with the byte array, the length of the `String` that was entered by the user, the IP address to which the packet is to be sent (`InetAddress.getLocalHost()` in this example) and the port number at which the Server is waiting for packets (5000 in this example). Line 47 sends the packet. The client in this example must know that the server is receiving packets at port 5000—otherwise, the server will *not* receive the packets.

The `DatagramSocket` constructor call (Fig. 28.9, line 71) in this application does not specify any arguments. This no-argument constructor allows the computer to select the next available port number for the `DatagramSocket`. The client does not need a specific port number, because the server receives the client's port number as part of each `DatagramPacket` sent by the client. Thus, the server can send packets back to the same computer and port number from which it receives a packet of information.

```

1 // Fig. 28.9: Client.java
2 // Client side of connectionless client/server computing with datagrams.
3 import java.io.IOException;
4 import java.net.DatagramPacket;
5 import java.net.DatagramSocket;
6 import java.net.InetAddress;
7 import java.net.SocketException;
8 import java.awt.BorderLayout;
9 import java.awt.event.ActionEvent;
10 import java.awt.event.ActionListener;
11 import javax.swing.JFrame;
12 import javax.swing.JScrollPane;
13 import javax.swing.JTextArea;
14 import javax.swing.JTextField;
15 import javax.swing.SwingUtilities;
16
17 public class Client extends JFrame
18 {
19     private JTextField enterField; // for entering messages
20     private JTextArea displayArea; // for displaying messages
21     private DatagramSocket socket; // socket to connect to server
22
23     // set up GUI and DatagramSocket
24     public Client()
25     {
26         super("Client");
27
28         enterField = new JTextField("Type message here");
29         enterField.addActionListener(
30             new ActionListener()
31             {
32                 public void actionPerformed(ActionEvent event)
33                 {
34                     try // create and send packet
35                     {

```

Fig. 28.9 | Client side of connectionless client/server computing with datagrams. (Part I of 3.)

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```

36          // get message from textfield
37          String message = event.getActionCommand();
38          displayArea.append("\nSending packet containing: " +
39                      message + "\n");
40
41          byte[] data = message.getBytes(); // convert to bytes
42
43          // create sendPacket
44          DatagramPacket sendPacket = new DatagramPacket(data,
45                      data.length, InetAddress.getLocalHost(), 5000);
46
47          socket.send(sendPacket); // send packet
48          displayArea.append("Packet sent\n");
49          displayArea.setCaretPosition(
50                      displayArea.getText().length());
51      }
52      catch (IOException ioException)
53      {
54          displayMessage(ioException + "\n");
55          ioException.printStackTrace();
56      }
57  }
58 }
59 );
60
61 add(enterField, BorderLayout.NORTH);
62
63 displayArea = new JTextArea();
64 add(new JScrollPane(displayArea), BorderLayout.CENTER);
65
66 setSize(400, 300); // set window size
67 setVisible(true); // show window
68
69 try // create DatagramSocket for sending and receiving packets
70 {
71     socket = new DatagramSocket();
72 }
73 catch (SocketException socketException)
74 {
75     socketException.printStackTrace();
76     System.exit(1);
77 }
78 }
79
80 // wait for packets to arrive from Server, display packet contents
81 public void waitForPackets()
82 {
83     while (true)
84     {
85         try // receive packet and display contents
86         {
87             byte[] data = new byte[100]; // set up packet

```

Fig. 28.9 | Client side of connectionless client/server computing with datagrams. (Part 2 of 3.)

```

88         DatagramPacket receivePacket = new DatagramPacket(
89             data, data.length);
90
91         socket.receive(receivePacket); // wait for packet
92
93         // display packet contents
94         displayMessage("\nPacket received:" +
95             "\nFrom host: " + receivePacket.getAddress() +
96             "\nHost port: " + receivePacket.getPort() +
97             "\nLength: " + receivePacket.getLength() +
98             "\nContaining:\n\t" + new String(receivePacket.getData(),
99                 0, receivePacket.getLength()));
100    }
101    catch (IOException exception)
102    {
103        displayMessage(exception + "\n");
104        exception.printStackTrace();
105    }
106 }
107 }
108
109 // manipulates displayArea in the event-dispatch thread
110 private void displayMessage(final String messageToDisplay)
111 {
112     SwingUtilities.invokeLater(
113         new Runnable()
114     {
115         public void run() // updates displayArea
116         {
117             displayArea.append(messageToDisplay);
118         }
119     });
120 }
121 }
122 }
```

Fig. 28.9 | Client side of connectionless client/server computing with datagrams. (Part 3 of 3.)

```

1 // Fig. 28.10: ClientTest.java
2 // Tests the Client class.
3 import javax.swing.JFrame;
4
5 public class ClientTest
6 {
7     public static void main(String[] args)
8     {
9         Client application = new Client(); // create client
10        application.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
11        application.waitForPackets(); // run client application
12    }
13 }
```

Fig. 28.10 | Class that tests the Client. (Part 1 of 2.)

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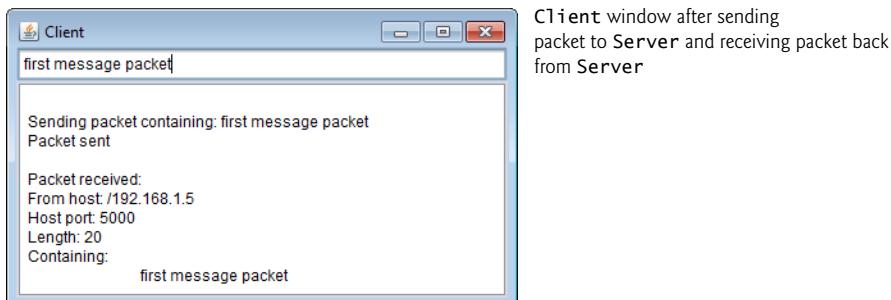


Fig. 28.10 | Class that tests the Client. (Part 2 of 2.)

Method `waitForPackets`

Client method `waitForPackets` (lines 81–107) uses an infinite loop to wait for packets from the server. Line 91 blocks until a packet arrives. This does not prevent the user from sending a packet, because the *GUI events are handled in the event-dispatch thread*. It only prevents the `while` loop from continuing until a packet arrives at the Client. When a packet arrives, line 91 stores it in `receivePacket`, and lines 94–99 call method `displayMessage` (declared at lines 110–121) to display the packet's contents in the text area.

28.7 Client/Server Tic-Tac-Toe Using a Multithreaded Server

This section presents the popular game Tic-Tac-Toe implemented by using client/server techniques with stream sockets. The program consists of a `TicTacToeServer` application (Figs. 28.11–28.12) that allows two `TicTacToeClient` applications (Figs. 28.13–28.14) to connect to the server and play Tic-Tac-Toe. Sample outputs are shown in Fig. 28.15.

`TicTacToeServer` Class

As the `TicTacToeServer` receives each client connection, it creates an instance of inner-class `Player` (Fig. 28.11, lines 182–304) to process the client in a *separate thread*. These threads enable the clients to play the game independently. The first client to connect to the server is player X and the second is player O. Player X makes the first move. The server maintains the information about the board so it can determine if a player's move is valid.

```

1 // Fig. 28.11: TicTacToeServer.java
2 // Server side of client/server Tic-Tac-Toe program.
3 import java.awt.BorderLayout;
4 import java.net.ServerSocket;
5 import java.net.Socket;
6 import java.io.IOException;
7 import java.util.Formatter;
8 import java.util.Scanner;
9 import java.util.concurrent.ExecutorService;
10 import java.util.concurrent.Executors;
```

Fig. 28.11 | Server side of client/server Tic-Tac-Toe program. (Part I of 7.)

28.7 Client/Server Tic-Tac-Toe Using a Multithreaded Server

28_29

```

11 import java.util.concurrent.locks.Lock;
12 import java.util.concurrent.locks.ReentrantLock;
13 import java.util.concurrent.locks.Condition;
14 import javax.swing.JFrame;
15 import javax.swing.JTextArea;
16 import javax.swing.SwingUtilities;
17
18 public class TicTacToeServer extends JFrame
19 {
20     private String[] board = new String[9]; // tic-tac-toe board
21     private JTextArea outputArea; // for outputting moves
22     private Player[] players; // array of Players
23     private ServerSocket server; // server socket to connect with clients
24     private int currentPlayer; // keeps track of player with current move
25     private final static int PLAYER_X = 0; // constant for first player
26     private final static int PLAYER_O = 1; // constant for second player
27     private final static String[] MARKS = { "X", "O" }; // array of marks
28     private ExecutorService runGame; // will run players
29     private Lock gameLock; // to lock game for synchronization
30     private Condition otherPlayerConnected; // to wait for other player
31     private Condition otherPlayerTurn; // to wait for other player's turn
32
33     // set up tic-tac-toe server and GUI that displays messages
34     public TicTacToeServer()
35     {
36         super("Tic-Tac-Toe Server"); // set title of window
37
38         // create ExecutorService with a thread for each player
39         runGame = Executors.newFixedThreadPool(2);
40         gameLock = new ReentrantLock(); // create lock for game
41
42         // condition variable for both players being connected
43         otherPlayerConnected = gameLock.newCondition();
44
45         // condition variable for the other player's turn
46         otherPlayerTurn = gameLock.newCondition();
47
48         for (int i = 0; i < 9; i++)
49             board[i] = new String(""); // create tic-tac-toe board
50         players = new Player[2]; // create array of players
51         currentPlayer = PLAYER_X; // set current player to first player
52
53         try
54         {
55             server = new ServerSocket(12345, 2); // set up ServerSocket
56         }
57         catch (IOException ioException)
58         {
59             ioException.printStackTrace();
60             System.exit(1);
61         }
62
63         outputArea = new JTextArea(); // create JTextArea for output

```

Fig. 28.11 | Server side of client/server Tic-Tac-Toe program. (Part 2 of 7.)

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```

64      add(outputArea, BorderLayout.CENTER);
65      outputArea.setText("Server awaiting connections\n");
66
67      setSize(300, 300); // set size of window
68      setVisible(true); // show window
69  }
70
71 // wait for two connections so game can be played
72 public void execute()
73 {
74     // wait for each client to connect
75     for (int i = 0; i < players.length; i++)
76     {
77         try // wait for connection, create Player, start runnable
78         {
79             players[i] = new Player(server.accept(), i);
80             runGame.execute(players[i]); // execute player runnable
81         }
82         catch (IOException ioException)
83         {
84             ioException.printStackTrace();
85             System.exit(1);
86         }
87     }
88
89     gameLock.lock(); // Tock game to signal player X's thread
90
91     try
92     {
93         players[PLAYER_X].setSuspended(false); // resume player X
94         otherPlayerConnected.signal(); // wake up player X's thread
95     }
96     finally
97     {
98         gameLock.unlock(); // unlock game after signalling player X
99     }
100 }
101
102 // display message in outputArea
103 private void displayMessage(final String messageToDisplay)
104 {
105     // display message from event-dispatch thread of execution
106     SwingUtilities.invokeLater(
107         new Runnable()
108         {
109             public void run() // updates outputArea
110             {
111                 outputArea.append(messageToDisplay); // add message
112             }
113         }
114     );
115 }

```

Fig. 28.11 | Server side of client/server Tic-Tac-Toe program. (Part 3 of 7.)

28.7 Client/Server Tic-Tac-Toe Using a Multithreaded Server

28_31

```

116     // determine if move is valid
117     public boolean validateAndMove(int location, int player)
118     {
119         // while not current player, must wait for turn
120         while (player != currentPlayer)
121         {
122             gameLock.lock(); // lock game to wait for other player to go
123
124             try
125             {
126                 otherPlayerTurn.await(); // wait for player's turn
127             }
128             catch (InterruptedException exception)
129             {
130                 exception.printStackTrace();
131             }
132             finally
133             {
134                 gameLock.unlock(); // unlock game after waiting
135             }
136         }
137
138         // if location not occupied, make move
139         if (!isOccupied(location))
140         {
141             board[location] = MARKS[currentPlayer]; // set move on board
142             currentPlayer = (currentPlayer + 1) % 2; // change player
143
144             // let new current player know that move occurred
145             players[currentPlayer].otherPlayerMoved(location);
146
147             gameLock.lock(); // lock game to signal other player to go
148
149             try
150             {
151                 otherPlayerTurn.signal(); // signal other player to continue
152             }
153             finally
154             {
155                 gameLock.unlock(); // unlock game after signaling
156             }
157
158             return true; // notify player that move was valid
159         }
160         else // move was not valid
161             return false; // notify player that move was invalid
162     }
163
164     // determine whether location is occupied
165     public boolean isOccupied(int location)
166     {

```

Fig. 28.11 | Server side of client/server Tic-Tac-Toe program. (Part 4 of 7.)

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```

168     if (board[location].equals(MARKS[PLAYER_X]) ||
169         board [location].equals(MARKS[PLAYER_O]))
170     return true; // Location is occupied
171   else
172     return false; // Location is not occupied
173 }
174
175 // place code in this method to determine whether game over
176 public boolean isGameOver()
177 {
178   return false; // this is left as an exercise
179 }
180
181 // private inner class Player manages each Player as a runnable
182 private class Player implements Runnable
183 {
184   private Socket connection; // connection to client
185   private Scanner input; // input from client
186   private Formatter output; // output to client
187   private int playerNumber; // tracks which player this is
188   private String mark; // mark for this player
189   private boolean suspended = true; // whether thread is suspended
190
191   // set up Player thread
192   public Player(Socket socket, int number)
193   {
194     playerNumber = number; // store this player's number
195     mark = MARKS[playerNumber]; // specify player's mark
196     connection = socket; // store socket for client
197
198     try // obtain streams from Socket
199     {
200       input = new Scanner(connection.getInputStream());
201       output = new Formatter(connection.getOutputStream());
202     }
203     catch (IOException ioException)
204     {
205       ioException.printStackTrace();
206       System.exit(1);
207     }
208   }
209
210   // send message that other player moved
211   public void otherPlayerMoved(int location)
212   {
213     output.format("Opponent moved\n");
214     output.format("%d\n", location); // send location of move
215     output.flush(); // flush output
216   }
217 }
```

Fig. 28.11 | Server side of client/server Tic-Tac-Toe program. (Part 5 of 7.)

28.7 Client/Server Tic-Tac-Toe Using a Multithreaded Server

28_33

```

218     // control thread's execution
219     public void run()
220     {
221         // send client its mark (X or O), process messages from client
222         try
223         {
224             displayMessage("Player " + mark + " connected\n");
225             output.format("%s\n", mark); // send player's mark
226             output.flush(); // flush output
227
228             // if player X, wait for another player to arrive
229             if (playerNumber == PLAYER_X)
230             {
231                 output.format("%s\n%s", "Player X connected",
232                             "Waiting for another player\n");
233                 output.flush(); // flush output
234
235                 gameLock.lock(); // lock game to wait for second player
236
237                 try
238                 {
239                     while(suspended)
240                     {
241                         otherPlayerConnected.await(); // wait for player O
242                     }
243                 }
244                 catch (InterruptedException exception)
245                 {
246                     exception.printStackTrace();
247                 }
248                 finally
249                 {
250                     gameLock.unlock(); // unlock game after second player
251                 }
252
253             // send message that other player connected
254             output.format("Other player connected. Your move.\n");
255             output.flush(); // flush output
256         }
257         else
258         {
259             output.format("Player O connected, please wait\n");
260             output.flush(); // flush output
261         }
262
263         // while game not over
264         while (!isGameOver())
265         {
266             int location = 0; // initialize move location
267
268             if (input.hasNext())
269                 location = input.nextInt(); // get move location
270

```

Fig. 28.11 | Server side of client/server Tic-Tac-Toe program. (Part 6 of 7.)

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```

271             // check for valid move
272             if (validateAndMove(location, playerNumber))
273             {
274                 displayMessage("\nlocation: " + location);
275                 output.format("Valid move.\n"); // notify client
276                 output.flush(); // flush output
277             }
278             else // move was invalid
279             {
280                 output.format("Invalid move, try again\n");
281                 output.flush(); // flush output
282             }
283         }
284     }
285     finally
286     {
287         try
288         {
289             connection.close(); // close connection to client
290         }
291         catch (IOException ioException)
292         {
293             ioException.printStackTrace();
294             System.exit(1);
295         }
296     }
297 }
298
299 // set whether or not thread is suspended
300 public void setSuspended(boolean status)
301 {
302     suspended = status; // set value of suspended
303 }
304 }
305 }
```

Fig. 28.11 | Server side of client/server Tic-Tac-Toe program. (Part 7 of 7.)

```

1 // Fig. 28.12: TicTacToeServerTest.java
2 // Class that tests Tic-Tac-Toe server.
3 import javax.swing.JFrame;
4
5 public class TicTacToeServerTest
6 {
7     public static void main(String[] args)
8     {
9         TicTacToeServer application = new TicTacToeServer();
10        application.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
11        application.execute();
12    }
13 }
```

Fig. 28.12 | Class that tests Tic-Tac-Toe server. (Part 1 of 2.)

28.7 Client/Server Tic-Tac-Toe Using a Multithreaded Server

28_35

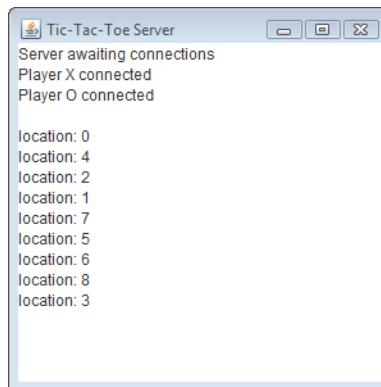


Fig. 28.12 | Class that tests Tic-Tac-Toe server. (Part 2 of 2.)

We begin with a discussion of the server side of the Tic-Tac-Toe game. When the `TicTacToeServer` application executes, the `main` method (lines 7–12 of Fig. 28.12) creates a `TicTacToeServer` object called `application`. The constructor (Fig. 28.11, lines 34–69) attempts to set up a `ServerSocket`. If successful, the program displays the server window, then `main` invokes the `TicTacToeServer` method `execute` (lines 72–100). Method `execute` loops twice, blocking at line 79 each time while waiting for a client connection. When a client connects, line 79 creates a new `Player` object to manage the connection as a separate thread, and line 80 executes the `Player` in the `runGame` thread pool.

When the `TicTacToeServer` creates a `Player`, the `Player` constructor (lines 192–208) receives the `Socket` object representing the connection to the client and gets the associated input and output streams. Line 201 creates a `Formatter` (see Chapter 15) by wrapping it around the output stream of the socket. The `Player`'s `run` method (lines 219–297) controls the information that's sent to and received from the client. First, it passes to the client the character that the client will place on the board when a move is made (line 225). Line 226 calls `Formatter` method `flush` to force this output to the client. Line 241 suspends player X's thread as it starts executing, because player X can move only after player O connects.

When player O connects, the game can be played, and the `run` method begins executing its `while` statement (lines 264–283). Each iteration of this loop reads an integer (line 269) representing the location where the client wants to place a mark (blocking to wait for input, if necessary), and line 272 invokes the `TicTacToeServer` method `validateAndMove` (declared at lines 118–163) to check the move. If the move is valid, line 275 sends a message to the client to this effect. If not, line 280 sends a message indicating that the move was invalid. The program maintains board locations as numbers from 0 to 8 (0 through 2 for the first row, 3 through 5 for the second row and 6 through 8 for the third row).

Method `validateAndMove` (lines 118–163 in class `TicTacToeServer`) allows only one player at a time to move, thereby preventing them from modifying the state information of the game simultaneously. If the `Player` attempting to validate a move is *not* the current player (i.e., the one allowed to make a move), it's placed in a `wait` state until its turn to move. If the position for the move being validated is already occupied on the board,

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`validMove` returns `false`. Otherwise, the server places a mark for the player in its local representation of the board (line 142), notifies the other `Player` object (line 146) that a move has been made (so that the client can be sent a message), invokes method `signal` (line 152) so that the waiting `Player` (if there is one) can validate a move and returns `true` (line 159) to indicate that the move is valid.

TicTacToeClient Class

Each `TicTacToeClient` application (Figs. 28.13–28.14; sample outputs in Fig. 28.15) maintains its own GUI version of the Tic-Tac-Toe board on which it displays the state of the game. The clients can place a mark only in an empty square. Inner class `Square` (Fig. 28.13, lines 205–261) implements each of the nine squares on the board. When a `TicTacToeClient` begins execution, it creates a `JTextArea` in which messages from the server and a representation of the board using nine `Square` objects are displayed. The `startClient` method (lines 80–100) opens a connection to the server and gets the associated input and output streams from the `Socket` object. Lines 85–86 make a connection to the server. Class `TicTacToeClient` implements interface `Runnable` so that a separate thread can read messages from the server. This approach enables the user to interact with the board (in the event-dispatch thread) while waiting for messages from the server. After establishing the connection to the server, line 99 executes the client with the worker `ExecutorService`. The `run` method (lines 103–126) controls the separate thread of execution. The method first reads the mark character (X or O) from the server (line 105), then loops continuously (lines 121–125) and reads messages from the server (line 124). Each message is passed to the `processMessage` method (lines 129–156) for processing.

```

1 // Fig. 28.13: TicTacToeClient.java
2 // Client side of client/server Tic-Tac-Toe program.
3 import java.awt.BorderLayout;
4 import java.awt.Dimension;
5 import java.awt.Graphics;
6 import java.awt.GridLayout;
7 import java.awt.event.MouseAdapter;
8 import java.awt.event.MouseEvent;
9 import java.net.Socket;
10 import java.net.InetAddress;
11 import java.io.IOException;
12 import javax.swing.JFrame;
13 import javax.swing.JPanel;
14 import javax.swing.JScrollPane;
15 import javax.swing.JTextArea;
16 import javax.swing.JTextField;
17 import javax.swing.SwingUtilities;
18 import java.util.Formatter;
19 import java.util.Scanner;
20 import java.util.concurrent.Executors;
21 import java.util.concurrent.ExecutorService;
22
23 public class TicTacToeClient extends JFrame implements Runnable
24 {

```

Fig. 28.13 | Client side of client/server Tic-Tac-Toe program. (Part I of 6.)

28.7 Client/Server Tic-Tac-Toe Using a Multithreaded Server

28_37

```

25  private JTextField idField; // textfield to display player's mark
26  private JTextArea displayArea; // JTextArea to display output
27  private JPanel boardPanel; // panel for tic-tac-toe board
28  private JPanel panel2; // panel to hold board
29  private Square[][] board; // tic-tac-toe board
30  private Square currentSquare; // current square
31  private Socket connection; // connection to server
32  private Scanner input; // input from server
33  private Formatter output; // output to server
34  private String ticTacToeHost; // host name for server
35  private String myMark; // this client's mark
36  private boolean myTurn; // determines which client's turn it is
37  private final String X_MARK = "X"; // mark for first client
38  private final String O_MARK = "O"; // mark for second client
39
40  // set up user-interface and board
41  public TicTacToeClient(String host)
42  {
43      ticTacToeHost = host; // set name of server
44      displayArea = new JTextArea(4, 30); // set up JTextArea
45      displayArea.setEditable(false);
46      add(new JScrollPane(displayArea), BorderLayout.SOUTH);
47
48      boardPanel = new JPanel(); // set up panel for squares in board
49      boardPanel.setLayout(new GridLayout(3, 3, 0, 0));
50
51      board = new Square[3][3]; // create board
52
53      // loop over the rows in the board
54      for (int row = 0; row < board.length; row++)
55      {
56          // loop over the columns in the board
57          for (int column = 0; column < board[row].length; column++)
58          {
59              // create square
60              board[row][column] = new Square(' ', row * 3 + column);
61              boardPanel.add(board[row][column]); // add square
62          }
63      }
64
65      idField = new JTextField(); // set up textfield
66      idField.setEditable(false);
67      add(idField, BorderLayout.NORTH);
68
69      panel2 = new JPanel(); // set up panel to contain boardPanel
70      panel2.add(boardPanel, BorderLayout.CENTER); // add board panel
71      add(panel2, BorderLayout.CENTER); // add container panel
72
73      setSize(300, 225); // set size of window
74      setVisible(true); // show window
75
76      startClient();
77  }

```

Fig. 28.13 | Client side of client/server Tic-Tac-Toe program. (Part 2 of 6.)

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```

78
79     // start the client thread
80     public void startClient()
81     {
82         try // connect to server and get streams
83         {
84             // make connection to server
85             connection = new Socket(
86                 InetAddress.getByName(ticTacToeHost), 12345);
87
88             // get streams for input and output
89             input = new Scanner(connection.getInputStream());
90             output = new Formatter(connection.getOutputStream());
91         }
92         catch (IOException ioException)
93         {
94             ioException.printStackTrace();
95         }
96
97         // create and start worker thread for this client
98         ExecutorService worker = Executors.newFixedThreadPool(1);
99         worker.execute(this); // execute client
100    }
101
102   // control thread that allows continuous update of displayArea
103   public void run()
104   {
105       myMark = input.nextLine(); // get player's mark (X or O)
106
107       SwingUtilities.invokeLater(
108           new Runnable()
109           {
110               public void run()
111               {
112                   // display player's mark
113                   idField.setText("You are player \""
114                         + myMark + "\"");
115               }
116           });
117
118       myTurn = (myMark.equals(X_MARK)); // determine if client's turn
119
120       // receive messages sent to client and output them
121       while (true)
122       {
123           if (input.hasNextLine())
124               processMessage(input.nextLine());
125       }
126   }
127
128   // process messages received by client
129   private void processMessage(String message)
130   {

```

Fig. 28.13 | Client side of client/server Tic-Tac-Toe program. (Part 3 of 6.)

28.7 Client/Server Tic-Tac-Toe Using a Multithreaded Server

28_39

```

131     // valid move occurred
132     if (message.equals("Valid move."))
133     {
134         displayMessage("Valid move, please wait.\n");
135         setMark(currentSquare, myMark); // set mark in square
136     }
137     else if (message.equals("Invalid move, try again"))
138     {
139         displayMessage(message + "\n"); // display invalid move
140         myTurn = true; // still this client's turn
141     }
142     else if (message.equals("Opponent moved"))
143     {
144         int location = input.nextInt(); // get move location
145         input.nextLine(); // skip newline after int location
146         int row = location / 3; // calculate row
147         int column = location % 3; // calculate column
148
149         setMark( board[row][column],
150                 (myMark.equals(X_MARK) ? O_MARK : X_MARK)); // mark move
151         displayMessage("Opponent moved. Your turn.\n");
152         myTurn = true; // now this client's turn
153     }
154     else
155         displayMessage(message + "\n"); // display the message
156 }
157
158 // manipulate displayArea in event-dispatch thread
159 private void displayMessage(final String messageToDisplay)
160 {
161     SwingUtilities.invokeLater(
162         new Runnable()
163     {
164         public void run()
165         {
166             displayArea.append(messageToDisplay); // updates output
167         }
168     });
169 }
170
171
172 // utility method to set mark on board in event-dispatch thread
173 private void setMark(final Square squareToMark, final String mark)
174 {
175     SwingUtilities.invokeLater(
176         new Runnable()
177     {
178         public void run()
179         {
180             squareToMark.setMark(mark); // set mark in square
181         }
182     });
183 }
```

Fig. 28.13 | Client side of client/server Tic-Tac-Toe program. (Part 4 of 6.)

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```

182         }
183     );
184 }
185
186 // send message to server indicating clicked square
187 public void sendClickedSquare(int location)
188 {
189     // if it is my turn
190     if (myTurn)
191     {
192         output.format("%d\n", location); // send location to server
193         output.flush();
194         myTurn = false; // not my turn any more
195     }
196 }
197
198 // set current Square
199 public void setCurrentSquare(Square square)
200 {
201     currentSquare = square; // set current square to argument
202 }
203
204 // private inner class for the squares on the board
205 private class Square extends JPanel
206 {
207     private String mark; // mark to be drawn in this square
208     private int location; // location of square
209
210     public Square(String squareMark, int squareLocation)
211     {
212         mark = squareMark; // set mark for this square
213         location = squareLocation; // set location of this square
214
215         addMouseListener(
216             new MouseAdapter()
217             {
218                 public void mouseReleased(MouseEvent e)
219                 {
220                     setCurrentSquare(Square.this); // set current square
221
222                     // send location of this square
223                     sendClickedSquare(getSquareLocation());
224                 }
225             }
226         );
227     }
228
229     // return preferred size of Square
230     public Dimension getPreferredSize()
231     {
232         return new Dimension(30, 30); // return preferred size
233     }

```

Fig. 28.13 | Client side of client/server Tic-Tac-Toe program. (Part 5 of 6.)

28.7 Client/Server Tic-Tac-Toe Using a Multithreaded Server

28_41

```

234      // return minimum size of Square
235      public Dimension getMinimumSize()
236      {
237          return getPreferredSize(); // return preferred size
238      }
239
240
241      // set mark for Square
242      public void setMark(String newMark)
243      {
244          mark = newMark; // set mark of square
245          repaint(); // repaint square
246      }
247
248      // return Square location
249      public int getSquareLocation()
250      {
251          return location; // return location of square
252      }
253
254      // draw Square
255      public void paintComponent(Graphics g)
256      {
257          super.paintComponent(g);
258
259          g.drawRect(0, 0, 29, 29); // draw square
260          g.drawString(mark, 11, 20); // draw mark
261      }
262  }
263 }
```

Fig. 28.13 | Client side of client/server Tic-Tac-Toe program. (Part 6 of 6.)

```

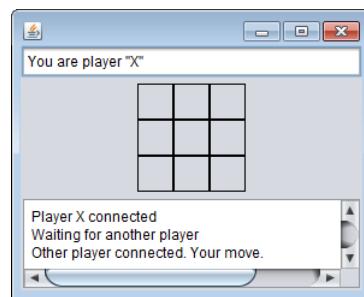
1 // Fig. 28.14: TicTacToeClientTest.java
2 // Test class for Tic-Tac-Toe client.
3 import javax.swing.JFrame;
4
5 public class TicTacToeClientTest
6 {
7     public static void main(String[] args)
8     {
9         TicTacToeClient application; // declare client application
10
11         // if no command line args
12         if (args.length == 0)
13             application = new TicTacToeClient("127.0.0.1"); // localhost
14         else
15             application = new TicTacToeClient(args[0]); // use args
16
17         application.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
18     }
19 }
```

Fig. 28.14 | Test class for Tic-Tac-Toe client.

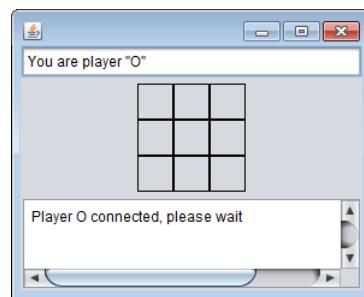
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If the message received is "Valid move.", lines 134–135 display the message "Valid move, please wait." and call method `setMark` (lines 173–184) to set the client's mark in the current square (the one in which the user clicked), using `SwingUtilities` method `invokeLater` to ensure that the GUI updates occur in the event-dispatch thread. If the message received is "Invalid move, try again.", line 139 displays the message so that the user can click a different square. If the message received is "Opponent moved.", line 144 reads an integer from the server indicating where the opponent moved, and lines 149–150 place a mark in that square of the board (again using `SwingUtilities` method `invokeLater` to ensure that the GUI updates occur in the event-dispatch thread). If any other message is received, line 155 simply displays the message.

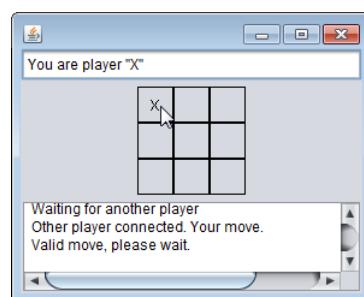
a) Player X connected to server.



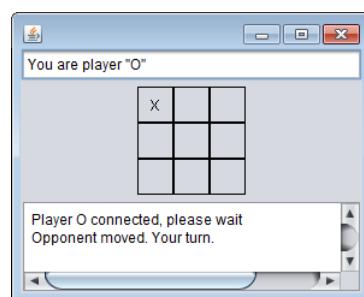
b) Player O connected to server.



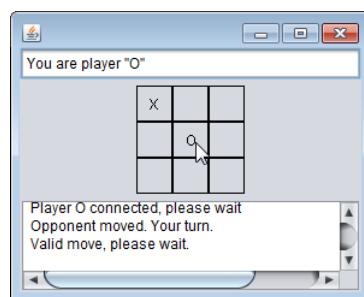
c) Player X moved.



d) Player O sees Player X's move.



e) Player O moved.



f) Player X sees Player O's move.

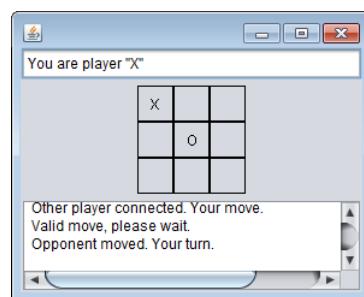
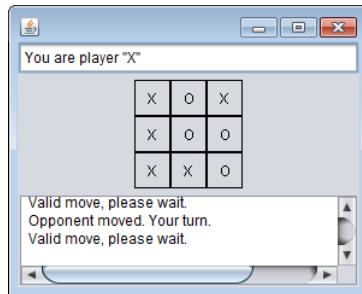
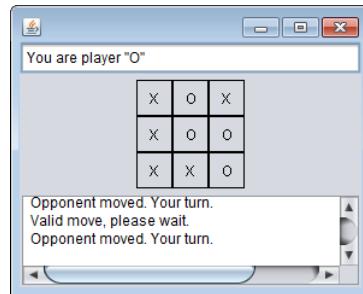


Fig. 28.15 | Sample outputs from the client/server Tic-Tac-Toe program. (Part I of 2.)

g) Player X moved.



h) Player O sees Player X's last move.

**Fig. 28.15** | Sample outputs from the client/server Tic-Tac-Toe program. (Part 2 of 2.)

28.8 Optional Online Case Study: DeitelMessenger²

This case study is available at <http://www.deitel.com/books/jhttp11>. Chat rooms provide a central location where users can chat with each other via short text messages. Each participant can see all the messages that the other users post, and each user can post messages. This case study integrates many of the Java networking, multithreading and Swing GUI features you've learned thus far to build an online chat system. We also introduce **multicasting**, which enables an application to send **DatagramPackets** to *groups* of clients.

The DeitelMessenger case study is a significant application that uses many intermediate Java features, such as networking with Sockets, DatagramPackets and Multicast-Sockets, multithreading and Swing GUI. The case study also demonstrates good software engineering practices by separating interface from implementation and enabling developers to support different network protocols and provide different user interfaces. After reading this case study, you'll be able to build more significant networking applications.

28.9 Wrap-Up

In this chapter, you learned the basics of network programming in Java. You learned two different methods of sending data over a network—streams-based networking using TCP/IP and datagrams-based networking using UDP. We showed how to build simple client/server chat programs using both streams-based and datagram-based networking. You then saw a client/server Tic-Tac-Toe game that enables two clients to play by interacting with a multithreaded server that maintains the game's state and logic. In the next chapter, you'll learn basic database concepts, how to interact with data in a database using SQL and how to use JDBC to allow Java applications to manipulate database data.

2. This case study is from the Seventh Edition of this book and is provided as is. We no longer provide support for it.

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Summary

Section 28.1 Introduction

- Java provides stream sockets and datagram sockets (p. 2). With stream sockets (p. 2), a process establishes a connection (p. 2) to another process. While the connection is in place, data flows between the processes in streams. Stream sockets are said to provide a connection-oriented service (p. 2). The protocol used for transmission is the popular TCP (Transmission Control Protocol; p. 2).
- With datagram sockets (datagram socket), individual packets of information are transmitted. UDP (User Datagram Protocol; p. 2) is a connectionless service that does not guarantee that packets will not be lost, duplicated or arrive out of sequence.

Section 28.2 Reading a File on a Web Server

- `JEditorPane` (p. 3) method `setPage` (p. 5) downloads the document specified by its argument and displays it.
- Typically, an HTML document contains hyperlinks that link to other documents on the web. If an HTML document is displayed in an uneditable `JEditorPane` and the user clicks a hyperlink (p. 5), a `HyperlinkEvent` (p. 5) occurs and the `HyperlinkListeners` are notified.
- `HyperlinkEvent` method `getEventType` (p. 5) determines the event type. `HyperlinkEvent` contains nested class `EventType` (p. 5), which declares event types ACTIVATED, ENTERED and EXITED. `HyperlinkEvent` method `getURL` (p. 5) obtains the URL represented by the hyperlink.

Section 28.3 Establishing a Simple Server Using Stream Sockets

- Stream-based connections (p. 2) are managed with `Socket` objects (p. 6).
- A `ServerSocket` object (p. 6) establishes the port (p. 6) where a server (p. 2) waits for connections from clients (p. 2). `ServerSocket` method `accept` (p. 6) waits indefinitely for a connection from a client and returns a `Socket` object when a connection is established.
- `Socket` methods `getOutputStream` and `getInputStream` (p. 7) get references to a `Socket`'s `OutputStream` and `InputStream`, respectively. Method `close` (p. 7) terminates a connection.

Section 28.4 Establishing a Simple Client Using Stream Sockets

- A server name and port number (p. 6) are specified when creating a `Socket` object to enable it to connect a client to the server. A failed connection attempt throws an `IOException`.
- `InetAddress` method `getByName` (p. 20) returns an `InetAddress` object (p. 14) containing the IP address of the specified computer. `InetAddress` method `getLocalHost` (p. 20) returns an `InetAddress` object containing the IP address of the local computer executing the program.

Section 28.6 Datagrams: Connectionless Client/Server Interaction

- Connection-oriented transmission is like the telephone system—you dial and are given a connection to the telephone of the person with whom you wish to communicate. The connection is maintained for the duration of your phone call, even when you aren't talking.
- Connectionless transmission (p. 20) with datagrams is similar to mail carried via the postal service. A large message that will not fit in one envelope can be broken into separate message pieces that are placed in separate, sequentially numbered envelopes. All the letters are then mailed at once. They could arrive in order, out of order or not at all.
- `DatagramPacket` objects store packets of data that are to be sent or that are received by an application. `DatagramSockets` send and receive `DatagramPackets`.

Self-Review Exercises 28_45

- The `DatagramSocket` constructor that takes no arguments binds the `DatagramSocket` to a port chosen by the computer executing the program. The one that takes an integer port-number argument binds the `DatagramSocket` to the specified port. If a `DatagramSocket` constructor fails to bind the `DatagramSocket` to a port, a `SocketException` occurs (p. 21). `DatagramSocket` method `receive` (p. 24) blocks (waits) until a packet arrives, then stores the packet in its argument.
- `DatagramPacket` method `getAddress` (p. 24) returns an `InetAddress` object containing information about the computer from or to which the packet was sent. Method `getPort` (p. 24) returns an integer specifying the port number (p. 6) through which the `DatagramPacket` was sent or received. Method `getLength` (`getLength`) returns the number of bytes of data in a `DatagramPacket`. Method `getData` (p. 24) returns a byte array containing the data.
- The `DatagramPacket` constructor for a packet to be sent takes four arguments—the byte array to be sent, the number of bytes to be sent, the client address to which the packet will be sent and the port number where the client is waiting to receive packets.
- `DatagramSocket` method `send` (p. 24) sends a `DatagramPacket` out over the network.
- If an error occurs when receiving or sending a `DatagramPacket`, an `IOException` occurs.

Self-Review Exercises

28.1 Fill in the blanks in each of the following statements:

- Exception _____ occurs when an input/output error occurs when closing a socket.
- Exception _____ occurs when a hostname indicated by a client cannot be resolved to an address.
- If a `DatagramSocket` constructor fails to set up a `DatagramSocket` properly, an exception of type _____ occurs.
- Many of Java's networking classes are contained in package _____.
- Class _____ binds the application to a port for datagram transmission.
- An object of class _____ contains an IP address.
- The two types of sockets we discussed in this chapter are _____ and _____.
- Method `getLocalHost` returns a(n) _____ object containing the local IP address of the computer on which the program is executing.
- The `URL` constructor determines whether its `String` argument is a valid URL. If so, the `URL` object is initialized with that location. If not, a(n) _____ exception occurs.

28.2 State whether each of the following is *true or false*. If *false*, explain why.

- UDP is a connection-oriented protocol.
- With stream sockets a process establishes a connection to another process.
- A server waits at a port for connections from a client.
- Datagram packet transmission over a network is reliable—packets are guaranteed to arrive in sequence.

Answers to Self-Review Exercises

28.1 a) `IOException`. b) `UnknownHostException`. c) `SocketException`. d) `java.net`. e) `DatagramSocket`. f) `InetAddress`. g) stream sockets, datagram sockets. h) `InetAddress`. i) `MalformedURLException`.

28.2 a) False; UDP is a connectionless protocol and TCP is a connection-oriented protocol.
b) True. c) True. d) False; packets can be lost, arrive out of order or be duplicated.

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Exercises

- 28.3** Distinguish between connection-oriented and connectionless network services.
- 28.4** How does a client determine the hostname of the client computer?
- 28.5** Under what circumstances would a `SocketException` be thrown?
- 28.6** How can a client get a line of text from a server?
- 28.7** Describe how a client connects to a server.
- 28.8** Describe how a server sends data to a client.
- 28.9** Describe how to prepare a server to receive a stream-based connection from a single client.
- 28.10** How does a server listen for streams-based socket connections at a port?
- 28.11** What determines how many connect requests from clients can wait in a queue to connect to a server?
- 28.12** As described in the text, what reasons might cause a server to refuse a connection request from a client?
- 28.13** Use a socket connection to allow a client to specify a filename of a text file and have the server send the contents of the file or indicate that the file does not exist.
- 28.14** Modify Exercise 28.13 to allow the client to modify the contents of the file and send the file back to the server for storage. The user can edit the file in a `JTextArea`, then click a *save changes* button to send the file back to the server.
- 28.15** (*Multithreaded Server*) Multithreaded servers are quite popular today, especially because of the increasing use of multi-core servers. Modify the simple server application presented in Section 28.5 to be a multithreaded server. Then use several client applications and have each of them connect to the server simultaneously. Use an `ArrayList` to store the client threads. `ArrayList` provides several methods to use in this exercise. Method `size` determines the number of elements in an `ArrayList`. Method `get` returns the element in the location specified by its argument. Method `add` places its argument at the end of the `ArrayList`. Method `remove` deletes its argument from the `ArrayList`.
- 28.16** (*Checkers Game*) In the text, we presented a Tic-Tac-Toe program controlled by a multithreaded server. Develop a checkers program modeled after the Tic-Tac-Toe program. The two users should alternate making moves. Your program should mediate the players' moves, determining whose turn it is and allowing only valid moves. The players themselves will determine when the game is over.
- 28.17** (*Chess Game*) Develop a chess-playing program modeled after Exercise 28.16.
- 28.18** (*Blackjack Game*) Develop a blackjack card game program in which the server application deals cards to each of the clients. The server should deal additional cards (per the rules of the game) to each player as requested.
- 28.19** (*Poker Game*) Develop a poker game in which the server application deals cards to each client. The server should deal additional cards (per the rules of the game) to each player as requested.
- 28.20** (*Modifications to the Multithreaded Tic-Tac-Toe Program*) The programs in Figs. 28.11 and 28.13 implemented a multithreaded, client/server version of the game of Tic-Tac-Toe. Our goal in developing this game was to demonstrate a multithreaded server that could process multiple connections from clients at the same time. The server in the example is really a mediator between the two clients—it makes sure that each move is valid and that each client moves in the proper order. The server does not determine who won or lost or whether there was a draw. Also, there's no capability to allow a new game to be played or to terminate an existing game.

The following is a list of suggested modifications to Figs. 28.11 and 28.13:

Exercises 28-47

- Modify the `TicTacToeServer` class to test for a win, loss or draw after each move. Send a message to each client that indicates the result of the game when the game is over.
- Modify the `TicTacToeClient` class to display a button that when clicked allows the client to play another game. The button should be enabled only when a game completes. Both class `TicTacToeClient` and class `TicTacToeServer` must be modified to reset the board and all state information. Also, the other `TicTacToeClient` should be notified that a new game is about to begin so that its board and state can be reset.
- Modify the `TicTacToeClient` class to provide a button that allows a client to terminate the program at any time. When the user clicks the button, the server and the other client should be notified. The server should then wait for a connection from another client so that a new game can begin.
- Modify the `TicTacToeClient` class and the `TicTacToeServer` class so that the winner of a game can choose game piece X or O for the next game. Remember: X always goes first.
- If you'd like to be ambitious, allow a client to play against the server while the server waits for a connection from another client.

28.21 (3-D Multithreaded Tic-Tac-Toe) Modify the multithreaded, client/server Tic-Tac-Toe program to implement a three-dimensional 4-by-4-by-4 version of the game. Implement the server application to mediate between the two clients. Display the three-dimensional board as four boards containing four rows and four columns each. If you're ambitious, try the following modifications:

- Draw the board in a three-dimensional manner.
- Allow the server to test for a win, loss or draw. Beware! There are many possible ways to win on a 4-by-4-by-4 board!

28.22 (Networked Morse Code) Perhaps the most famous of all coding schemes is the Morse code, developed by Samuel Morse in 1832 for use with the telegraph system. The Morse code assigns a series of dots and dashes to each letter of the alphabet, each digit, and a few special characters (e.g., period, comma, colon and semicolon). In sound-oriented systems, the dot represents a short sound and the dash a long sound. Other representations of dots and dashes are used with light-oriented systems and signal-flag systems. Separation between words is indicated by a space or, simply, the absence of a dot or dash. In a sound-oriented system, a space is indicated by a short time during which no sound is transmitted. The international version of the Morse code appears in Fig. 28.16.

Character	Code	Character	Code	Character	Code	Character	Code
A	.-	J	.---	S	...	1	.----
B	-...	K	-.-	T	-	2	..---
C	-.-.	L	-...-	U	..-	3-
D	-..	M	--	V	4-
E	.	N	-.	W	.--	5
F	...-.	O	---	X	-...-	6	-....
G	---.	P	---.	Y	-.--	7	-....-
H	Q	---.-	Z	--..	8	-----
I	..	R	-..			9	-----.
						0	-----

Fig. 28.16 | Letters and digits in international Morse code.

Write a client/server application in which two clients can send Morse-code messages to each other through a multithreaded server application. The client application should allow the user to type English-language phrases in a `JTextArea`. When the user sends the message, the client application encodes the text into Morse code and sends the coded message through the server to the other

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client. Use one blank between each Morse-coded letter and three blanks between each Morse-coded word. When messages are received, they should be decoded and displayed as normal characters and as Morse code. The client should have one `JTextField` for typing and one `JTextArea` for displaying the other client's messages.