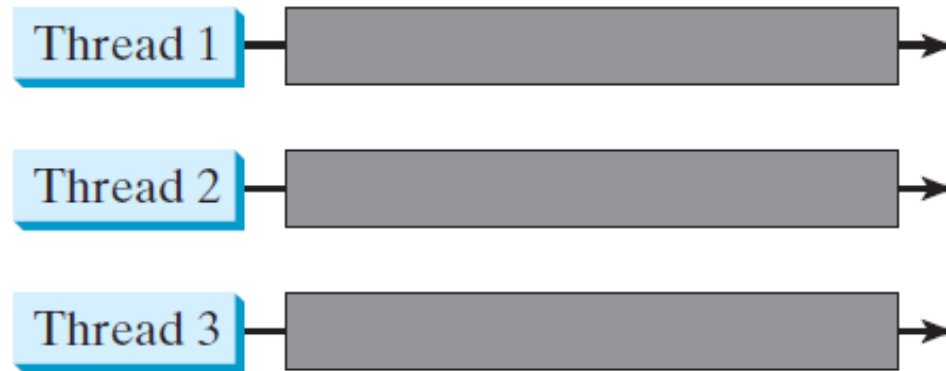


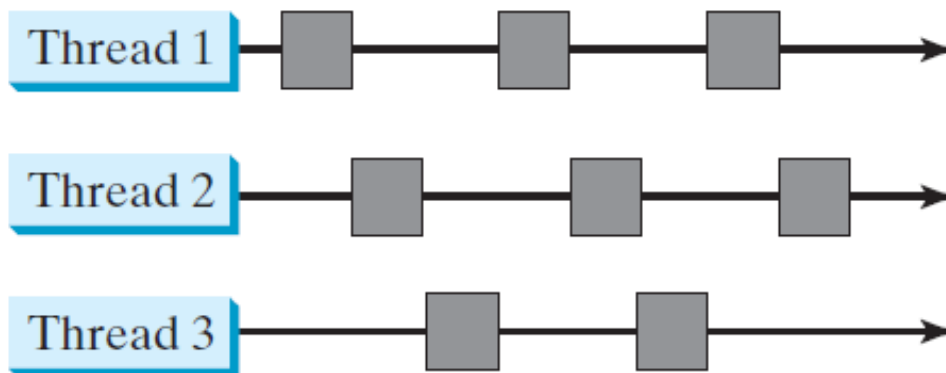
Chapter 32 Multithreading

Threads Concept

Multiple
threads on
multiple
CPUs



Multiple
threads
sharing a
single CPU



Creating Tasks and Threads

`java.lang.Runnable`  `TaskClass`

```
// Custom task class
public class TaskClass implements Runnable {
    ...
    public TaskClass(...) {
        ...
    }

    // Implement the run method in Runnable
    public void run() {
        // Tell system how to run custom thread
        ...
    }
    ...
}
```

(a)

```
// Client class
public class Client {
    ...
    public void someMethod() {
        ...
        // Create an instance of TaskClass
        TaskClass task = new TaskClass(...);

        // Create a thread
        Thread thread = new Thread(task);

        // Start a thread
        thread.start();
        ...
    }
    ...
}
```

(b)

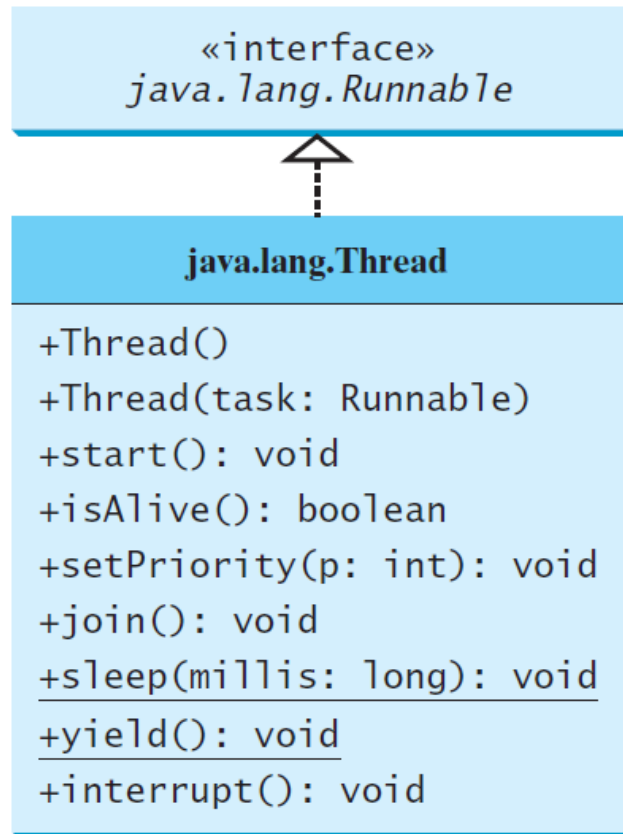
Example:

Using the Runnable Interface to Create and Launch Threads

- ♦ Objective: Create and run three threads:
 - The first thread prints the letter *a* 100 times.
 - The second thread prints the letter *b* 100 times.
 - The third thread prints the integers 1 through 100.

TaskThreadDemo

The Thread Class



Creates an empty thread.

Creates a thread for a specified task.

Starts the thread that causes the run() method to be invoked by the JVM.

Tests whether the thread is currently running.

Sets priority p (ranging from 1 to 10) for this thread.

Waits for this thread to finish.

Puts a thread to sleep for a specified time in milliseconds.

Causes a thread to pause temporarily and allow other threads to execute.

Interrupts this thread.

ExtendedThread

The Static yield() Method

You can use the yield() method to temporarily release time for other threads. For example, suppose you modify the code in Lines 53-57 in TaskThreadDemo.java as follows:

```
public void run() {  
    for (int i = 1; i <= lastNum; i++) {  
        System.out.print(" " + i);  
        Thread.yield();  
    }  
}
```

Every time a number is printed, the print100 thread is yielded. So, the numbers are printed just once then the characters follows.

The Static sleep(milliseconds) Method

The sleep(long mills) method puts the thread to sleep for the specified time in milliseconds. For example, suppose you modify the code in Lines 53-57 in TaskThreadDemo.java as follows:

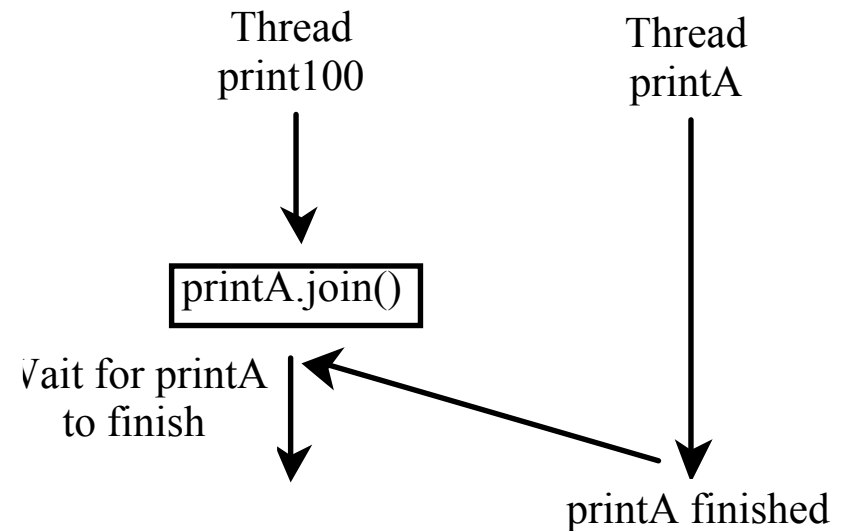
```
public void run() {  
    for (int i = 1; i <= lastNum; i++) {  
        System.out.print(" " + i);  
        try {  
            if (i >= 50) Thread.sleep(1);  
        }  
        catch (InterruptedException ex) {  
        }  
    }  
}
```

Every time a number (≥ 50) is printed, the print100 thread is put to sleep for 1 millisecond.

The join() Method

You can use the join() method to force one thread to wait for another thread to finish. For example, suppose you modify the code in Lines 53-57 in TaskThreadDemo.java as follows:

```
public void run() {  
    Thread thread4 = new Thread(  
        new PrintChar('c', 40));  
    thread4.start();  
    try {  
        for (int i = 1; i <= lastNum; i++) {  
            System.out.print(" " + i);  
            if (i == 50) thread4.join();  
        }  
    }  
    catch (InterruptedException ex) {  
    }  
}
```



The numbers after 50 are printed after thread printC is finished.

isAlive(), interrupt(), and isInterrupted()

The `isAlive()` method is used to find out the state of a thread. It returns `true` if a thread is in the Ready, Blocked, or Running state; it returns `false` if a thread is new and has not started or if it is finished.

The `interrupt()` method interrupts a thread in the following way: If a thread is currently in the Ready or Running state, its interrupted flag is set; if a thread is currently blocked, it is awakened and enters the Ready state, and an `java.io.InterruptedIOException` is thrown.

The `isInterrupted()` method tests whether the thread is interrupted.

Thread Priority

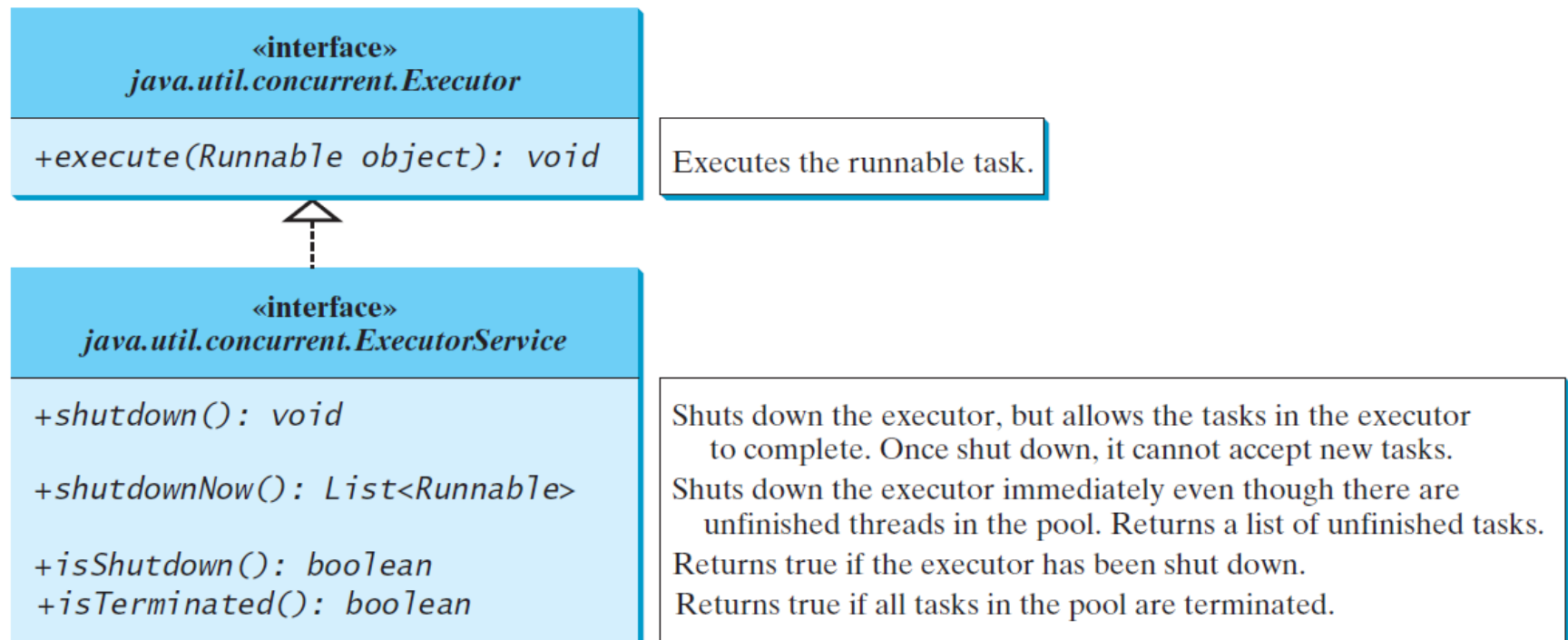
- ◆ Each thread is assigned a default priority of `Thread.NORM_PRIORITY`. You can reset the priority using `setPriority(int priority)`.
- ◆ Some constants for priorities include
`Thread.MIN_PRIORITY`
`Thread.MAX_PRIORITY`
`Thread.NORM_PRIORITY`

start() should be overridden carefully

MachineStartOverriden

Thread Pools

Starting a new thread for each task could limit throughput and cause poor performance. A thread pool is ideal to manage the number of tasks executing concurrently. JDK 1.5 uses the `Executor` interface for executing tasks in a thread pool and the `ExecutorService` interface for managing and controlling tasks. `ExecutorService` is a subinterface of `Executor`.



Creating Executors

To create an Executor object, use the static methods in the Executors class.

java.util.concurrent.Executors

**+newFixedThreadPool(numberOfThreads:
int): ExecutorService**

**+newCachedThreadPool():
ExecutorService**

Creates a thread pool with a fixed number of threads executing concurrently. A thread may be reused to execute another task after its current task is finished.

Creates a thread pool that creates new threads as needed, but will reuse previously constructed threads when they are available.

ExecutorDemo

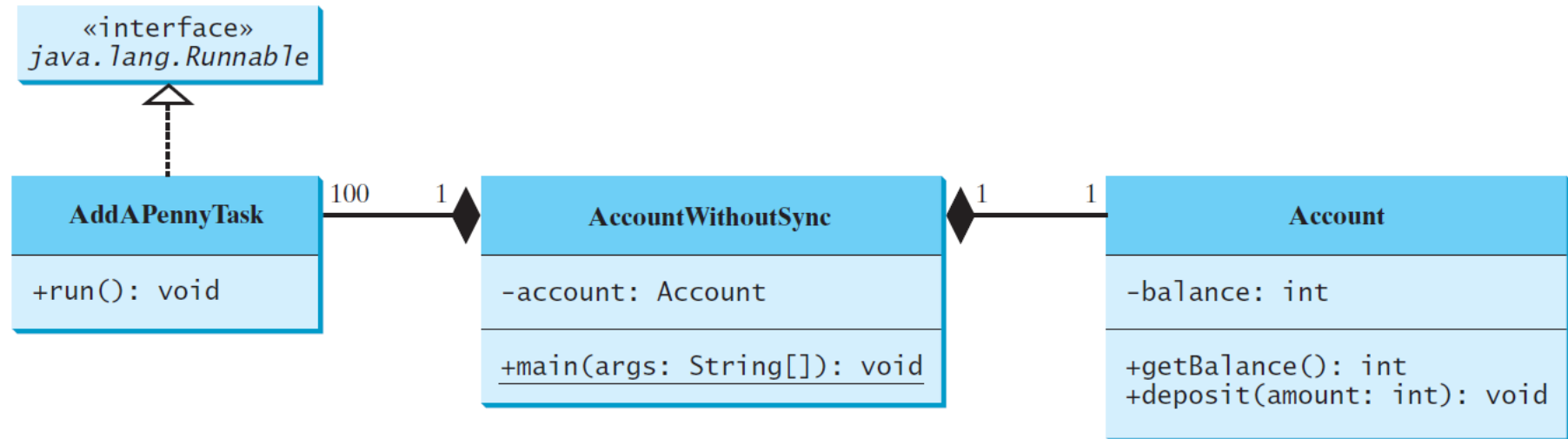
Thread Synchronization

A shared resource may be corrupted if it is accessed simultaneously by multiple threads. For example, two unsynchronized threads accessing the same bank account may cause conflict.

Step	balance	thread[i]	thread[j]
1	0	newBalance = balance + 1;	
2	0		newBalance = balance + 1;
3	1	balance = newBalance;	
4	1		balance = newBalance;

Example: Showing Resource Conflict

Objective: Write a program that demonstrates the problem of resource conflict. Suppose that you create and launch one hundred threads, each of which adds a penny to an account. Assume that the account is initially empty.



```
Command Prompt
C:\book>java AccountWithoutSync
What is balance ? 5

C:\book>java AccountWithoutSync
What is balance ? 4

C:\book>java AccountWithoutSync
What is balance ? 7

C:\book>
```

AccountWithoutSync

Race Condition

What, then, caused the error in the example? Here is a possible scenario:

Step	balance	Task 1	Task 2
1	0	newBalance = balance + 1;	
2	0		newBalance = balance + 1;
3	1	balance = newBalance;	
4	1		balance = newBalance;

The effect of this scenario is that Task 1 did nothing, because in Step 4 Task 2 overrides Task 1's result. Obviously, the problem is that Task 1 and Task 2 are accessing a common resource in a way that causes conflict. This is a common problem known as a *race condition* in multithreaded programs. A class is said to be *thread-safe* if an object of the class does not cause a race condition in the presence of multiple threads. As demonstrated in the preceding example, the Account class is not thread-safe.

The synchronized keyword

To avoid race conditions, more than one thread must be prevented from simultaneously entering certain part of the program, known as critical region. The critical region in *AccountWithoutSync.java* is the entire deposit method. You can use the synchronized keyword to synchronize the method so that only one thread can access the method at a time.

There are several ways to correct the problem in *AccountWithoutSync.java* is, one approach is to make Account thread-safe by adding the synchronized keyword in the deposit method in Line 45 as follows:

```
public synchronized void deposit(double amount)
```

Synchronizing Instance Methods and Static Methods

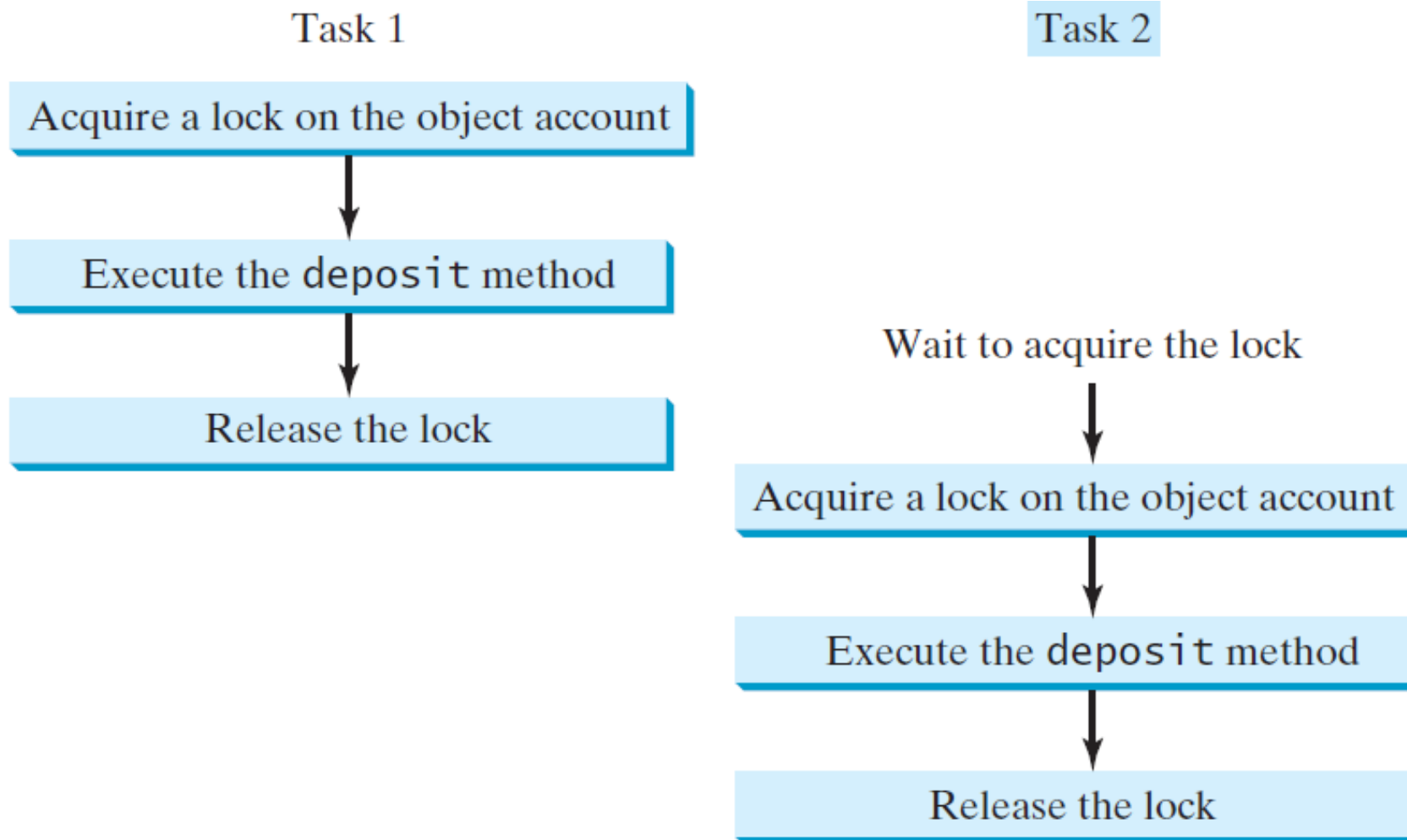
A synchronized method acquires a lock before it executes. In the case of an instance method, the lock is on the object for which the method was invoked. In the case of a static method, the lock is on the class. If one thread invokes a synchronized instance method (respectively, static method) on an object, the lock of that object (respectively, class) is acquired first, then the method is executed, and finally the lock is released. Another thread invoking the same method of that object (respectively, class) is blocked until the lock is released.

Synchronizing Instance Methods and Static Methods

With the deposit method synchronized, the preceding scenario cannot happen. If Task 2 starts to enter the method, and Task 1 is already in the method, Task 2 is blocked until Task 1 finishes the method.

Step	Balance	Task 1	Task 2
1	0	<code>newBalance = balance + 1;</code>	
2	0		<code>newBalance = balance + 1;</code>
3	1	<code>balance = newBalance;</code>	
4	1		<code>balance = newBalance;</code>

Synchronizing Tasks



Synchronizing Statements

Invoking a synchronized instance method of an object acquires a lock on the object, and invoking a synchronized static method of a class acquires a lock on the class

A synchronized statement can be used to acquire a lock on any object, not just *this* object, when executing a block of the code in a method. This block is referred to as a *synchronized block*. The general form of a synchronized statement is as follows:

```
synchronized (expr) {  
    statements;  
}
```

The expression `expr` must evaluate to an object reference. If the object is already locked by another thread, the thread is blocked until the lock is released. When a lock is obtained on the object, the statements in the synchronized block are executed, and then the lock is released.

Synchronizing Statements vs. Methods

Any synchronized instance method can be converted into a synchronized statement. Suppose that the following is a synchronized instance method:

```
public synchronized void xMethod() {  
    // method body  
}
```

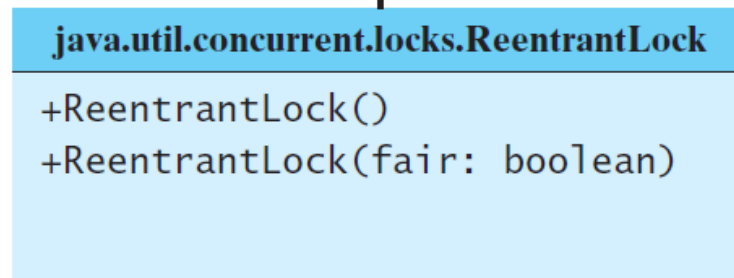
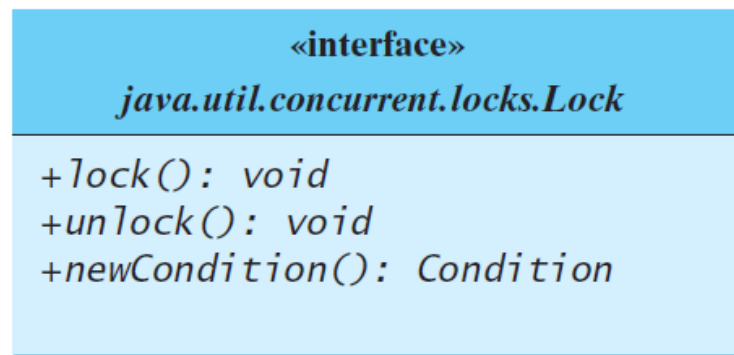
This method is equivalent to

```
public void xMethod() {  
    synchronized (this) {  
        // method body  
    }  
}
```

Synchronization Using Locks

A synchronized instance method implicitly acquires a lock on the instance before it executes the method.

JDK 1.5 enables you to use locks explicitly. The new locking features are flexible and give you more control for coordinating threads. A lock is an instance of the Lock interface, which declares the methods for acquiring and releasing locks. A lock may also use the newCondition() method to create any number of Condition objects, which can be used for thread communications.



AccountWithSyncUsingLock

Acquires the lock.
Releases the lock.
Returns a new Condition instance that is bound to this Lock instance.

Same as ReentrantLock(false).
Creates a lock with the given fairness policy. When the fairness is true, the longest-waiting thread will get the lock. Otherwise, there is no particular access order.

Cooperation Among Threads

The conditions can be used to facilitate communications among threads. A thread can specify what to do under a certain condition. Conditions are objects created by invoking the `newCondition()` method on a `Lock` object. Once a condition is created, you can use its `await()`, `signal()`, and `signalAll()` methods for thread communications. The `await()` method causes the current thread to wait until the condition is signaled. The `signal()` method wakes up one waiting thread, and the `signalAll()` method wakes all waiting threads.

«interface»

java.util.concurrent.Condition

+await(): void

+signal(): void

+signalAll(): Condition

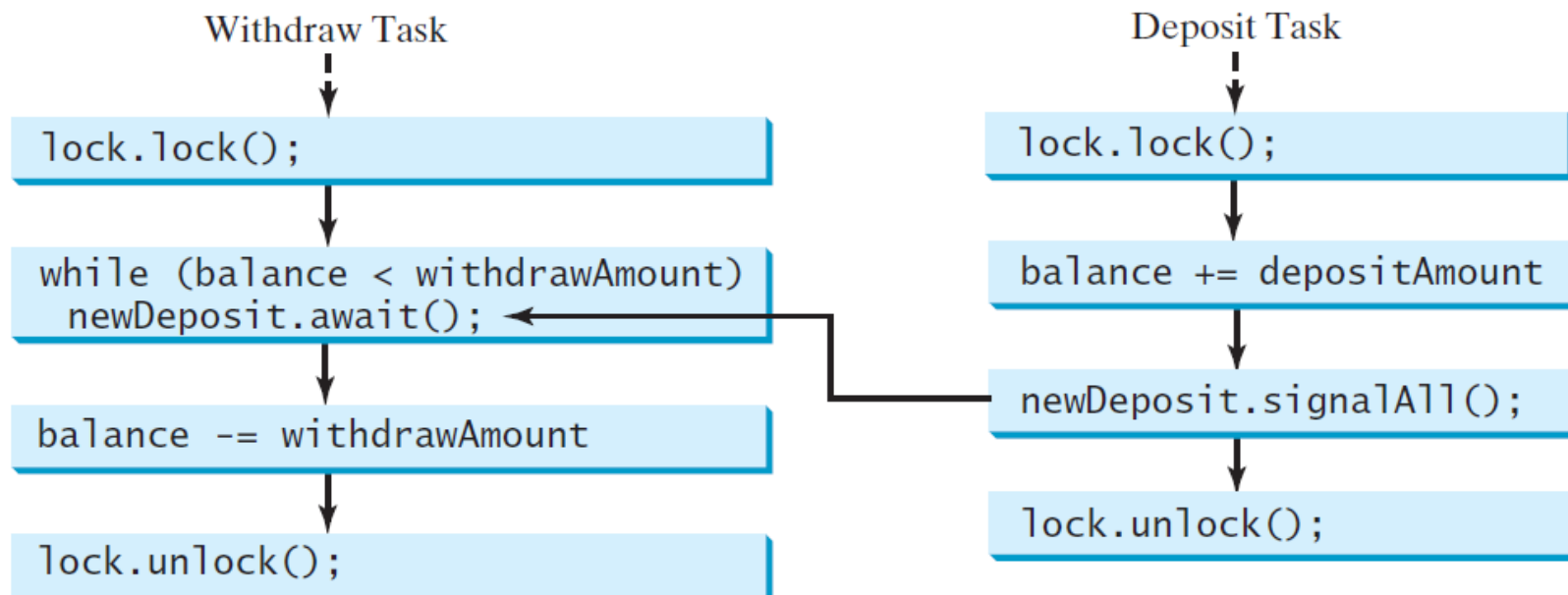
Causes the current thread to wait until the condition is signaled.

Wakes up one waiting thread.

Wakes up all waiting threads.

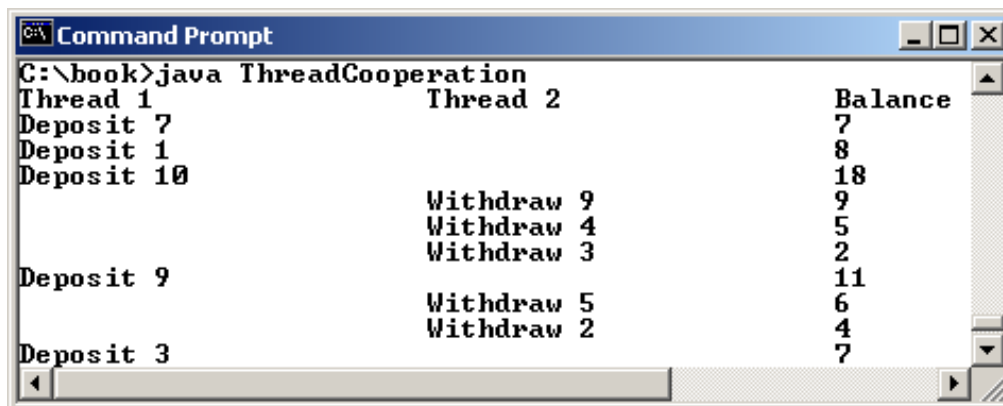
Cooperation Among Threads

To synchronize the operations, use a lock with a condition: `newDeposit` (i.e., new deposit added to the account). If the balance is less than the amount to be withdrawn, the withdraw task will wait for the `newDeposit` condition. When the deposit task adds money to the account, the task signals the waiting withdraw task to try again.



Example: Thread Cooperation

Write a program that demonstrates thread cooperation. Suppose that you create and launch two threads, one deposits to an account, and the other withdraws from the same account. The second thread has to wait if the amount to be withdrawn is more than the current balance in the account. Whenever new fund is deposited to the account, the first thread notifies the second thread to resume. If the amount is still not enough for a withdrawal, the second thread has to continue to wait for more fund in the account. Assume the initial balance is 0 and the amount to deposit and to withdraw is randomly generated.



```
C:\book>java ThreadCooperation
Thread 1          Thread 2          Balance
Deposit 7         Withdraw 9         7
Deposit 1         Withdraw 4         8
Deposit 10        Withdraw 3         18
                  Withdraw 5         9
                  Withdraw 4         5
                  Withdraw 3         2
Deposit 9         Withdraw 5         11
                  Withdraw 2         6
Deposit 3         Withdraw 2         4
                  Withdraw 2         7
```

ThreadCooperation

wait(), notify(), and notifyAll()

Use the wait(), notify(), and notifyAll() methods to facilitate communication among threads.

The wait(), notify(), and notifyAll() methods must be called in a synchronized method or a synchronized block on the calling object of these methods. Otherwise, an IllegalMonitorStateException would occur.

The wait() method lets the thread wait until some condition occurs. When it occurs, you can use the notify() or notifyAll() methods to notify the waiting threads to resume normal execution. The notifyAll() method wakes up all waiting threads, while notify() picks up only one thread from a waiting queue.

Example: Using Monitor

Task 1

```
synchronized (anObject) {  
    try {  
        // Wait for the condition to become true  
        while (!condition)  
            anObject.wait();  
        // Do something when condition is true  
    }  
    catch (InterruptedException ex) {  
        ex.printStackTrace();  
    }  
}
```

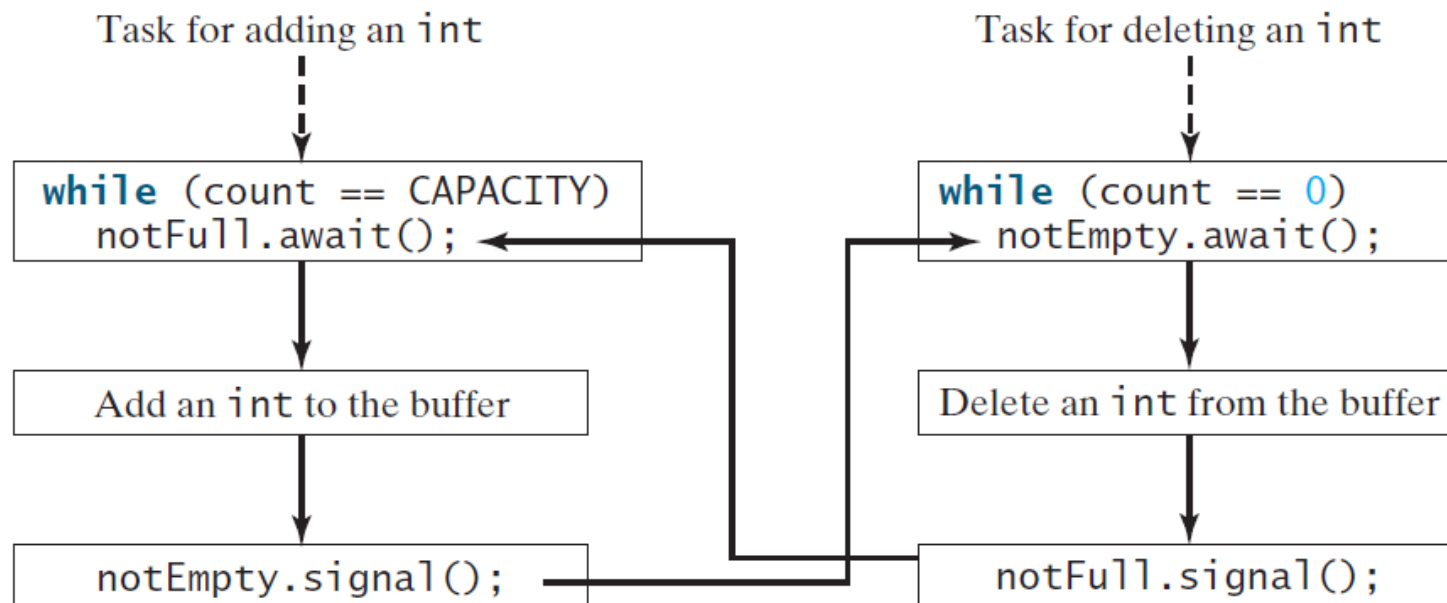
Task 2

```
synchronized (anObject) {  
    // When condition becomes true  
    anObject.notify(); or anObject.notifyAll();  
    ...  
}
```

- ✦ The wait(), notify(), and notifyAll() methods must be called in a synchronized method or a synchronized block on the receiving object of these methods. Otherwise, an IllegalMonitorStateException will occur.
- ✦ When wait() is invoked, it pauses the thread and simultaneously releases the lock on the object. When the thread is restarted after being notified, the lock is automatically reacquired.
- ✦ The wait(), notify(), and notifyAll() methods on an object are analogous to the await(), signal(), and signalAll() methods on a condition.

Case Study: Producer/Consumer (Optional)

Consider the classic Consumer/Producer example. Suppose you use a buffer to store integers. The buffer size is limited. The buffer provides the method `write(int)` to add an `int` value to the buffer and the method `read()` to read and delete an `int` value from the buffer. To synchronize the operations, use a lock with two conditions: `notEmpty` (i.e., buffer is not empty) and `notFull` (i.e., buffer is not full). When a task adds an `int` to the buffer, if the buffer is full, the task will wait for the `notFull` condition. When a task deletes an `int` from the buffer, if the buffer is empty, the task will wait for the `notEmpty` condition.



Case Study: Producer/Consumer (Optional)

Listing 30.8 presents the complete program. The program contains the Buffer class (lines 43-89) and two tasks for repeatedly producing and consuming numbers to and from the buffer (lines 15-41). The write(int) method (line 58) adds an integer to the buffer. The read() method (line 75) deletes and returns an integer from the buffer.

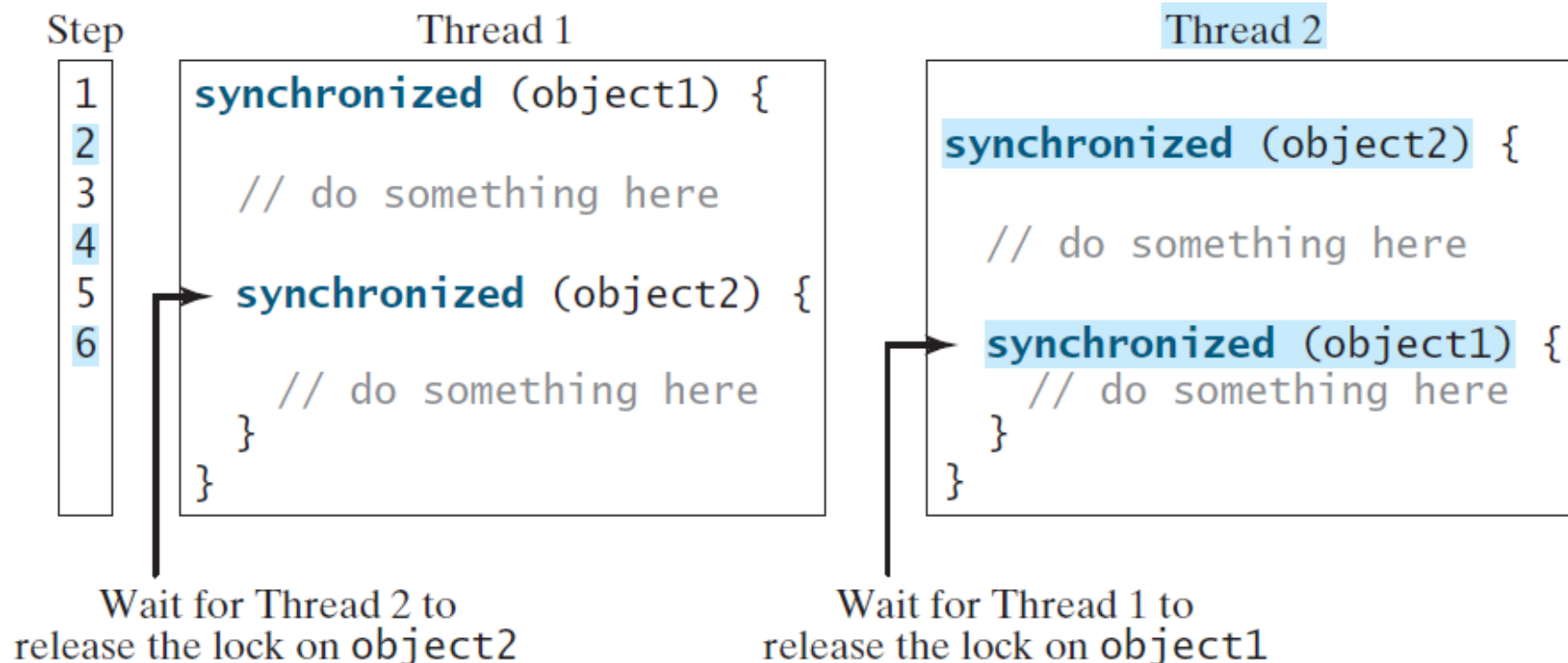
For simplicity, the buffer is implemented using a linked list (lines 48-49). Two conditions notEmpty and notFull on the lock are created in lines 55-56. The conditions are bound to a lock. A lock must be acquired before a condition can be applied. If you use the wait() and notify() methods to rewrite this example, you have to designate two objects as monitors.

ConsumerProducer

ConsumerProducerUsingBlockingQueue

Deadlock

Sometimes two or more threads need to acquire the locks on several shared objects. This could cause *deadlock*, in which each thread has the lock on one of the objects and is waiting for the lock on the other object. Consider the scenario with two threads and two objects. Thread 1 acquired a lock on object1 and Thread 2 acquired a lock on object2. Now Thread 1 is waiting for the lock on object2 and Thread 2 for the lock on object1. The two threads wait for each other to release the in order to get the lock, and neither can continue to run.

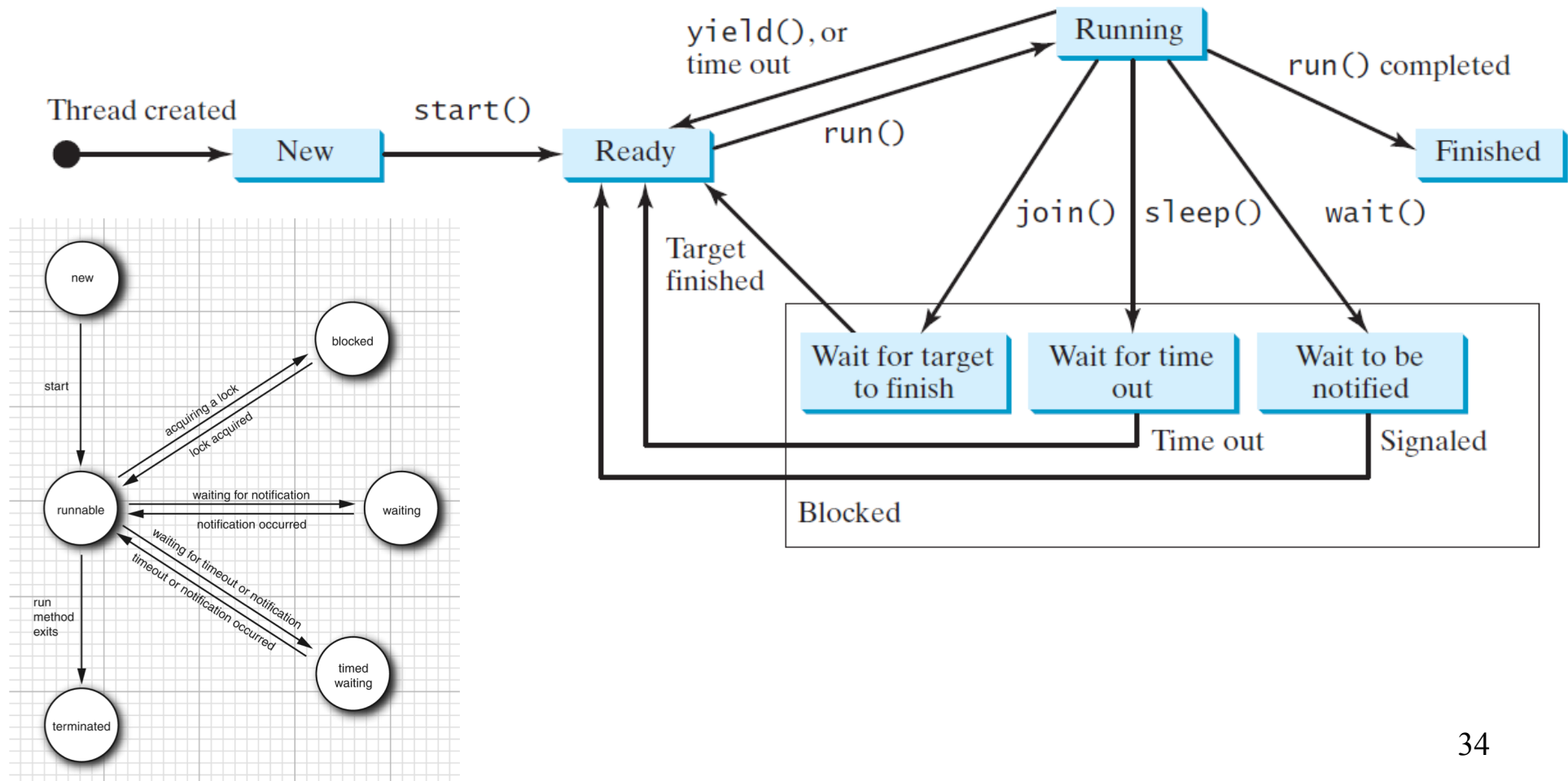


Preventing Deadlock

Deadlock can be easily avoided by using a simple technique known as resource ordering. With this technique, you assign an order on all the objects whose locks must be acquired and ensure that each thread acquires the locks in that order. For the example, suppose the objects are ordered as object1 and object2. Using the resource ordering technique, Thread 2 must acquire a lock on object1 first, then on object2. Once Thread 1 acquired a lock on object1, Thread 2 has to wait for a lock on object1. So Thread 1 will be able to acquire a lock on object2 and no deadlock would occur.

Thread States

A thread can be in one of five states:
New, Ready, Running, Blocked, or
Finished.



Synchronized Collections

The classes in the Java Collections Framework are not thread-safe, i.e., the contents may be corrupted if they are accessed and updated concurrently by multiple threads. You can protect the data in a collection by locking the collection or using synchronized collections.

The Collections class provides six static methods for wrapping a collection into a synchronized version. The collections created using these methods are called *synchronization wrappers*.

java.util.Collections

```
+synchronizedCollection(c: Collection): Collection  
+synchronizedList(list: List): List  
+synchronizedMap(m: Map): Map  
+synchronizedSet(s: Set): Set  
+synchronizedSortedMap(s: SortedMap): SortedMap  
+synchronizedSortedSet(s: SortedSet): SortedSet
```

Returns a synchronized collection.
Returns a synchronized list from the specified list.
Returns a synchronized map from the specified map.
Returns a synchronized set from the specified set.
Returns a synchronized sorted map from the specified sorted map.
Returns a synchronized sorted set.

Chapter 33 Networking

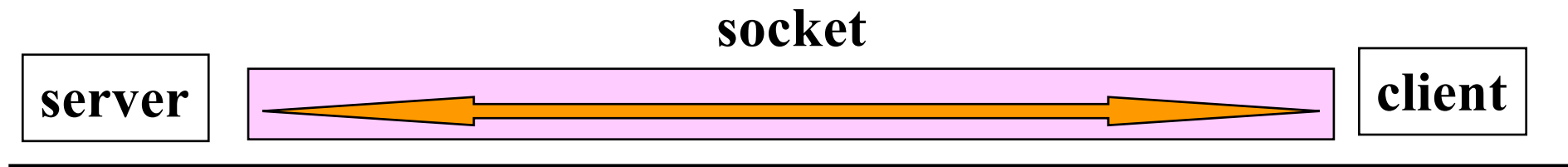
Objectives

- ♦ To explain terms: TCP, IP, domain name, domain name server, stream-based communications, and packet-based communications (§ 33.2).
- ♦ To create servers using server sockets (§ 33.2.1) and clients using client sockets (§ 33.2.2).
- ♦ To implement Java networking programs using stream sockets (§ 33.2.3).
- ♦ To develop an example of a client/server application (§ 33.2.4).
- ♦ To obtain Internet addresses using the **InetAddress** class (§ 33.3).
- ♦ To develop servers for multiple clients (§ 33.4).
- ♦ To send and receive objects on a network (§ 33.5).
- ♦ To develop an interactive tic-tac-toe game played on the Internet (§ 33.6).

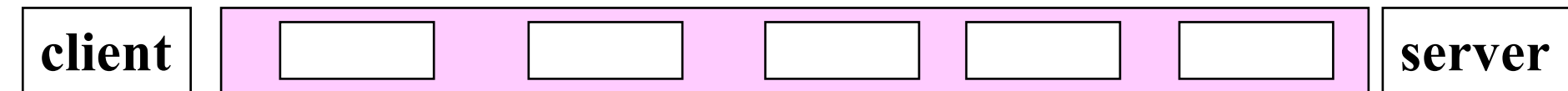
Stream Socket vs. Datagram Socket

Stream socket

- ◆ A dedicated point-to-point channel between a client and server.
- ◆ Use TCP (Transmission Control Protocol) for data transmission.
- ◆ Lossless and reliable.
- ◆ Sent and received in the same order.



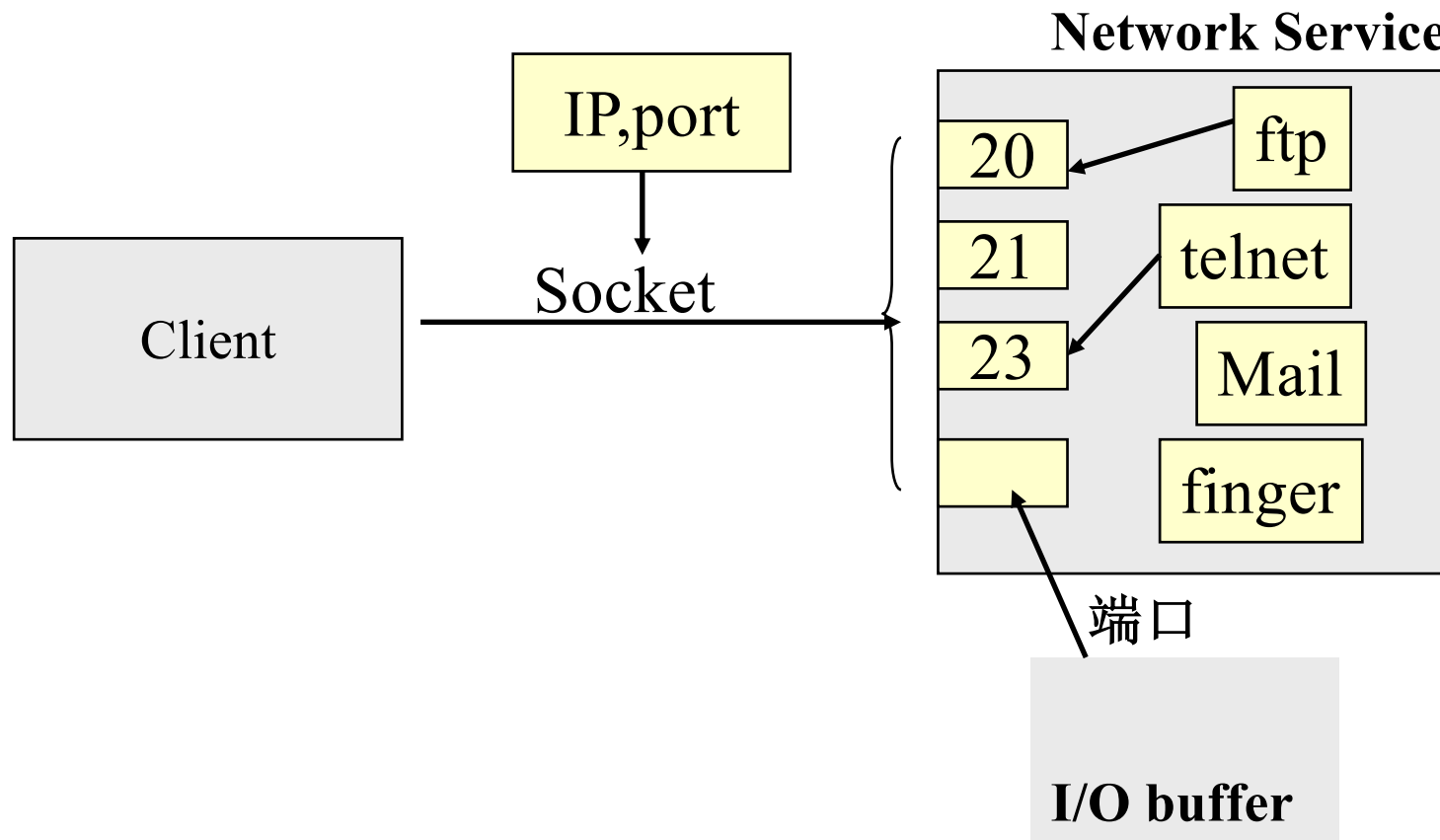
datagram



Datagram socket

- ◆ No dedicated point-to-point channel between a client and server.
- ◆ Use UDP (User Datagram Protocol) for data transmission.
- ◆ May lose data and not 100% reliable.
- ◆ Data may not be received in the same order as sent.

Socket based Service

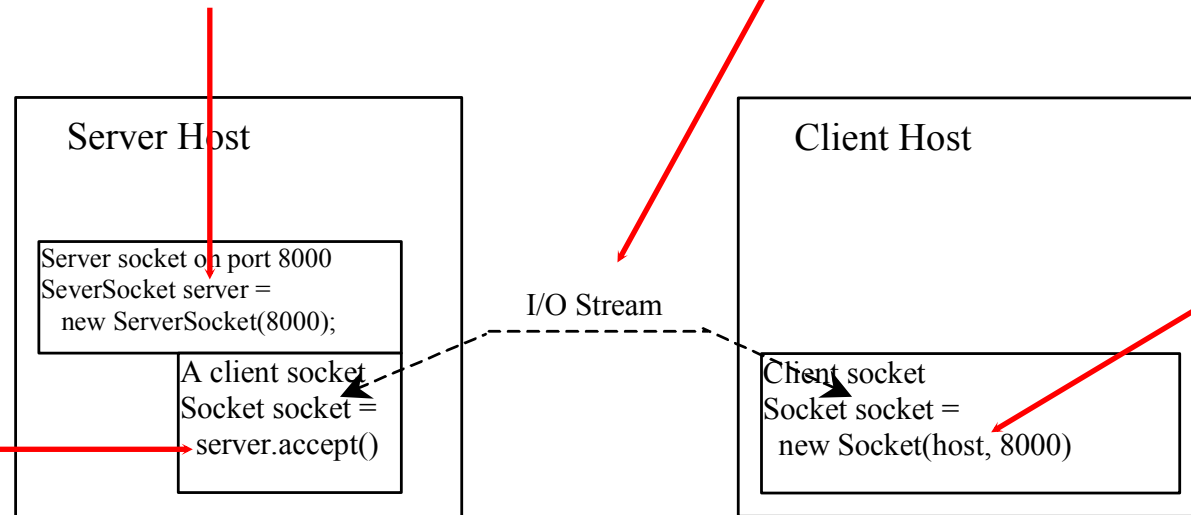


Client/Server Communications

The server must be running when a client starts. The server waits for a connection request from a client. To establish a server, you need to create a server socket and attach it to a port, which is where the server listens for connections.

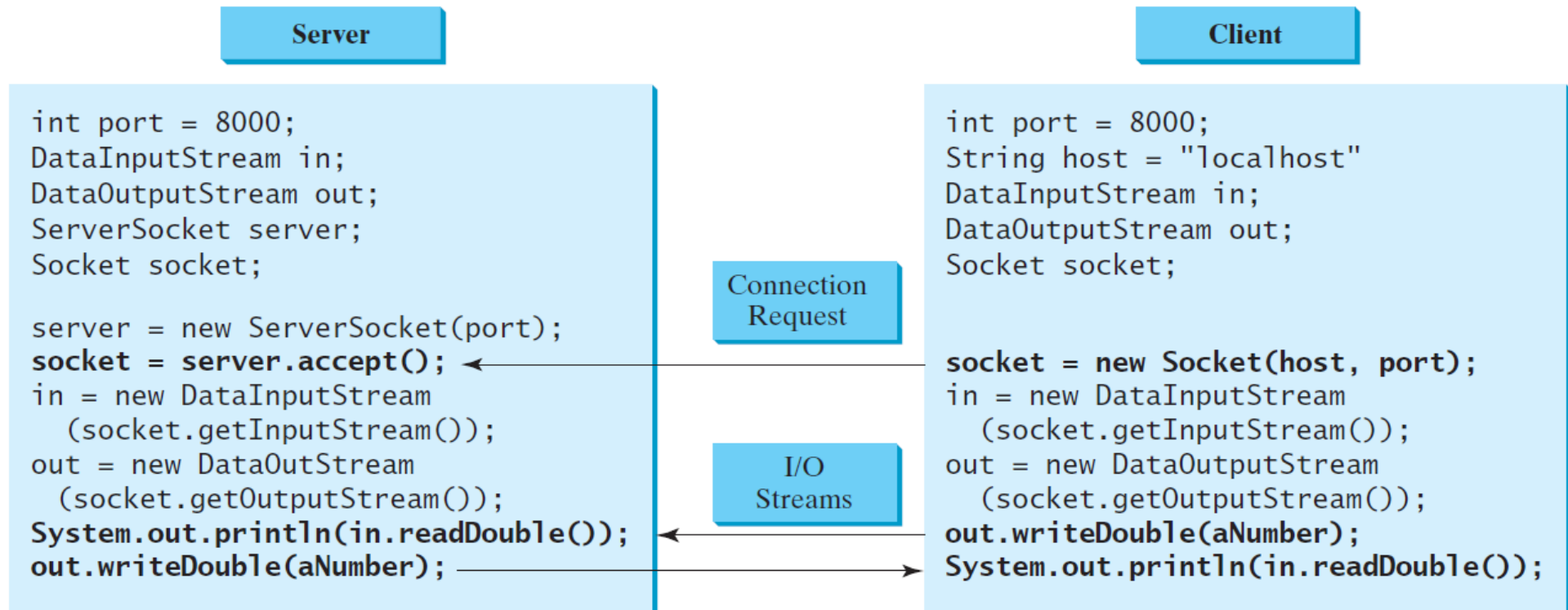
After the server accepts the connection, communication between server and client is conducted the same as for I/O streams.

After a server socket is created, the server can use this statement to listen for connections.



The client issues this statement to request a connection to a server.

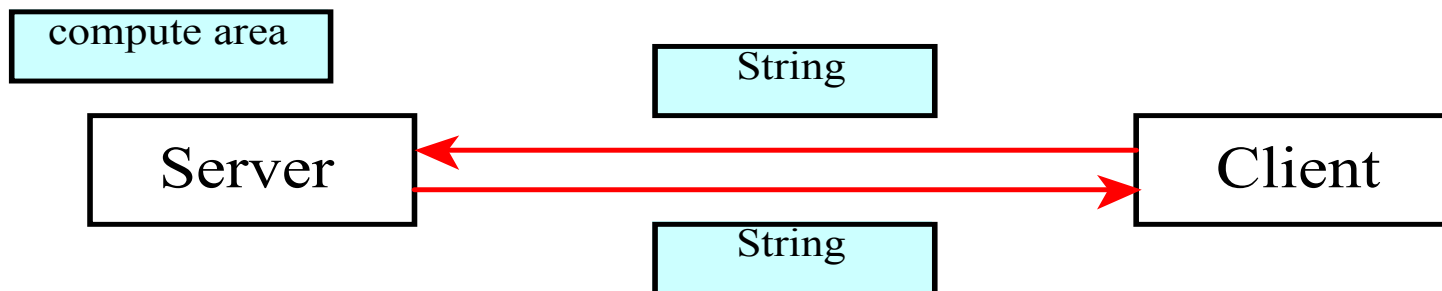
Data Transmission through Sockets



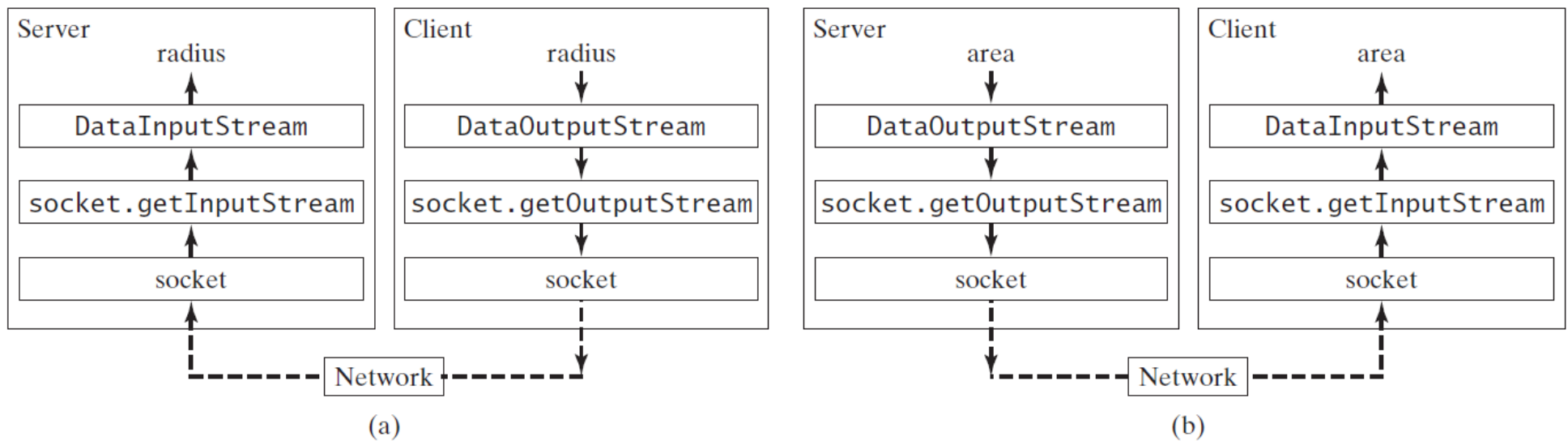
```
InputStream input = socket.getInputStream();
OutputStream output = socket.getOutputStream();
```


A Client/Server Example

- ◆ Problem: Write a client to send data to a server. The server receives the data, uses it to produce a result, and then sends the result back to the client. The client displays the result on the console.



A Client/Server Example, cont.



Server Code

Client Code

Note: Start the server, then the client.

The InetAddress Class

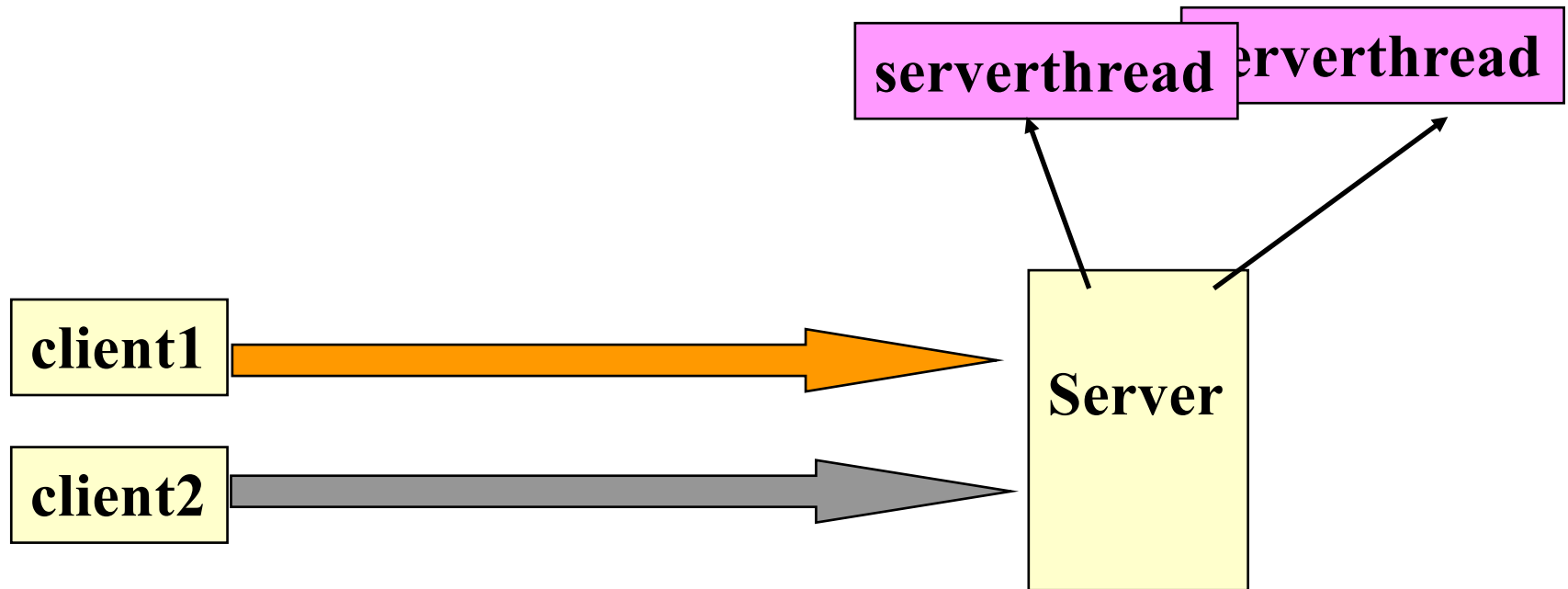
Occasionally, you would like to know who is connecting to the server. You can use the `InetAddress` class to find the client's host name and IP address. The `InetAddress` class models an IP address. You can use the statement shown below to create an instance of `InetAddress` for the client on a socket.

```
InetAddress inetAddress = socket.getInetAddress();
```

Next, you can display the client's host name and IP address, as follows:

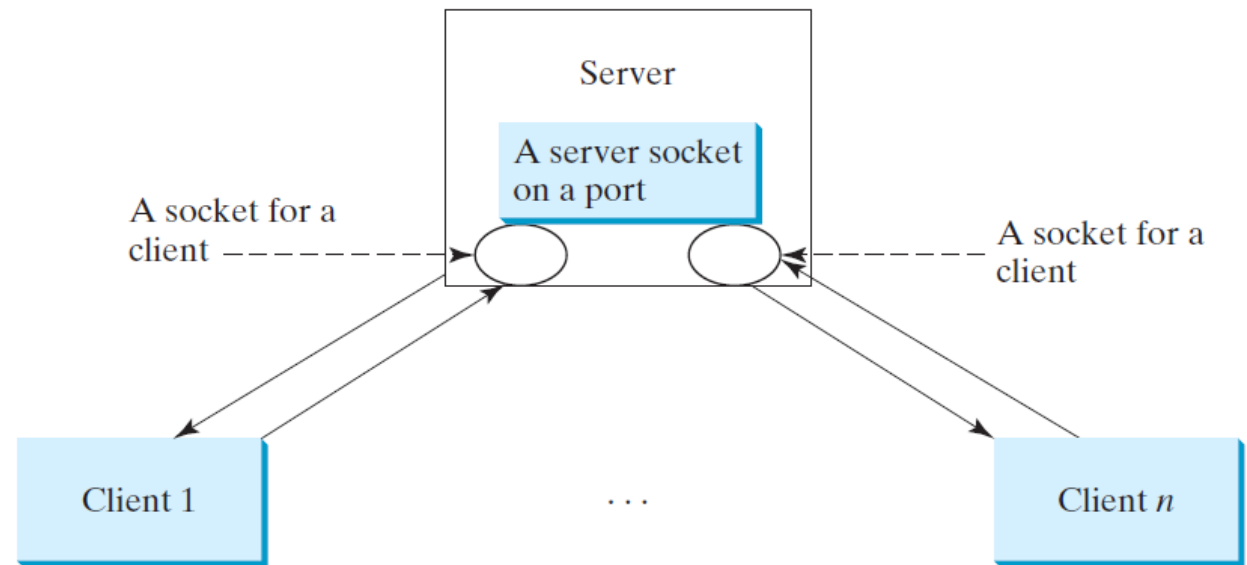
```
System.out.println("Client's host name is " +  
    inetAddress.getHostName());  
System.out.println("Client's IP Address is " +  
    inetAddress.getHostAddress());
```

Serving Multiple Clients



MultiClientServer

Example: Serving Multiple Clients

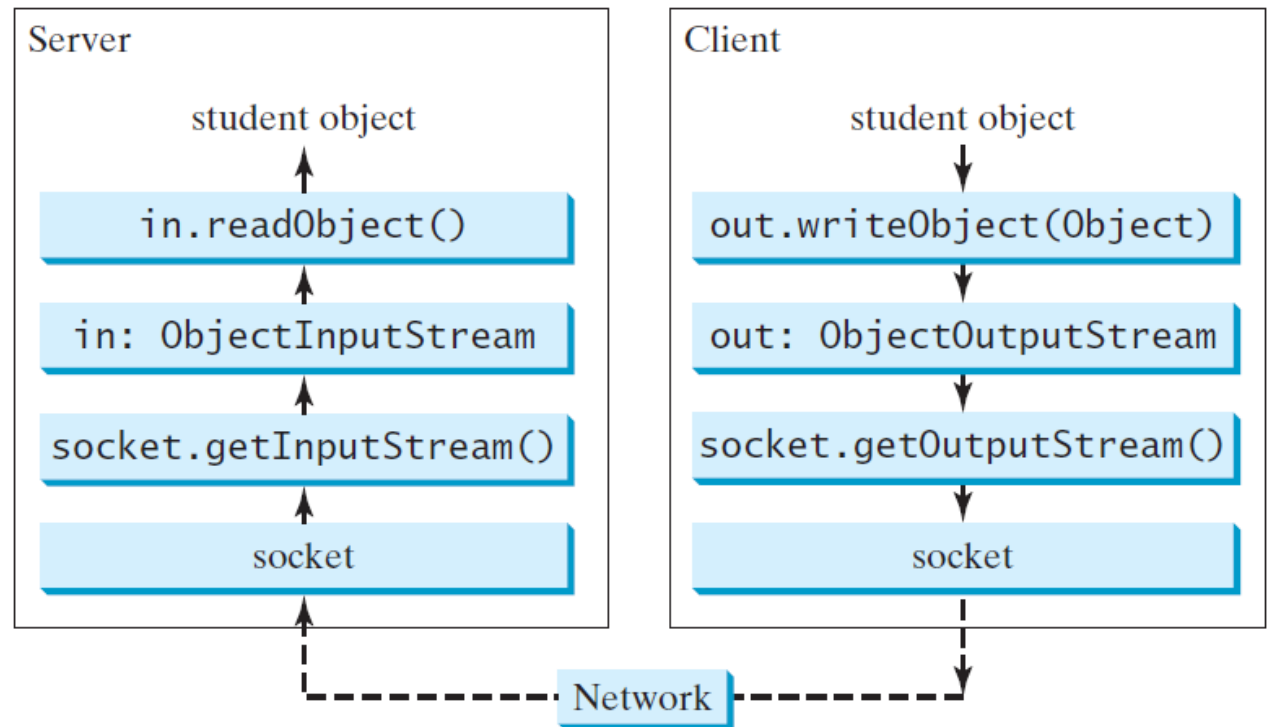


ServerWithThreadPool

Note: Start the server first, then start multiple clients.

Example: Passing Objects in Network Programs

Write a program that collects student information from a client and send them to a server. Passing student information in an object.



StudentAddres Class

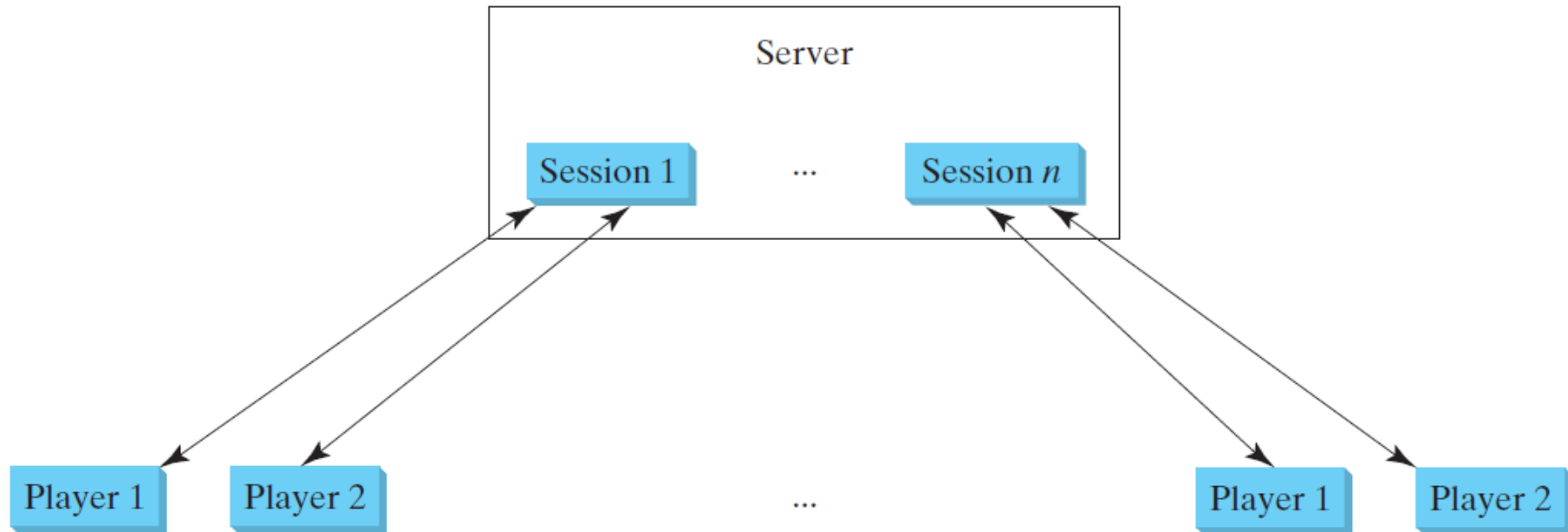
StudentServer

StudentClient

Note: Start the server first, then the client.

Optional

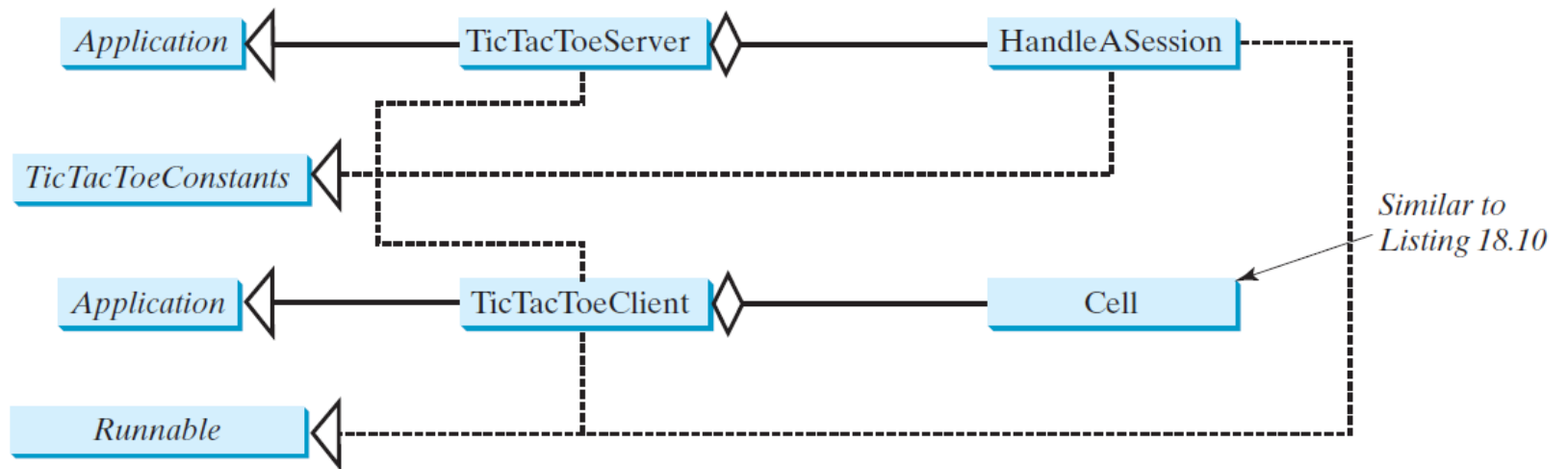
Case Studies: Distributed TicTacToe Games



TicTacToeServer

TicTacToeClient

Distributed TicTacToe, cont.



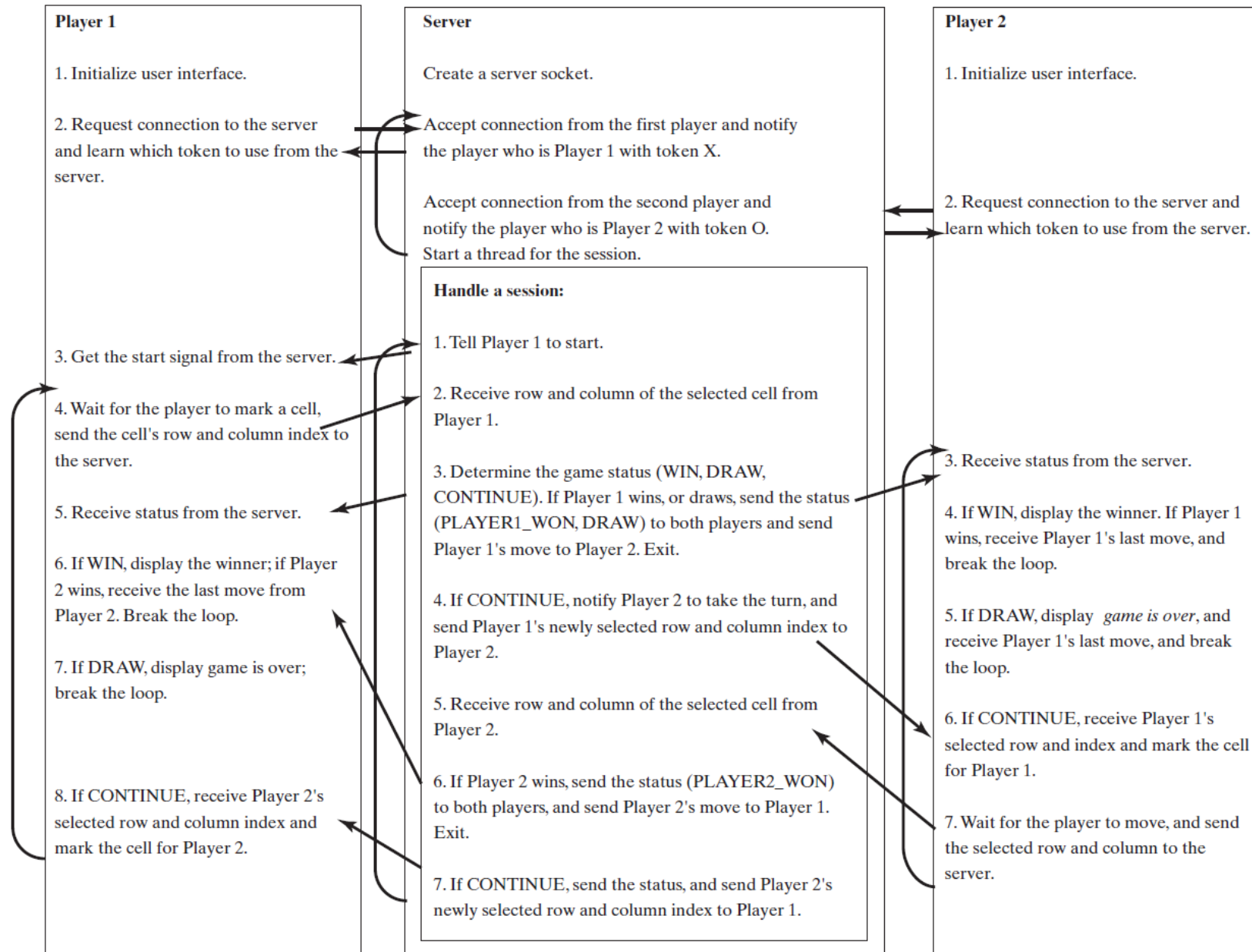
TicTacToeServer
start(primaryStage: Stage): void

«interface» TicTacToeConstants
+PLAYER1 = 1: int
+PLAYER2 = 2: int
+PLAYER1_WON = 1: int
+PLAYER2_WON = 2: int
+DRAW = 3: int
+CONTINUE = 4: int

HandleASession
-player1: Socket
-player2: Socket
-cell: char[][]
-continueToPlay: boolean
+run(): void
-isWon(): boolean
-isFull(): boolean
-sendMove(out: DataOutputStream, row: int, column: int): void

TicTacToeClient
-myTurn: boolean
-myToken: char
-otherToken: char
-cell: Cell[][]
-continueToPlay: boolean
-rowSelected: int
-columnSelected: int
-fromServer: DataInputStream
-toServer: DataOutputStream
-waiting: boolean
+run(): void
-connectToServer(): void
-receiveMove(): void
-sendMove(): void
-receiveInfoFromServer(): void
-waitForPlayerAction(): void

Distributed TicTacToe Game



Stream Socket vs. Datagram Socket

Stream socket

- ◆ A dedicated point-to-point channel between a client and server.
- ◆ Use TCP (Transmission Control Protocol) for data transmission.
- ◆ Lossless and reliable.
- ◆ Sent and received in the same order.

Datagram socket

- ◆ No dedicated point-to-point channel between a client and server.
- ◆ Use UDP (User Datagram Protocol) for data transmission.
- ◆ May lose data and not 100% reliable.
- ◆ Data may not be received in the same order as sent.

DatagramPacket

The DatagramPacket class represents a datagram packet. Datagram packets are used to implement a connectionless packet delivery service. Each message is routed from one machine to another based solely on information contained within the packet.

java.net.DatagramPacket	
length: int	A JavaBeans property to specify the length of buffer.
address: InetAddress	A JavaBeans property to specify the address of the machine where the package is sent or received.
port: int	A JavaBeans property to specify the port of the machine where the package is sent or received.
+DatagramPacket(buf: byte[], length: int, host: InetAddress, port: int)	Constructs a datagram packet in a byte array <u>buf</u> of the specified <u>length</u> with the <u>host</u> and the <u>port</u> for which the packet is sent. This constructor is often used to construct a packet for delivery from a client.
+DatagramPacket(buf: byte[], length: int)	Constructs a datagram packet in a byte array <u>buf</u> of the specified <u>length</u> .
+getData(): byte[]	Returns the data from the package.
+setData(buf: byte[]): void	Sets the data in the package.

DatagramSocket

DatagramSocket The DatagramSocket class represents a socket for sending and receiving datagram packets. A datagram socket is the sending or receiving point for a packet delivery service. Each packet sent or received on a datagram socket is individually addressed and routed. Multiple packets sent from one machine to another may be routed differently, and may arrive in any order.

**Create a server
DatagramSocket** To create a server DatagramSocket, use the constructor `DatagramSocket(int port)`, which binds the socket with the specified port on the local host machine.

**Create a client
DatagramSocket** To create a client DatagramSocket, use the constructor `DatagramSocket()`, which binds the socket with any available port on the local host machine.

Sending and Receiving a DatagramSocket

Sending

To send data, you need to create a packet, fill in the contents, specify the Internet address and port number for the receiver, and invoke the `send(packet)` method on a `DatagramSocket`.

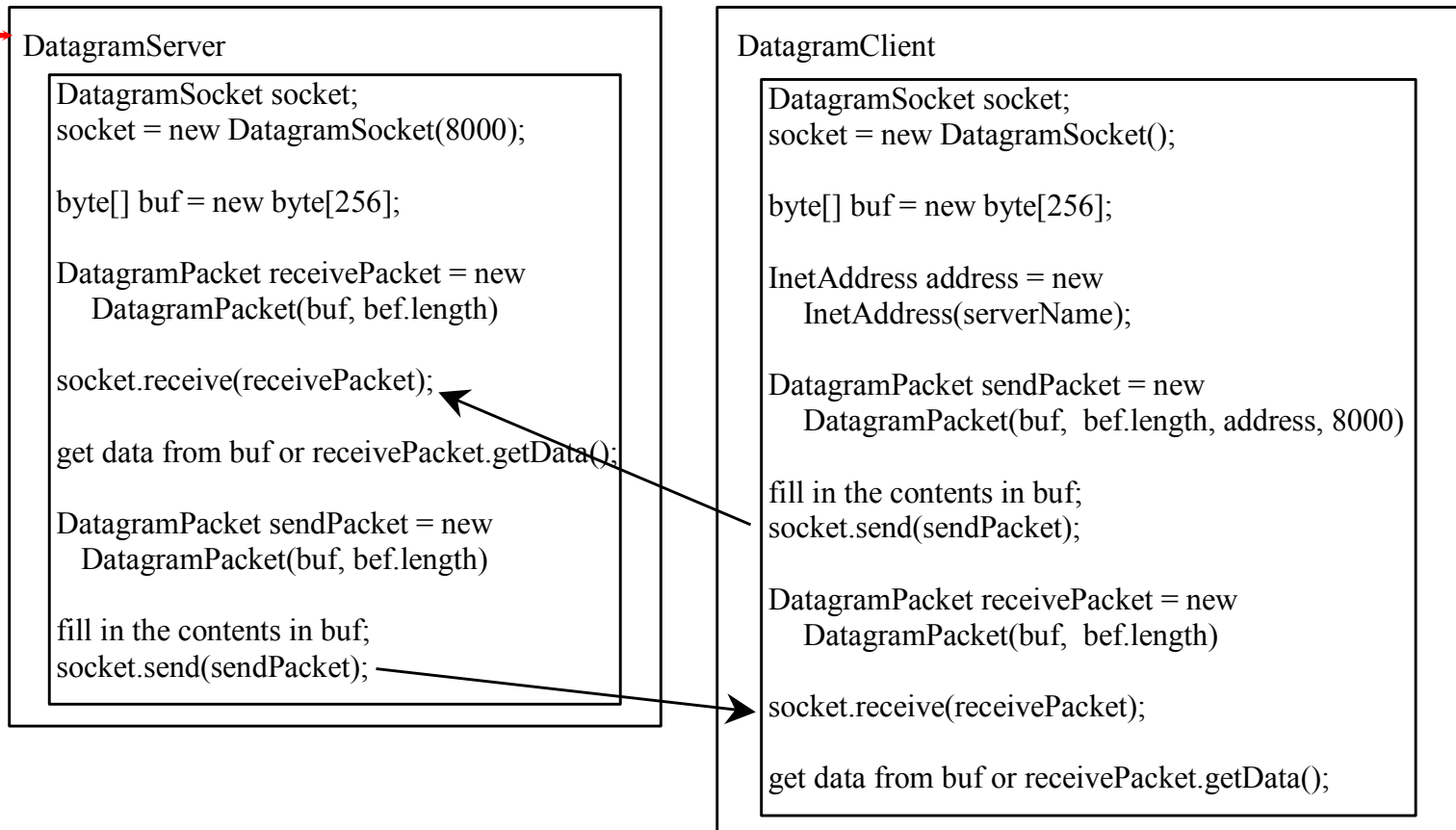
Receiving

To receive data, create an empty packet and invoke the `receive(packet)` method on a `DatagramSocket`.

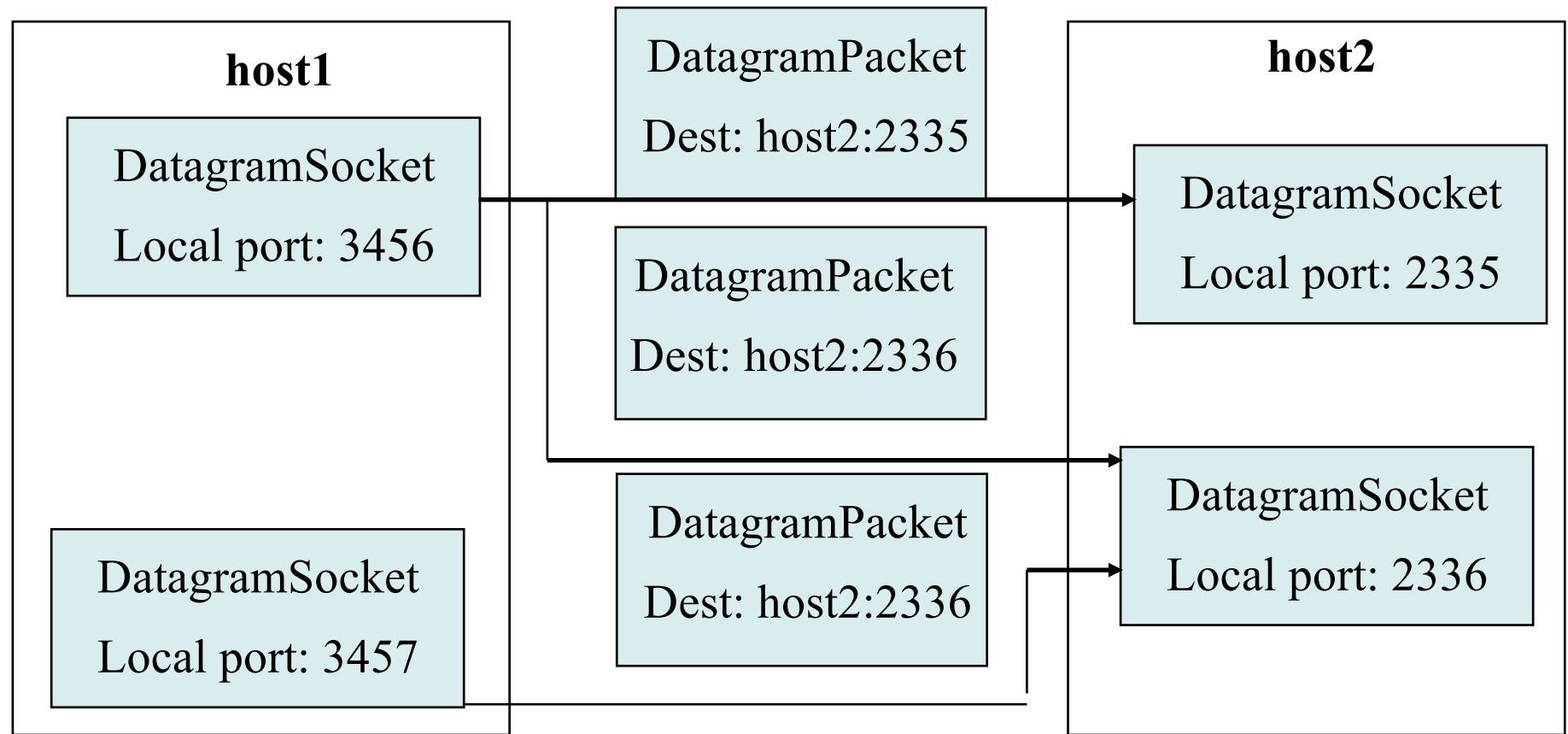
Datagram Programming

Datagram programming is different from stream socket programming in the sense that there is no concept of a ServerSocket for datagrams. Both client and server use DatagramSocket to send and receive packets.

Designate
one a server



*DatagramSocket DatagramPacket



ServerWithUDP

ClientWithUDP

Note: Start the server first, then start multiple clients.

*Multicast

- ◆ MulticastSender.java
- ◆ MulticastReceiver.java