Programación concurrente en Java idioma

Presentado por developerWorks, su fuente de grandes clases particulares

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Tabla de contenido

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Section 1. About this tutorial Should

I take this tutorial?

One of the important features of the Java language is support for multithreaded (also called concurrent) programming.

This tutorial is an introduction to the use of multiple threads in a Java program and will appeal to systems or application programmers who want to learn about multithreaded Java programming.

Un programa de multiproceso puede tomar ventaja de las CPUs adicionales en una arquitectura multiprocesador de memoria compartida con el fin de ejecutar con mayor rapidez. El uso de múltiples hilos también puede simplificar el diseño de un programa. Como ejemplo, considere un programa de servidor en el que cada petición de cliente entrante es manejado por un hilo dedicado.

Sin embargo, para evitar las condiciones de carrera y la corrupción de los datos compartidos, los hilos en un programa concurrente deben estar sincronizados correctamente. Muchos programas de ejemplo se utilizan en este tutorial para ilustrar estos conceptos.

Este tutorial asume un conocimiento general previo de programación Java; el contexto y el nivel de conocimiento usado en este tutorial es el equivalente de un curso de sistemas operativos de grado. Para una explicación más explícita de la experiencia necesaria para obtener el máximo provecho de este tutorial, consulte Supuestos y el contexto en la página 3.

Sobre el Autor

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Si tiene preguntas sobre el contenido de este tutorial, por favor, póngase en contacto con el autor. Presentado por

Sección 2. Metas y objetivos

Introducción

Los dos objetivos de este tutorial son:

* Aprender las "tuercas y tornillos" de la creación de múltiples hilos de control en un programa Java.
* Aprender las trampas y las áreas que pueden hacerte tropezar al sincronizar esos hilos para evitar condiciones de carrera y la corrupción de los datos compartidos.

Supuestos y el contexto

Antes de pasar a los aspectos prácticos de la programación concurrente, vamos a explicar en detalle los conocimientos y la experiencia necesaria para exprimir más eficazmente el uso de este tutorial.

Suponemos que usted tiene un conocimiento general de los problemas de concurrencia, a un nivel acorde con un curso de licenciatura sistemas operativos informática. También asumimos una familiaridad con los siguientes términos y conceptos: múltiples hilos, datos compartidos, las condiciones de carrera, las secciones críticas, exclusión mutua, monitores, y los semáforos. Por último, debe tener conocimientos de programación orientada a objetos y Java secuencial: clases, objetos, las interfaces, herencia, polimorfismo, paquetes, y las excepciones.

Para mayor referencia, recursos en la página 122 al final del tutorial incluye recursos en línea e imprimir en la programación concurrente y el lenguaje Java.

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especificaciones de la plataforma de tutoría

Todos los programas de ejemplo de Java en este tutorial se han ejecutado en un PC con ***La versión de Red Hat Linux 7.0 del*** , utilizando la ***IBM Java kit de desarrollador de software versión 1.3.0 para Linux*** . Este kit de desarrollador utiliza subprocesos nativos y por lo tanto el tiempo les rebana automáticamente.

Los ejemplos son compilados y ejecutados con el compilador Just-In-Time (JIT) discapacitados (comando **JAVA_COMPILER exportación = NONE)** para facilitar la manifestación de las condiciones de carrera en Ejemplo race.java en la página 24 y Ejemplo rac2.java en la página 25.

Puede descargar un archivo zip que contiene todos los programas de ejemplo de Java en este tutorial en recursos en la página 122.

Section 3. Starting Java threads Two ways to start Java threads

There are two ways to start Java threads. One way is to subclass the **Thread** class:

```
class A extends Thread {
      public void run() {
            . . .   // code for the new thread to execute } }


. . .
      A a = new A(); // create the thread object
      a.start();                  // start the new thread executing
. . .
```

The second way is to implement the **Runnable** interface:

```
class B extends ... implements Runnable {
      public void run() {
            . . .   // code for the new thread to execute } }


. . .
      B b = new B();                        // create the Runnable object
      Thread t = new Thread(b); // create a thread object
      t.start();                            // start the new thread
. . .
```

Example prit.java on page 6 demonstrates multithreaded prime number generation with one thread per number checked. Sample run of prit.java on page 7 shows the results. The Class Prime.java on page 7 is used. Unit testing of Prime.java en la página 8 demuestra la unidad de pruebas de la **Prime.java** clase.

siguientes motivaciones para la programación concurrente con hilos: Presentado por developerWorks, su fuente de grandes clases

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El material de base en las roscas

En primer lugar un rápido repaso de rosca.

UNA ***proceso*** es un programa en ejecución. Se ha asignado la memoria por el sistema operativo. UNA ***hilo*** es una ejecución o flujo de control en el espacio de direcciones de un proceso; los puntos de registro contador de programa a la siguiente instrucción a ejecutar.

Un proceso es un programa con al menos un hilo. Un proceso puede tener más de un hilo. Todos los hilos en un proceso tienen su propio contador de programa y su propia pila de local (también llamado ***automático)*** variables y direcciones de retorno de procedimientos invocados.

En el lenguaje Java, un hilo en el intérprete de tiempo de ejecución llama al **principal()** método de la clase en la **Java** línea de comando. Cada objeto creado puede tener uno o más hilos, los cuales comparten el acceso a los campos de datos del objeto.

El artículo " ***Una Introducción a la programación con hilos*** "por Andrew D. Birrell (1989, un informe de investigación DEC) ofrece los

* multiprocesadores de memoria compartida son más baratos y más común de modo que cada hilo se pueden asignar una CPU.

* Es menos costoso y más eficiente para crear varios hilos en un proceso que comparte los datos que crear varios procesos que comparten datos.

* I / O en dispositivos lentos (por ejemplo, redes, terminales, y discos) se puede hacer en un solo hilo, mientras otro hilo hace cálculo útil en paralelo.

* Varios subprocesos pueden manejar los eventos (como clics del ratón) en varias ventanas en el sistema de ventanas en una estación de trabajo.

* En un clúster de LAN de estaciones de trabajo o en un entorno de sistema operativo distribuido, un servidor que se ejecuta en una máquina puede generar un hilo para manejar una petición entrante en paralelo con el hilo principal continua a aceptar solicitudes entrantes adicionales.

Cuando dos hilos realizan una función tal como **N = N + 1** más o menos al mismo tiempo, tiene una ***condición de carrera.*** Ambos hilos son "de carreras" entre sí para acceder a los datos y una de las actualizaciones puede perderse. En general, las condiciones de carrera son posibles cuando dos o más hilos de compartir datos, que están leyendo y escribiendo los datos compartidos al mismo tiempo, y el resultado final depende de lo que uno hace cuando.

Al mismo tiempo la ejecución de hilos que comparten datos necesitan sincronizar sus operaciones y tratamiento para evitar las condiciones de carrera sobre los datos compartidos. la sincronización de hilos se puede hacer con ***variables de la bandera*** y ***de espera ocupada.*** Debido a que utiliza una gran cantidad de ciclos de CPU, espera ocupada es ineficiente. El bloqueo sería mejor.

UNA ***sección crítica*** es un bloque de código en un hilo que tiene acceso a una o más variables compartidas de una manera actualización de lectura-escritura. En tal situación, queremos ***exclusión mutua*** en el que sólo un hilo puede acceder (lectura y escritura al día) una variable compartida a la vez.

los ***problema exclusión mutua*** es cómo mantener dos o más hilos de estar en su sección crítica al mismo tiempo, en los que no se ofrece ninguna hipótesis sobre el número de CPU o de sus velocidades relativas.

Un hilo fuera de su sección crítica no debe mantener otros hilos fuera de sus secciones críticas de entrar. Esto también se llama una ***la seguridad*** propiedad (o la ausencia de una demora innecesaria).

Además, ningún hilo debería tener que esperar por siempre para entrar en su sección crítica. Esto también se llama una ***liveness*** property (or eventual entry).

Andrews characterizes an ***atomic action*** as one that "makes an indivisible state transition: any intermediate state that might exist in the implementation of the action must not be visible to other threads." This means that nothing from another thread can be interleaved in the implementation of the action for it to be atomic.

Critical sections need to be defined as if they were one atomic action to avoid race conditions.

Here are the basic issues to keep in mind to solve the mutual exclusion problem when Presented by

devising a pre-protocol and a post-protocol based on either hardware or software. The protocols must:

* Evitar que dos hilos de estar en sus secciones críticas al mismo tiempo
* Tener la seguridad y las propiedades deseables LIVENESS
* Permitir que las secciones críticas que se ejecuten de forma atómica

reglas básicas del sistema son los siguientes:

* Es una arquitectura de registro de carga / almacenamiento.
* Múltiples, hilos se ejecutan simultáneamente están compartiendo datos.
* Hay CPU simples o múltiples y no podemos hacer hipótesis sobre la velocidad relativa.
* El acceso a las variables compartidas puede ser intercalada si dos hilos están en su sección crítica al mismo tiempo.

* Hilos no pueden detener en su pre- o post-protocolos.
* Hilos no pueden detener en sus secciones críticas.
* Las roscas se pueden detener fuera de sus secciones críticas.

Hilo Ti, i = 1, 2, 3, ...

```
    while (true) {
        outsideCS ();
        wantToEnterCS (i); // insideCS pre-protocolo ();
        finishedInCS (I);
                                    // post-protocolo
    }
```

The next several panels display the code described in this section. To view the code, click **Next;** or you can go directly to the next section, Thread states, priorities, and methods on page 9 , and return to the code samples at another time.

Example prit.java

```
class PrimeThread extends Thread {
    private int m = 0;
    PrimeThread(int m) { this.m = m; } public void run() {

        if (Prime.prime(m)) System.out.println(m + " is prime"); } }


class TestPrimeThreads {
    public static void main(String[] args) {
        int n1 = 0, n2 = 0; try {

            n1 = Integer.parseInt(args[0]); n2 =
          Integer.parseInt(args[1]); } catch
          (NumberFormatException e) {
            System.out.println("improper format"); System.exit(1);

        } catch (ArrayIndexOutOfBoundsException e) {
            System.out.println("not enough command line arguments"); System.exit(1); }


        if (n1 < 2 || n2 < 2 || n1 > n2) {
            System.out.println ( "argumentos de línea de comandos ilegales"
                +   n1 + "" + n2);
```

```
        System.exit (1); }

    System.out.println ( "primos de impresión"
        +   n1 + "a" + n2);
    nuevo PseudoTimeSlicing (); // para Solaris, no Windows 95 / NT for (int i = n1; i <= n2; i ++)
    {
        Thread t = new PrimeThread (i);
        t.Start ();
    }}}
```

---

muestra de ejecución de prit.java

```
prit.java% javac
% TestPrimeThreads java 10 20 primos de
impresión de 10 a 20 versión Java = 1.3.0

proveedor de Java = nombre de IBM Corporation
SO = SO Linux arco = i586

versión del sistema operativo = # 1 Lun Sep 27 de 10:25:54 EDT 1999.2.2.12-20 No se necesita
PseudoTimeSlicing 11 es primo es un número primo 13 17 19 es primo es un número primo



TestPrimeThreads% java 1000000 1000060 1000000 primos de
impresión de hasta 1.000.060 versión de Java 1.3.0 =

proveedor de Java = nombre de IBM Corporation
SO = SO Linux arco = i586

versión del sistema operativo = # 1 Lun Sep 27 de 10:25:54 EDT 1999.2.2.12-20 No se necesita
PseudoTimeSlicing 1000003 1000033 es primo es un número primo es un número primo
1.000.037 1.000.039 es primo
```

---

clase Prime.java

```
public class Primer {
    public static boolean primer (int k) {
        si (k <2) return false; int límite = k / 2;

        for (int i = 2; i <= k / 2; i ++) {
            if ((k% i) == 0) return false; }

        return true; }

    principales (args String []) {public static void
        int n = 0; tratar {

            n = Integer.parseInt (args [0]); } Catch
        (NumberFormatException e) {
```

```
        System.out.println ( "formato incorrecto"); System.exit (1);

} Catch (ArrayIndexOutOfBoundsException e) {
        System.out.println ( "ningún argumento de línea de comandos"); System.exit
    (1); }

si (n <2) {
        System.out.println ( "argumento de línea de comando" + n
                +   " Es demasiado pequeño");
    System.exit (1); }

System.out.println ( "números primos de impresión de 2 a" + n); for (int i = 2; i <= n;
i ++) {
        si (Prime.prime (i)) System.out.println (i + "es primo"); }}}
```

Prueba de la unidad de Prime.java

```
% Javac Prime.java% java
primer
hay una línea de comandos argumento%
java primer abc formato inapropiado%
java primer 0

la línea de comandos argumento es demasiado pequeño 0% java
primer 10
números primos de impresión de 2 a 10 2 es
prime 3 es primo 5 es primo 7 es primo
```

Sección 4. Los Estados del flujo, estados prioridades y métodos de rosca

Estados del flujo se definen como:

* ***Nuevo*** antes de la rosca **comienzo()** método se llama
* ***ejecutable*** Si el hilo está en la cola de listo
* ***Corriendo*** Si el hilo está ejecutando en la CPU
* ***Muerto*** después del subproceso **correr()** método o completa **detener()** método se llama
* ***Obstruido*** Si el hilo está bloqueado en I / O, una **unirse()** llamada a un método, o una **dormir(*Sra)*** llamada al método
* ***Suspendido*** Si el hilo de **suspender()** método es llamado desde la ***corriendo*** o ***ejecutable*** estados
* ***Suspendido-bloqueado*** Si el hilo de **suspender()** método es llamado desde la ***obstruido*** estado

segmentación de tiempo, pero funciona en la práctica. Presentado por developerWorks, su fuente de grandes clases particulares

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prioridades de los hilos

prioridades de los hilos (variables de clase) son:

* **MAX_PRIORITY**
* **NORM_PRIORITY**
* **MIN_PRIORITY**

Prioridad **conjunto** y **obtener** métodos de instancia incluyen:

* **setPriority (Tema. *prioridad)***
* **getPriority ()**

El planificador JVM normalmente permite garantizar la máxima prioridad del hilo se está ejecutando en la CPU, anticipándose a la rosca actualmente en ejecución cuando sea necesario, pero esto no es una garantía. (Véase la página 415 de ***La especificación del lenguaje Java,*** en recursos en la página 122).

---

segmentación de tiempo

segmentación de tiempo de hilos es también conocido como ***programación round-robin.*** Se realiza mediante la JVM. El IBM JDK 1.3.0 para Linux y las ventanas de Microsoft JVM realizar esta tarea; la versión de Solaris no lo hace.

los clase PseudoTimeSlicing.java en la página 11 implementa "pseudo" segmentación de tiempo. El uso de esta clase no garantiza la

métodos de la clase hilo

Los siguientes métodos son **estático** en la clase **Hilo** y se aplican a la subproceso de llamada:

* **Thread.sleep (*Sra)*** bloquea el subproceso de llamada durante el tiempo especificado.

* En **Thread.yield (),** el subproceso de llamada renuncia a la CPU (pero no está garantizada por la *JLS).*

* Cualquier método puede utilizar **Thread.currentThread ()** para obtener una referencia a la rosca que llama el método, por ejemplo, **Thread.currentThread (). GetPriority () ;.**

* Utilizar **Thread.interrupted ()** para ver si el hilo de **interrumpir()** método ha sido llamado (que borra la bandera interrumpe).

Los métodos de instancia

Y aquí están los métodos de instancia (por ejemplo, **t.Start ()** en el cual **t** es una variable de referencia a una **Hilo** objeto):

* **comienzo():** Iniciar un nuevo hilo de ejecutar el **correr()** método.

* **detener():** Terminar el hilo (en desuso, no utilizar).

* **suspender():** Suspender el hilo (en desuso, no utilizar).

* **currículum():** Reanudar el hilo suspendido (en desuso, no utilizar).

* **unirse():** Unir con otro hilo cuando ésta termina.

* **interrumpir():** Decirle al hilo para comprobar si hay un cambio en lo que debería estar haciendo.

* **isInterrupted ():** Compruebe si el hilo de **interrumpir()** método ha sido llamado (no consigue eliminar la bandera interrumpido).

* **isAlive ():** Comprobar si el mensaje ha terminado.

* **setDaemon (*boolean):*** Hacer que el hilo de una ***daemon (*** la JVM ignora este hilo cuando se determina si todos los hilos en un programa han terminado).

* **isDaemon ():** Compruebe si el hilo es un demonio.

* **fijar prioridad(*En t):*** Cambiar la prioridad de la rosca.

* **getPriority ():** Devolver el prioritiy de la rosca.

* **escoger un nombre(*cuerda):*** Cambiar el nombre de la rosca para que sea igual al argumento **nombre.**

* **getName ():** Devolver el nombre del hilo.

Ejemplos

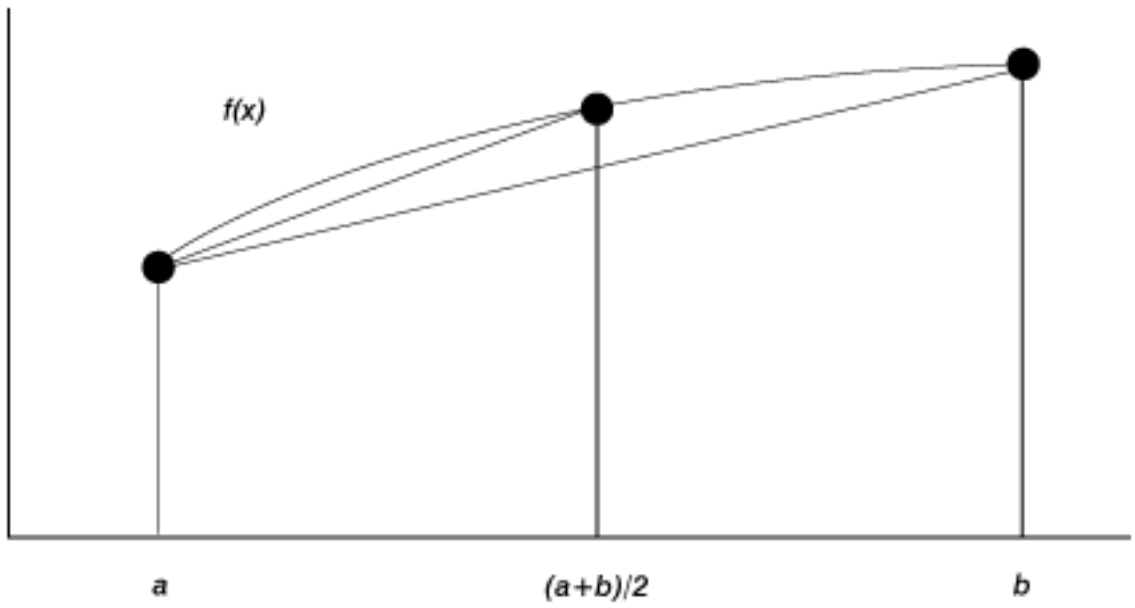
Los siguientes programas de ejemplo demuestran lo que hemos estado cubriendo.

clase Sugar.java en la página 12 es "azúcar sintáctico". Proporciona método de clase **años(),** que devuelve el número de milisegundos desde que se inició el programa, y método de clase **aleatorio(*distancia).***

Ejemplo beep.java en la página 13 le permite probar una plataforma para timeslicing. muestra de ejecución de beep.java en la página 14 muestra los resultados.

Ejemplo quad.java en la página 15 implementa cuadratura de integración numérica adaptativo con múltiples hilos y usos **unirse()** para la sincronización. Si la suma de las áreas de los dos sub-trapezoides no está lo suficientemente cerca de la zona del trapecio que los contienen, dos hilos son generados a repetir el cálculo para cada sub-trapezoide. El hilo de desove no puede continuar hasta que cada uno de los dos acabados hilos generados. muestra de ejecución de quad.java en la página 16 muestra los resultados.

Esta figura muestra la implementación de cuadratura adaptativa integración numérica con varios subprocesos.



Los próximos varios paneles muestran el código descrito en esta sección. Para ver el código, haga clic **Siguiente;** o puede ir directamente a la siguiente sección, El modificador volátil en la página 18, y volver a los ejemplos de código en otro momento.

clase PseudoTimeSlicing.java

PseudoTimeSlicing clase pública implementa Ejecutable {

```
Static final String privada
      Versión_java = System.getProperty ( "java.version"), JAVA_VENDOR =
    System.getProperty ( "java.vendor"), OS_NAME = System.getProperty (
    "os.name"), OS_ARCH = System.getProperty ( "os.arch" ), OS_VERSION =
    System.getProperty ( "os.version"); private static Me = null Autor; TimeSlice
    static int privado;


PseudoTimeSlicing pública () {esto (100); } PseudoTimeSlicing
pública (int) {ts
// // Ver http://www.javaworld.com/javaworld/jw-04-1999/ JW-04-toolbox_p.html para la forma
correcta de hacer únicos // en una situación multiproceso.

      Si (Me == null) {
            System.out.println ( "versión de Java =" + versión_java
                  +   "Proveedor \ nJava =" + JAVA_VENDOR
                  +   "\ Nombre nos =" + OS_NAME + "\ nOS arco =" + OS_ARCH
                  +   "\ Versión nos =" + OS_VERSION); si
            (OS_NAME.equals ( "Solaris") ||
                        (OS_NAME.equals ( "Linux") &&
                  JAVA_VENDOR.startsWith ( "IBM")!)) {TimeSlice = ts; Me
                  = new Thread (this);

                  me.setPriority (Thread.MAX_PRIORITY); me.setDaemon
                  (true); me.start ();

                  System.out.println ( "PseudoTimeSlicing instalado"); } else

                  System.out.println ( "No se necesita PseudoTimeSlicing"); } Else
      System.out.println (
                  "PseudoTimeSlicing ya instalado");
}
public void run () {
      si (Thread.currentThread () = yo!) return; // este hilo de mayor prioridad despertar //
      envía el hilo que se está ejecutando de nuevo al conjunto ejecutable while (true) {


            try {Thread.sleep (TimeSlice); }
            captura (InterruptedException e) {/ * ignorado * /}}}}
```

---

clase Sugar.java

```
java.util.Random importación; clase abstracta
pública azúcar {
      horalnicio largo static final privado
            = System.currentTimeMillis ();
      rnd privado static final aleatoria = new Random ();
            // métodos de utilidad
      protegida edad largo static final () {
            volver System.currentTimeMillis () - fecha de inicio; }

      protegida static final doble aleatorio () {
            rnd.nextDouble retorno (); // en el rango [0, 1)}

      protegida static final doble aleatorio (int ub) {
            volver rnd.nextDouble () * UB; // en el rango [0, ub)}

      protegida static final doble aleatorio (int lb, int ub) {
```

```
        volver lb + rnd.nextDouble () * (UB - lb); // en el rango [lb, ub)}}
```

Ejemplo beep.java

```
Pitido clase extiende azúcar implementa Ejecutable {
    int pitido privada = 0; private String
    nombre = null;
    Pitido pública (String nombre, int pitido) {
        this.name = nombre;
        this.beep = pitido;
        System.out.println (nombre + "está vivo, bip =" + beep); }

    public void run () {
        largo valor = 1;
        System.out.println ( "edad () =" + edad () + ""
            + Nombre + "funcionamiento");
        // () hilo para principal tiene prioridad y seguramente // obtiene la
        CPU después de interrumpir () nos Thread.currentThread ().
        SetPriority (
            . Thread.currentThread () getPriority () - 1); while (true) {

            si (valor ++% == pitido 0) {
                System.out.println ( "edad () =" + edad ()
                    + " "+ Nombre +" bips, valor =" + valor); si (Thread.interrupted ())
                {
                    System.out.println ( "edad =" + edad () + ""
                        + nombre + "interrumpidas"); regreso;
          }}}}}
```

```
clase de pitido se extiende azúcar {
    principales (args String []) {public static void
        int numBeepers = 4; int pitido =
        100.000; Cadena TimeSlice = "no";

        int tiempo de ejecución = 60; // defecto en segundo try {

            numBeepers = Integer.parseInt (args [0]); bip =
            Integer.parseInt (args [1]); TimeSlice = args [2];

            tiempo de ejecución = Integer.parseInt (args [3]); } Catch (Exception e) {/ * Usar
        los valores * /} System.out.println ( "pitido: numBeepers =" + numBeepers

            + "Bip =" + pitido + "TimeSlice =" + TimeSlice
            + "Tiempo de ejecución =" + tiempo de
        ejecución); (si timeSlice.equals ( "sí"))
            // para Solaris, no Windows 95 / NT nueva
         PseudoTimeSlicing (); // Start los hilos Beeper Tema [] b
         = new Thread [numBeepers]; for (int i = 0; i
         <numBeepers; i ++)

            b [i] = new Thread (nuevo Beeper ( "Beeper" + i, beep)); for (int i = 0; i
        <numBeepers; i ++) b [i] .start (); System.out.println ( "Todos los hilos del indicador
        sonoro comenzaron"); // dejar que los buscapersonas funcionamiento para una
        prueba mientras {
```

```
            Thread.sleep(runTime*1000);
            System.out.println("age=" + age()
                  +   ", time to interrupt the Beepers and exit"); for (int i = 0; i <
            numBeepers; i++)
                  b[i].interrupt();
            for (int i = 0; i < numBeepers; i++)
                  b[i].join();
      } catch (InterruptedException e) { /* ignored */ } System.out.println("All Beeper
threads interrupted"); System.exit(0); } }
```

Sample run of beep.java

```
% javac beep.java
% java Beeping 4 100000 no 3
Beeping: numBeepers=4, beep=100000, timeSlice=no, runTime=3 Beeper0 is alive,
beep=100000 Beeper1 is alive, beep=100000 Beeper2 is alive, beep=100000 Beeper3 is alive,
beep=100000 age()=36, Beeper0 running age()=134, Beeper1 running age()=195, Beeper2
running All Beeper threads started age()=225, Beeper3 running
```

```
age()=374, Beeper3 beeps, value=100001 age()=600, Beeper2 beeps,
value=100001 age()=769, Beeper1 beeps, value=100001 age()=901, Beeper0
beeps, value=100001 age()=1050, Beeper0 beeps, value=200001 age()=1125,
Beeper1 beeps, value=200001 age()=1287, Beeper3 beeps, value=200001
age()=1392, Beeper2 beeps, value=200001 age()=1671, Beeper1 beeps,
value=300001 age()=1757, Beeper0 beeps, value=300001 age()=1988,
Beeper3 beeps, value=300001 age()=2063, Beeper2 beeps, value=300001
age()=2209, Beeper2 beeps, value=400001 age()=2426, Beeper0 beeps,
value=400001 age()=2499, Beeper1 beeps, value=400001 age()=2688,
Beeper3 beeps, value=400001 age()=2979, Beeper1 beeps, value=500001
age()=3073, Beeper0 beeps, value=500001 age()=3219, Beeper0 beeps,
value=600001 age=3234, time to interrupt the Beepers and exit age()=3290,
Beeper2 beeps, value=500001 age=3291, Beeper2 interrupted age()=3321,
Beeper3 beeps, value=500001 age=3322, Beeper3 interrupted age()=3444,
Beeper1 beeps, value=600001 age=3445, Beeper1 interrupted age()=3578,
Beeper0 beeps, value=700001 age=3578, Beeper0 interrupted All Beeper
threads interrupted % java Beeping 4 100000 yes 3
```

```
Pitidos: numBeepers = 4, bip = 100000, TimeSlice = sí, el tiempo de ejecución = 3 versión de Java
1.3.0 =
proveedor de Java = IBM Corporation Nombre del
sistema operativo Linux =
```

```
arco OS = i586
versión del sistema operativo = # 1 Lun Sep 27 de 10:25:54 EDT 1999.2.2.12-20 Sin
PseudoTimeSlicing necesaria Beeper0 está vivo, bip = 100000 Beeper1 está vivo,
bip = 100000 Beeper2 está vivo, bip = 100000 Beeper3 está vivo, bip = 100000 edad
() = 38, edad corriendo Beeper0 () = 168, Beeper1 correr



edad () = 293, Beeper0 pitidos, valor = 100001 edad () = 439,
Beeper0 pitidos, valor = 200001 edad () = 536, Beeper1
pitidos, valor = 100001 edad () = 618, Beeper2 corriendo
Todas las roscas Beeper comenzaron edad ( ) = 741,
Beeper3 correr

edad () = 855, Beeper2 pitidos, valor = 100001 edad () = 922, Beeper1 pitidos,
valor = 200001 edad () = 1195, Beeper0 pitidos, valor = 300001 edad () =
1319, Beeper3 pitidos, valor = 100001 edad ( ) = 1562, Beeper2 pitidos, valor
= 200001 edad () = 1702, Beeper0 pitidos, valor = 400001 edad () = 1977,
Beeper2 pitidos, valor = 300001 edad () = 2078, Beeper1 pitidos, valor =
300001 edad () = 2225, Beeper1 pitidos, valor = 400001 edad () = 2266,
Beeper3 pitidos, valor = 200001 edad () = 2413, Beeper3 pitidos, valor =
300001 edad () = 2561, Beeper1 pitidos, valor = 500001 edad () = 2740,
Beeper2 pitidos, valor = 400001 edad () = 2743, Beeper0 pitidos, valor =
500001 edad () = 3021, Beeper2 pitidos, valor = 500001 edad () = 3124,
Beeper0 pitidos, valor = 600001 edad () = 3185, pitidos Beeper3 , valor =
400001 edad () = 3322, Beeper1 pitidos, valor = 600001 edad () = 3672,
Beeper0 pitidos, valor = 700001 edad () = 3723, Beeper3 pitidos, valor =
500001 edad = 3748, momento para interrumpir el Beepers y edad de salida
() = 3840,Beeper1 pitidos, valor = 700001 edad = 3,841, Beeper1 interrumpió
edad () = 3906, Beeper2 pitidos, valor = 600001 edad = 3,906, Beeper2
interrumpió edad () = 4066, Beeper3 pitidos, valor = 600001 edad = 4,067,
Beeper3 interrumpió la edad ( ) = 4108, Beeper0 pitidos, valor = 800001 edad
= 4,109, Beeper0 interrumpido Todas las roscas Beeper interrumpido
```

Example quad.java

```
interface TheFunction {
      public double evaluate(double x); public String
   toString(); }

class MyFunction implements TheFunction {
      public double evaluate(double x) { return x*x; } public String toString() {
   return " x**2"; } }

class Area extends Thread {
      private double p, q, epsilon, result; private TheFunction f;

      public Area(double a, double b, double eps, TheFunction fn) {
            p = a; q = b; epsilon = eps; f = fn;
```

```
    }
    public double getResult() { return result; } private static double
    trapezoidArea
            (double p, double q, TheFunction f) { double area =

            (Math.abs(q-p))/2 * (f.evaluate(p) + f.evaluate(q)); return area; }


      public void run() {
          double bigArea = trapezoidArea(p, q, f);
          double leftSmallArea = trapezoidArea (p, ((p+q)/2), f); double rightSmallArea =
          trapezoidArea(((p+q)/2), q, f); double sumOfAreas = leftSmallArea + rightSmallArea;
          double relError = Math.abs(bigArea - sumOfAreas); if (relError <= (epsilon * sumOfAreas))
          result = bigArea; else {


              Area leftArea = new Area(p, (p+q)/2, epsilon, f); leftArea.start();

              Area rightArea = new Area((p+q)/2, q, epsilon, f); rightArea.start(); try {
              leftArea.join(); }

                  catch (InterruptedException e) { /* ignored */ } try { rightArea.join(); }

                  catch (InterruptedException e) { /* ignored */ } result = leftArea.getResult() +
       rightArea.getResult(); } } }



class AdaptiveQuadrature {
    public static void main(String[] args) {
        double a = 0, b = 0, epsilon = 0; try {

            a = (Double.valueOf(args[0])).doubleValue(); b =
          (Double.valueOf(args[1])).doubleValue(); epsilon =
          (Double.valueOf(args[2])).doubleValue(); } catch (NumberFormatException e) {

            System.out.println("improper format"); System.exit(1);

        } catch (ArrayIndexOutOfBoundsException e) {
            System.out.println("not enough command line arguments"); System.exit(1); }


        if (b <= a || epsilon <= 0) {
            System.err.println("b <= a || epsilon <=0, exit"); System.exit(1); }


        TheFunction fn = new MyFunction();
        System.out.println("Adaptive Quadrature of" + fn + " from "
            +   a + " to " + b + " with relative error " + epsilon); Area area = new Area(a, b, epsilon,
        fn);
        new PseudoTimeSlicing(); // for Solaris, not Windows 95/NT area.start(); try { area.join(); }


            catch (InterruptedException e) { /* ignored */ } double result =
        area.getResult();
        System.out.println("Result for" + fn + " = " + result); System.exit(0); } }
```

Sample run of quad.java

```
% javac quad.java
% java AdaptiveQuadrature 0.5 1.5 0.001
Adaptive Quadrature of x**2 from 0.5 to 1.5 with relative error 0.0010 Java version=1.3.0

Java vendor=IBM Corporation OS
name=Linux OS arch=i586

OS version=#1 Mon Sep 27 10:25:54 EDT 1999.2.2.12-20 No PseudoTimeSlicing
needed Result for x**2 = 1.084136962890625
```

Section 5. The volatile modifier Some definitions

The **volatile** modifier tells the compiler that the variable is accessed by more than one thread at a time and inhibits inappropriate code optimizations by the compiler, such as caching the value of the variable in a CPU register instead of updating main memory with each assignment to the variable.

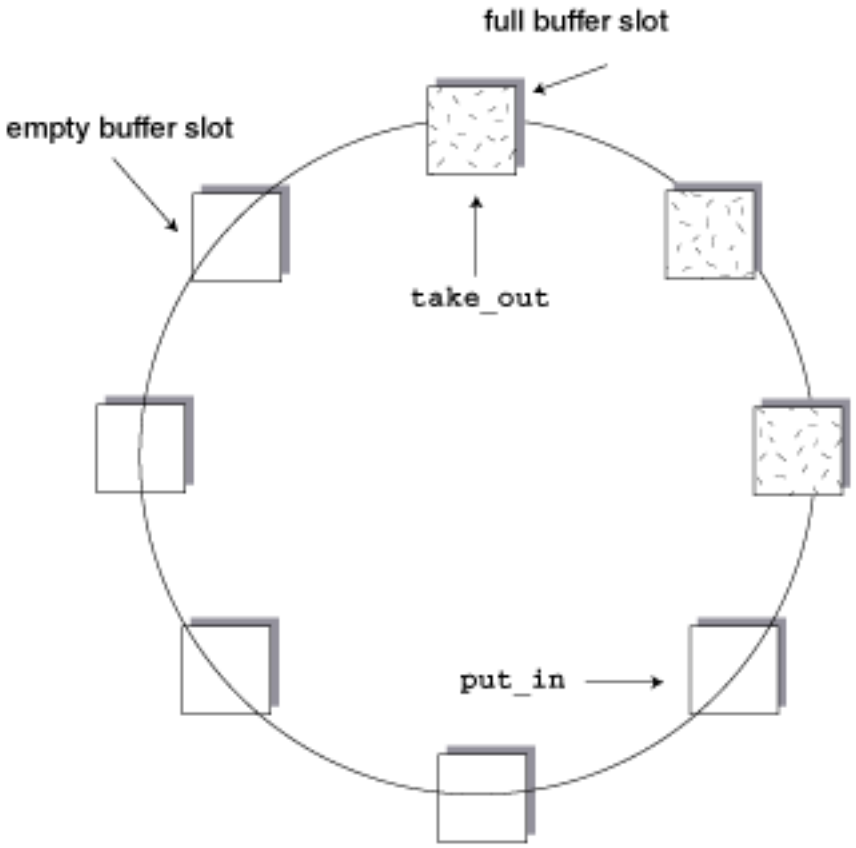
The ***Java Language Specification*** guarantees that updates to any one shared variable by a particular thread are seen by other threads in the order performed by that particular thread. However, the JLS does not require other threads to see updates to different shared variables in the order performed by the updating thread unless the variables are declared **volatile.**

Examples of the volatile modifier

Example bwbb.java on page 19 implements a busy waiting bounded buffer for a producer and consumer. The producer thread deposits items and busy waits if the bounded buffer fills up. The consumer thread fetches items and busy waits if the bounded buffer is empty.

The producer thread must "see" the **value** and **occupied** fields updated by the consumer thread in the exact order the updates are performed by the consumer thread (or the consumer must see the producer updates in the order performed). If not, the producer thread might overwrite an item in a buffer slot that the consumer has not yet read (or the consumer might read again an item from a buffer slot it has already read). Driver bbdr.java on page 20 creates the producer and consumer threads. Sample run of bwbb.java on page 22 shows the results of **bwbb.java.**

The figure below illustrates this interaction. Presented by developerWorks,



The next several panels display the code described in this section. To view the code, click **Next;** or you can go directly to the next section, Race conditions on page 24 , and return to the code samples at another time.

Example bwbb.java

```
class BufferItem {
      // multiple threads access so make these 'volatile' public volatile double value =
    0; public volatile boolean occupied = false; }


class BoundedBuffer {
      // designed for a single producer thread and // a single consumer
      thread private int numSlots = 0; private BufferItem[] buffer = null;
      private int putIn = 0, takeOut = 0; public BoundedBuffer(int numSlots)
      {


            if (numSlots <= 0)
                  throw new IllegalArgumentException("numSlots <= 0"); this.numSlots = numSlots;
            buffer = new BufferItem[numSlots]; for (int i = 0; i < numSlots; i++)


                  buffer[i] = new BufferItem(); }

      public void deposit(double value)
                  throws InterruptedException { while (buffer[putIn].occupied) //
            busy wait
```

```
            Thread.currentThread().yield();
        buffer[putIn].value = value; buffer[putIn].occupied =
        true; putIn = (putIn + 1) % numSlots; }


    public double fetch()
            throws InterruptedException { double value;

        while (!buffer[takeOut].occupied) // busy wait
            Thread.currentThread().yield(); value =
      buffer[takeOut].value; buffer[takeOut].occupied = false;
      takeOut = (takeOut + 1) % numSlots; return value; } }
```

Driver bbdr.java

```
class Producer extends Sugar implements Runnable {
    private String name = null; private int pNap = 0; //
    milliseconds private BoundedBuffer bb = null; private
    Thread me = null;

    public Producer(String name, int pNap, BoundedBuffer bb) {
        this.name = name;
        this.pNap = pNap; this.bb =
        bb;
        (me = new Thread(this)).start(); }

    public void timeToQuit() { me.interrupt(); } public void pauseTilDone() throws
    InterruptedException
        { me.join(); } public void
    run() {
        if (Thread.currentThread() != me) return; double item; int
        napping; while (true) {


            if (Thread.interrupted()) {
                System.out.println("age=" + age() + ", " + name
                    +   " interrupted"); return; }


            napping = 1 + (int) random(pNap);
            System.out.println("age=" + age() + ", " + name
                +   " napping for " + napping + " ms"); try {
            Thread.sleep(napping); } catch (InterruptedException e) {

                System.out.println("age=" + age() + ", " + name
                    +   " interrupted from sleep"); return; }


            item = random();
            System.out.println("age=" + age() + ", " + name
                +   " produced item " + item); try {
            bb.deposit(item); } catch (InterruptedException e) {

                System.out.println("age=" + age() + ", " + name
                    +   " interrupted from deposit"); return; }
```

```
                System.out.println("age=" + age() + ", " + name
                    +   " deposited item " + item); } } }


class Consumer extends Sugar implements Runnable {
    private String name = null; private int cNap = 0; //
    milliseconds private BoundedBuffer bb = null; private
    Thread me = null;

    public Consumer(String name, int cNap, BoundedBuffer bb) {
        this.name = name;
        this.cNap = cNap; this.bb =
        bb;
        (me = new Thread(this)).start(); }

    public void timeToQuit() { me.interrupt(); } public void pauseTilDone() throws
    InterruptedException
        { me.join(); } public void
    run() {
        if (Thread.currentThread() != me) return; double item; int
        napping; while (true) {


            if (Thread.interrupted()) {
                System.out.println("age=" + age() + ", " + name
                    +   " interrupted"); return; }


            napping = 1 + (int) random(cNap);
            System.out.println("age=" + age() + ", " + name
                +   " napping for " + napping + " ms"); try {
            Thread.sleep(napping); } catch (InterruptedException e) {

                System.out.println("age=" + age() + ", " + name
                    +   " interrupted from sleep"); return; }


            System.out.println("age=" + age() + ", " + name
                +   " wants to consume"); try { item =
            bb.fetch(); } catch (InterruptedException e) {

                System.out.println("age=" + age() + ", " + name
                    +   " interrupted from fetch"); return; }


            System.out.println("age=" + age() + ", " + name
                +   " fetched item " + item); } } }


class ProducersConsumers extends Sugar {
    public static void main(String[] args) {
        int numSlots = 10; int
        numProducers = 1; int
        numConsumers = 1; int pNap = 2;
                                    // defaults
        int cNap = 2;               // in
        int runTime = 60; // seconds // following set true in srbb.java
        runs // so as not to try to join with a // suspended thread and
        thus deadlock boolean doJoin = true; try {


            numSlots = Integer.parseInt(args[0]);
```

```
            numProducers = Integer.parseInt(args[1]); numConsumers =
          Integer.parseInt(args[2]); pNap = Integer.parseInt(args[3]); cNap =
          Integer.parseInt(args[4]); runTime = Integer.parseInt(args[5]); doJoin =
          args[6].equals("yes"); } catch (Exception e) { /* use defaults */ }
          System.out.println("ProducersConsumers:\n numSlots="



          +   numSlots + ", numProducers=" + numProducers
          +   ", numConsumers=" + numConsumers + ", pNap="
          +   pNap + ", cNap=" + cNap + ", runTime=" + runTime); // create the bounded
      buffer
      BoundedBuffer bb = new BoundedBuffer(numSlots); // start the Producers
      and Consumers // (they have self-starting threads) Producer[] p = new
      Producer[numProducers]; Consumer[] c = new
      Consumer[numConsumers];

      new PseudoTimeSlicing(); // for Solaris, not Windows 95/NT for (int i = 0; i < numProducers;
      i++)
          p[i] = new Producer("PRODUCER"+i, pNap*1000, bb); for (int i = 0; i <
      numConsumers; i++)
          c[i] = new Consumer("Consumer"+i, cNap*1000, bb); System.out.println("All
      threads started"); // let them run for a while try {


          Thread.sleep(runTime*1000);
          System.out.println("age=" + age()
              +   ", time to terminate the threads and exit"); for (int i = 0; i <
          numProducers; i++)
              p[i].timeToQuit();
          for (int i = 0; i < numConsumers; i++)
              c[i].timeToQuit();
          Thread.sleep(1000); if (doJoin) {

              for (int i = 0; i < numProducers; i++)
                  p[i].pauseTilDone();
              for (int i = 0; i < numConsumers; i++)
                  c[i].pauseTilDone(); } else

              System.out.println(" skipping pauseTilDone()"); } catch
      (InterruptedException e) { /* ignored */ } System.out.println("age=" + age()

          +   ", all threads are done"); System.exit(0); }
  }
```

Sample run of bwbb.java

```
% javac bwbb.java bbdr.java
% java ProducersConsumers 10 1 1 2 2 5
ProducersConsumers:
  numSlots=10, numProducers=1, numConsumers=1, pNap=2, cNap=2, runTime=5 Java version=1.3.0

Java vendor=IBM Corporation OS
name=Linux OS arch=i586

OS version=#1 Mon Sep 27 10:25:54 EDT 1999.2.2.12-20 No PseudoTimeSlicing
needed
age=47, PRODUCER0 napping for 1349 ms age=66,
Consumer0 napping for 201 ms
```

```
All threads started
age=286, Consumer0 wants to consume
age=1406, PRODUCER0 produced item 0.11775977233610768 age=1422, PRODUCER0
deposited item 0.11775977233610768 age=1423, PRODUCER0 napping for 1203 ms

age=1424, Consumer0 fetched item 0.11775977233610768 age=1426, Consumer0
napping for 39 ms age=1475, Consumer0 wants to consume

age=2636, PRODUCER0 produced item 0.717652488961075 age=2637,
PRODUCER0 deposited item 0.717652488961075 age=2638, PRODUCER0 napping
for 143 ms age=2640, Consumer0 fetched item 0.717652488961075 age=2641,
Consumer0 napping for 1020 ms

age=2795, PRODUCER0 produced item 0.29972388090543556 age=2797, PRODUCER0
deposited item 0.29972388090543556 age=2798, PRODUCER0 napping for 1898 ms
age=3668, Consumer0 wants to consume

age=3668, Consumer0 fetched item 0.29972388090543556 age=3669, Consumer0
napping for 1046 ms
age=4708, PRODUCER0 produced item 0.5794441336470957 age=4709,
PRODUCER0 deposited item 0.5794441336470957 age=4710, PRODUCER0 napping
for 955 ms age=4725, Consumer0 wants to consume

age=4726, Consumer0 fetched item 0.5794441336470957 age=4727, Consumer0
napping for 528 ms age=5078, time to terminate the threads and exit age=5081,
PRODUCER0 interrupted from sleep age=5082, Consumer0 interrupted from
sleep age=6088, all threads are done
```

Section 6. Race conditions Some definitions

If two threads execute **n=n+1** on a shared variable **n** at about the same time, their load and store instructions might interleave so that one thread overwrites the update of the other.

This ***lost update*** leads to an erroneous result and is an example of a ***race condition.*** Race conditions are possible when two or more threads share data, they are reading and writing the shared data concurrently, and the final result of the computation depends on which one does what when.

Examples of race conditions

Example race.java on page 24 demonstrates a lost update in which **sum=fn(sum,m)** plays the role of **n=n+1.** Sample run of race.java on page 25 illustrates the results.

In Example rac2.java on page 25 , a race condition between an ATM thread and an Auditor thread in a bank exists. Sample run of rac2.java on page 26 shows the results.

Example srbb.java on page 27 shows we should not synchronize threads with **suspend()** and **resume()** because a race condition is possible. If we try to replace busy waiting with blocking in the bounded-buffer producer and consumer by having a thread suspend itself until resumed by the other thread, we run the risk of both the producer thread and the consumer thread becoming suspended, each waiting for the other to resume it.

Driver bbdr.java on page 20 creates the producer and consumer threads. Sample run of srbb.java on page 28 demonstrates a sample run.

The next several panels display the code described in this section. To view the code, click **Next;** or you can go directly to the next section, Synchronized blocks on page 30 , and return to the code samples at another time.

Example race.java

```
class Racer implements Runnable {
    // these two fields are shared by both threads since // there is only ONE object
    created from this class private int M = 0;

    private volatile long sum = 0; // note `volatile' public Racer(int M) { this.M = M; }
    private long fn(long j, int k) {

        long total = j;
        for (int i = 1; i <= k; i++) total += i; return total; }


    public void run() {
        for (int m = 1; m <= M; m++) sum = fn(sum, m); System.out.println("sum
    = " + sum); } }


class Racing {
```

```
public static void main(String[] args) {
    Racer racerObject = new Racer(2000); Thread racerThread1 = new Thread(racerObject);
  Thread racerThread2 = new Thread(racerObject); new PseudoTimeSlicing(); // for Solaris, not
  Windows 95/NT racerThread1.start(); racerThread2.start(); try { racerThread1.join();
  racerThread2.join(); } catch (InterruptedException e) { /* ignored */ } } }
```

Sample run of race.java

```
% javac race.java % java
Racing Java version=1.3.0

Java vendor=IBM Corporation OS
name=Linux OS arch=i586

OS version=#1 Mon Sep 27 10:25:54 EDT 1999.2.2.12-20 No PseudoTimeSlicing
needed sum = 1335334000 sum = 1394734020
```

Example rac2.java

```
class SavingsAccount { public volatile int balance = 0; } class ATM extends Sugar
implements Runnable {
    private int numAccounts = 0;
    private SavingsAccount[] savingsAccount = null; public ATM(int numAccounts, SavingsAccount[]
    savingsAccount) {
        this.numAccounts = numAccounts; this.savingsAccount =
      savingsAccount; }

    public void run() {
        int fromAccount, toAccount, amount; while (true) {

            if (Thread.interrupted()) {
                System.out.println("age()=" + age()
                    +   ", ATM was interrupted"); return; }


            fromAccount = (int) random(numAccounts); toAccount = (int)
            random(numAccounts); amount = 1 +

                (int) random(savingsAccount[fromAccount].balance);
        savingsAccount[fromAccount].balance -= amount; savingsAccount[toAccount].balance
        += amount; } } }



class Auditor extends Sugar implements Runnable {
    private int numAccounts = 0;
    private SavingsAccount[] savingsAccount = null;
    public Auditor(int numAccounts, SavingsAccount[] savingsAccount) {
        this.numAccounts = numAccounts;
```

```
        this.savingsAccount = savingsAccount; }

    public void run() {
        int total; while (true) {

            try { Thread.sleep(1000); } catch
            (InterruptedException e) {
                System.out.println("age()=" + age()
                +   ", Auditor interrupted from sleep"); return; }


            total = 0;
            for (int i = 0; i < numAccounts; i++)
                total += savingsAccount[i].balance;
            System.out.println("age()=" + age()
                +   ", total is $" + total); if
            (Thread.interrupted()) {
                System.out.println("age()=" + age()
                    +   ", Auditor was interrupted"); return; } } } }




class Bank extends Sugar {
    public static void main(String[] args) {
        int numAccounts = 100;
        int initialValue = 1000; // dollars SavingsAccount[]
        savingsAccount = null; try {

            numAccounts = Integer.parseInt(args[0]); initialValue =
          Integer.parseInt(args[1]); } catch (Exception e) { /* use defaults */ }
          savingsAccount = new SavingsAccount[numAccounts]; for (int i = 0; i <
          numAccounts; i++) {

            savingsAccount[i] = new SavingsAccount();
          savingsAccount[i].balance = initialValue; }

        System.out.println("Bank open with " + numAccounts
            +   " accounts, each starting with $" + initialValue); new PseudoTimeSlicing(); // for
        Solaris, not Windows 95/NT Thread atm = new Thread(

            new ATM(numAccounts, savingsAccount)); Thread auditor
        = new Thread(
            new Auditor(numAccounts, savingsAccount)); atm.start();
        auditor.start(); try {

            Thread.sleep(10000); atm.interrupt();
            atm.join(); Thread.sleep(3000);

            auditor.interrupt(); auditor.join(); } catch (InterruptedException e) { /*
      ignored */ } System.exit(0); } }
```

Sample run of rac2.java

```
% javac rac2.java % java
Bank
Bank open with 100 accounts, each starting with $1000
```

```
Java version=1.3.0
Java vendor=IBM Corporation OS
name=Linux OS arch=i586

OS version=#1 Mon Sep 27 10:25:54 EDT 1999.2.2.12-20 No PseudoTimeSlicing
needed age()=1171, total is $100000 age()=2191, total is $100000 age()=3201, total
is $100000 age()=4211, total is $100000 age()=5221, total is $100000 age()=6231,
total is $100000 age()=7241, total is $100000 age()=8251, total is $100000
age()=9261, total is $99999 age()=10171, ATM was interrupted age()=10271, total is
$100000 age()=11283, total is $100000 age()=12291, total is $100000




age()=13182, Auditor interrupted from sleep % java Bank 500000

Bank open with 500000 accounts, each starting with $1000 Java version=1.3.0

Java vendor=IBM Corporation OS
name=Linux OS arch=i586

OS version=#1 Mon Sep 27 10:25:54 EDT 1999.2.2.12-20 No PseudoTimeSlicing
needed age()=10763, total is $499996968 age()=12418, total is $499992296
age()=14018, total is $499990606 age()=15669, total is $499986034 age()=17326,
total is $500012696 age()=19020, total is $499974189 age()=19213, ATM was
interrupted age()=20968, total is $500000000 age()=23113, total is $500000000
age()=23114, Auditor was interrupted
```

Example srbb.java

```
class BufferItem {
      public volatile double value = 0; public volatile boolean occupied
    = false; public volatile Thread thread = null; }


class BoundedBuffer {
      // designed for a single producer thread and // a single consumer
      thread private int numSlots = 0; private BufferItem[] buffer = null;
      private int putIn = 0, takeOut = 0; public BoundedBuffer(int numSlots)
      {


            if (numSlots <= 0)
                  throw new IllegalArgumentException("numSlots <= 0"); this.numSlots = numSlots;
            buffer = new BufferItem[numSlots]; for (int i = 0; i < numSlots; i++)


                  buffer[i] = new BufferItem(); }

      public void deposit(double value)
```

```
            throws InterruptedException { if
        (buffer[putIn].occupied) {
            Thread producer = Thread.currentThread(); buffer[putIn].thread =
            producer;
                                                  // context switch possible here
            producer.suspend(); buffer[putIn].thread =
          null; }

        buffer[putIn].value = value; buffer[putIn].occupied = true;
       Thread consumer = buffer[putIn].thread; putIn = (putIn + 1) %
       numSlots; if (consumer != null) consumer.resume(); }



    public double fetch()
            throws InterruptedException { double value;

        if (!buffer[takeOut].occupied) {
            Thread consumer = Thread.currentThread();
            buffer[takeOut].thread = consumer;
                                                  // context switch possible here
            consumer.suspend();
            buffer[takeOut].thread = null; }

        value = buffer[takeOut].value; buffer[takeOut].occupied = false;
      Thread producer = buffer[takeOut].thread; takeOut = (takeOut + 1)
      % numSlots; if (producer != null) producer.resume(); return value; }
      }
```

Sample run of srbb.java

```
% javac srbb.java bbdr.java
% java ProducersConsumers 10 1 1 2 2 5 no
ProducersConsumers:
  numSlots=10, numProducers=1, numConsumers=1, pNap=2, cNap=2, runTime=5 Java version=1.3.0

Java vendor=IBM Corporation OS
name=Linux OS arch=i586

OS version=#1 Mon Sep 27 10:25:54 EDT 1999.2.2.12-20 No PseudoTimeSlicing
needed
age=48, PRODUCER0 napping for 1549 ms age=67,
Consumer0 napping for 1861 ms All threads started

age=1609, PRODUCER0 produced item 0.37648945305426074 age=1625, PRODUCER0
deposited item 0.37648945305426074 age=1626, PRODUCER0 napping for 974 ms
age=1949, Consumer0 wants to consume

age=1950, Consumer0 fetched item 0.37648945305426074 age=1952, Consumer0
napping for 381 ms age=2347, Consumer0 wants to consume

age=2617, PRODUCER0 produced item 0.7493684193792439 age=2618,
Consumer0 fetched item 0.7493684193792439 age=2619, Consumer0 napping for
377 ms
age=2638, PRODUCER0 deposited item 0.7493684193792439 age=2640,
PRODUCER0 napping for 1014 ms age=3009, Consumer0 wants to consume
```

```
age=3667, PRODUCER0 produced item 0.8117997960074402 age=3668,
Consumer0 fetched item 0.8117997960074402 age=3669, Consumer0 napping for
365 ms
age=3686, PRODUCER0 deposited item 0.8117997960074402 age=3688,
PRODUCER0 napping for 484 ms age=4048, Consumer0 wants to consume

age=4187, PRODUCER0 produced item 0.8961043263431506 age=4188,
Consumer0 fetched item 0.8961043263431506 age=4189, Consumer0 napping for
675 ms
age=4207, PRODUCER0 deposited item 0.8961043263431506 age=4208,
PRODUCER0 napping for 504 ms
age=4727, PRODUCER0 produced item 0.34322613800540913 age=4728, PRODUCER0
deposited item 0.34322613800540913 age=4729, PRODUCER0 napping for 1195 ms
age=4877, Consumer0 wants to consume

age=4877, Consumer0 fetched item 0.34322613800540913 age=4878, Consumer0
napping for 19 ms age=4906, Consumer0 wants to consume age=5077, time to
terminate the threads and exit age=5098, PRODUCER0 interrupted from sleep
skipping pauseTilDone() age=6087, all threads are done
```

Section 7. Synchronized blocks Object locks

Every Java object has a lock. A ***synchronized block*** uses an object's lock to act like a binary semaphore with the initial value "1", solving the mutual exclusion critical section problem:

```
Object obj = new Object();
    . . .
synchronized (obj) { // in a method
    . . .   // any code, e.g., critical section }
```

The construct:

```
    . . .   synchronized method(...) {
        . . .     // body of method }
```

is an abbreviation for:

```
    . . .   method(...) { synchronized (this)
        {
            . . .     // body of method } }
```

That is, the entire body of the instance method is a synchronized block on the object (keyword **this)** the method is in.

The JLS does not guarantee that the thread that has waited the longest to lock an object will be the next to obtain the lock when the object is unlocked.

Examples of synchronized blocks

Example parp.java on page 31 offers multithreaded prime number generation with a fixed number of threads (using Class Prime.java on page 7). Sample run of parp.java on page 31 shows the results.

In Example norc.java on page 32 , only one thread at a time is allowed to execute **sum=fn(sum,m).** Sample run of norc.java on page 32 demonstrates the sample run.

The next several panels contain an exercise and display the code described in this section. To view the exercise and code, click **Next;** or you can go directly to the next section, Monitors on page 33 , and return to the code samples at another time.

Try this exercise

Use a synchronized block to eliminate the race condition in Example rac2.java on page 25 . Presented by

Example parp.java

```
class ParallelPrimes implements Runnable {
    private static int n1, n2, nChecked, nThreads, next; private static boolean[] taken,
    isPrime; private Object mutex = this; // or = new Object(); public void run() {


        int mine = 0; while
        (true) {
            synchronized (mutex) {
                while (next < nChecked && taken[next]) next++; mine = next;

                if (mine >= nChecked) return; taken[mine] =
              true; }

            if (Prime.prime(n1 + mine)) isPrime[mine] = true; } }


    public static void main(String[] args) {
        try {
            n1 = Integer.parseInt(args[0]); n2 =
          Integer.parseInt(args[1]); nThreads =
          Integer.parseInt(args[2]); } catch (NumberFormatException
          e) {
            System.out.println("improper format"); System.exit(1);

        } catch (ArrayIndexOutOfBoundsException e) {
            System.out.println("not enough command line arguments"); System.exit(1); }


        System.out.println("printing primes from " + n1 + " to "
            +  n2 + " using " + nThreads + " threads"); nChecked = n2 - n1 + 1;

        if (nChecked < 1 || nThreads > nChecked) {
            System.out.println("bad command line arguments"); System.exit(1); }


        taken = new boolean[nChecked]; isPrime = new
        boolean[nChecked]; for (int i = 0; i < nChecked; i++)

            taken[i] = isPrime[i] = false; next = 0;

        Thread[] t = new Thread[nThreads];
        // All threads execute inside the SAME object and thus // SHARE all data.

        Runnable a = new ParallelPrimes();
        for (int i = 0; i < nThreads; i++) t[i] = new Thread(a); new PseudoTimeSlicing(); // for Solaris,
        not Windows 95/NT for (int i = 0; i < nThreads; i++) t[i].start(); try {


            for (int i = 0; i < nThreads; i++) t[i].join(); } catch (InterruptedException e) {
        /* ignored */ } for (int i = 0; i < nChecked; i++)

            if (isPrime[i])
                System.out.println((n1 + i) + " is prime");
    }
}
```

Sample run of parp.java

```
% javac parp.java
% java ParallelPrimes 1000000 1000060 5
printing primes from 1000000 to 1000060 using 5 threads Java version=1.3.0

Java vendor=IBM Corporation OS
name=Linux OS arch=i586

OS version=#1 Mon Sep 27 10:25:54 EDT 1999.2.2.12-20 No PseudoTimeSlicing
needed 1000003 is prime 1000033 is prime 1000037 is prime 1000039 is prime
```

Example norc.java

```
class Racer implements Runnable {
    // these two fields are shared by both threads since // there is only ONE object
    created from this class private int M = 0;

    private long sum = 0; // `volatile' no longer needed public Racer(int M) { this.M = M; }
    private long fn(long j, int k) {

        long total = j;
        for (int i = 1; i <= k; i++) total += i; return total; }


    public void run() {
        for (int m = 1; m <= M; m++)
            synchronized (this) { // entry protocol
                sum = fn(sum, m); // critical section }
                                                // exit protocol
        System.out.println("sum = " + sum); } }
```

Sample run of norc.java

```
% javac norc.java % java
Racing Java version=1.3.0

Java vendor=IBM Corporation OS
name=Linux OS arch=i586

OS version=#1 Mon Sep 27 10:25:54 EDT 1999.2.2.12-20 No PseudoTimeSlicing
needed sum = 1335334000 sum = 2670668000
```

Section 8. Monitors

Monitor structure and properties

Every Java object possesses a lock and these methods: **wait(), notify(),** and **notifyAll().**

A thread invoking a **synchronized** method must acquire the lock of the object containing the method before executing the method's code. The thread blocks if the object is already locked.

A ***monitor*** has the following structure or pattern:

```
class Monitor extends ... {
    private ... // data fields (state variables) Monitor(...) {...} // constructor
    public synchronized type method1(...)

            throws InterruptedException {
        . . .
        notifyAll(); // if any wait conditions altered while (! condition1) wait();

        . . .
        notifyAll(); // if any wait conditions altered }

    public synchronized type method2(...)
            throws InterruptedException {
        . . .
        notifyAll(); // if any wait conditions altered while (! condition2) wait();

        . . .
        notifyAll(); // if any wait conditions altered }

    . . .
}
```

A Java thread is ***interrupted*** when its **interrupt()** method is called by another thread. This call sets a flag in the interrupted thread that the latter can check periodically, allowing one thread to tell another thread to stop itself or return allocated resources if it is not in the middle of some critical operation. (A thread should check its interrupt flag before or after such operations and take appropriate action when interrupted.)

Note the following important points:

* The thread blocked the longest on a monitor **synchronized** method call is not guaranteed to be the next thread to acquire the monitor lock when the monitor lock is released.

* The thread blocked the longest in a monitor **wait()** call is not guaranteed to be the one removed from the wait set when a **notify()** is done by some other thread in the monitor.

* The signaling discipline is signal-and-continue so ***barging*** is possible -- a thread waiting for the monitor lock to execute a monitor **synchronized** method might get the lock before a signaled thread re-acquires it, even if the **notify()** occurred earlier than the monitor method call. Thus:

while (! ***condition)*** **... wait() ... notifyAll()**

is safer than:
if (! ***condition)*** **... wait() ... notify()**

* Each monitor object has a single nameless anonymous condition variable. We cannot signal with **notify()** one of several threads waiting on a specific condition. It is safer to use **notifyAll()** to awaken all waiting threads so they can recheck their waiting conditions.

* A **notifyAll()** needs to be done by a thread before a **wait()** if any state variables were altered by the thread after entering the monitor, which might affect other thread-waiting conditions. This also applies before leaving the monitor (returning from the method).

* The data fields in a monitor need not be declared **volatile** because all writes to shared variables by a thread are completed before obtaining and before releasing the monitor lock.

* If a thread that is blocked inside a call to **sleep(** ***ms),*** **join(),** or **wait()** is interrupted, then these methods clear the thread's interrupt flag and throw an **InterruptedException** instead of returning normally. Note that no exception is thrown if a thread is interrupted while blocked waiting to acquire a monitor's lock to execute a synchronized method.

* In contrast, **InterruptedException** ***is*** thrown by **wait()** if a thread that has been notified is interrupted while blocked and waiting to reacquire the monitor lock. If an **InterruptedException** occurs while a thread is in **wait(),** the thread must reacquire the monitor lock before executing the code in the **catch** block.

* Ignoring **InterruptedException,** as in:
```
while (! condition) try { wait(); }
    catch (InterruptedException e) { }
```
is undesirable. The enclosing method should throw the exception back to the caller.

* The following code:
```
if (! condition) try { wait(); }
    catch (InterruptedException e) { }
```
is incorrect because a thread interrupted out of its **wait()** then re-enters the monitor without being notified.

* When a call to **wait(** ***milliseconds)*** returns, the program cannot tell for sure if the wait was notified or if the wait timed out after the number of milliseconds elapsed.

* In some situations, we can use **notify()** instead of **notifyAll()** and **if ... wait()** instead of **while ... wait().** However, it is ***extremely*** tricky and not recommended because of a race condition between **interrupt()** and **notify().**

Suppose several threads are blocked inside **wait()** and then one of them is notified and then interrupted before it reacquires the monitor lock. The **notify()** gets "lost" in that one of the other waiting threads should now proceed. We need to catch the exception when a thread is interrupted out of **wait()** and regenerate the **notify().**

* It is usually wrong to **Thread.sleep(** ***ms)*** while inside a monitor object holding the lock (during a synchronized method invocation). Other threads wanting to enter the monitor will block to acquire the monitor object's lock and they cannot be interrupted from this state.

  It is better to set a flag and leave the monitor; other threads can then **wait()** for the flag to change. No thread holds the monitor's lock for any longer than to set or check this flag.

Are now right that thread can ***signal*** a monitor. Presented by developerWorks, your source for great tutorials
As the following examples show, monitors can be used by threads that request resources from and return resources to a server. This is called a ***client/server*** relationship.

The clients interact with the server but not with each other. The server monitor is a passive object in the sense that no independent thread executes inside it; the code in the monitor is executed only when a monitor method is invoked by a client thread.

Monitors can be awkward to use if the threads have a relationship other than a client/server one.

Background material on monitors

Semaphores are like gotos and pointers -- they work okay but are error prone and lack structure and "discipline."

For example, a disastrous typo such as:

in the monitor. Some other thread can then get in the monitor and perhaps change the state of the monitor. If conditions
V(S); criticalSection(); V(S)

can lead to deadlock:

P(S); criticalSection(); P(S).

Nested critical sections can also lead to deadlock:

P1: P(Q); P(S); ... V(S); V(Q); P2:

P(S); P(Q); ... V(Q); V(S);

A ***monitor*** is an object with some built-in mutual exclusion and thread-synchronization capabilities. Monitors are an integral part of the programming language so the compiler can generate the correct code to implement the monitor. Only one thread can be active at a time in the monitor ("active" meaning executing a method of the monitor).

Monitors also have ***condition variables*** on which a thread can ***wait*** if conditions are not right for it to continue executing

waiting thread, moving the latter to the ready queue to get back into the monitor when it becomes free.

Monitors can use either a ***signal-and-exit*** or ***signal-and-continue*** signaling discipline. In ***signal-and-exit ,*** a signaling thread must leave the monitor immediately, at which point it is guaranteed that the signaled thread is the next one in the monitor.

In ***signal-and-continue ,*** the signaled thread is not guaranteed to be the next one in the monitor. In fact, ***barging*** can take place -- some thread that has called a monitor method and is blocked until the monitor is free can get into the monitor before a signaled thread.

Semaphores and monitors can be used to solve the so-called "classical" synchronization problems found in many operating systems books: the ***sleeping barber,*** the five ***dining philosophers,*** and the database ***readers and writers.***

The sleeping barber. A barber waits to cut hair. Customers enter the waiting room and take a seat if one is available. If the waiting room is full, they try again later. Otherwise, they wait until their turn for a hair cut.

Five dining philosophers. Five philosophers sit around a table and think until hungry. Between each is a fork (for a total of five forks). To eat, a hungry philosopher must have exclusive access to both the fork on his left and right. If both forks are not free, the philosopher waits.

number of current readers is always above zero. Presented by developerWorks, your source for great tutorials
The algorithm in Example dpmo.java on page 39 does not deadlock (it never happens that all philosophers are hungry, each holding one fork and waiting for the other), allows maximal parallelism (a philosopher never picks up and holds a fork while waiting for the other fork to become available when the fork he is holding could be used for eating by its neighbor), but also allows starvation (a philosopher's two neighbors can collaborate and alternate their eating so the one in the middle never can use the forks).

If a philosopher can hold a fork while waiting for the other fork, deadlock is possible, an extreme case of not having maximal parallelism. However, starvation is not possible. Each fork is represented by a semaphore and each hungry philosopher does a "P" on its left fork and then its right fork.

We can fix the deadlock problem and retain no starvation, but we still do not have maximal parallelism. All philosophers pick up left then right except one designated philosopher who picks up right then left.

Philosopher starvation can also be prevented by introducing a new state: very hungry. A philosopher is put into this state if he is hungry, if one of his neighbors puts down his forks, and if he cannot eat because the other fork is in use. A new rule is added -- a hungry philosopher cannot eat if he has a very hungry neighbor. These changes prevent a collaboration of two philosophers trying to starve the philosopher between them.

Readers and writers. A database can be accessed concurrently by threads that only want to read, but a writer thread must have exclusive access with respect to other readers and writers.

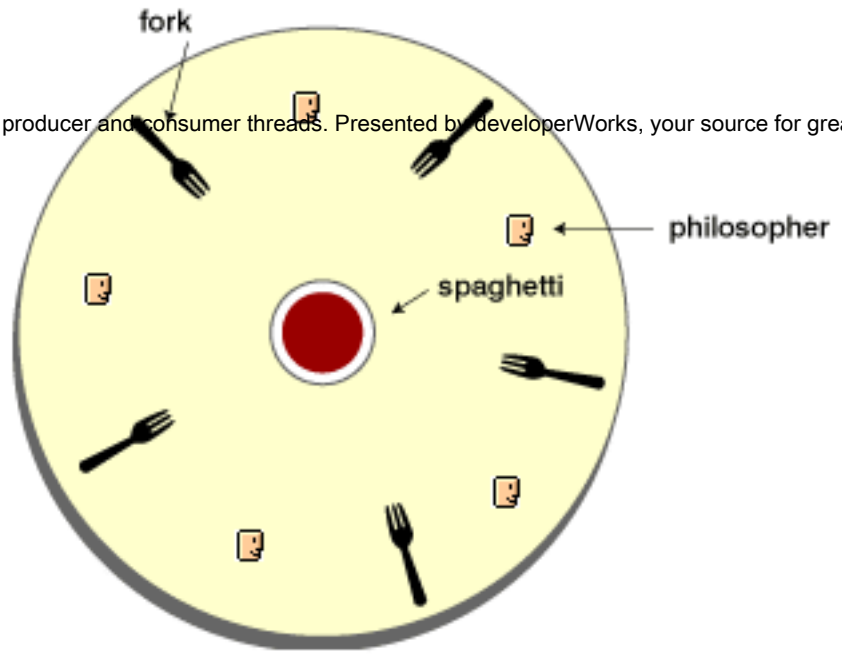
A solution might allow writers to starve if enough readers keep coming along to read the database so that the

Writer starvation is prevented by requiring readers that come along to read the database to wait if there is a waiting writer even if other readers are currently reading the database. When the current readers finish, the waiting writer writes the database and then signals into the database a waiting reader. Each entering reader signals another waiting reader into the database.

Examples of monitors

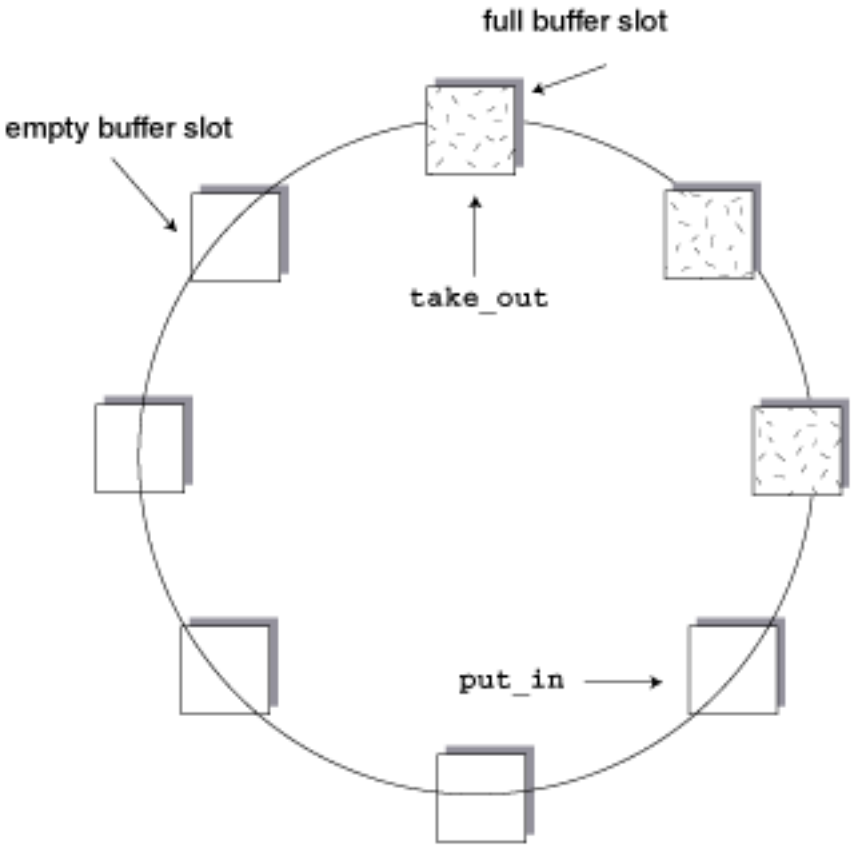
Example dpmo.java on page 39 illustrates the dining philosophers monitor. Five philosophers sit around a table and think until hungry. Between each pair of philosophers is one fork. A hungry philosopher must have exclusive simultaneous access to both its left and right forks in order to eat. If they are not both free, the philosopher waits. Driver dpdr.java on page 40 creates the philosopher threads. Sample run of dpmo.java on page 42 shows the sample run.

The figure below illustrates the dining philosophers monitor.



Example bbmo.java on page 42 shows a bounded buffer monitor for a producer and consumer. Multiple producer threads and multiple consumer threads are handled. A producer thread deposits items and blocks if the bounded buffer fills up. A consumer thread fetches items and blocks if the bounded buffer is empty. Driver bbdr.java on page 20 creates the producer and consumer threads. Sample run of bbmo.java on page 43 shows the sample run.

The figure below illustrates the bounded buffer monitor for a producer and consumer, handling multiple



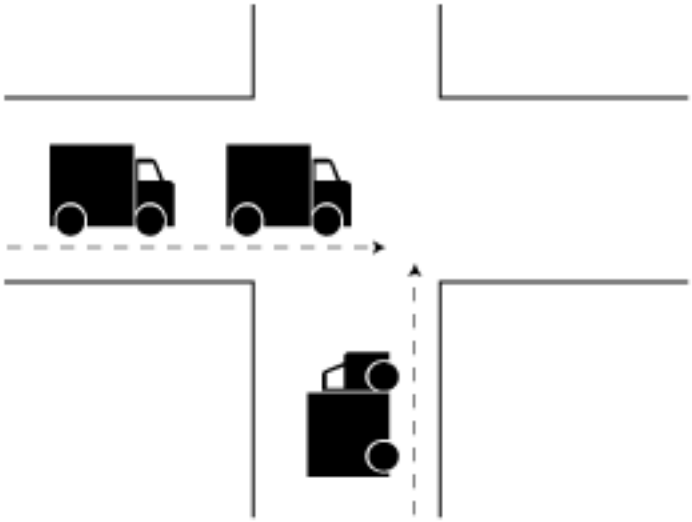
Example inmo.java on page 44 simulates cars crossing at an intersection of two one-way streets so that:

* Only one car can cross at a time
* A car can cross if there are no cars on the intersecting street waiting to cross
* If two cars approach the intersection at about the same time, one of them will cross (no deadlock)

* If there are cars on the intersecting streets waiting to cross, then cars from the intersecting streets take turns to prevent starvation

Driver indr.java on page 45 creates the car threads. Sample run of inmo.java on page 47 shows the results.

The following figure illustrates cars crossing at an intersection of two one-way streets. Presented by



Los próximos paneles contienen ejercicios y mostrar el código descrito en esta sección. Para ver los ejercicios y el código, haga clic **Siguiente;** o puede ir directamente a la siguiente sección,
Los semáforos en la página 50, y volver a los ejemplos de código en otro momento.

Pruebe estos ejercicios

Ejercicio 1: Escribir un monitor para la base de datos lectores y escritores problema. hilos de lectura múltiple pueden leer la base de datos de forma simultánea, pero las discusiones escritor debe tener acceso exclusivo con respecto a otros hilos lector y escritor.

Ejercicio 2: Escribir un monitor de barrera. Hilos esperan hasta que todas las discusiones llegan a la barrera, entonces son puestos en libertad.

Ejercicio 3: Cuando un **notificar()** o **notifyAll ()** is done inside a Java monitor, the next thread to get inside the monitor (acquire the lock) is arbitrary. Therefore, the cars in the intersection simulation going in the same direction do not necessarily go through the intersection in the order they arrived at it (it is not FCFS). Fix this.

Example dpmo.java

```
class DiningServer extends Sugar {
    private int numPhils = 0; private int[] state
    = null;
    private static final int THINKING = 0, HUNGRY = 1, EATING = 2; public DiningServer(int numPhils)
    {
        this.numPhils = numPhils; state = new
        int[numPhils];
        for (int i = 0; i < numPhils; i++) state[i] = THINKING; }

    public void dine(String name, int id, int napEat)
            throws InterruptedException { try {

            takeForks(id); eat(name,
            napEat);
```

```
        } finally {                         // Make sure we return the
            putForks(id); // forks if interrupted } }


    private final int left(int i)
        { return (numPhils + i - 1) % numPhils;} private final int right(int
    i)
        { return (i + 1) % numPhils; } private void
    test(int k) {
        if (state[left(k)] != EATING && state[k] == HUNGRY &&
                state[right(k)] != EATING) state[k] =
        EATING; }

    private void eat(String name, int napEat)
            throws InterruptedException { int napping;

        napping = 1 + (int) random(napEat); System.out.println("age=" + age() + ",
        " + name
            +   " is eating for " + napping + " ms"); Thread.sleep(napping);
      }

    private synchronized void takeForks(int i)
            throws InterruptedException { state[i] =
       HUNGRY; test(i); while (state[i] != EATING) wait(); }


    private synchronized void putForks(int i) {
        if (state[i] != EATING) return; state[i] = THINKING;

        test(left(i)); test(right(i)); notifyAll(); } }
```

Driver dpdr.java

```
class Philosopher extends Sugar implements Runnable {
    private String name = null; private int id =
    0;
    private int napThink = 0; // both are in private int napEat = 0; //
    milliseconds private DiningServer ds = null; private Thread me =
    null;

    public Philosopher(int id, int napThink, int napEat,
            DiningServer ds) {
        this.name = "Philosopher " + id; this.id = id;

        this.napThink = napThink; this.napEat =
        napEat; this.ds = ds;

        (me = new Thread(this)).start(); }

    public void timeToQuit() { me.interrupt(); } public void pauseTilDone() throws
    InterruptedException
        { me.join(); }
    private void think() throws InterruptedException {
        int napping;
        napping = 1 + (int) random(napThink); System.out.println("age=" + age() +
        ", " + name
            +   " is thinking for " + napping + " ms"); Thread.sleep(napping);
```

```
    }
    public void run() {
        if (Thread.currentThread() != me) return; while (true) {

            if (Thread.interrupted()) {
                System.out.println("age=" + age() + ", " + name
                    +   " interrupted"); return; }
              try {


                think();
            } catch (InterruptedException e) {
                System.out.println("age=" + age() + ", " + name
                    +   " interrupted out of think"); return; }


            System.out.println("age=" + age() + ", " + name
                +   " wants to dine"); try {

                ds.dine(name, id, napEat); } catch
            (InterruptedException e) {
                System.out.println("age=" + age() + ", " + name
                    +   " interrupted out of dine"); return; } } } }




class DiningPhilosophers extends Sugar {
    public static void main(String[] args) {
        int numPhilosophers = 5; int runTime
        = 60;                                   // seconds
        int napThink = 8, napEat = 2; try {

            numPhilosophers = Integer.parseInt(args[0]); runTime = Integer.parseInt(args[1]);
          napThink = Integer.parseInt(args[2]); napEat = Integer.parseInt(args[3]); } catch
          (Exception e) { /* use defaults */ } System.out.println("DiningPhilosophers:
          numPhilosophers="


            +   numPhilosophers + ", runTime=" + runTime
            +   ", napThink=" + napThink + ", napEat=" + napEat); // create the DiningServer
        object
        DiningServer ds = new DiningServer(numPhilosophers); // create the Philosophers
        // (they have self-starting threads)

        Philosopher[] p = new Philosopher[numPhilosophers]; for (int i = 0; i <
        numPhilosophers; i++) p[i] =
            new Philosopher(i, napThink*1000, napEat*1000, ds); System.out.println("All
        Philosopher threads started"); // let the Philosophers run for a while try {


            Thread.sleep(runTime*1000);
            System.out.println("age=" + age()
                +   ", time to terminate the Philosophers and exit"); for (int i = 0; i <
            numPhilosophers; i++)
                p[i].timeToQuit();
            Thread.sleep(1000);
            for (int i = 0; i < numPhilosophers; i++)
                p[i].pauseTilDone();
        } catch (InterruptedException e) { /* ignored */ } System.out.println("age=" +
        age()
            +   ", all Philosophers are done"); System.exit(0); }
```

```
}
```

Sample run of dpmo.java

```
% javac dpmo.java dpdr.java % java
DiningPhilosophers 5 6 4 1
DiningPhilosophers: numPhilosophers=5, runTime=6, napThink=4, napEat=1 age=37, Philosopher 0 is thinking
for 2952 ms age=56, Philosopher 1 is thinking for 3012 ms age=59, Philosopher 2 is thinking for 508 ms
age=61, Philosopher 3 is thinking for 456 ms All Philosopher threads started



age=63, Philosopher 4 is thinking for 120 ms age=186, Philosopher 4 wants to dine
age=187, Philosopher 4 is eating for 205 ms age=406, Philosopher 4 is thinking for
839 ms age=525, Philosopher 3 wants to dine age=526, Philosopher 3 is eating for
107 ms age=575, Philosopher 2 wants to dine age=646, Philosopher 2 is eating for
111 ms age=646, Philosopher 3 is thinking for 1746 ms age=776, Philosopher 2 is
thinking for 3522 ms age=1258, Philosopher 4 wants to dine age=1259, Philosopher
4 is eating for 861 ms age=2136, Philosopher 4 is thinking for 3759 ms age=2406,
Philosopher 3 wants to dine age=2406, Philosopher 3 is eating for 878 ms age=3008,
Philosopher 0 wants to dine age=3009, Philosopher 0 is eating for 881 ms age=3086,
Philosopher 1 wants to dine age=3296, Philosopher 3 is thinking for 546 ms
age=3855, Philosopher 3 wants to dine age=3856, Philosopher 3 is eating for 648 ms
age=3908, Philosopher 0 is thinking for 2945 ms age=3909, Philosopher 1 is eating
for 102 ms age=4026, Philosopher 1 is thinking for 3699 ms age=4316, Philosopher
2 wants to dine age=4516, Philosopher 2 is eating for 10 ms age=4517, Philosopher
3 is thinking for 414 ms age=4536, Philosopher 2 is thinking for 1593 ms age=4947,
Philosopher 3 wants to dine age=4948, Philosopher 3 is eating for 898 ms age=5856,
Philosopher 3 is thinking for 687 ms age=5905, Philosopher 4 wants to dine
age=5906, Philosopher 4 is eating for 516 ms age=6066, time to terminate the
Philosophers and exit age=6069, Philosopher 1 interrupted out of think age=6070,
Philosopher 2 interrupted out of think age=6071, Philosopher 4 interrupted out of
dine age=6073, Philosopher 3 interrupted out of think age=6086, Philosopher 0
interrupted out of think age=7076, all Philosophers are done
```

Example bbmo.java

```
class BoundedBuffer {
```

```
// designed for multiple producer threads and // multiple consumer
threads private int numSlots = 0; private double[] buffer = null; private
int putIn = 0, takeOut = 0; private int count = 0;



public BoundedBuffer(int numSlots) {
      if (numSlots <= 0)
            throw new IllegalArgumentException("numSlots <= 0"); this.numSlots = numSlots;
    buffer = new double[numSlots]; }


public synchronized void deposit(double value)
            throws InterruptedException { while (count ==
      numSlots) wait(); buffer[putIn] = value; putIn = (putIn
      + 1) % numSlots; count++;

                              // wake up all those waiting due to
      notifyAll(); // signal-and-continue and barging }

public synchronized double fetch()
            throws InterruptedException { double value;

      while (count == 0) wait(); value =
      buffer[takeOut];
      takeOut = (takeOut + 1) % numSlots; count--;
                              // wake up all those waiting due to
      notifyAll(); // signal-and-continue and barging return value; } }
```

Sample run of bbmo.java

```
% javac bbmo.java bbdr.java
% java ProducersConsumers 10 2 3 2 3 6
ProducersConsumers:
  numSlots=10, numProducers=2, numConsumers=3, pNap=2, cNap=3, runTime=6 Java version=1.3.0

Java vendor=IBM Corporation OS
name=Linux OS arch=i586

OS version=#1 Mon Sep 27 10:25:54 EDT 1999.2.2.12-20 No PseudoTimeSlicing
needed
age=42, PRODUCER0 napping for 1248 ms age=61,
PRODUCER1 napping for 1702 ms age=65, Consumer0
napping for 226 ms age=67, Consumer1 napping for 94 ms
All threads started

age=69, Consumer2 napping for 2504 ms age=171,
Consumer1 wants to consume age=301, Consumer0 wants
to consume
age=1303, PRODUCER0 produced item 0.5251246705209369 age=1319,
PRODUCER0 deposited item 0.5251246705209369 age=1320, PRODUCER0 napping
for 889 ms
age=1321, Consumer0 fetched item 0.5251246705209369 age=1323, Consumer0
napping for 1049 ms
age=1781, PRODUCER1 produced item 0.9915848089197059 age=1782,
PRODUCER1 deposited item 0.9915848089197059 age=1783, PRODUCER1 napping
for 297 ms
age=1784, Consumer1 fetched item 0.9915848089197059
```

age=1785, Consumer1 napping for 1253 ms
age=2093, PRODUCER1 produced item 0.4866393343763298 age=2094, PRODUCER1 deposited item 0.4866393343763298 age=2095, PRODUCER1 napping for 1018 ms
age=2221, PRODUCER0 produced item 0.40569282834803577 age=2222, PRODUCER0 deposited item 0.40569282834803577 age=2223, PRODUCER0 napping for 974 ms
age=2380, Consumer0 wants to consume

age=2381, Consumer0 fetched item 0.4866393343763298 age=2382, Consumer0 napping for 1531 ms age=2580, Consumer2 wants to consume

age=2581, Consumer2 fetched item 0.40569282834803577 age=2582, Consumer2 napping for 2197 ms age=3051, Consumer1 wants to consume

age=3123, PRODUCER1 produced item 0.9581218200181911 age=3124, PRODUCER1 deposited item 0.9581218200181911 age=3125, PRODUCER1 napping for 1125 ms age=3126, Consumer1 fetched item 0.9581218200181911 age=3127, Consumer1 napping for 2387 ms

age=3211, PRODUCER0 produced item 0.9155450402123771 age=3212, PRODUCER0 deposited item 0.9155450402123771 age=3213, PRODUCER0 napping for 118 ms
age=3340, PRODUCER0 produced item 0.2431689653301975 age=3342, PRODUCER0 deposited item 0.2431689653301975 age=3343, PRODUCER0 napping for 235 ms
age=3590, PRODUCER0 produced item 0.06587542278093239 age=3592, PRODUCER0 deposited item 0.06587542278093239 age=3593, PRODUCER0 napping for 1014 ms
age=3931, Consumer0 wants to consume

age=3931, Consumer0 fetched item 0.9155450402123771 age=3932, Consumer0 napping for 1100 ms
age=4261, PRODUCER1 produced item 0.2895572679671733 age=4262, PRODUCER1 deposited item 0.2895572679671733 age=4263, PRODUCER1 napping for 1776 ms
age=4624, PRODUCER0 produced item 0.08728828492428509 age=4625, PRODUCER0 deposited item 0.08728828492428509 age=4626, PRODUCER0 napping for 446 ms
age=4790, Consumer2 wants to consume

age=4791, Consumer2 fetched item 0.2431689653301975 age=4792, Consumer2 napping for 2471 ms age=5041, Consumer0 wants to consume

age=5041, Consumer0 fetched item 0.06587542278093239 age=5042, Consumer0 napping for 1068 ms
age=5081, PRODUCER0 produced item 0.8313015436389664 age=5082, PRODUCER0 deposited item 0.8313015436389664 age=5083, PRODUCER0 napping for 1416 ms age=5521, Consumer1 wants to consume

age=5521, Consumer1 fetched item 0.2895572679671733 age=5522, Consumer1 napping for 2887 ms
age=6051, PRODUCER1 produced item 0.14766226608250066 age=6052, PRODUCER1 deposited item 0.14766226608250066 age=6053, PRODUCER1 napping for 534 ms
age=6071, time to terminate the threads and exit age=6074, PRODUCER1 interrupted from sleep age=6075, Consumer0 interrupted from sleep age=6077, Consumer2 interrupted from sleep age=6078, Consumer1 interrupted from sleep age=6091, PRODUCER0 interrupted from sleep age=7081, all threads are done

Example inmo.java

```
class Intersection extends Sugar {
    public static final int LEFT = 0, RIGHT = 1; private int[] waiting = {0, 0};
    private int lastToCross = 0; private boolean crossing = false; public
    String how(int direction) {


        if (direction == LEFT) return "left"; else if (direction == RIGHT) return
      "right"; else return "invalid"; }


    public void crossIntersection
            (String name, int direction, int cNap) throws
        InterruptedException { wantToCross(direction); try {


            cross(name, direction, cNap); } finally {

        // If we are interrupted while crossing, we must do this.
            doneCrossing(); } }


    private int other(int direction) {
        if (direction == LEFT) return RIGHT; else if (direction == RIGHT)
      return LEFT; else return -1; }


    private synchronized void wantToCross (int direction)
            throws InterruptedException {
        waiting[direction]++; try {

            while (crossing || (waiting[other(direction)] > 0
                && lastToCross == direction))
                    wait();
            lastToCross = direction; crossing =
          true; } finally {
                                                    // If we are interrupted while
            waiting[direction]--; // waiting to cross, do this. } }


    private void cross(String name, int direction, int cNap)
            throws InterruptedException { int napping;

        napping = 1 + (int) random(cNap);
        System.out.println("age=" + age() + ", " + name
            +   " CROSSING " + how(direction) + " for "
            +   napping + " ms");
      Thread.sleep(napping); }

    private synchronized void doneCrossing () {
        crossing = false;
    notifyAll(); } }
```

Driver indr.java

```
class Car extends Sugar implements Runnable {
    private String name = null; private int dNap = 0; //
    milliseconds private int cNap = 0; // milliseconds private
    int direction;
```

```
    private Intersection in = null; private Thread me =
    null;
    public Car(String name, int dNap, int cNap,
            int direction, Intersection in) { this.name = name;
        this.dNap = dNap; this.cNap = cNap;


        this.direction = direction; this.in = in;

        (me = new Thread(this)).start(); }

    public void timeToQuit() { me.interrupt(); } public void pauseTilDone() throws
    InterruptedException
        { me.join(); } public void
    run() {
        if (Thread.currentThread() != me) return; int napping; while (true)
        {

            if (Thread.interrupted()) {
                System.out.println("age=" + age() + ", " + name
                    +   " interrupted"); return; }


            napping = 1 + (int) random(dNap);
            System.out.println("age=" + age() + ", " + name
                +   " napping for " + napping + " ms"); try {
            Thread.sleep(napping); } catch (InterruptedException e) {

                System.out.println("age=" + age() + ", " + name
                    +   " interrupted from sleep"); return; }


            System.out.println("age=" + age() + ", " + name
                +   " wants to cross " + in.how(direction)); try { in.crossIntersection(name,
            direction, cNap); } catch (InterruptedException e) {

                System.out.println("age=" + age() + ", " + name
                    +   " interrupted from crossing"); return; }


            System.out.println("age=" + age() + ", " + name
                +   " crossed " + in.how(direction)); } } }



class LeftRightCars extends Sugar {
    public static void main(String[] args) {
        int numLefts = 3; int
        numRights = 3; int lNap = 2;
                                        // defaults
        int rNap = 2;                   // are
        int cNap = 2;                   // in
        int runTime = 60; // seconds try {

            numLefts = Integer.parseInt(args[0]); numRights = Integer.parseInt(args[1]); lNap =
            Integer.parseInt(args[2]); rNap = Integer.parseInt(args[3]); cNap =
            Integer.parseInt(args[4]); runTime = Integer.parseInt(args[5]); } catch (Exception e) {
            /* use defaults */ } System.out.println("LeftsRights:\n numLefts=" + numLefts




            +   ", numRights=" + numRights + ", lNap=" + lNap
            +   ", rNap=" + rNap + ", cNap=" + cNap
            +   ", runTime=" + runTime);
```

```
        // create the intersection Intersection in = new Intersection(); // start the
        left crossing and right crossing // cars (they have self-starting threads)
        Car[] c = new Car[numLefts + numRights]; for (int i = 0; i < numLefts +
        numRights; i++)


            c[i] = new Car("Car"+i, (i<numLefts?lNap:rNap)*1000,
                cNap*1000, (i<numLefts?in.LEFT:in.RIGHT), in); System.out.println("All
        threads started"); // let them run for a while try {


            Thread.sleep(runTime*1000);
            System.out.println("age=" + age()
                +   ", time to terminate the threads and exit"); for (int i = 0; i < numLefts +
            numRights; i++)
                c[i].timeToQuit();
            Thread.sleep(1000);
            for (int i = 0; i < numLefts + numRights; i++)
                c[i].pauseTilDone();
        } catch (InterruptedException e) { /* ignored */ } System.out.println("age=" +
        age()
            +   ", all threads are done"); System.exit(0); }
    }
```

Sample run of inmo.java

```
% javac inmo.java indr.java % java LeftRightCars 3
3 2 2 2 5 LeftsRights:

  numLefts=3, numRights=3, lNap=2, rNap=2, cNap=2, runTime=5 age=40, Car0 napping for
1040 ms age=59, Car1 napping for 1187 ms age=62, Car2 napping for 1603 ms age=64, Car3
napping for 1932 ms age=66, Car4 napping for 986 ms All threads started




age=68, Car5 napping for 1426 ms age=1061, Car4 wants to
cross right age=1063, Car4 CROSSING right for 1791 ms
age=1088, Car0 wants to cross left age=1258, Car1 wants to
cross left age=1509, Car5 wants to cross right age=1679, Car2
wants to cross left age=2011, Car3 wants to cross right
age=2869, Car2 CROSSING left for 1180 ms age=2870, Car4
crossed right age=2871, Car4 napping for 1441 ms age=4061,
Car2 crossed left age=4062, Car2 napping for 580 ms age=4063,
Car3 CROSSING right for 974 ms age=4329, Car4 wants to cross
right age=4648, Car2 wants to cross left age=5051, Car2
CROSSING left for 405 ms age=5052, Car3 crossed right
age=5052, Car3 napping for 1988 ms




age=5069, time to terminate the threads and exit age=5072, Car2 interrupted
from crossing age=5073, Car4 interrupted from crossing age=5075, Car3
interrupted from sleep
```

age=5076, Car5 interrupted from crossing age=5089, Car0 interrupted from crossing age=5090, Car1 interrupted from crossing age=6079, all threads are done % java LeftRightCars 5 1 1 5 1 5 LeftsRights:

numLefts=5, numRights=1, lNap=1, rNap=5, cNap=1, runTime=5 age=33, Car0 napping for 550 ms age=53, Car1 napping for 760 ms age=55, Car2 napping for 123 ms age=57, Car3 napping for 59 ms age=59, Car4 napping for 874 ms All threads started

age=61, Car5 napping for 1033 ms age=122, Car3 wants to cross left age=123, Car3 CROSSING left for 220 ms age=191, Car2 wants to cross left age=352, Car2 CROSSING left for 499 ms age=353, Car3 crossed left age=354, Car3 napping for 295 ms age=591, Car0 wants to cross left age=661, Car3 wants to cross left age=821, Car1 wants to cross left age=863, Car1 CROSSING left for 161 ms age=865, Car2 crossed left age=867, Car2 napping for 134 ms age=944, Car4 wants to cross left age=1011, Car2 wants to cross left age=1042, Car0 CROSSING left for 867 ms age=1043, Car1 crossed left age=1043, Car1 napping for 936 ms age=1111, Car5 wants to cross right age=1924, Car0 crossed left age=1925, Car0 napping for 129 ms age=1926, Car5 CROSSING right for 682 ms age=1992, Car1 wants to cross left age=2062, Car0 wants to cross left age=2622, Car0 CROSSING left for 377 ms age=2623, Car5 crossed right age=2624, Car5 napping for 276 ms age=2914, Car5 wants to cross right age=3012, Car0 crossed left age=3012, Car0 napping for 417 ms age=3013, Car5 CROSSING right for 740 ms age=3441, Car0 wants to cross left age=3762, Car0 CROSSING left for 95 ms age=3763, Car5 crossed right age=3764, Car5 napping for 2783 ms age=3872, Car0 crossed left age=3872, Car0 napping for 307 ms age=3873, Car1 CROSSING left for 165 ms age=4053, Car1 crossed left age=4054, Car1 napping for 24 ms age=4055, Car2 CROSSING left for 681 ms age=4091, Car1 wants to cross left age=4191, Car0 wants to cross left age=4752, Car0 CROSSING left for 566 ms age=4753, Car2 crossed left age=4754, Car2 napping for 329 ms

age=5062, time to terminate the threads and exit age=5065, Car1 interrupted from crossing age=5067, Car2 interrupted from sleep age=5068, Car4 interrupted from crossing age=5069, Car3 interrupted from crossing age=5070, Car5 interrupted from sleep

age=5082, Car0 interrupted from crossing age=6072, all threads are done

Section 9. Semaphores

User-written classes

The following user-written semaphore classes are Java monitors:

* Abstract Class Semaphore.java on page 53
* Counting semaphore Class CountingSemaphore.java on page 54
* Binary semaphore Class BinarySemaphore.java on page 54
* Syntactic sugar Class SugarSM.java on page 54 so **P(S)** can be used instead of **S.P()**

Background material on semaphores

Semaphores can be used for mutual exclusion and thread synchronization. Instead of busy waiting and wasting CPU cycles, a thread can block on a semaphore (the operating system removes the thread from the CPU scheduling or "ready" queue) if it must wait to enter its critical section or if the resource it wants is not available.

Here's an example of mutual exclusion pseudocode:

```
semaphore S = 1; ... P(S); N=N+1; V(S);
```

And here's an example of condition synchronization pseudocode (resource availability):

```
semaphore tapeDrives = 7; ... P(tapeDrives); useTapeDrive(); V(tapeDrives);
```

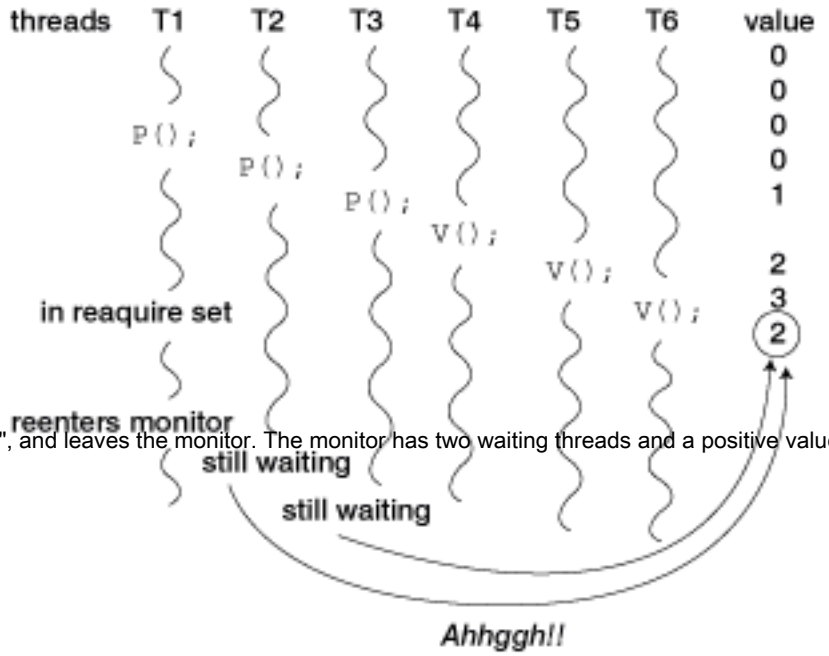
Java does not have explicit binary and ***counting*** semaphores, so they are provided as classes.

Pitfalls

The example of a counting semaphore shown in the following figure and in Class BadCountingSemaphore1.java on page 54 is not correct because of ***barging.*** We can repair the problem by changing the semantics of the semaphore **value** field. For code samples, see Class Semaphore.java on page 53 , Class CountingSemaphore.java on page 54 , Class BinarySemaphore.java on page 54 , Class SugarSM.java on page 54 , Class BadCountingSemaphore1.java on page 54 , and Class BadCountingSemaphore2.java on page 55 .

```
public class CountingSemaphore {
  private int value = 0;
  public CountingSemaphore(int initial)
    { value = initial; }
  public synchronized void P()
      throws InterruptedException {
    while (value == 0) wait();
    value--;
  }
  public synchronized void V() {
    if (value == 0) notify();
    value++;
  }
}
```

a counting semaphore. Presented by developerWorks, your source for great tutorials



to "2", and leaves the monitor. The monitor has two waiting threads and a positive value. This is an inconsistent state for

Suppose the semaphore's current value is "0". Three threads invoke the semaphore's **P()** method and wait. Then another thread calls **V(),** which moves one of the three waiting threads to the runnable set.

Now suppose a couple of other threads barge ahead of the signaled thread and perform two more **V()** operations on the semaphore. Because the semaphore's value is positive, **notify()** is not called and none of the waiting threads is moved to the runnable set.

Finally, the thread signaled by the first **V()** re-enters the semaphore monitor, decrements the semaphore value from "3"

To fix this, we could try changing the semantics of the semaphore **value** field, as in this counting semaphore, Class BadCountingSemaphore2.java on page 55 . The value is allowed to go negative, in which case its absolute value equals the number of waiting threads.

This approach fixes the barging problems but introduces an **interrupt()** problem. Suppose the semaphore value is "-1" due to one thread blocked in **wait()** inside **P().** Then suppose that thread is interrupted. The value is left at "-1" even though no threads are blocked in **P().** The next **V()** will increment the value to "0" whereas it should now be "1".

Another, more insidious problem is present: a race condition between **interrupt()** and **notify().** Suppose several threads are blocked inside **wait()** and then one of them is notified and then interrupted before it reacquires the monitor lock. The **notify()** gets "lost" in that one of the other waiting threads should now proceed.

So we need to catch the exception when a thread is interrupted out of **wait()** and regenerate the **notify().**

Examples of semaphores

Example bbou.java on page 56 shows the bounded buffer producer and consumer. Driver bbdr.java on page 20 creates the producer and consumer threads. Sample run of bbou.java on page 56 is the sample run.

Example dphi.java on page 57 highlights dining philosophers. Driver dpdr.java on page 40 creates the philosopher threads. The sample run is Sample run of dphi.java on page 58 .

Try these exercises

Exercise 1: Modify Example bbou.java on page 56 so that it correctly handles multiple producer and multiple consumer threads.

Exercise 2: Write a semaphore solution for the database readers and writers problem.

Exercise 3: Write a semaphore solution for the cars at an intersection problem.

Security issues in monitors and synchronization

The **public void run()** method in a **Thread** or **Runnable** object can be invoked by any thread that has a reference to the **Thread** or **Runnable** object. So we prevent that at the beginning of the **run()** method with **if (Thread.currentThread() != me) return;.**

An object's lock is accessible to any thread that has a reference to the object. This can upset the operation of a monitor if some thread decides to do something like this:

```
synchronized (monitor) {
    Thread.sleep(veryLongTime); // or

    invert(veryLargeMatrix); }
```

The following technique is not so bad because of the **while (!condition)** loop that a **wait()** is done in. But it does add overhead:

```
synchronized (monitor) {
    monitor.notifyAll(); }
```

To protect our code from this mischief, we can code a monitor as follows, using a counting semaphore as an example. We use a wrapper class and delegate **P()** and **V()** to a private counting semaphore inside the wrapper class:

```
class SecureCountingSemaphore {
    private CountingSemaphore S = null;
    SecureCountingSemaphore(int initial)
        { S = new CountingSemaphore(initial); } void P() throws
  InterruptedException { S.P(); } void V() { S.V(); } }
```

Another way is to use a private lock object inside the semaphore class and change synchronized methods to use the private lock:

```
class SecureCountingSemaphore {
    private int value = 0;
    private Object mutex = new Object();
    SecureCountingSemaphore(int initial)
        { value = initial; }
    void P() throws InterruptedException {
        synchronized (mutex)
            { while (value == 0) mutex.wait(); value--; } }

    void V() {
        synchronized (mutex)
            { value++; mutex.notifyAll(); } } }
```

The next several panels display the code described in this section. To view the code, click **Next;** or you can go directly to the next section, Message passing on page 60 , and return to the code samples at another time.

Class Semaphore.java

```
public abstract class Semaphore {
    private int value = 0;
    public Semaphore() {} // constructors public Semaphore(int
    initial) {
        if (initial >= 0) value = initial;
        else throw new IllegalArgumentException("initial < 0"); }

    public final synchronized void P()
            throws InterruptedException { while (value ==
        0) wait(); value--;
```

```
    }
    protected final synchronized void Vc() {
        value++; notifyAll(); }

    protected final synchronized void Vb() {
        this.Vc(); if (value > 1) value = 1; }

    public abstract void V();
    public String toString() { return ".value=" + value; } }
```

Class CountingSemaphore.java

```
public final class CountingSemaphore extends Semaphore {
    public CountingSemaphore() { super(); } // constructors public CountingSemaphore(int
  initial) { super(initial); } public final synchronized void V() { super.Vc(); } }
```

Class BinarySemaphore.java

```
public final class BinarySemaphore extends Semaphore {
    public BinarySemaphore() { super(); } // constructors public BinarySemaphore(int
    initial) {
        super(initial); if (initial >
        1)
            throw new IllegalArgumentException("initial > 1"); }

    public final synchronized void V() { super.Vb(); } }
```

Class SugarSM.java

```
public abstract class SugarSM extends Sugar {
        // syntactic sugar for semaphores protected static final void
    P(Semaphore s)
        throws InterruptedException { s.P(); } protected static final void V(Semaphore
  s) { s.V(); } }
```

Class BadCountingSemaphore1.java

```
public class BadCountingSemaphore1 {
    private int value = 0;
    public BadCountingSemaphore1(int initial)
        { if (initial > 0) value = initial; } public synchronized void
    P()
            throws InterruptedException {
```

```
        while (value == 0) wait(); value--; }

    public synchronized void V() {
        if (value == 0) notify(); // barging causes problems value++; } }
```

Class BadCountingSemaphore2.java

```
public class BadCountingSemaphore2 {
    private int value = 0;
    public BadCountingSemaphore2(int initial)
        { if (initial > 0) value = initial; } public synchronized void
    P()
            throws InterruptedException { value--;

        if (value < 0) wait(); }

    public synchronized void V() {
        value++;
        if (value <= 0) notify(); // interrupt causes problems } }
```

Class EfficientCountingSemaphore.java

```
public class EfficientCountingSemaphore {
    private int value = 0; private int waitCount =
    0; private int notifyCount = 0;

    public EfficientCountingSemaphore() {} // constructors public
    EfficientCountingSemaphore(int initial) {
        if (initial >= 0) value = initial;
        else throw new IllegalArgumentException("initial < 0"); }

    public synchronized void P()
            throws InterruptedException { if (value <=
        waitCount) {
            waitCount++; try {

                do { wait(); }
                    while (notifyCount == 0); }
            catch(InterruptedException e) {
                notify(); throw
                e;
            } finally { waitCount--; } notifyCount--; }
          else {

            if (notifyCount > waitCount)
                notifyCount--; }

        value--; }

    public synchronized void V() {
```

```
    value++;
    if (waitCount > notifyCount) {
        notifyCount++;
notify(); } } }
```

Example bbou.java

```
class BoundedBuffer extends SugarSM {
    // designed for a single producer thread and // a single consumer
    thread private int numSlots = 0; private double[] buffer = null; private
    int putIn = 0, takeOut = 0; private int count = 0;



    private BinarySemaphore mutex = null; private
    CountingSemaphore elements = null; private CountingSemaphore
    spaces = null; public BoundedBuffer(int numSlots) {

        if (numSlots <= 0)
            throw new IllegalArgumentException("numSlots <= 0"); this.numSlots = numSlots;
        buffer = new double[numSlots]; mutex = new BinarySemaphore(1); elements = new
        CountingSemaphore(0); spaces = new CountingSemaphore(numSlots); }



    public void deposit(double value)
            throws InterruptedException { P(spaces);

        buffer[putIn] = value; putIn = (putIn + 1) %
        numSlots; P(mutex); count++; V(mutex);
        V(elements); }


    public double fetch()
            throws InterruptedException { double value;
        P(elements);

        value = buffer[takeOut];
        takeOut = (takeOut + 1) % numSlots; P(mutex); count--;
    V(mutex); V(spaces); return value; } }
```

Sample run of bbou.java

```
% javac bbou.java bbdr.java
% java ProducersConsumers 10 1 1 2 2 5
ProducersConsumers:
  numSlots=10, numProducers=1, numConsumers=1, pNap=2, cNap=2, runTime=5 Java version=1.3.0
```

```
Java vendor=IBM Corporation OS
name=Linux OS arch=i586

OS version=#1 Mon Sep 27 10:25:54 EDT 1999.2.2.12-20 No PseudoTimeSlicing
needed
age=44, PRODUCER0 napping for 1701 ms age=63,
Consumer0 napping for 982 ms All threads started

age=1065, Consumer0 wants to consume
age=1763, PRODUCER0 produced item 0.8235080062047989 age=1779,
PRODUCER0 deposited item 0.8235080062047989 age=1780, PRODUCER0 napping
for 1223 ms age=1781, Consumer0 fetched item 0.8235080062047989 age=1783,
Consumer0 napping for 529 ms age=2325, Consumer0 wants to consume


age=3016, PRODUCER0 produced item 0.5752891675481963 age=3018,
PRODUCER0 deposited item 0.5752891675481963 age=3019, PRODUCER0 napping
for 1794 ms age=3020, Consumer0 fetched item 0.5752891675481963 age=3021,
Consumer0 napping for 1824 ms

age=4825, PRODUCER0 produced item 0.5010012702583668 age=4826,
PRODUCER0 deposited item 0.5010012702583668 age=4827, PRODUCER0 napping
for 1299 ms age=4852, Consumer0 wants to consume

age=4853, Consumer0 fetched item 0.5010012702583668 age=4854, Consumer0
napping for 273 ms age=5074, time to terminate the threads and exit age=5077,
Consumer0 interrupted from sleep age=5093, PRODUCER0 interrupted from
sleep age=6083, all threads are done
```

Example dphi.java

```
class DiningServer extends SugarSM {
      private int numPhils = 0; private int[] state
      = null;
      private static final int THINKING = 0, HUNGRY = 1, EATING = 2; private BinarySemaphore[] self =
      null; private BinarySemaphore mutex = null; public DiningServer(int numPhils) {


            this.numPhils = numPhils; state = new
            int[numPhils];
            for (int i = 0; i < numPhils; i++) state[i] = THINKING; self = new
            BinarySemaphore[numPhils]; for (int i = 0; i < numPhils; i++)

                  self[i] = new BinarySemaphore(0); mutex = new
         BinarySemaphore(1); }

      public void dine(String name, int id, int napEat)
                  throws InterruptedException { try {

                  takeForks(id); eat(name,
               napEat); } finally {
                                          // Make sure we return the
                  putForks(id); // forks if interrupted } }


      private final int left(int i)
            { return (numPhils + i - 1) % numPhils;} private final int right(int
      i)
            { return (i + 1) % numPhils; }
```

```
private void test(int k) {
      if (state[left(k)] != EATING && state[k] == HUNGRY &&
                  state[right(k)] != EATING) { state[k] =
        EATING; V(self[k]); } }



private void eat(String name, int napEat)
            throws InterruptedException { int napping;

      napping = 1 + (int) random(napEat); System.out.println("age=" + age() + ",
      " + name
            +   " is eating for " + napping + " ms"); Thread.sleep(napping);
  }

private void takeForks(int i)
            throws InterruptedException {
      P(mutex); state[i] = HUNGRY; test(i); V(mutex); P(self[i]); }


private void putForks(int i)
            throws InterruptedException { if (state[i] !=
      EATING) return; P(mutex);

            state[i] = THINKING; test(left(i)); test(right(i)); V(mutex); } }
```

Sample run of dphi.java

```
% javac dphi.java dpdr.java % java
DiningPhilosophers 5 6 4 1
DiningPhilosophers: numPhilosophers=5, runTime=6, napThink=4, napEat=1 age=42, Philosopher 0 is thinking
for 683 ms age=61, Philosopher 1 is thinking for 437 ms age=64, Philosopher 2 is thinking for 3039 ms age=66,
Philosopher 3 is thinking for 3190 ms All Philosopher threads started



age=68, Philosopher 4 is thinking for 3893 ms age=511, Philosopher 1
wants to dine age=513, Philosopher 1 is eating for 82 ms age=648,
Philosopher 1 is thinking for 3631 ms age=740, Philosopher 0 wants to
dine age=741, Philosopher 0 is eating for 699 ms age=1453, Philosopher 0
is thinking for 2390 ms age=3111, Philosopher 2 wants to dine age=3111,
Philosopher 2 is eating for 526 ms age=3260, Philosopher 3 wants to dine
age=3651, Philosopher 2 is thinking for 2095 ms age=3652, Philosopher 3
is eating for 448 ms age=3850, Philosopher 0 wants to dine age=3851,
Philosopher 0 is eating for 324 ms age=3973, Philosopher 4 wants to dine
age=4111, Philosopher 3 is thinking for 2346 ms age=4191, Philosopher 0
is thinking for 3695 ms age=4192, Philosopher 4 is eating for 477 ms
age=4290, Philosopher 1 wants to dine age=4291, Philosopher 1 is eating
for 259 ms age=4561, Philosopher 1 is thinking for 127 ms age=4681,
Philosopher 4 is thinking for 751 ms
```

age=4700, Philosopher 1 wants to dine age=4701, Philosopher 1 is eating for 355 ms age=5073, Philosopher 1 is thinking for 3921 ms age=5450, Philosopher 4 wants to dine age=5451, Philosopher 4 is eating for 492 ms age=5761, Philosopher 2 wants to dine age=5761, Philosopher 2 is eating for 323 ms age=5962, Philosopher 4 is thinking for 3225 ms age=6071, time to terminate the Philosophers and exit age=6074, Philosopher 1 interrupted out of think age=6075, Philosopher 2 interrupted out of dine age=6077, Philosopher 4 interrupted out of think age=6078, Philosopher 3 interrupted out of think age=6091, Philosopher 0 interrupted out of think age=7081, all Philosophers are done

Section 10. Message passing Some definitions

Object-oriented programming blurs the distinction between invoking a method and sending a message. It also blurs the distinction between shared and distributed memory computer architectures.

The figure below shows the difference between (1) invoking a method and (2) sending a message:

1. Thread leaves code in one object to execute code in another object, then comes back (shown at the top of the figure).
2. Thread sends an object to another thread, then optionally blocks until the other thread receives the message (shown at the bottom of the figure).

Message passing leads to "safer" concurrent programming since the receiving object only has one thread executing inside it.

send) message passing (receive always blocks) include: Presented by developerWorks, your source for great

It is important to note that multiple threads invoking methods in an object might lead to race conditions unless synchronization is properly done by making the object a monitor. With message passing, the receiving object has just one thread executing inside it, leading to "safer" concurrent programming.

If the threads have a relationship other than client/server, monitors can be awkward to use. Using message passing between the threads is easier in these situations. If the threads communicate with each other, they are called ***peers*** or ***filters.*** In this situation, the threads form a pipeline in which each thread gets its input from its predecessor in the pipeline and sends its output to its successor in the pipeline.

Options for user-written classes implementing synchronous (blocking send) and asynchronous (non-blocking

* Sending object references from one thread to another within the same JVM
* Sending serialized objects through connected sockets from a thread in one JVM to a thread in another JVM

Each message passing class implements a ***mailbox*** or ***channel*** shared by a collection of threads. The one-way flow of information from sender to receiver in synchronous message passing is sometimes called a ***simple rendezvous.*** Following are examples:

* Shared type:
```
class Message { ... }
```

* Shared mailbox:
```
    // non-blocking sends:
MessagePassing mailbox = new MessagePassing();
    // capacity controlled:
MessagePassing mailbox = new MessagePassing(capacity);
```

* One thread:
```
Message ms = new Message(...); send(mailbox,
ms);
```

* Another thread:
```
Message mr;
mr = (Message) receive(mailbox);
```

Values like **int** and **double** can be sent using the wrapper classes **Integer** and **Double.**

Background material on message passing

Sometimes the phrase "send a message to an object" is used to describe a thread in one object calling a method in another object. Here, that phrase is used to describe a thread in one object sending a message to a thread in another object, where the message is itself an object.

This technique is used for thread communication and synchronization in a computing environment where the threads do not have shared memory (since the threads reside in different virtual or physical machines). Hence the threads cannot share semaphores or monitors and cannot use shared variables to communicate. Message passing can still be used, of course, in a shared memory platform.

Messages are sent through a port or channel with an operation like ***send(channel, message)*** and received from a port or channel with an operation like ***receive(channel, message).*** Messages can be passed ***synchronously,*** meaning the sender blocks until the receiver does a receive and the receiver blocks until the sender does a send.

Because the sender and receiver are at specific known points in their code at a known Presented by

specific instant of time, synchronous message passing is also called a ***simple rendezvous*** with a one-way flow of information from the sender to the receiver.

In ***asynchronous*** message passing, the sender does not block. If there is not a receiver waiting to receive the message, the message is queued or buffered. The receiver still blocks if there is no queued or buffered message when a receive is executed.

In ***conditional*** message passing, the message remains queued until some condition, specified by the receiver, becomes true. At that time, the message is passed to the receiver, unblocking it.

A two-way flow of information, perhaps over the network, is called an ***extended rendezvous*** and can be implemented with a pair of sends and receives. Typically a ***client*** thread uses this technique to communicate with a ***server*** thread and requests a service to be performed on its behalf.

A similar situation exists when a ***worker*** thread contacts a ***master*** thread, asking for more work to do. The client or worker sends a request and receives the reply. The server or master receives the request, performs the service, and sends the reply.

The Example qsrt.java on page 65 algorithm can be parallelized for a shared-memory, multiple-CPU machine by dedicating each CPU to a worker thread and using a message passing channel as a ***bag of tasks.*** The **main()** method puts the whole array to be sorted into the bag.

A worker extracts the task, chooses a pivot point, and partitions the array. Each of the two partitions is then put back into the bag as a task for one of the workers to perform.

Even though message passing is being used for a bag of tasks, shared memory is still required because the array is being sorted "in place" and the work requests being put into the bag are array index pairs and not pieces of the array itself.

A bag of tasks communication channel, object **task,** is shared by the quicksort worker threads:

```
MessagePassing task = new MessagePassing();
```

The quicksort worker threads get tasks from the **task** bag inside a **while** loop:

```
while (true) {
      m = (Task) receive(task); quickSort(id, m.left,
   m.right); }
```

The quicksort worker threads create tasks and put them into the **task** bag:

```
if (right-(l+1) > 0) send(task, new Task(l+1, right)); if ((l-1)-left > 0) send(task, new
Task(left, l-1));
```

User-written classes

The following are two user-written classes:

* Class SugarMP.java on page 64 provides syntactic sugar so that **send(mailbox, ms)** can be used instead of **mailbox.send(ms)** and **mr = receive(mailbox)** instead of **mr = mailbox.receive().**

* Class MessagePassing.java on page 64 sends object references within one JVM asynchronously. Synchronous message passing can be done with the **Rendezvous** class, which we'll discuss later.

Examples of message passing

The first example contains ***worker*** threads and a bag of tasks, the second example contains ***filter*** threads, and the third example contains ***peer*** threads.

* Example qsrt.java on page 65 : Quicksort (worker threads). Sample run of qsrt.java on page 67 is the sample run.
* Example pasv.java on page 67 : Parallel Sieve of Eratosthenes (filter threads). Sample run of pasv.java on page 69 is the sample run.
* Example rads.java on page 69 : Parallel Radix Sort (peer threads). Sample run of rads.java on page 71 is the sample run.

You can use Remote Method Invocation (RMI) on page 98 to implement message passing between threads in different JVMs that may also be on different physical machines.

The next several panels display the code described in this section. To view the code, click **Next;** or you can go directly to the next section, Rendezvous on page 72 , and return to the code samples at another time.

Class SugarMP.java

```
public abstract class SugarMP extends Sugar {
        // syntactic sugar for message passing
    protected static final void send(MessagePassing mp, Object o)
        throws InterruptedException { mp.send(o); } protected static final Object
    receive(MessagePassing mp)
        throws InterruptedException { return mp.receive(); } }
```

Class MessagePassing.java

```
import java.util.Vector;
public final class MessagePassing {
    // Implements asynchronous message passing: // sends do not block
    (until the message is // received), receives block of course until // a
    message is received.

    private int capacity = 0; // for capacity control // messages are delivered FIFO (in the order
    they are sent) private final Vector messages = new Vector();
```

```
// receivers get messages FIFO (in the order they call receive) private final Vector receivers = new
Vector(); public MessagePassing() { this(0); }

public MessagePassing(int c) { // capacity limit
      super();
      if (c < 0) throw new IllegalArgumentException("capacity < 0"); // zero means no limit imposed here
      else if (c > 0) {

            capacity = c;
            messages.ensureCapacity(capacity); } }


public final synchronized void send(Object m)
            throws InterruptedException {
      if (m == null) throw new NullPointerException("null message"); if (capacity > 0)

            while (messages.size() == capacity) wait();
    messages.addElement(m); // add at end notifyAll(); }


public final synchronized Object receive()
            throws InterruptedException { Object receivedMessage =
      null; Thread me = Thread.currentThread();
      receivers.addElement(me); // add at end try {


            while (messages.isEmpty() || me != receivers.elementAt(0))
                  wait();
            // If we are interrupted after being notified and there is a // message here for us, pretend we
            were interrupted before // being notified and leave the message for someone else. // Thus,
            there is no `catch (InterruptedException e) {...}' // block here.


            receivedMessage = messages.elementAt(0);
          messages.removeElementAt(0); return receivedMessage; }
          finally {

            // We need to do this if we get a message or if we were // interrupted.

            receivers.removeElement(me);
            // The notifyAll is needed because several messages // might be put in the messages
        vector before any // waiting receivers get back in. The receiver who // is first in the
        receivers vector might not get back // in until last! So it needs to cause the waiting //
        receivers to come back in again so the second in // line can get a message. notifyAll(); }
        } }
```

Example qsrt.java

```
class Task {
      public int left = -1, right = -1; public Task(int left, int
      right)
            { this.left = left; this.right = right; } }

class QuickSort extends SugarMP implements Runnable {
      private static int N = 10;
```

```
private static int RANGE = 100; private static int
NCPU = 4;
private static final MessagePassing doneCount
      = new MessagePassing();
private static final MessagePassing task
      = new MessagePassing(); private static int[]
nums = null; private String name = null; private int id
= -1; private Thread me = null; private QuickSort(int
id) {


      this.name = "Worker" + id; this.id = id;

      (me = new Thread(this)).start(); }

private static void quickSort
            (int worker, int left, int right) throws
        InterruptedException { int pivot = nums[left]; int l = left,
        r = right; boolean done = false;


      Integer doneMessage = new Integer(worker); while (!done) {

            if (nums[l+1] > pivot) {
                  while (r > l+1 && nums[r] > pivot) { r--; } if (r > l+1) { l++;

                        int temp = nums[r]; nums[r] = nums[l]; nums[l] = temp; done
               = l >= r-1; } else done = true; } else { l++; done = l >= r; } }




      int temp = nums[left]; nums[left] = nums[l]; nums[l] = temp;

      if (right-(l+1) > 0) send(task, new Task(l+1, right)); else if (right-(l+1) == 0)
      send(doneCount, doneMessage); send(doneCount, doneMessage);

      if ((l-1)-left > 0) send(task, new Task(left, l-1)); else if ((l-1)-left == 0) send(doneCount,
   doneMessage); }

public void timeToQuit() { me.interrupt(); } public void pauseTilDone() throws
InterruptedException
      { me.join(); } public void
run() {
      Task m = null; while
      (true) {
            if (Thread.interrupted()) {
                  System.out.println("age=" + age() + ", " + name
                        +   " interrupted"); return; }
              try {


                  m = (Task) receive(task); quickSort(id, m.left,
               m.right); } catch (InterruptedException e) {

                  System.out.println("age=" + age() + ", " + name
                        +   " interrupted out of send/receive"); return; } } }




public static void main(String[] args) {
      try {
            N = Integer.parseInt(args[0]); RANGE =
            Integer.parseInt(args[1]);
```

```
        NCPU = Integer.parseInt(args[2]); } catch (Exception e) { /* use
    defaults */ } System.out.println("Quick sorting " + N

        +   " random numbers between 1 and " + RANGE
        +   " using " + NCPU + " CPUs"); nums = new
    int[N]; for (int i = 0; i < N; i++)

        nums[i] = 1 + (int) (random()*RANGE);
    System.out.println("Original numbers:"); for (int i = 0; i < N; i++)

        System.out.print(" " + nums[i]); System.out.println(); // create the workers with
    self-starting threads QuickSort[] q = new QuickSort[NCPU];

    new PseudoTimeSlicing(); // for Solaris, not Windows 95/NT for (int i = 0; i < NCPU; i++) q[i]
    = new QuickSort(i); try {

        send(task, new Task(0, N-1));
        // wait for enough "singletons" to be produced for (int i = 0; i < N; i++)
        receive(doneCount); System.out.println("Sorted numbers:"); for (int i = 0; i
        < N; i++)

            System.out.print(" " + nums[i]);
          System.out.println();
        for (int i = 0; i < NCPU; i++) q[i].timeToQuit(); Thread.sleep(1000);

        for (int i = 0; i < NCPU; i++) q[i].pauseTilDone(); } catch (InterruptedException e) {
/* ignored */ } System.out.println("age()=" + age() + ", done"); System.exit(0); } }
```

Sample run of qsrt.java

```
% javac qsrt.java
% java QuickSort 15 1000 3
Quick sorting 15 random numbers between 1 and 1000 using 3 CPUs Original numbers:

  594 637 361 87 207 803 8 870 979 333 121 601 353 613 586 Java version=1.3.0

Java vendor=IBM Corporation OS
name=Linux OS arch=i586

OS version=#1 Mon Sep 27 10:25:54 EDT 1999.2.2.12-20 No PseudoTimeSlicing
needed Sorted numbers:

  8 87 121 207 333 353 361 586 594 601 613 637 803 870 979 age=77, Worker2 interrupted

age=96, Worker0 interrupted out of send/receive age=97, Worker1
interrupted out of send/receive age()=1087, done
```

Example pasv.java

```
class Filter extends SugarMP implements Runnable {
    private MessagePassing in = null, out = null;
```

```
    private int prime = 0, countIn = 0, countOut = 0; public Filter(MessagePassing in,
    MessagePassing out) {
        this.in = in; this.out = out; }

    private void print() {
        System.out.println("age()=" + age() + " received prime " + prime
            +   ", countIn=" + countIn + ", countOut=" + countOut); }

    public void run () {
        if (in == null) {                       // source thread
            int number = 3; while
            (true) {
                try { send(out, new Integer(number)); } catch
              (InterruptedException e) { return; } number += 2; } } else {


                                            // filter threads
            int number = 0;
            try { prime = ((Integer) receive(in)).intValue(); } catch (InterruptedException e) {
            return; } while (true) {

                if (Thread.interrupted()) { print(); return; } try {

                    number = ((Integer) receive(in)).intValue(); countIn++; if (number % prime != 0) {

                        send(out, new Integer(number)); countOut++; }

                } catch (InterruptedException e) { print(); return; } } } } }



class ParallelSieve extends SugarMP {
    public static void main(String[] args) {
        int n = 8;
        try { n = Integer.parseInt(args[0]); } catch (Exception e) { /* use
        default */ } if (n < 1) {

            System.out.println("Generate at least one prime number."); System.exit(1); }


        System.out.println("ParallelSieve: generating the first "
            +   n + " prime numbers greater than 2"); MessagePassing in
        = null, out = null; Thread[] filter = new Thread[n]; for (int i = 0; i < n;
        i++) {

            // Use capacity control so the early threads do // not get way ahead of what
            is needed by the // latter threads and fill up JVM memory. out = new
            MessagePassing(n);

            filter[i] = new Thread(new Filter(in, out)); in = out; }


        new PseudoTimeSlicing(); // for Solaris, not Windows 95/NT for (int i = 0; i < n; i++)
        filter[i].start(); try {

            int prime = ((Integer) receive(out)).intValue(); for (int i = 0; i < n; i++)
            filter[i].interrupt(); for (int i = 0; i < n; i++) filter[i].join();
            System.out.println("age()=" + age() + " last
                                                                    prime " + prime);
        } catch (InterruptedException e) { /* ignored */ } System.exit(0); } }
```

Sample run of pasv.java

```
% javac pasv.java % java
ParallelSieve 20
ParallelSieve: generating the first 20 prime numbers greater than 2 Java version=1.3.0

Java vendor=IBM Corporation OS
name=Linux OS arch=i586

OS version=#1 Mon Sep 27 10:25:54 EDT 1999.2.2.12-20 No PseudoTimeSlicing
needed
age()=2158 received prime 11, countIn=458, countOut=416 age()=2165 received prime
13, countIn=395, countOut=365 age()=2166 received prime 7, countIn=559,
countOut=479 age()=2167 received prime 5, countIn=725, countOut=580 age()=2169
received prime 29, countIn=230, countOut=223 age()=2171 received prime 19,
countIn=301, countOut=284 age()=2172 received prime 17, countIn=344, countOut=322
age()=2174 received prime 43, countIn=133, countOut=132 age()=2175 received prime
23, countIn=263, countOut=251 age()=2176 received prime 47, countIn=111,
countOut=110 age()=2178 received prime 37, countIn=177, countOut=176 age()=2179
received prime 31, countIn=202, countOut=198 age()=2180 received prime 3,
countIn=1120, countOut=746 age()=2182 received prime 41, countIn=155,
countOut=154 age()=2184 received prime 53, countIn=89, countOut=88 age()=2185
received prime 59, countIn=67, countOut=66 age()=2187 received prime 61, countIn=45,
countOut=44 age()=2188 received prime 67, countIn=23, countOut=22 age()=2190
received prime 71, countIn=1, countOut=1 age()=2191 last
```

prime 73

Example rads.java

```
class Result { public int number, count;
    public Result(int n, int c) { number = n; count = c; } }

class Peer extends SugarMP implements Runnable {
    private int N = -1, id = -1, mine = 0; private MessagePassing[]
    channel = null; private MessagePassing reply = null;

    public Peer(int N, int id, int mine, MessagePassing[] channel,
            MessagePassing reply) { this.N = N;
        this.id = id; this.mine = mine; this.channel
        = channel; this.reply = reply; new
        Thread(this).start(); }



    public void run() {
        int count = 0, other = 0; try {

            // Send my number to all the other workers. for (int i = 0; i < N; i++)

                if (i != id) send(channel[i], new Integer(mine)); // Of the N-1 numbers sent to me
            by the other workers,
```

```
            // count how many are less than my number. for (int i = 1; i < N;
            i++) {
                  other = ((Integer) receive(channel[id])).intValue(); if (other < mine) count++; }


            // Send my count of less-than-mine-seen back to main(). send(reply, new Result(mine,
      count)); } catch (InterruptedException e) { return; } } }



class RadixSort extends SugarMP {
      public static void main(String[] args) {
            int N = 15; int RANGE =
            1000; int[] nums = null;

            MessagePassing[] channel = null;
            MessagePassing reply = null; try {

                  N = Integer.parseInt(args[0]); RANGE = Integer.parseInt(args[1]);
              } catch (Exception e) { /* use defaults */ } System.out.println("Radix
              sorting " + N

                  +   " random integers between 1 and " + RANGE); nums = new int[N];
            for (int i = 0; i < N; i++)

                  nums[i] = 1 + (int)random(RANGE);
            System.out.println("Original numbers:"); for (int i = 0; i < N; i++)

                  System.out.print(" " + nums[i]); System.out.println(); // Set up the reply channel. reply =
            new MessagePassing(); channel = new MessagePassing[N]; // Set up the communication
            channels. for (int i = 0; i < N; i++)



                  channel[i] = new MessagePassing(); // Start the
            worker threads. for (int i = 0; i < N; i++)

                  new Peer(N, i, nums[i], channel, reply); int[] tallyCounts = new
            int[N];
            for (int i = 0; i < N; i++) tallyCounts[i] = 0; try {

                  // Gather the results. for (int i = 0; i < N; i++) {

                        Result r = (Result) receive(reply);
                        // Put the number where it belongs in the sorted order, // which is the value of the counter
                      in which it recorded // the number of less-than-its-own numbers it saw. nums[r.count] =
                      r.number; tallyCounts[r.count]++; }



            } catch (InterruptedException e) { /* ignored */ } System.out.println("Sorted
            numbers:"); for (int i = 0; i < N; i++)

                  System.out.print(" " + nums[i]); System.out.println(); for (int i = 0; i < N; i++)

                  // Zeros show where duplicates have occured.
                  System.out.print(" " + tallyCounts[i]); System.out.println(); System.out.println("age()=" + age() + ",
      done"); System.exit(0); } }
```

Sample run of rads.java

```
% javac rads.java % java RadixSort
20 100
Radix sorting 20 random integers between 1 and 100 Original numbers:

 58 71 78 26 47 34 30 9 99 60 60 70 51 71 93 76 2 87 49 14 Sorted numbers:

 2 9 14 26 30 34 47 49 51 58 60 70 70 71 93 76 78 87 93 99 1 1 1 1 1 1 1 1 1 1 1 2 0 1 2 0 1 1 1 1
1 age()=164, done
```

Section 11. Rendezvous Some definitions

In general client-server programming, a client thread interacts with the server thread by sending a request message followed immediately by a receive that blocks until the server sends a reply message containing the results of the request. This is called a ***rendezvous (*** or sometimes an ***extended rendezvous).***

A monitor is a passive object and can be used to implement a server. An active object, in which an independent thread executes, can also act as a server by using the rendezvous style of message passing. Here are a few examples:

* Mailbox shared by the client and server:
the client uses the server's machine Presented by developerWorks, your source for great tutorials
```
MessagePassing mailbox = new MessagePassing();
```

* Client:
```
send(mailbox, request); reply =
receive(mailbox);
```

* Server:
```
request = receive(mailbox);
    compute reply;
send(mailbox, reply);
```

Background material on rendezvous

two-way flow of information. This object contains a message passing channel shared by them. In the remote case,

An extended rendezvous is also called a ***remote procedure call*** from a client to a server (or a worker to the master) because it resembles (and syntactic sugar can make it nearly identical to) a call to a procedure on a remote machine that is executed there.

Typically the call represents a request for service, such as reading a file that resides on the remote machine. The server may handle the request in its main thread or the server may spawn a new thread to handle the request while the server's main thread handles additional requests for service from other clients. The latter gives greater throughput and efficiency because a lengthy request would otherwise delay the handling of requests from the other clients.

An addressing mechanism is needed so the client can contact an appropriate server. In the local case (everything in the same JVM), an object can be used as the place for the client and server to "meet" and establish a rendezvous. The server calls a method in the object and blocks until the client calls a method.

At this point in time, both methods return a newly created object that the client and server subsequently use for the

name and a TCP/IP port number to address the server; the server "listens" on the TCP/IP port. A client creates an addressing object using the server's machine name and port number in the object's constructor; the server uses just the port number.

When the rendezvous occurs, the object is constructed and returned to both the client and server. In the local case (within the same JVM), the client and server share this object and use it to transact (synchronous message passing of object references).

In the remote case (between JVMs that might be on different physical machines), each gets its own object and the object contains a socket to the other JVM (and machine). Objects are serialized through the socket.

User-written classes

Now let's look at some user-written classes and definitions.

In a ***transaction,*** two threads exchange information synchronously. Class Transaction.java on page 76 is a user-written class used for one such exchange. Coding is as follows:

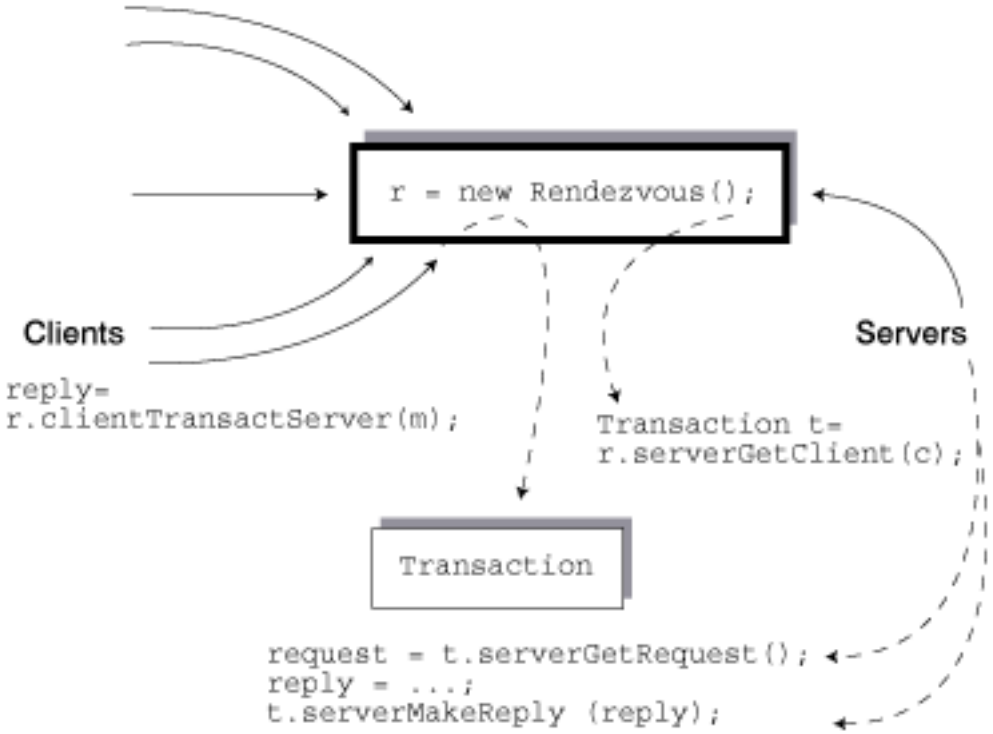
* Created by the client, shared by the client and server:
  Transaction t = new Transaction(request);

* Client:
  reply = t.clientAwaitReply();

* Server:
  request = t.serverGetRequest();
  compute reply;
  t.serverMakeReply(reply);

A ***conditional rendezvous*** builds on the idea of a transaction. It allows the server to specify criteria of whom to rendezvous with next.

The figure below illustrates the concepts of rendezvous. Presented by



(meaning after calling **serverGetClient** to get a client's request Presented by developerWorks, your source for Interface RendezvousCondition.java on page 76 demonstrates the criterion interface.

An object created from Class Rendezvous.java on page 77 is shared by the client and server.

Coding is as follows:

* Shared by the client and server:
  Rendezvous r = new Rendezvous();

* Client:
  reply = r.clientTransactServer(request);

* Server:
  RendezvousCondition c =
  new RendezvousCondition(...); Transaction t =
  r.serverGetClient(c); Object request = t.serverGetRequest();
  Object reply = ...; // compute reply

  t.serverMakeReply(reply);

Multiple servers can share a single **Rendezvous** object.

A server can call **serverGetClient(c) (** a "nested" call) again while in the middle of a transaction with a client

but before calling **serverMakeReply** to reply to that client).

Remote Method Invocation (RMI) on page 98 can be used to implement rendezvous between threads in different JVMs that may also be on different physical machines.

Peer-to-peer programming offers other options.

Class Rendezvous.java on page 77 has four more methods -- **send(m), call(m), receive(c),** and **receive() --** that can be used for asynchronous and synchronous (conditional) message passing among a collection of peer threads.

A receiving peer can specify a condition for messages it is willing to receive, just as can be specified by a server for a rendezvous. To block until the message is received, use **call(m)** instead of **send(m).**

Class SugarRE.java on page 79 provides syntactic sugar so that **send(rn, ms)** can be used instead of **rn.send(ms) (** ditto for **call(ms))** and **mr = receive(rn, rc)** instead of **mr = rn.receive(rc) (** ditto for **receive()).**

Examples of rendezvous

Example of clients and a server include:

* Example dpre.java on page 79 : Rendezvous dining philosophers
* Driver dpdr.java on page 40 : Creates the philosopher threads
* Sample run of dpre.java on page 81 : Displays the sample run

Because the philosophers only need to block until their request is conditionally received by the server and because they are not interested in the reply message, the philosophers use **call** instead of **clientTransactServer.** Similarly, the server uses **receive** instead of **serverGetClient.**

Example pcre.java on page 82 is an example of producer and consumer peers in which a consumer specifies that it receive the message with the smallest value among the yet unreceived messages. A producer can act asynchronously by using **send** or synchronously to find out which consumer got its message by using **clientTransactServer.** Sample run of pcre.java on page 85 is the sample run.

The next several panels contain an exercise and display the code described in this section. To view the exercise and code, click **Next;** or you can go directly to the next section, Remote Method Invocation (RMI) on page 98 , and return to the code samples at another time.

Try this exercise

Consider a bank that makes loans and accepts loan repayments from its customers. Use nested **serverGetClient(c)** calls by the bank server thread to prevent starvation of a customer needing a particularly large loan: the bank accepts only repayments until it has enough funds to make the large loan.

Try implementing the same bank server as a passive monitor object. Which is easier? Presented by

Class Transaction.java

```
public class Transaction {
    // Designed to be used by exactly one client // transacting exactly once with one
    specific server. private Object request = null; private Object reply = null; public
    Transaction (Object m) {


        if (m == null)
            throw new NullPointerException("m == null"); request = m; }


    public synchronized Object clientAwaitReply()
            throws InterruptedException { Object m =
        null; try {

            while (reply == null) wait(); } catch
        (InterruptedException e) {
            // We have been interrupted while waiting for the // server to process our
            request and/or generate // a reply. Since we no longer want the server to //
            process our request, we will null it out. This // means the server must check for
            a null return // value from the serverGetRequest method. If the // request is
            already null at this point, then the // server must have already gotten it. request
            = null; if (reply == null)




                throw new InterruptedException("reply not available"); else

                Thread.currentThread().interrupt(); // reply available }

        m = reply; reply =
      null; return m; }


    public synchronized Object serverGetRequest() {
        Object m = request; request =
      null; return m; }


    public synchronized void serverMakeReply(Object m) {
        if (m == null)
            throw new NullPointerException("m == null"); reply = m;

        notify(); // at most one thread (the client) waiting } }
```

Interface RendezvousCondition.java

```
import java.util.Vector;
public interface RendezvousCondition { /*

 *  The information available to the checkCondition method is:
 *      the particular message being evaluated,
 *          blockedMessages.elementAt(messageNum);
 *      the queue of blocked messages itself, blockedMessages; and
 *      the number of blocked servers, numBlockedServers.
```

```
    *   This is the state of the Rendezvous object. The
    *   particular message can be checked to see if it meets the
    *   condition and this test may involve counting how many
    *   blocked messages meet some other criterion and/or the number
    *   of blocked servers.
    *
    *   We are depending on the programmer not to mess with the
    *   blockedMessages Vector. The Rendezvous object is
    *   graciously making it available, so do not abuse!
    * /
        public abstract boolean checkCondition
            (int messageNum, Vector blockedMessages,
                int numBlockedServers);
}
```

Class Rendezvous.java

```
import java.util.Vector; public final class
Rendezvous {
    private final Vector messages = new Vector(); private final Vector
    transactions = new Vector(); private int numServers = 0;

// An anonymous class whose checkCondition method returns true.
    private RendezvousCondition alwaysTrue =
        new RendezvousCondition() {
            public boolean checkCondition(int messageNum,
                    Vector blockedMessages, int numBlockedServers) { return true; } };



// If there are more waiting servers than messages, then // starvation might occur among the
waiting servers because // no attempt is made to match a message with the longest // waiting
server. On the other hand, messages are checked // for a matching condition in the order the
messages arrive.

    public Rendezvous() { super(); }
// The server calls this method to get the Transaction object to // use with the client. When this
method returns, the server // will do two things with the Transaction return value: invoke //
serverGetRequest() and then invoke serverMakeReply(). // The Transaction object is then discarded
by the server.

    public synchronized Transaction serverGetClient
                (RendezvousCondition condition) throws
          InterruptedException { if (condition == null)

            throw new NullPointerException("null condition"); numServers++;

        Transaction client = null; boolean
        matched = false; try {

            while (true) {
                int numMessages = messages.size(); for (int j = 0; j <
                numMessages; j++) {
    /*
      *   We are running security and protection risks making the
      *   messages Vector available to the outside.
      *   Caveat emptor!
      * /
                    if (condition.checkCondition(j, messages, numServers)) {
                        messages.removeElementAt(j);
                        client = (Transaction) transactions.elementAt(j);
```

```
                        transactions.removeElementAt(j); matched = true;
                    break; } }


                if (matched) return client;
                else wait(); // for another message to arrive }

            } finally {
                // We need to do this if we get a message or if we were // interrupted. numServers--;


                // Since we have changed numServers, we need to force // all servers to check for a
              match again because // numServers is passed to checkCondition(). notifyAll(); } }



// Transact with any waiting client.
    public synchronized Transaction serverGetClient()
            throws InterruptedException { return
      serverGetClient(alwaysTrue); }

// The client calls this method to transact with the server.
    public Object clientTransactServer(Object message)
            throws InterruptedException { return
      put(message, true); }

// The client calls this method indirectly.
    private Object put(Object message, boolean synchronous)
            throws InterruptedException { if (message ==
        null)
            throw new NullPointerException("null message"); Transaction t = new
        Transaction(message); synchronized (this) {

            messages.addElement(message);
          transactions.addElement(t); this.notifyAll(); }


        Object m = null;
        // If not synchronous, the server removes the message // and transaction from their
        vectors. if (synchronous) {

            try { m = t.clientAwaitReply(); }
            finally { // in case interrupted out of waiting
                synchronized (this) {
                    messages.removeElement(message);
                transactions.removeElement(t); } } }



        return m; }

// A peer calls this method to send asynchronously a message // to another peer (using
receive).
    public void send(Object message)
            throws InterruptedException { put(message,
      false); }

// A peer calls this method to send synchronously a message // to another peer.

    public void call(Object message)
            throws InterruptedException { put(message, true); // Discard
      the reply. }
```

```
// A peer calls this method to receive a message conditionally // from another peer.

    public Object receive(RendezvousCondition condition)
            throws InterruptedException { Transaction t = serverGetClient(condition);
        Object m = t.serverGetRequest(); // A kludge just in case receive() is called //
        erroneously when a client is waiting inside t's // clientAwaitReply() inside
        clientTransactServer(); // but really is needed when a client is waiting // inside
        call().



        t.serverMakeReply("Fake reply."); return m; }


// Receive any waiting message.
    public Object receive() throws InterruptedException {
        return receive(alwaysTrue); } }
```

Class SugarRE.java

```
import java.rmi.*;
public abstract class SugarRE extends Sugar { // syntactic sugar for
rendezvous
    protected static final void send(Rendezvous rn, Object o)
        throws InterruptedException { rn.send(o); } protected static final void
    call(Rendezvous rn, Object o)
        throws InterruptedException { rn.call(o); } protected static final Object
    receive(Rendezvous rn,
            RendezvousCondition rc)
        throws InterruptedException { return rn.receive(rc); } protected static final Object
    receive(Rendezvous rn)
        throws InterruptedException { return rn.receive(); } // syntactic sugar for remote
rendezvous
    protected static final void send(RemoteRendezvous rn, Object o)
            throws RemoteException, InterruptedException { rn.send(o); }

    protected static final void call(RemoteRendezvous rn, Object o)
            throws RemoteException, InterruptedException { rn.call(o); }

    protected static final Object receive(RemoteRendezvous rn,
                RendezvousCondition rc)
            throws RemoteException, InterruptedException { return
            rn.receive(rc); }
    protected static final Object receive(RemoteRendezvous rn)
            throws RemoteException, InterruptedException { return rn.receive(); }

}
```

Example dpre.java

```
import java.util.Vector;
class EatCondition implements RendezvousCondition {
    private int numPhils = 0; private int[] state
    = null;
```

```
    private int EATING = -1;
    public EatCondition(int[] state, int EATING) {
        this.state = state; numPhils =
       state.length; this.EATING = EATING; }


    private final int left(int i)
        { return (numPhils + i-1) % numPhils; } private final int
    right(int i)
        { return (i+1) % numPhils; } public boolean
    checkCondition
                    (int messageNum, Vector blockedMessages, int
              numBlockedServers) {
        Object message = blockedMessages.elementAt(messageNum); int id = ((Integer)
        message).intValue(); int size = blockedMessages.size(); // not used if (id < 0) return
        true;
                                                                  // putForks()
        else if (state[left(id)] != EATING
                    && state[right(id)] != EATING) return true;
                                                                  // takeForks()
        else return false; } }


class DiningServer extends SugarRE implements Runnable {
    private int numPhils = 0; private int[] state =
    null; private Rendezvous r = null;

    private static final int THINKING = 0, HUNGRY = 1, EATING = 2; private String name =
    "DiningServer"; private Thread me = null; public DiningServer(int numPhils) {


        this.numPhils = numPhils; state = new
        int[numPhils];
        for (int i = 0; i < numPhils; i++) state[i] = THINKING; r = new Rendezvous();

        (me = new Thread(this)).start(); }

    public void dine(String name, int id, int napEat)
              throws InterruptedException { try {

              takeForks(id); eat(name,
            napEat); } finally {
                                      // Make sure we return the
              putForks(id); // forks if interrupted } }


    private void eat(String name, int napEat)
              throws InterruptedException { int napping;

        napping = 1 + (int) random(napEat); System.out.println("age=" + age() + ",
        " + name
              +   " is eating for " + napping + " ms"); Thread.sleep(napping);
      }

    private void takeForks(int id) throws InterruptedException {
        state[id] = HUNGRY;                                       // not used
        call(r, new Integer(id)); }

    private void putForks(int id) throws InterruptedException {
        if (state[id] != EATING) return; call(r, new
      Integer(-id-1)); }

    public void run() { // makes atomic state changes
        if (Thread.currentThread() != me) return; while (true) {
```

```
if (Thread.interrupted()) {
      System.out.println("age=" + age() + ", " + name
            +   " interrupted"); return; }
  try {


      Object m = receive(r,
            new EatCondition(state, EATING)); if (m != null) {

            int id = ((Integer) m).intValue(); if (id < 0) state[-id-1] =
          THINKING; else state[id] = EATING; } else


            System.out.println("age=" + age() + ", " + name
                  +   " received null request");
} catch (InterruptedException e) {
      System.out.println("age=" + age() + ", " + name
            +   " interrupted out of rendezvous"); return; } } } }
```

Sample run of dpre.java

```
% javac dpre.java dpdr.java % java
DiningPhilosophers 5 6 4 1
DiningPhilosophers: numPhilosophers=5, runTime=6, napThink=4, napEat=1 age=315, Philosopher 0 is
thinking for 3524 ms age=323, Philosopher 1 is thinking for 1910 ms age=325, Philosopher 2 is thinking for
2383 ms age=327, Philosopher 3 is thinking for 1477 ms All Philosopher threads started


age=329, Philosopher 4 is thinking for 3131 ms age=1845, Philosopher 3
wants to dine age=1851, Philosopher 3 is eating for 264 ms age=2127,
Philosopher 3 is thinking for 1336 ms age=2234, Philosopher 1 wants to
dine age=2236, Philosopher 1 is eating for 151 ms age=2405, Philosopher
1 is thinking for 143 ms age=2564, Philosopher 1 wants to dine age=2565,
Philosopher 1 is eating for 680 ms age=2724, Philosopher 2 wants to dine
age=3257, Philosopher 1 is thinking for 1453 ms age=3258, Philosopher 2
is eating for 539 ms age=3475, Philosopher 3 wants to dine age=3476,
Philosopher 4 wants to dine age=3477, Philosopher 4 is eating for 963 ms
age=3805, Philosopher 2 is thinking for 3403 ms age=3854, Philosopher 0
wants to dine age=4458, Philosopher 0 is eating for 367 ms age=4459,
Philosopher 3 is eating for 502 ms age=4459, Philosopher 4 is thinking for
814 ms age=4725, Philosopher 1 wants to dine age=4835, Philosopher 0 is
thinking for 2087 ms age=4836, Philosopher 1 is eating for 689 ms
age=4975, Philosopher 3 is thinking for 1231 ms age=5285, Philosopher 4
wants to dine age=5286, Philosopher 4 is eating for 857 ms age=5535,
Philosopher 1 is thinking for 3514 ms
```

```
age=6155, Philosopher 4 is thinking for 704 ms age=6252, Philosopher 3 wants to
dine age=6253, Philosopher 3 is eating for 618 ms age=6335, time to terminate the
Philosophers and exit age=6337, Philosopher 0 interrupted out of think age=6339,
Philosopher 1 interrupted out of think age=6340, Philosopher 2 interrupted out of
think age=6342, Philosopher 3 interrupted out of dine age=6343, Philosopher 4
interrupted out of think age=7345, all Philosophers are done
```

Example pcre.java

```
import java.util.Vector;
class Producer extends SugarRE implements Runnable {
      private String name = null; private boolean synchronous =
      false; private int pNap = 0; // milliseconds private
      Rendezvous rn = null; private Thread me = null;


      public Producer(String name, boolean synchronous,
                  int pNap, Rendezvous rn) { this.name =
            name;
            this.synchronous = synchronous; this.pNap =
            pNap; this.rn = rn;

            (me = new Thread(this)).start(); }

      public void timeToQuit() { me.interrupt(); } public void pauseTilDone() throws
      InterruptedException
            { me.join(); } public void
      run() {
            if (Thread.currentThread() != me) return; double item; int
            napping; while (true) {


                  if (Thread.interrupted()) {
                        System.out.println("age=" + age() + ", " + name
                              +   " interrupted"); return; }


                  napping = 1 + (int) random(pNap);
                  System.out.println("age=" + age() + ", " + name
                        +   " napping for " + napping + " ms"); try {
                  Thread.sleep(napping); } catch (InterruptedException e) {

                        System.out.println("age=" + age() + ", " + name
                              +   " interrupted from sleep"); return; }


                  item = random();
                  System.out.println("age=" + age() + ", " + name
                        +   " produced item " + item); try {

                        Double d = new Double(item); if
                        (synchronous) {
                              Object reply = rn.clientTransactServer(d); System.out.println("age=" +
                              age() + ", " + name
                                    +   ", reply= " + reply); } else
                        send(rn, d);
                  } catch (InterruptedException e) {
```

```
                    System.out.println("age=" + age() + ", " + name
                        +   " interrupted from send"); return; }


                System.out.println("age=" + age() + ", " + name
                    +   " sent item " + item); } } }



class ConsumerCondition implements RendezvousCondition {
    public ConsumerCondition() { } public boolean
    checkCondition
                    (int messageNum, Vector blockedMessages, int
        numBlockedServers) { int size = blockedMessages.size(); if (size == 1)
        return true; /*


 *   Select the smallest value in the queue.
 * /
          double smallest = ((Double) blockedMessages.elementAt(0)).doubleValue(); int where = 0;

          for (int i = 1; i < size; i++) {
              double d = ((Double) blockedMessages.elementAt(i)).doubleValue(); if (d < smallest) { smallest = d;
            where = i; } }

          if (where == messageNum) return true; else return false; } }



class Consumer extends SugarRE implements Runnable {
    private String name = null; private boolean synchronous =
    false; private int cNap = 0; // milliseconds private
    Rendezvous rn = null; private Thread me = null;


    private RendezvousCondition rc = null; public Consumer(String name,
    boolean synchronous,
            int cNap, Rendezvous rn) { this.name =
        name;
        this.synchronous = synchronous; this.cNap =
        cNap; this.rn = rn;

        rc = new ConsumerCondition(); (me = new
      Thread(this)).start(); }

    public void timeToQuit() { me.interrupt(); } public void pauseTilDone() throws
    InterruptedException
        { me.join(); } public void
    run() {
        if (Thread.currentThread() != me) return; double item; int
        napping; while (true) {


            if (Thread.interrupted()) {
                System.out.println("age=" + age() + ", " + name
                    +   " interrupted"); return; }


            napping = 1 + (int) random(cNap);
            System.out.println("age=" + age() + ", " + name
                +   " napping for " + napping + " ms"); try {
            Thread.sleep(napping); } catch (InterruptedException e) {

                System.out.println("age=" + age() + ", " + name
                    +   " interrupted from sleep");
```

```
            return; }

        System.out.println("age=" + age() + ", " + name
            +   " wants to consume"); try {

            if (synchronous) {
                Transaction t = rn.serverGetClient(rc); Double d = (Double)
                t.serverGetRequest(); if (d != null) {

                    item = d.doubleValue();
                    t.serverMakeReply(name + " got it!"); System.out.println("age=" + age() +
                    ", " + name
                        +   " received item " + item); } else {

                    System.out.println("age=" + age() + ", " + name
                        +   " received null item"); } } else {


                Double d = (Double) receive(rn, rc); if (d != null) {

                    item = d.doubleValue();
                    System.out.println("age=" + age() + ", " + name
                        +   " received item " + item); } else {

                    System.out.println("age=" + age() + ", " + name
                        +   " received null item"); } }


        } catch (InterruptedException e) {
            System.out.println("age=" + age() + ", " + name
                +   " interrupted from receive"); return; } } } }




class ProducersConsumers extends Sugar {
    public static void main(String[] args) {
        boolean synchronous = false; int
        numProducers = 1; int numConsumers = 1;
        int pNap = 2;
                                    // defaults
        int cNap = 2;               // in
        int runTime = 60; // seconds try {

          synchronous = args[0].equals("yes"); numProducers = Integer.parseInt(args[1]);
        numConsumers = Integer.parseInt(args[2]); pNap = Integer.parseInt(args[3]); cNap
        = Integer.parseInt(args[4]); runTime = Integer.parseInt(args[5]); } catch (Exception
        e) { /* use defaults */ } System.out.println("ProducersConsumers:\n synchronous="




          +   synchronous + ", numProducers="
          +   numProducers + ", numConsumers=" + numConsumers
          +   "\n pNap=" + pNap + ", cNap=" + cNap
          +   ", runTime=" + runTime); // create the message passing
        channel Rendezvous rn = new Rendezvous(); // start the
        Producers and Consumers // (they have self-starting threads)
        Producer[] p = new Producer[numProducers]; Consumer[] c = new
        Consumer[numConsumers]; for (int i = 0; i < numProducers; i++)



            p[i] = new Producer("PRODUCER"+i, synchronous, pNap*1000, rn);
```

```
        for (int i = 0; i < numConsumers; i++)
            c[i] = new Consumer("Consumer"+i, synchronous, cNap*1000, rn); System.out.println("All threads
        started"); // let them run for a while try {


            Thread.sleep(runTime*1000);
            System.out.println("age=" + age()
                +   ", time to terminate the threads and exit"); for (int i = 0; i <
            numProducers; i++)
                p[i].timeToQuit();
            for (int i = 0; i < numConsumers; i++)
                c[i].timeToQuit();
            Thread.sleep(1000);
            for (int i = 0; i < numProducers; i++)
                p[i].pauseTilDone();
            for (int i = 0; i < numConsumers; i++)
                c[i].pauseTilDone();
        } catch (InterruptedException e) { /* ignored */ } System.out.println("age=" +
        age()
            +   ", all threads are done"); System.exit(0); }
    }
```

Sample run of pcre.java

```
% javac pcre.java
% java ProducersConsumers yes 1 1 2 2 6
ProducersConsumers:
  synchronous=true, numProducers=1, numConsumers=1 pNap=2, cNap=2,
  runTime=6
age=45, PRODUCER0 napping for 185 ms age=64,
Consumer0 napping for 1202 ms All threads started

age=244, PRODUCER0 produced item 0.15382515179890965 age=1286,
Consumer0 wants to consume age=1289, PRODUCER0, reply= Consumer0 got it!
age=1290, PRODUCER0 sent item 0.15382515179890965 age=1292, PRODUCER0
napping for 745 ms

age=1292, Consumer0 received item 0.15382515179890965 age=1294, Consumer0
napping for 816 ms
age=2046, PRODUCER0 produced item 0.3602103173386145 age=2123,
Consumer0 wants to consume age=2124, PRODUCER0, reply= Consumer0 got it!
age=2125, PRODUCER0 sent item 0.3602103173386145 age=2126, PRODUCER0
napping for 1954 ms

age=2127, Consumer0 received item 0.3602103173386145 age=2128, Consumer0
napping for 313 ms age=2453, Consumer0 wants to consume

age=4096, PRODUCER0 produced item 0.9710857065446037 age=4098,
PRODUCER0, reply= Consumer0 got it! age=4098, PRODUCER0 sent item
0.9710857065446037 age=4099, PRODUCER0 napping for 961 ms

age=4100, Consumer0 received item 0.9710857065446037 age=4101, Consumer0
napping for 1231 ms
age=5075, PRODUCER0 produced item 0.5231916912410289 age=5343,
Consumer0 wants to consume age=5344, PRODUCER0, reply= Consumer0 got it!
age=5345, PRODUCER0 sent item 0.5231916912410289 age=5346, PRODUCER0
napping for 113 ms

age=5347, Consumer0 received item 0.5231916912410289
```

```
age=5348, Consumer0 napping for 661 ms
age=5473, PRODUCER0 produced item 0.5591064157961917 age=6024,
Consumer0 wants to consume age=6025, PRODUCER0, reply= Consumer0 got it!
age=6025, PRODUCER0 sent item 0.5591064157961917 age=6026, PRODUCER0
napping for 153 ms

age=6027, Consumer0 received item 0.5591064157961917 age=6028, Consumer0
napping for 721 ms age=6074, time to terminate the threads and exit age=6077,
Consumer0 interrupted from sleep age=6094, PRODUCER0 interrupted from sleep
age=7084, all threads are done % java ProducersConsumers no 1 1 2 2 6
ProducersConsumers:


  synchronous=false, numProducers=1, numConsumers=1 pNap=2, cNap=2,
  runTime=6
age=47, PRODUCER0 napping for 810 ms age=66,
Consumer0 napping for 48 ms All threads started

age=126, Consumer0 wants to consume
age=875, PRODUCER0 produced item 0.7568324366583216 age=893,
PRODUCER0 sent item 0.7568324366583216 age=894, PRODUCER0 napping for
308 ms
age=896, Consumer0 received item 0.7568324366583216 age=898, Consumer0
napping for 290 ms age=1195, Consumer0 wants to consume

age=1206, PRODUCER0 produced item 0.5312913550562778 age=1207,
PRODUCER0 sent item 0.5312913550562778 age=1208, PRODUCER0 napping for
1326 ms
age=1208, Consumer0 received item 0.5312913550562778 age=1209, Consumer0
napping for 1840 ms age=2548, PRODUCER0 produced item 0.034237591810933
age=2550, PRODUCER0 sent item 0.034237591810933 age=2551, PRODUCER0
napping for 989 ms age=3058, Consumer0 wants to consume


age=3059, Consumer0 received item 0.034237591810933 age=3060, Consumer0
napping for 1558 ms
age=3546, PRODUCER0 produced item 0.6571437055152907 age=3547,
PRODUCER0 sent item 0.6571437055152907 age=3548, PRODUCER0 napping for
1848 ms age=4627, Consumer0 wants to consume

age=4628, Consumer0 received item 0.6571437055152907 age=4629, Consumer0
napping for 1445 ms
age=5406, PRODUCER0 produced item 0.9481282378191348 age=5407,
PRODUCER0 sent item 0.9481282378191348 age=5408, PRODUCER0 napping for
618 ms
age=6036, PRODUCER0 produced item 0.626005963354672 age=6037,
PRODUCER0 sent item 0.626005963354672 age=6038, PRODUCER0 napping for
47 ms age=6076, time to terminate the threads and exit age=6097, PRODUCER0
interrupted from sleep age=6098, Consumer0 interrupted from sleep age=7086,
all threads are done % java ProducersConsumers yes 1 5 2 2 6
ProducersConsumers:


  synchronous=true, numProducers=1, numConsumers=5 pNap=2, cNap=2,
  runTime=6
age=43, PRODUCER0 napping for 1429 ms age=62,
Consumer0 napping for 388 ms age=66, Consumer1
napping for 657 ms age=68, Consumer2 napping for 1679
ms age=70, Consumer3 napping for 495 ms All threads
started

age=73, Consumer4 napping for 1088 ms age=462,
Consumer0 wants to consume
```

**age=571, Consumer3 wants to consume age=731,
Consumer1 wants to consume age=1174, Consumer4
wants to consume
age=1482, PRODUCER0 produced item 0.5470149827381032 age=1501,
PRODUCER0, reply= Consumer0 got it! age=1503, PRODUCER0 sent item
0.5470149827381032 age=1504, PRODUCER0 napping for 847 ms**

**age=1505, Consumer0 received item 0.5470149827381032 age=1506, Consumer0
napping for 4 ms age=1507, Consumer0 wants to consume age=1752, Consumer2
wants to consume**

**age=2364, PRODUCER0 produced item 0.39132362870008386 age=2366,
PRODUCER0, reply= Consumer0 got it! age=2366, PRODUCER0 sent item
0.39132362870008386 age=2368, PRODUCER0 napping for 729 ms**

**age=2368, Consumer0 received item 0.39132362870008386 age=2370, Consumer0
napping for 1825 ms
age=3124, PRODUCER0 produced item 0.9201218658294597 age=3126,
PRODUCER0, reply= Consumer1 got it! age=3127, PRODUCER0 sent item
0.9201218658294597 age=3128, PRODUCER0 napping for 1292 ms**

**age=3129, Consumer1 received item 0.9201218658294597 age=3130, Consumer1
napping for 552 ms age=3692, Consumer1 wants to consume age=4203,
Consumer0 wants to consume**

**age=4432, PRODUCER0 produced item 0.1103752768928924 age=4433,
PRODUCER0, reply= Consumer0 got it! age=4434, PRODUCER0 sent item
0.1103752768928924 age=4435, PRODUCER0 napping for 887 ms**

**age=4436, Consumer0 received item 0.1103752768928924 age=4437, Consumer0
napping for 947 ms
age=5332, PRODUCER0 produced item 0.615086398663721 age=5334,
PRODUCER0, reply= Consumer1 got it! age=5334, PRODUCER0 sent item
0.615086398663721 age=5335, PRODUCER0 napping for 1651 ms age=5336,
Consumer1 received item 0.615086398663721 age=5337, Consumer1 napping for
801 ms age=5392, Consumer0 wants to consume age=6082, time to terminate the
threads and exit age=6085, Consumer0 interrupted from receive age=6087,
Consumer1 interrupted from sleep age=6088, Consumer3 interrupted from
receive age=6089, Consumer2 interrupted from receive age=6091, Consumer4
interrupted from receive age=6102, PRODUCER0 interrupted from sleep
age=7092, all threads are done % java ProducersConsumers no 1 5 2 2 6
ProducersConsumers:**

**synchronous=false, numProducers=1, numConsumers=5 pNap=2, cNap=2,
runTime=6
age=48, PRODUCER0 napping for 295 ms age=77,
Consumer0 napping for 1571 ms age=98, Consumer1
napping for 162 ms age=100, Consumer2 napping for 160
ms age=102, Consumer3 napping for 39 ms All threads
started**

**age=104, Consumer4 napping for 848 ms age=147,
Consumer3 wants to consume age=266, Consumer2 wants
to consume age=276, Consumer1 wants to consume**

**age=357, PRODUCER0 produced item 0.581001917177535 age=374,
PRODUCER0 sent item 0.581001917177535 age=376, PRODUCER0 napping for
1586 ms age=378, Consumer1 received item 0.581001917177535 age=379,
Consumer1 napping for 596 ms**

**age=959, Consumer4 wants to consume age=986,
Consumer1 wants to consume age=1667, Consumer0
wants to consume
age=1969, PRODUCER0 produced item 0.5306153831037835 age=1970,
PRODUCER0 sent item 0.5306153831037835 age=1971, PRODUCER0 napping for
1347 ms
age=1972, Consumer0 received item 0.5306153831037835 age=1973, Consumer0
napping for 636 ms age=2617, Consumer0 wants to consume**

**age=3329, PRODUCER0 produced item 0.2682601940276499 age=3330,
PRODUCER0 sent item 0.2682601940276499 age=3331, PRODUCER0 napping for
241 ms
age=3332, Consumer0 received item 0.2682601940276499 age=3333, Consumer0
napping for 400 ms
age=3587, PRODUCER0 produced item 0.47542284179688665 age=3588,
PRODUCER0 sent item 0.47542284179688665 age=3589, PRODUCER0 napping for
371 ms
age=3590, Consumer3 received item 0.47542284179688665 age=3591, Consumer3
napping for 497 ms age=3736, Consumer0 wants to consume**

**age=3978, PRODUCER0 produced item 0.1426846229950136 age=3979,
PRODUCER0 sent item 0.1426846229950136 age=3980, PRODUCER0 napping for
539 ms
age=3981, Consumer0 received item 0.1426846229950136 age=3982, Consumer0
napping for 1760 ms age=4096, Consumer3 wants to consume**

**age=4527, PRODUCER0 produced item 0.8579208083111102 age=4528,
PRODUCER0 sent item 0.8579208083111102 age=4529, PRODUCER0 napping for
891 ms
age=4530, Consumer2 received item 0.8579208083111102 age=4531, Consumer2
napping for 744 ms age=5287, Consumer2 wants to consume**

**age=5437, PRODUCER0 produced item 0.7190220228546758 age=5438,
PRODUCER0 sent item 0.7190220228546758 age=5439, PRODUCER0 napping for
1192 ms
age=5440, Consumer1 received item 0.7190220228546758 age=5441, Consumer1
napping for 97 ms age=5546, Consumer1 wants to consume age=5746,
Consumer0 wants to consume age=6107, time to terminate the threads and exit
age=6110, Consumer3 interrupted from receive age=6112, Consumer2 interrupted
from receive age=6113, Consumer1 interrupted from receive age=6114,
Consumer4 interrupted from receive age=6127, PRODUCER0 interrupted from
sleep age=6128, Consumer0 interrupted from receive age=7117, all threads are
done % java ProducersConsumers yes 5 1 2 2 6 ProducersConsumers:**

**synchronous=true, numProducers=5, numConsumers=1 pNap=2, cNap=2,
runTime=6
age=46, PRODUCER0 napping for 904 ms age=66,
PRODUCER1 napping for 257 ms age=67, PRODUCER2
napping for 1740 ms age=70, PRODUCER3 napping for
1405 ms age=73, PRODUCER4 napping for 670 ms All
threads started**

**age=76, Consumer0 napping for 1620 ms
age=335, PRODUCER1 produced item 0.17631033059969203 age=745,
PRODUCER4 produced item 0.5982192991443873 age=967, PRODUCER0
produced item 0.346069281928469 age=1485, PRODUCER3 produced item
0.1777369982527307 age=1705, Consumer0 wants to consume age=1708,
PRODUCER1, reply= Consumer0 got it! age=1709, PRODUCER1 sent item
0.17631033059969203**

```
age=1711, PRODUCER1 napping for 1185 ms
age=1712, Consumer0 received item 0.17631033059969203 age=1713, Consumer0
napping for 1381 ms
age=1815, PRODUCER2 produced item 0.11184681708602617 age=2907,
PRODUCER1 produced item 0.03828430977553221 age=3105, Consumer0 wants to
consume age=3106, PRODUCER1, reply= Consumer0 got it! age=3107,
PRODUCER1 sent item 0.03828430977553221 age=3108, PRODUCER1 napping for
1362 ms

age=3108, Consumer0 received item 0.03828430977553221 age=3109, Consumer0
napping for 1281 ms age=4407, Consumer0 wants to consume age=4408,
PRODUCER2, reply= Consumer0 got it! age=4409, PRODUCER2 sent item
0.11184681708602617 age=4410, PRODUCER2 napping for 654 ms


age=4411, Consumer0 received item 0.11184681708602617 age=4412, Consumer0
napping for 1190 ms
age=4485, PRODUCER1 produced item 0.08158951384451485 age=5076,
PRODUCER2 produced item 0.0983728197982997 age=5605, Consumer0 wants to
consume age=5606, PRODUCER1, reply= Consumer0 got it! age=5606,
PRODUCER1 sent item 0.08158951384451485 age=5608, PRODUCER1 napping for
969 ms

age=5608, Consumer0 received item 0.08158951384451485 age=5609, Consumer0
napping for 1542 ms age=6085, time to terminate the threads and exit age=6089,
PRODUCER4 interrupted from send age=6091, PRODUCER3 interrupted from send
age=6092, PRODUCER2 interrupted from send age=6093, PRODUCER1 interrupted
from sleep age=6094, Consumer0 interrupted from sleep age=6105, PRODUCER0
interrupted from send age=7095, all threads are done % java ProducersConsumers
no 5 1 2 2 6 ProducersConsumers:




  synchronous=false, numProducers=5, numConsumers=1 pNap=2, cNap=2,
  runTime=6
age=49, PRODUCER0 napping for 1009 ms age=68,
PRODUCER1 napping for 499 ms age=89, PRODUCER2
napping for 570 ms age=91, PRODUCER3 napping for 676
ms age=94, PRODUCER4 napping for 1718 ms All threads
started

age=97, Consumer0 napping for 1153 ms
age=578, PRODUCER1 produced item 0.654109824432186 age=596,
PRODUCER1 sent item 0.654109824432186 age=597, PRODUCER1 napping for
1240 ms
age=667, PRODUCER2 produced item 0.18068514475674902 age=669,
PRODUCER2 sent item 0.18068514475674902 age=670, PRODUCER2 napping for
589 ms
age=778, PRODUCER3 produced item 0.4102712629046613 age=779,
PRODUCER3 sent item 0.4102712629046613 age=780, PRODUCER3 napping for
1802 ms
age=1070, PRODUCER0 produced item 0.5091696195916051 age=1071,
PRODUCER0 sent item 0.5091696195916051 age=1072, PRODUCER0 napping for
1319 ms
age=1268, PRODUCER2 produced item 0.11994991872131833 age=1269,
PRODUCER2 sent item 0.11994991872131833 age=1270, PRODUCER2 napping for
1459 ms age=1271, Consumer0 wants to consume

age=1274, Consumer0 received item 0.11994991872131833 age=1275, Consumer0
napping for 983 ms
age=1818, PRODUCER4 produced item 0.3179813502495561 age=1819,
PRODUCER4 sent item 0.3179813502495561 age=1820, PRODUCER4 napping for
904 ms
```

age=1848, PRODUCER1 produced item 0.6786836744500554 age=1849, PRODUCER1 sent item 0.6786836744500554 age=1850, PRODUCER1 napping for 584 ms age=2270, Consumer0 wants to consume

age=2271, Consumer0 received item 0.18068514475674902 age=2272, Consumer0 napping for 1020 ms
age=2398, PRODUCER0 produced item 0.6765052327934625 age=2399, PRODUCER0 sent item 0.6765052327934625 age=2400, PRODUCER0 napping for 112 ms
age=2448, PRODUCER1 produced item 0.6087623006574409 age=2449, PRODUCER1 sent item 0.6087623006574409 age=2450, PRODUCER1 napping for 1110 ms
age=2527, PRODUCER0 produced item 0.2943617678806405 age=2529, PRODUCER0 sent item 0.2943617678806405 age=2530, PRODUCER0 napping for 52 ms
age=2597, PRODUCER0 produced item 0.43951489579213454 age=2599, PRODUCER0 sent item 0.43951489579213454 age=2600, PRODUCER0 napping for 1010 ms
age=2601, PRODUCER3 produced item 0.6752658089401261 age=2602, PRODUCER3 sent item 0.6752658089401261 age=2603, PRODUCER3 napping for 1878 ms
age=2738, PRODUCER2 produced item 0.3501856253437148 age=2739, PRODUCER2 sent item 0.3501856253437148 age=2740, PRODUCER2 napping for 163 ms
age=2741, PRODUCER4 produced item 0.08523336769878354 age=2742, PRODUCER4 sent item 0.08523336769878354 age=2743, PRODUCER4 napping for 1810 ms
age=2920, PRODUCER2 produced item 0.13301474356217313 age=2921, PRODUCER2 sent item 0.13301474356217313 age=2922, PRODUCER2 napping for 1163 ms age=3355, Consumer0 wants to consume

age=3357, Consumer0 received item 0.08523336769878354 age=3358, Consumer0 napping for 1003 ms
age=3568, PRODUCER1 produced item 0.7517292199496083 age=3569, PRODUCER1 sent item 0.7517292199496083 age=3570, PRODUCER1 napping for 1800 ms age=3618, PRODUCER0 produced item 0.268743465819824 age=3619, PRODUCER0 sent item 0.268743465819824 age=3620, PRODUCER0 napping for 337 ms

age=3969, PRODUCER0 produced item 0.32319739222576216 age=3970, PRODUCER0 sent item 0.32319739222576216 age=3971, PRODUCER0 napping for 1715 ms
age=4098, PRODUCER2 produced item 0.8618141010061056 age=4099, PRODUCER2 sent item 0.8618141010061056 age=4100, PRODUCER2 napping for 1896 ms age=4377, Consumer0 wants to consume

age=4379, Consumer0 received item 0.13301474356217313 age=4380, Consumer0 napping for 1435 ms
age=4488, PRODUCER3 produced item 0.23912464069393813 age=4489, PRODUCER3 sent item 0.23912464069393813 age=4490, PRODUCER3 napping for 263 ms
age=4558, PRODUCER4 produced item 0.10655946770202618 age=4559, PRODUCER4 sent item 0.10655946770202618 age=4560, PRODUCER4 napping for 924 ms
age=4767, PRODUCER3 produced item 0.12318563460348397 age=4769, PRODUCER3 sent item 0.12318563460348397 age=4770, PRODUCER3 napping for 591 ms
age=5378, PRODUCER1 produced item 0.3722613130125716 age=5379, PRODUCER1 sent item 0.3722613130125716 age=5380, PRODUCER1 napping for 1625 ms
age=5381, PRODUCER3 produced item 0.16025856103329428 age=5382, PRODUCER3 sent item 0.16025856103329428 age=5383, PRODUCER3 napping for 1701 ms age=5498, PRODUCER4 produced item 0.733038334914754 age=5499, PRODUCER4 sent item 0.733038334914754

**age=5500, PRODUCER4 napping for 688 ms
age=5698, PRODUCER0 produced item 0.5541625041131112 age=5699,
PRODUCER0 sent item 0.5541625041131112 age=5700, PRODUCER0 napping for
1411 ms age=5827, Consumer0 wants to consume**

**age=5830, Consumer0 received item 0.10655946770202618 age=5831, Consumer0
napping for 1386 ms
age=6008, PRODUCER2 produced item 0.7258819670653431 age=6009,
PRODUCER2 sent item 0.7258819670653431 age=6010, PRODUCER2 napping for
1982 ms age=6098, time to terminate the threads and exit age=6101, PRODUCER4
interrupted from sleep age=6103, PRODUCER3 interrupted from sleep age=6104,
PRODUCER2 interrupted from sleep age=6105, PRODUCER1 interrupted from
sleep age=6106, Consumer0 interrupted from sleep age=6118, PRODUCER0
interrupted from sleep age=7108, all threads are done % java
ProducersConsumers yes 5 5 2 2 6 ProducersConsumers:**

**synchronous=true, numProducers=5, numConsumers=5 pNap=2, cNap=2,
runTime=6
age=42, PRODUCER0 napping for 1664 ms age=61,
PRODUCER1 napping for 38 ms age=64, PRODUCER2
napping for 1016 ms age=65, PRODUCER3 napping for
1829 ms age=69, PRODUCER4 napping for 60 ms age=72,
Consumer0 napping for 56 ms age=74, Consumer1
napping for 1142 ms age=76, Consumer2 napping for 1969
ms age=78, Consumer3 napping for 1500 ms All threads
started**

**age=81, Consumer4 napping for 25 ms
age=111, PRODUCER1 produced item 0.9185428067197055 age=129, Consumer4
wants to consume age=292, PRODUCER1, reply= Consumer4 got it! age=294,
PRODUCER1 sent item 0.9185428067197055 age=295, PRODUCER1 napping for
914 ms**

**age=296, Consumer4 received item 0.9185428067197055 age=297, Consumer4
napping for 766 ms
age=131, PRODUCER4 produced item 0.08777957250723711 age=190, Consumer0
wants to consume
age=299, Consumer0 received item 0.08777957250723711 age=300, Consumer0
napping for 620 ms age=301, PRODUCER4, reply= Consumer0 got it! age=302,
PRODUCER4 sent item 0.08777957250723711 age=303, PRODUCER4 napping for
1479 ms age=933, Consumer0 wants to consume age=1070, Consumer4 wants to
consume**

**age=1091, PRODUCER2 produced item 0.8940799526535598 age=1092,
PRODUCER2, reply= Consumer4 got it! age=1093, PRODUCER2 sent item
0.8940799526535598 age=1094, PRODUCER2 napping for 87 ms**

**age=1095, Consumer4 received item 0.8940799526535598 age=1096, Consumer4
napping for 1535 ms
age=1190, PRODUCER2 produced item 0.10081751591092203 age=1192,
PRODUCER2, reply= Consumer0 got it! age=1193, PRODUCER2 sent item
0.10081751591092203 age=1194, PRODUCER2 napping for 1821 ms**

**age=1195, Consumer0 received item 0.10081751591092203 age=1196, Consumer0
napping for 1396 ms
age=1221, PRODUCER1 produced item 0.3663133766503859 age=1230,
Consumer1 wants to consume age=1231, PRODUCER1, reply= Consumer1 got it!
age=1232, PRODUCER1 sent item 0.3663133766503859**

**age=1233, PRODUCER1 napping for 918 ms
age=1234, Consumer1 received item 0.3663133766503859 age=1235, Consumer1 napping for 503 ms age=1581, Consumer3 wants to consume**

age=1721, PRODUCER0 produced item 0.16926696419542775 age=1722, PRODUCER0, reply= Consumer3 got it! age=1723, PRODUCER0 sent item 0.16926696419542775 age=1724, PRODUCER0 napping for 1393 ms

age=1725, Consumer3 received item 0.16926696419542775 age=1726, Consumer3 napping for 1382 ms age=1750, Consumer1 wants to consume

age=1791, PRODUCER4 produced item 0.24476649246179505 age=1792, Consumer1 received item 0.24476649246179505 age=1794, Consumer1 napping for 484 ms age=1796, PRODUCER4, reply= Consumer1 got it! age=1798, PRODUCER4 sent item 0.24476649246179505 age=1799, PRODUCER4 napping for 220 ms

age=1903, PRODUCER3 produced item 0.800190863174061 age=2021, PRODUCER4 produced item 0.8202427064995859 age=2051, Consumer2 wants to consume age=2052, PRODUCER3, reply= Consumer2 got it! age=2053, PRODUCER3 sent item 0.800190863174061 age=2054, PRODUCER3 napping for 1756 ms age=2055, Consumer2 received item 0.800190863174061 age=2056, Consumer2 napping for 638 ms

**age=2161, PRODUCER1 produced item 0.9924100353971543 age=2290, Consumer1 wants to consume
age=2291, Consumer1 received item 0.8202427064995859 age=2292, Consumer1 napping for 1935 ms age=2293, PRODUCER4, reply= Consumer1 got it! age=2294, PRODUCER4 sent item 0.8202427064995859 age=2295, PRODUCER4 napping for 816 ms age=2600, Consumer0 wants to consume age=2601, PRODUCER1, reply= Consumer0 got it! age=2602, PRODUCER1 sent item 0.9924100353971543 age=2603, PRODUCER1 napping for 52 ms**

age=2604, Consumer0 received item 0.9924100353971543 age=2605, Consumer0 napping for 203 ms age=2640, Consumer4 wants to consume

age=2670, PRODUCER1 produced item 0.5720839002063113 age=2672, PRODUCER1, reply= Consumer4 got it! age=2673, PRODUCER1 sent item 0.5720839002063113 age=2674, PRODUCER1 napping for 830 ms

age=2674, Consumer4 received item 0.5720839002063113 age=2676, Consumer4 napping for 135 ms age=2700, Consumer2 wants to consume age=2820, Consumer4 wants to consume age=2821, Consumer0 wants to consume

age=3033, PRODUCER2 produced item 0.38032840213175745 age=3034, PRODUCER2, reply= Consumer2 got it! age=3035, PRODUCER2 sent item 0.38032840213175745 age=3036, PRODUCER2 napping for 1095 ms

age=3037, Consumer2 received item 0.38032840213175745 age=3038, Consumer2 napping for 1230 ms age=3120, Consumer3 wants to consume

age=3121, PRODUCER4 produced item 0.9604224841343072 age=3123, Consumer3 received item 0.9604224841343072 age=3124, Consumer3 napping for 1633 ms age=3125, PRODUCER4, reply= Consumer3 got it! age=3125, PRODUCER4 sent item 0.9604224841343072 age=3126, PRODUCER4 napping for 608 ms

age=3131, PRODUCER0 produced item 0.9650427611915405 age=3132, PRODUCER0, reply= Consumer4 got it! age=3133, PRODUCER0 sent item 0.9650427611915405 age=3134, PRODUCER0 napping for 1713 ms

age=3135, Consumer4 received item 0.9650427611915405 age=3136, Consumer4 napping for 307 ms age=3450, Consumer4 wants to consume

age=3511, PRODUCER1 produced item 0.918506532764693 age=3512, PRODUCER1, reply= Consumer4 got it! age=3513, PRODUCER1 sent item 0.918506532764693 age=3514, PRODUCER1 napping for 1238 ms age=3515, Consumer4 received item 0.918506532764693 age=3516, Consumer4 napping for 1264 ms age=3740, PRODUCER4 produced item 0.754027144422452 age=3742, PRODUCER4, reply= Consumer0 got it! age=3743, PRODUCER4 sent item 0.754027144422452 age=3744, PRODUCER4 napping for 1578 ms age=3745, Consumer0 received item 0.754027144422452 age=3746, Consumer0 napping for 208 ms

age=3821, PRODUCER3 produced item 0.27122994909004716 age=3962, Consumer0 wants to consume age=3963, PRODUCER3, reply= Consumer0 got it! age=3964, PRODUCER3 sent item 0.27122994909004716 age=3965, PRODUCER3 napping for 579 ms

age=3966, Consumer0 received item 0.27122994909004716 age=3967, Consumer0 napping for 372 ms
age=4141, PRODUCER2 produced item 0.27589255387330824 age=4240, Consumer1 wants to consume age=4241, PRODUCER2, reply= Consumer1 got it! age=4242, PRODUCER2 sent item 0.27589255387330824 age=4243, PRODUCER2 napping for 1469 ms

age=4244, Consumer1 received item 0.27589255387330824 age=4245, Consumer1 napping for 1952 ms age=4270, Consumer2 wants to consume age=4350, Consumer0 wants to consume

age=4550, PRODUCER3 produced item 0.8619194399545967 age=4552, PRODUCER3, reply= Consumer2 got it! age=4553, PRODUCER3 sent item 0.8619194399545967 age=4554, PRODUCER3 napping for 398 ms

age=4554, Consumer2 received item 0.8619194399545967 age=4556, Consumer2 napping for 472 ms
age=4761, PRODUCER1 produced item 0.7701099520047171 age=4762, PRODUCER1, reply= Consumer0 got it! age=4763, PRODUCER1 sent item 0.7701099520047171 age=4764, PRODUCER1 napping for 1625 ms

age=4765, Consumer0 received item 0.7701099520047171 age=4766, Consumer0 napping for 129 ms age=4771, Consumer3 wants to consume age=4790, Consumer4 wants to consume

age=4861, PRODUCER0 produced item 0.2228435588271499 age=4862, PRODUCER0, reply= Consumer3 got it! age=4863, PRODUCER0 sent item 0.2228435588271499 age=4864, PRODUCER0 napping for 951 ms

age=4864, Consumer3 received item 0.2228435588271499 age=4866, Consumer3 napping for 675 ms age=4900, Consumer0 wants to consume

age=4961, PRODUCER3 produced item 0.6894975962370399 age=4962, PRODUCER3, reply= Consumer4 got it! age=4963, PRODUCER3 sent item 0.6894975962370399 age=4964, PRODUCER3 napping for 743 ms

age=4965, Consumer4 received item 0.6894975962370399 age=4966, Consumer4 napping for 403 ms age=5041, Consumer2 wants to consume

age=5331, PRODUCER4 produced item 0.8065414987883718 age=5332, Consumer2 received item 0.8065414987883718 age=5333, Consumer2 napping for 1824 ms age=5334, PRODUCER4, reply= Consumer2 got it! age=5334, PRODUCER4 sent item 0.8065414987883718 age=5336, PRODUCER4 napping for 1217 ms

**age=5380, Consumer4 wants to consume age=5551,
Consumer3 wants to consume
age=5721, PRODUCER2 produced item 0.9920886064917681 age=5722,
PRODUCER3 produced item 0.903554039796397 age=5723, PRODUCER3, reply=
Consumer3 got it! age=5724, PRODUCER3 sent item 0.903554039796397
age=5725, PRODUCER3 napping for 828 ms**

**age=5726, Consumer3 received item 0.903554039796397 age=5727, Consumer3
napping for 997 ms age=5728, PRODUCER2, reply= Consumer4 got it! age=5729,
PRODUCER2 sent item 0.9920886064917681 age=5730, PRODUCER2 napping for
1454 ms**

**age=5731, Consumer4 received item 0.9920886064917681 age=5732, Consumer4
napping for 1344 ms
age=5831, PRODUCER0 produced item 0.13174758677755616 age=5832,
PRODUCER0, reply= Consumer0 got it! age=5833, PRODUCER0 sent item
0.13174758677755616 age=5834, PRODUCER0 napping for 689 ms**

**age=5835, Consumer0 received item 0.13174758677755616 age=5836, Consumer0
napping for 1170 ms age=6091, time to terminate the threads and exit age=6094,
PRODUCER3 interrupted from sleep age=6096, PRODUCER1 interrupted from sleep
age=6097, PRODUCER2 interrupted from sleep age=6098, Consumer1 interrupted
from sleep age=6099, Consumer2 interrupted from sleep age=6100, Consumer3
interrupted from sleep age=6101, Consumer4 interrupted from sleep age=6103,
PRODUCER4 interrupted from sleep age=6104, Consumer0 interrupted from sleep
age=6111, PRODUCER0 interrupted from sleep age=7101, all threads are done %
java ProducersConsumers no 5 5 2 2 6 ProducersConsumers:**

**synchronous=false, numProducers=5, numConsumers=5 pNap=2, cNap=2,
runTime=6
age=44, PRODUCER0 napping for 1548 ms age=63,
PRODUCER1 napping for 677 ms age=66, PRODUCER2
napping for 1441 ms age=68, PRODUCER3 napping for
1283 ms age=71, PRODUCER4 napping for 435 ms age=74,
Consumer0 napping for 1925 ms age=76, Consumer1
napping for 1681 ms age=78, Consumer2 napping for 1632
ms age=81, Consumer3 napping for 1953 ms All threads
started**

**age=83, Consumer4 napping for 1600 ms
age=513, PRODUCER4 produced item 0.3410400811142391 age=530,
PRODUCER4 sent item 0.3410400811142391 age=532, PRODUCER4 napping for
1 ms
age=532, PRODUCER4 produced item 0.9047856169302597 age=533,
PRODUCER4 sent item 0.9047856169302597 age=534, PRODUCER4 napping for
1025 ms
age=753, PRODUCER1 produced item 0.8843759516570732 age=754,
PRODUCER1 sent item 0.8843759516570732 age=755, PRODUCER1 napping for
357 ms
age=1125, PRODUCER1 produced item 0.19197557779325958 age=1126,
PRODUCER1 sent item 0.19197557779325958 age=1127, PRODUCER1 napping for
491 ms
age=1363, PRODUCER3 produced item 0.830373247233264 age=1364,
PRODUCER3 sent item 0.830373247233264 age=1365, PRODUCER3 napping for
901 ms
age=1523, PRODUCER2 produced item 0.8098838675941346 age=1524,
PRODUCER2 sent item 0.8098838675941346 age=1525, PRODUCER2 napping for
436 ms**

age=1573, PRODUCER4 produced item 0.6027106304058345 age=1574, PRODUCER4 sent item 0.6027106304058345 age=1575, PRODUCER4 napping for 319 ms
age=1603, PRODUCER0 produced item 0.4292486419460507 age=1604, PRODUCER0 sent item 0.4292486419460507 age=1605, PRODUCER0 napping for 325 ms
age=1632, PRODUCER1 produced item 0.5872721123774989 age=1634, PRODUCER1 sent item 0.5872721123774989 age=1635, PRODUCER1 napping for 1474 ms age=1693, Consumer4 wants to consume

age=1695, Consumer4 received item 0.19197557779325958 age=1697, Consumer4 napping for 1939 ms age=1722, Consumer2 wants to consume

age=1723, Consumer2 received item 0.3410400811142391 age=1724, Consumer2 napping for 608 ms age=1772, Consumer1 wants to consume

age=1773, Consumer1 received item 0.4292486419460507 age=1774, Consumer1 napping for 148 ms
age=1905, PRODUCER4 produced item 0.15349615717846132 age=1906, PRODUCER4 sent item 0.15349615717846132 age=1907, PRODUCER4 napping for 974 ms age=1932, Consumer1 wants to consume

age=1933, Consumer1 received item 0.15349615717846132 age=1935, Consumer1 napping for 734 ms
age=1943, PRODUCER0 produced item 0.6143545981931535 age=1944, PRODUCER0 sent item 0.6143545981931535 age=1945, PRODUCER0 napping for 214 ms
age=1973, PRODUCER2 produced item 0.5517125342572194 age=1974, PRODUCER2 sent item 0.5517125342572194 age=1975, PRODUCER2 napping for 105 ms age=2012, Consumer0 wants to consume

age=2014, Consumer0 received item 0.5517125342572194 age=2015, Consumer0 napping for 896 ms age=2042, Consumer3 wants to consume

age=2043, Consumer3 received item 0.5872721123774989 age=2044, Consumer3 napping for 1964 ms
age=2093, PRODUCER2 produced item 0.6032968491632188 age=2094, PRODUCER2 sent item 0.6032968491632188 age=2095, PRODUCER2 napping for 1052 ms age=2173, PRODUCER0 produced item 0.306508087515337 age=2174, PRODUCER0 sent item 0.306508087515337 age=2175, PRODUCER0 napping for 346 ms

age=2283, PRODUCER3 produced item 0.039727663768907906 age=2284, PRODUCER3 sent item 0.039727663768907906 age=2285, PRODUCER3 napping for 1444 ms age=2342, Consumer2 wants to consume

age=2344, Consumer2 received item 0.039727663768907906 age=2345, Consumer2 napping for 32 ms age=2392, Consumer2 wants to consume

age=2393, Consumer2 received item 0.306508087515337 age=2395, Consumer2 napping for 1172 ms
age=2533, PRODUCER0 produced item 0.9501617999455061 age=2534, PRODUCER0 sent item 0.9501617999455061 age=2535, PRODUCER0 napping for 1394 ms age=2682, Consumer1 wants to consume

age=2683, Consumer1 received item 0.6027106304058345 age=2684, Consumer1 napping for 1554 ms
age=2902, PRODUCER4 produced item 0.9917188318473676 age=2903, PRODUCER4 sent item 0.9917188318473676 age=2904, PRODUCER4 napping for 940 ms age=2922, Consumer0 wants to consume

age=2923, Consumer0 received item 0.6032968491632188 age=2924, Consumer0 napping for 1654 ms
age=3123, PRODUCER1 produced item 0.9290907832359444 age=3124, PRODUCER1 sent item 0.9290907832359444

age=3125, PRODUCER1 napping for 897 ms
age=3163, PRODUCER2 produced item 0.7092244510592798 age=3164, PRODUCER2 sent item 0.7092244510592798 age=3165, PRODUCER2 napping for 775 ms age=3583, Consumer2 wants to consume

age=3584, Consumer2 received item 0.6143545981931535 age=3585, Consumer2 napping for 544 ms age=3642, Consumer4 wants to consume

age=3644, Consumer4 received item 0.7092244510592798 age=3645, Consumer4 napping for 371 ms
age=3743, PRODUCER3 produced item 0.09280502991799322 age=3744, PRODUCER3 sent item 0.09280502991799322 age=3745, PRODUCER3 napping for 1858 ms
age=3853, PRODUCER4 produced item 0.7592324485274388 age=3854, PRODUCER4 sent item 0.7592324485274388 age=3855, PRODUCER4 napping for 366 ms
age=3943, PRODUCER0 produced item 0.7209106579261657 age=3944, PRODUCER0 sent item 0.7209106579261657 age=3946, PRODUCER0 napping for 1845 ms
age=3953, PRODUCER2 produced item 0.47272956301074043 age=3954, PRODUCER2 sent item 0.47272956301074043 age=3955, PRODUCER2 napping for 365 ms age=4022, Consumer3 wants to consume

age=4024, Consumer3 received item 0.09280502991799322 age=4025, Consumer3 napping for 142 ms
age=4033, PRODUCER1 produced item 0.3280222480542785 age=4034, PRODUCER1 sent item 0.3280222480542785 age=4035, PRODUCER1 napping for 617 ms age=4035, Consumer4 wants to consume

age=4037, Consumer4 received item 0.3280222480542785 age=4038, Consumer4 napping for 23 ms age=4072, Consumer4 wants to consume

age=4074, Consumer4 received item 0.47272956301074043 age=4075, Consumer4 napping for 1886 ms age=4142, Consumer2 wants to consume

age=4144, Consumer2 received item 0.7209106579261657 age=4145, Consumer2 napping for 245 ms age=4182, Consumer3 wants to consume

age=4184, Consumer3 received item 0.7592324485274388 age=4185, Consumer3 napping for 1482 ms
age=4233, PRODUCER4 produced item 0.9186461316635379 age=4234, PRODUCER4 sent item 0.9186461316635379 age=4235, PRODUCER4 napping for 138 ms age=4252, Consumer1 wants to consume

age=4253, Consumer1 received item 0.8098838675941346 age=4254, Consumer1 napping for 601 ms
age=4333, PRODUCER2 produced item 0.35806399650517884 age=4334, PRODUCER2 sent item 0.35806399650517884 age=4335, PRODUCER2 napping for 166 ms
age=4383, PRODUCER4 produced item 0.2058488238208972 age=4384, PRODUCER4 sent item 0.2058488238208972 age=4385, PRODUCER4 napping for 1147 ms age=4402, Consumer2 wants to consume

age=4404, Consumer2 received item 0.2058488238208972 age=4405, Consumer2 napping for 1199 ms
age=4513, PRODUCER2 produced item 0.5743572081217496 age=4514, PRODUCER2 sent item 0.5743572081217496 age=4515, PRODUCER2 napping for 1721 ms age=4593, Consumer0 wants to consume

age=4594, Consumer0 received item 0.35806399650517884 age=4595, Consumer0 napping for 1554 ms
age=4663, PRODUCER1 produced item 0.2768196943978283 age=4664, PRODUCER1 sent item 0.2768196943978283 age=4665, PRODUCER1 napping for 1674 ms age=4872, Consumer1 wants to consume

age=4874, Consumer1 received item 0.2768196943978283 age=4875, Consumer1 napping for 17 ms age=4902, Consumer1 wants to consume

age=4903, Consumer1 received item 0.5743572081217496 age=4905, Consumer1 napping for 8 ms age=4923, Consumer1 wants to consume

age=4923, Consumer1 received item 0.830373247233264 age=4924, Consumer1 napping for 20 ms age=4952, Consumer1 wants to consume

age=4953, Consumer1 received item 0.8843759516570732 age=4954, Consumer1 napping for 361 ms age=5332, Consumer1 wants to consume

age=5333, Consumer1 received item 0.9047856169302597 age=5334, Consumer1 napping for 613 ms
age=5543, PRODUCER4 produced item 0.6109297009381629 age=5544, PRODUCER4 sent item 0.6109297009381629 age=5545, PRODUCER4 napping for 1325 ms age=5613, PRODUCER3 produced item 0.874675354317203 age=5614, PRODUCER3 sent item 0.874675354317203 age=5615, PRODUCER3 napping for 664 ms age=5615, Consumer2 wants to consume

age=5616, Consumer2 received item 0.6109297009381629 age=5617, Consumer2 napping for 1072 ms age=5682, Consumer3 wants to consume

age=5683, Consumer3 received item 0.874675354317203 age=5684, Consumer3 napping for 474 ms
age=5804, PRODUCER0 produced item 0.1782579961776114 age=5806, PRODUCER0 sent item 0.1782579961776114 age=5808, PRODUCER0 napping for 640 ms age=5963, Consumer1 wants to consume

age=5963, Consumer1 received item 0.1782579961776114 age=5965, Consumer1 napping for 1642 ms age=5972, Consumer4 wants to consume

age=5973, Consumer4 received item 0.9186461316635379 age=5974, Consumer4 napping for 891 ms age=6093, time to terminate the threads and exit age=6096, PRODUCER4 interrupted from sleep age=6098, Consumer0 interrupted from sleep age=6099, Consumer1 interrupted from sleep age=6100, Consumer4 interrupted from sleep age=6101, Consumer3 interrupted from sleep age=6103, Consumer2 interrupted from sleep age=6113, PRODUCER0 interrupted from sleep age=6114, PRODUCER1 interrupted from sleep age=6115, PRODUCER2 interrupted from sleep age=6116, PRODUCER3 interrupted from sleep age=7103, all threads are done

Section 12. Remote Method Invocation (RMI) Some definitions

RMI is a Java package (java.rmi) used to make *remote procedure calls.*

RMI allows a thread in one JVM to invoke a method in an object in another JVM that is perhaps on a different computer.

Object serialization is used to send an object from one JVM to another as an argument of a remote method invocation. This converts an object into a byte stream that is sent through a socket and converted into a copy of the object on the other end. A new thread is created in the remote object to execute the called method's code.

Example Compute.java on page 99 shows several clients accessing a remote server executing in a different JVM, which can be on a different physical machine. Sample run of Compute.java server on page 102 shows the sample server output; Sample run of Compute.java clients on page 105 shows the sample client output.

Notice that the sample output shows the clients' remote method invocations are interleaved -that is, overlapping executions by new threads created in the server for each RMI. There are no race conditions or synchronization problems in this example because the clients are independent and do not share any data.
the remote method and the method's return results, if any, are passed from one JVM to the other using object

In the sample run, the clients all execute in one JVM and the server in another JVM. Both JVMs are on the same physical machine. If the clients are on a different physical machine, pass the name of the machine on which the server runs as a command-line argument when starting the clients.

RMI can be used by a thread in one JVM to send a message to or rendezvous with a thread in another JVM. A thread willing to receive or rendezvous registers an interface that other threads can use and implements the interface using a message passing or rendezvous object.

Presumably the server is running on a computer architecture that can perform the work more efficiently. Parameters to

Background material on RMI

RMI, or remote method invocation, is the ability to make remote procedure calls. We use "remote procedure calls" to describe an extended rendezvous between two threads in different JVMs, perhaps on different physical machines.

Sun's RMI allows a thread in one JVM to invoke (call) a method in an object in another JVM that is perhaps on a different physical machine. A new thread is created in the other (remote) JVM to execute the called method.

The ComputeServer remote object implements a Compute interface containing a compute() method that a local Client can call, passing a Work object whose doWork() method the server calls. The client is using the remote server to have work performed on its behalf (adding vectors).

network.

User-written classes

Rendezvous client and server classes for RMI include:

* Interface RemoteRendezvous.java on page 107
* Class RemoteRendezvousClient.java on page 108 . Used by client or peer
* Class RemoteRendezvousServer.java on page 109 . Used by server or peer

Examples of RMI

Rendezvous Example Transact.java on page 110 -- Several clients access a remote server executing in a different JVM, which can be on a different physical machine. Server and client output is in Sample run of Transact.java server on page 113 and Sample run of Transact.java clients on page 114 .

Multiple clients transact (read and write operations) with a database on a remote server. The transactions are serialized to avoid race conditions on the shared database maintained by the server. Also, the server gives client number zero highest priority by always handling its transaction first among those waiting to be performed.

In the sample run, the clients all execute in one JVM and the server in another JVM. Both JVMs are on the same physical machine. If the clients are on a different physical machine, pass the name of the machine on which the server runs as a command-line argument when starting the clients.

Message passing Example Ring.java on page 115 -- Several peers are arranged in a circular ring. Each ring member executes in its own JVM and the ring members need not all be on the same physical machine. A single token object is passed around the ring from each member to its successor. These are the sample outputs (Sample run of Ring.java ring member 0 on page 119 , Sample run of Ring.java ring member 1 on page 120 , and Sample run of Ring.java ring member 2 on page 121) in a three-member ring.

In the sample run, the three ring members execute in different JVMs, all on the same physical machine. If the JVMs are on different physical machines, give each ring member on its command line the machine name of its successor. Each physical machine running one or more ring member JVMs needs to be executing one instance of **rmiregistry,** started either manually or internally by one of the ring members on that machine.

The next several panels display the code described in this section. To view the code, click **Next;** or you can go directly to the next section, Wrapup on page 122 , and return to the code samples at another time.

Example Compute.java

```
import java.io.Serializable; import java.rmi.*;

import java.rmi.server.UnicastRemoteObject;
```

```
import java.rmi.registry.*;
public interface Compute extends Remote {
    public static final String SERVER_NAME = "ComputeServer"; public static final String
    SERVER_MACHINE = "localhost"; public static final int SERVER_PORT = 8989; public
    static final int RUN_TIME = 20; public abstract Work compute(Work w)


        throws RemoteException, InterruptedException; }

class Work extends Sugar implements Serializable {
    private final int N = 3; private String name
    = null;
    private double[] a = null, b = null, c = null; private boolean performed =
    false; public Work(String name) {

        this.name = name;
        a = new double[N]; b = new double[N]; c = new double[N]; for (int i = 0; i < N; i++) {

            a[i] = random(-N, N); b[i] = random(-N, N); } }


    public void doWork() throws InterruptedException {
        // sleep to simulate some computation time
       Thread.sleep(1+(int)random(1000*N)); for (int i = 0; i < N; i++) c[i] = a[i] +
       b[i]; performed = true; }


    public String toString() {
        String value = "\n" + name; value +=
        "\na=";
        for (int i = 0; i < N; i++) value += " " + a[i]; value += "\nb=";

        for (int i = 0; i < N; i++) value += " " + b[i]; if (performed) {

            value += "\nc=";
            for (int i = 0; i < N; i++) value += " " + c[i]; }

        return value; } }


class ComputeServer extends UnicastRemoteObject
        implements Compute {
    public ComputeServer() throws RemoteException { } public Work
    compute(Work w)
            throws RemoteException, InterruptedException { System.out.println(SERVER_NAME + " " +
        Thread.currentThread()
            +   " got work request:" + w);
        w.doWork();
        System.out.println(SERVER_NAME + " " + Thread.currentThread()
            +   " sending reply:" + w); return w; }


    public static void main(String args[]) {
        int serverPort = Compute.SERVER_PORT; int runTime =
        Compute.RUN_TIME; // seconds try {

            serverPort = Integer.parseInt(args[0]); runTime =
          Integer.parseInt(args[1]); } catch (Exception e) { /* use defaults */ }

        System.out.println("Server: serverMachine=" + SERVER_MACHINE
            +   ", serverName=" + SERVER_NAME + ", serverPort="
            +   serverPort + ", runTime=" + runTime); // create a registry and
        register this server try {

            Registry registry = LocateRegistry.createRegistry(serverPort);
```

```
            ComputeServer server = new ComputeServer();
          registry.bind(SERVER_NAME, server); } catch (Exception e) {

            System.err.println(SERVER_NAME + " exception " + e); System.exit(1); }


      System.out.println("server " + SERVER_NAME
            +   " has been created and bound in the registry"); try {

            Thread.sleep((runTime+10)*1000);
      } catch (InterruptedException e) { /* ignored */ } System.out.println("time to terminate the
 Server and exit"); System.exit(0); } }



class Client extends Sugar implements Runnable {
      private String name = null; private int id =
      -1;
      private Compute server = null; private int
      napTime = 0; private Thread me = null;

      private Client(int id, Compute server, int napTime) {
            this.name = "Client " + id; this.id = id;

            this.server = server; this.napTime = napTime; (me
         = new Thread(this)).start(); }


      public void timeToQuit() { me.interrupt(); } public void pauseTilDone() throws
      InterruptedException
            { me.join(); } public void
      run() {
            int napping; Work w =
            null;
            if (Thread.currentThread() != me) return; while (true) {

                  if (Thread.interrupted()) {
                        System.out.println("age=" + age() + ", " + name
                              +   " interrupted"); return; }


                  napping = 1 + (int) random(napTime); try {

                        Thread.sleep(napping); } catch
                  (InterruptedException e) {
                        System.out.println("age=" + age() + ", " + name
                              +   " interrupted out of sleep"); return; }


                  w = new Work(name);
                  System.out.println("age=" + age() + ", "
                        +   name + " sending to server work:" + w); try {

                        w = server.compute(w); } catch
                  (Exception e) {
                        System.err.println("Client exception " + e); return; }


                  System.out.println("age=" + age() + ", "
                        +   name + " received from server reply:" + w); } }


      public static void main(String[] args) {
            String serverName = Compute.SERVER_NAME; String serverMachine =
            Compute.SERVER_MACHINE;
```

```
        int serverPort = Compute.SERVER_PORT; int numClients
        = 3; int napTime = 4;
                                                        // both in
        int runTime = Compute.RUN_TIME; // seconds try {

            serverMachine = args[0]; serverName
            = args[1];
            serverPort = Integer.parseInt(args[2]); numClients = Integer.parseInt(args[3]); napTime =
          Integer.parseInt(args[4]); runTime = Integer.parseInt(args[5]); } catch (Exception e) { /* use
          defaults */ } System.out.println("Client: serverMachine=" + serverMachine



            +   ", serverName=" + serverName + ", serverPort=" + serverPort
            +   "\n numClients=" + numClients + ", napTime=" + napTime
            +   ", runTime=" + runTime); Compute
        server = null; try {

            server = (Compute)
                Naming.lookup("rmi://" + serverMachine + ":"
                    +   serverPort + "/" + serverName);
        } catch (Exception e) {
            System.err.println("Client exception " + e); System.exit(1); }


        Client[] c = new Client[numClients]; for (int i = 0; i <
        numClients; i++)
            c[i] = new Client(i, server, 1000*napTime); System.out.println("All Client
        threads started"); // let the Clients run for a while try {


            Thread.sleep(runTime*1000);
            System.out.println("age=" + age()
                +   ", time to terminate the Clients and exit"); for (int i = 0; i < numClients;
            i++)
                c[i].timeToQuit();
            Thread.sleep(1000);
            for (int i = 0; i < numClients; i++)
                c[i].pauseTilDone();
        } catch (InterruptedException e) { /* ignored */ } System.out.println("age=" +
        age()
            +   ", all Clients are done"); System.exit(0); }
    }


/* ..... To run: machineA% javac
Compute.java machineA% rmic ComputeServer
machineA% java ComputeServer &

machineA% rsh machineB "java Client machineA"
* /
```

Sample run of Compute.java server

```
% javac Compute.java % rmic
ComputeServer % java
ComputeServer &
Server: serverMachine=localhost, serverName=ComputeServer, serverPort=8989, runTime=20 server ComputeServer has been created
and bound in the registry
ComputeServer Thread[TCP Connection(4)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    got work request:
```

```
Client 2
a= -2.6956833547799772 2.7056242913415076 1.5467036159966847 b= 0.9272845052351353
2.375308405708611 1.7315712879212102
ComputeServer Thread[TCP Connection(5)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    got work request: Client 1

a= 2.198285066955644 1.1014851982887102 2.1195367406109042 b= -2.40242980205884
-0.2716969010229877 1.7543779582559216
ComputeServer Thread[TCP Connection(4)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    sending reply: Client 2

a= -2.6956833547799772 2.7056242913415076 1.5467036159966847 b= 0.9272845052351353
2.375308405708611 1.7315712879212102 c= -1.768398849544842 5.080932697050119
3.278274903917895
ComputeServer Thread[TCP Connection(6)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    got work request: Client 0

a= 1.1018592459170318 2.998499863398912 -2.2753431857554913 b= 1.60740034099687
2.4918661638800934 -0.35813980483005325
ComputeServer Thread[TCP Connection(5)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    sending reply: Client 1

a= 2.198285066955644 1.1014851982887102 2.1195367406109042 b= -2.40242980205884
-0.2716969010229877 1.7543779582559216 c= -0.20414473510319597 0.8297882972657225
3.873914698866826
ComputeServer Thread[TCP Connection(5)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    got work request: Client 2

a= -0.8261092470419777 0.721414082931692 -0.42645707078792716 b= -0.5302742195582928
0.8483683515941847 -1.0025008898402417
ComputeServer Thread[TCP Connection(6)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    sending reply: Client 0

a= 1.1018592459170318 2.998499863398912 -2.2753431857554913 b= 1.60740034099687
2.4918661638800934 -0.35813980483005325 c= 2.709259586913902 5.490366027279006
-2.6334829905855446
ComputeServer Thread[TCP Connection(5)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    sending reply: Client 2

a= -0.8261092470419777 0.721414082931692 -0.42645707078792716 b= -0.5302742195582928
0.8483683515941847 -1.0025008898402417 c= -1.3563834666002705 1.5697824345258766
-1.4289579606281688
ComputeServer Thread[TCP Connection(5)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    got work request: Client 2

a= -0.10302907032858588 2.122280172623806 -2.972889012811118 b= -2.1063144034959604
1.2484700810438456 -0.34516873732456776
ComputeServer Thread[TCP Connection(5)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    sending reply: Client 2

a= -0.10302907032858588 2.122280172623806 -2.972889012811118 b= -2.1063144034959604
1.2484700810438456 -0.34516873732456776 c= -2.2093434738245463 3.3707502536676515
-3.3180577501356856
ComputeServer Thread[TCP Connection(5)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    got work request: Client 1

a= 1.8732549025182514 1.6775852683316153 -1.3943090135761338 b= 0.4459518118556396
0.010579789697764852 -2.106450761604641
ComputeServer Thread[TCP Connection(6)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    got work request: Client 0

a= -2.8410081979322523 2.5649645745053986 -0.026610740169620506 b= 0.7851856936449471
0.616151284898736 -2.9907779217992445
ComputeServer Thread[TCP Connection(4)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    got work request:
```

```
Client 2
a= -1.5686083274058547 1.9379634892476183 0.7979989612913752 b= -2.4602035559398168
2.111407097419087 -0.13995152334940153
ComputeServer Thread[TCP Connection(4)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    sending reply: Client 2

a= -1.5686083274058547 1.9379634892476183 0.7979989612913752 b= -2.4602035559398168
2.111407097419087 -0.13995152334940153 c= -4.028811883345671 4.049370586666705
0.6580474379419736
ComputeServer Thread[TCP Connection(6)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    sending reply: Client 0

a= -2.8410081979322523 2.5649645745053986 -0.026610740169620506 b= 0.7851856936449471
0.616151284898736 -2.9907779217992445 c= -2.0558225042873053 3.1811158594041347
-3.017388661968865
ComputeServer Thread[TCP Connection(5)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    sending reply: Client 1

a= 1.8732549025182514 1.6775852683316153 -1.3943090135761338 b= 0.4459518118556396
0.010579789697764852 -2.106450761604641 c= 2.319206714373891 1.68816505802938
-3.5007597751807746
ComputeServer Thread[TCP Connection(5)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    got work request: Client 1

a= 1.13032496867271 1.7356634369443213 -1.039424286223417 b= 1.6589595605000858
-2.2151755327196945 -2.2322555512103297
ComputeServer Thread[TCP Connection(5)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    sending reply: Client 1

a= 1.13032496867271 1.7356634369443213 -1.039424286223417 b= 1.6589595605000858
-2.2151755327196945 -2.2322555512103297 c= 2.7892845291727957 -0.4795120957753731
-3.271679837433747
ComputeServer Thread[TCP Connection(5)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    got work request: Client 0

a= -0.27919433374176084 -1.6389486800885282 0.49400802045625003 b= -1.0951363826810552
-1.7985257452276389 1.0206951985241437
ComputeServer Thread[TCP Connection(5)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    sending reply: Client 0

a= -0.27919433374176084 -1.6389486800885282 0.49400802045625003 b= -1.0951363826810552
-1.7985257452276389 1.0206951985241437 c= -1.374330716422816 -3.437474425316167
1.5147032189803937
ComputeServer Thread[TCP Connection(5)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    got work request: Client 2

a= -2.657830948742076 0.9247497273131033 -1.1837878935327522 b= -0.7360974998678449
-2.5187722515825985 1.3749770142429956
ComputeServer Thread[TCP Connection(5)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    sending reply: Client 2

a= -2.657830948742076 0.9247497273131033 -1.1837878935327522 b= -0.7360974998678449
-2.5187722515825985 1.3749770142429956 c= -3.393928448609921 -1.5940225242694952
0.1911891207102434
ComputeServer Thread[TCP Connection(5)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    got work request: Client 0

a= 1.4082232953660423 -0.9931870973853112 1.3910761385634984 b= -2.889407167103009
-0.7824050505085749 2.903892793441319
ComputeServer Thread[TCP Connection(6)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    got work request: Client 1

a= -0.955428681740063 -2.5673385086416904 -2.780364026600216 b= -1.8793447696742414
-1.1507818551369844 2.7499555247812895
ComputeServer Thread[TCP Connection(6)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
```

```
    sending reply: Client 1

a= -0.955428681740063 -2.5673385086416904 -2.780364026600216 b= -1.8793447696742414
-1.1507818551369844 2.7499555247812895 c= -2.8347734514143044 -3.7181203637786746
-0.030408501818926403
ComputeServer Thread[TCP Connection(5)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    sending reply: Client 0

a= 1.4082232953660423 -0.9931870973853112 1.3910761385634984 b= -2.889407167103009
-0.7824050505085749 2.903892793441319 c= -1.4811838717369668 -1.775592147893886
4.294968932004817
ComputeServer Thread[TCP Connection(5)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    got work request: Client 2

a= 1.9275748750871307 -1.585790045655693 -0.5744877856676425 b= -1.6055158235742573
-2.439632153002778 -1.8423081956633163
ComputeServer Thread[TCP Connection(5)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    sending reply: Client 2

a= 1.9275748750871307 -1.585790045655693 -0.5744877856676425 b= -1.6055158235742573
-2.439632153002778 -1.8423081956633163 c= 0.3220590515128734 -4.025422198658471
-2.4167959813309587
ComputeServer Thread[TCP Connection(5)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    got work request: Client 1

a= -2.0501067221742413 -0.8359759895038006 2.8004561794994416 b= 0.3434141542833764
1.5887901295117377 1.613726707462031
ComputeServer Thread[TCP Connection(6)-barry.popesteen.org/134.210.51.61,5,RMI runtime]
    got work request: Client 0

a= 2.6637065224520526 2.744898828042219 2.6241017194381673 b= -2.120103401814829
2.031211204287832 -0.6996379517312672 time to terminate the Server and exit
```

Sample run of Compute.java clients

```
% java Client
Client: serverMachine=localhost, serverName=ComputeServer, serverPort=8989 numClients=3, napTime=4,
 runTime=20 All Client threads started

age=2755, Client 2 sending to server work: Client 2

a= -2.6956833547799772 2.7056242913415076 1.5467036159966847 b= 0.9272845052351353
2.375308405708611 1.7315712879212102 age=2848, Client 1 sending to server work: Client 1


a= 2.198285066955644 1.1014851982887102 2.1195367406109042 b= -2.40242980205884
-0.2716969010229877 1.7543779582559216 age=3918, Client 0 sending to server work: Client 0


a= 1.1018592459170318 2.998499863398912 -2.2753431857554913 b= 1.60740034099687
2.4918661638800934 -0.3581398048300 5325 age=4362, Client 2 received from server reply:
Client 2

a= -2.6956833547799772 2.7056242913415076 1.5467036159966847 b= 0.9272845052351353
2.375308405708611 1.7315712879212102 c= -1.768398849544842 5.080932697050119
3.278274903917895 age=4423, Client 1 received from server reply: Client 1


a= 2.198285066955644 1.1014851982887102 2.1195367406109042 b= -2.40242980205884
-0.2716969010229877 1.7543779582559216
```

c= -0.20414473510319597 0.8297882972657225 3.873914698866826 age=4941, Client 2 sending to server work: Client 2

a= -0.8261092470419777 0.721414082931692 -0.42645707078792716 b= -0.5302742195582928 0.8483683515941847 -1.0025008898402417 age=5193, Client 0 received from server reply: Client 0

a= 1.1018592459170318 2.998499863398912 -2.2753431857554913 b= 1.60740034099687 2.4918661638800934 -0.35813980483005325 c= 2.709259586913902 5.490366027279006 -2.6334829905855446 age=5223, Client 2 received from server reply: Client 2

a= -0.8261092470419777 0.721414082931692 -0.42645707078792716 b= -0.5302742195582928 0.8483683515941847 -1.0025008898402417 c= -1.3563834666002705 1.5697824345258766 -1.4289579606281688 age=5912, Client 2 sending to server work: Client 2

a= -0.10302907032858588 2.122280172623806 -2.972889012811118 b= -2.1063144034959604 1.2484700810438456 -0.34516873732456776 age=8254, Client 2 received from server reply: Client 2

a= -0.10302907032858588 2.122280172623806 -2.972889012811118 b= -2.1063144034959604 1.2484700810438456 -0.34516873732456776 c= -2.2093434738245463 3.3707502536676515 -3.3180577501356856 age=8431, Client 1 sending to server work: Client 1

a= 1.8732549025182514 1.6775852683316153 -1.3943090135761338 b= 0.4459518118556396 0.010579789697764852 -2.106450761604641 age=8521, Client 0 sending to server work: Client 0

a= -2.8410081979322523 2.5649645745053986 -0.026610740169620506 b= 0.7851856936449471 0.616151284898736 -2.9907779217992445 age=8621, Client 2 sending to server work: Client 2

a= -1.5686083274058547 1.9379634892476183 0.7979989612913752 b= -2.4602035559398168 2.111407097419087 -0.13995152334940153 age=10054, Client 2 received from server reply: Client 2

a= -1.5686083274058547 1.9379634892476183 0.7979989612913752 b= -2.4602035559398168 2.111407097419087 -0.13995152334940153 c= -4.028811883345671 4.049370586666705 0.6580474379419736 age=10343, Client 0 received from server reply: Client 0

a= -2.8410081979322523 2.5649645745053986 -0.026610740169620506 b= 0.7851856936449471 0.616151284898736 -2.9907779217992445 c= -2.0558225042873053 3.1811158594041347 -3.017388661968865 age=11144, Client 1 received from server reply: Client 1

a= 1.8732549025182514 1.6775852683316153 -1.3943090135761338 b= 0.4459518118556396 0.010579789697764852 -2.106450761604641 c= 2.319206714373891 1.68816505802938 -3.5007597751807746 age=11591, Client 1 sending to server work: Client 1

a= 1.13032496867271 1.7356634369443213 -1.039424286223417 b= 1.6589595605000858 -2.2151755327196945 -2.2322555512103297 age=12303, Client 1 received from server reply: Client 1

a= 1.13032496867271 1.7356634369443213 -1.039424286223417 b= 1.6589595605000858 -2.2151755327196945 -2.2322555512103297 c= 2.7892845291727957 -0.4795120957753731 -3.271679837433747 age=12431, Client 0 sending to server work: Client 0

a= -0.27919433374176084 -1.6389486800885282 0.49400802045625003 b= -1.0951363826810552 -1.7985257452276389 1.0206951985241437 age=12709, Client 0 received from server reply:

```
Client 0
a= -0.27919433374176084 -1.6389486800885282 0.49400802045625003 b= -1.0951363826810552
-1.7985257452276389 1.0206951985241437 c= -1.374330716422816 -3.437474425316167
1.5147032189803937 age=12802, Client 2 sending to server work: Client 2


a= -2.657830948742076 0.9247497273131033 -1.1837878935327522 b= -0.7360974998678449
-2.5187722515825985 1.3749770142429956 age=14454, Client 2 received from server reply: Client
2

a= -2.657830948742076 0.9247497273131033 -1.1837878935327522 b= -0.7360974998678449
-2.5187722515825985 1.3749770142429956 c= -3.393928448609921 -1.5940225242694952
0.1911891207102434 age=15061, Client 0 sending to server work: Client 0


a= 1.4082232953660423 -0.9931870973853112 1.3910761385634984 b= -2.889407167103009
-0.7824050505085749 2.903892793441319 age=15711, Client 1 sending to server work: Client 1


a= -0.955428681740063 -2.5673385086416904 -2.780364026600216 b= -1.8793447696742414
-1.1507818551369844 2.7499555247812895 age=16123, Client 1 received from server reply: Client
1

a= -0.955428681740063 -2.5673385086416904 -2.780364026600216 b= -1.8793447696742414
-1.1507818551369844 2.7499555247812895 c= -2.8347734514143044 -3.7181203637786746
-0.030408501818926403 age=17493, Client 0 received from server reply: Client 0


a= 1.4082232953660423 -0.9931870973853112 1.3910761385634984 b= -2.889407167103009
-0.7824050505085749 2.903892793441319 c= -1.4811838717369668 -1.775592147893886
4.294968932004817 age=17761, Client 2 sending to server work: Client 2


a= 1.9275748750871307 -1.585790045655693 -0.5744877856676425 b= -1.6055158235742573
-2.439632153002778 -1.8423081956633163 age=18914, Client 2 received from server reply: Client
2

a= 1.9275748750871307 -1.585790045655693 -0.5744877856676425 b= -1.6055158235742573
-2.439632153002778 -1.8423081956633163 c= 0.3220590515128734 -4.025422198658471
-2.4167959813309587 age=19181, Client 1 sending to server work: Client 1


a= -2.0501067221742413 -0.8359759895038006 2.8004561794994416 b= 0.3434141542833764
1.5887901295117377 1.613726707462031 age=19621, Client 0 sending to server work: Client 0


a= 2.6637065224520526 2.744898828042219 2.6241017194381673 b= -2.120103401814829
2.031211204287832 -0.6996379517312672 age=20771, time to terminate the Clients and exit
age=20773, Client 2 interrupted out of sleep age=21781, all Clients are done
```

Interface RemoteRendezvous.java

```
import java.rmi.*;
public interface RemoteRendezvous extends Remote {
      public abstract Transaction serverGetClient
                        (RendezvousCondition condition) throws RemoteException,
            InterruptedException; public abstract Transaction serverGetClient()

                  throws RemoteException, InterruptedException;
```

```
    public abstract Object clientTransactServer(Object message)
            throws RemoteException, InterruptedException; public abstract void
    send(Object message)
            throws RemoteException, InterruptedException; public abstract void
    call(Object message)
            throws RemoteException, InterruptedException; public abstract Object
    receive(RendezvousCondition condition)
            throws RemoteException, InterruptedException; public abstract Object
    receive()
            throws RemoteException, InterruptedException;
}
```

Class RemoteRendezvousClient.java

```
import java.rmi.*;
import java.rmi.registry.*;
public class RemoteRendezvousClient implements RemoteRendezvous {
    private RemoteRendezvous server = null; public
    RemoteRendezvousClient(String serverName,
            String serverMachine, int serverPort)
            throws NotBoundException, UnknownHostException, RemoteException { Registry registry = null;

        System.out.println("RemoteRendezvousClient: calling getRegistry("
            +   serverMachine + "," + serverPort + ")"); if (serverPort > 0)

            registry = LocateRegistry.getRegistry(serverMachine, serverPort); else

            registry = LocateRegistry.getRegistry(serverMachine);
        System.out.println("RemoteRendezvousClient: getRegistry("
            +   serverMachine + "," + serverPort + ") called");
        System.out.println("RemoteRendezvousClient: calling lookup("
            +   serverName + ")");
        server = (RemoteRendezvous) registry.lookup(serverName);
        System.out.println("RemoteRendezvousClient: lookup("
            +   serverName + ") called"); }

    public RemoteRendezvousClient(String serverName, String serverMachine)
            throws NotBoundException, UnknownHostException, RemoteException { this(serverName,
      serverMachine, 0); }

    public Transaction serverGetClient
                (RendezvousCondition condition) throws RemoteException,
        InterruptedException { return server.serverGetClient(condition); }


    public Transaction serverGetClient()
            throws RemoteException, InterruptedException { return
      server.serverGetClient(); }

    public Object clientTransactServer(Object message)
            throws RemoteException, InterruptedException { return
      server.clientTransactServer(message); }

    public void send(Object message)
            throws RemoteException, InterruptedException { server.send(message);
      }

    public void call(Object message)
            throws RemoteException, InterruptedException { server.call(message); }
```

```
    public Object receive(RendezvousCondition condition)
            throws RemoteException, InterruptedException { return
       server.receive(condition); }

    public Object receive()
            throws RemoteException, InterruptedException { return server.receive();
    } }
```

Class RemoteRendezvousServer.java

```
import java.rmi.*;
import java.rmi.registry.*;
import java.rmi.server.UnicastRemoteObject; import
java.rmi.server.ExportException;
public class RemoteRendezvousServer extends UnicastRemoteObject
        implements RemoteRendezvous { private
    Rendezvous local = null;
    public RemoteRendezvousServer(String serverName, int serverPort)
            throws RemoteException, AccessException, AlreadyBoundException { super();

        local = new Rendezvous(); Registry
        registry = null; try {

            // See if a registry already exists.
            System.out.println("RemoteRendezvousServer: calling createRegistry("
                +   serverPort + ")"); if
            (serverPort > 0)
                registry = LocateRegistry.createRegistry(serverPort); else

                registry = LocateRegistry.createRegistry(Registry.REGISTRY_PORT);
            System.out.println("RemoteRendezvousServer: createRegistry("
                +   serverPort + ") called"); } catch
        (ExportException e) {
            System.out.println("ExportException: A regsitry already exists.");
            System.out.println("RemoteRendezvousServer: calling getRegistry("
                +   serverPort + ")"); if
            (serverPort > 0)
                registry = LocateRegistry.getRegistry(serverPort); else

                registry = LocateRegistry.getRegistry();
            System.out.println("RemoteRendezvousServer: getRegistry("
                +   serverPort + ") called"); }

        System.out.println("RemoteRendezvousServer: calling bind("
            +   serverName + ")");
        registry.bind(serverName, this);
        System.out.println("RemoteRendezvousServer: bind("
            +   serverName + ") called"); }

    public RemoteRendezvousServer(String serverName)
            throws RemoteException, AccessException, AlreadyBoundException { this(serverName, 0); }


    public Transaction serverGetClient
                (RendezvousCondition condition) throws RemoteException,
        InterruptedException { return local.serverGetClient(condition); }


    public Transaction serverGetClient()
```

```
            throws RemoteException, InterruptedException { return
        local.serverGetClient(); }

    public Object clientTransactServer(Object message)
            throws RemoteException, InterruptedException { return
        local.clientTransactServer(message); }

    public void send(Object message)
            throws RemoteException, InterruptedException { local.send(message); }


    public void call(Object message)
            throws RemoteException, InterruptedException { local.call(message); }


    public Object receive(RendezvousCondition condition)
            throws RemoteException, InterruptedException { return
        local.receive(condition); }

    public Object receive()
            throws RemoteException, InterruptedException { return local.receive(); }
    }
```

Example Transact.java

```
import java.util.Vector; import
java.io.Serializable; import java.rmi.*; public
class Transact {

    public static final String SERVER_NAME = "TransactServer"; public static final String
    SERVER_MACHINE = "localhost"; public static final int SERVER_PORT = 8989; public static
    final int RUN_TIME = 20; }


class Request extends Sugar implements Serializable {
    private String name = null; private int time;

    private int performed = 0;
    public Request(String name, int time) {
        this.name = name;
      this.time = time; }

    public void doRequest() throws InterruptedException {
        System.out.println("age=" + age() + ", performing:" + this); performed = 1+(int)random(time); //
        sleep to simulate some transaction time Thread.sleep(performed);


        System.out.println("age=" + age() + ", performed:" + this); }

    public String getName() { return name; } public String toString()
    {
        return "\n" + name + ", " + time + ", " + performed; } }


class ServerCondition implements RendezvousCondition {
    public ServerCondition() { } public boolean
    checkCondition
                (int messageNum, Vector blockedMessages, int
            numBlockedServers) {
```

```
        Object message = blockedMessages.elementAt(messageNum); String client =
      ((Request) message).getName(); if (client.equals("Client 0")) return true; int size =
      blockedMessages.size(); /*


 *    If "Client 0" is not anywhere in the queue, then rendezvous
 *    with any client.
 * /
        for (int i = 0; i < size; i++) {
            message = blockedMessages.elementAt(i); client = ((Request)
          message).getName(); if (client.equals("Client 0")) return false; }


        return true; } }


class TransactServer extends SugarRE implements Runnable {
    private String serverName = null; private RemoteRendezvousServer
    rend = null; private ServerCondition sc = null; private Thread me =
    null;

    public TransactServer(String serverName, int serverPort)
            throws AlreadyBoundException, AccessException, RemoteException { this.serverName =
        serverName;
        rend = new RemoteRendezvousServer(serverName, serverPort); sc = new
      ServerCondition(); (me = new Thread(this)).start(); }


    public void run() {
        if (Thread.currentThread() != me) return; while (true) {

            if (Thread.interrupted()) {
                System.out.println("age=" + age() + ", " + serverName
                    +   " interrupted"); return; }
              try {


                Transaction t = rend.serverGetClient(sc); Object m =
                t.serverGetRequest(); if (m != null) {

                    ((Request) m).doRequest();
                    t.serverMakeReply(m);
                } else
                    System.out.println(serverName + " got null request"); } catch (RemoteException e) {

                System.out.println("age=" + age() + ", " + serverName
                    +   " rendezvous remote exception");
                e.printStackTrace();
            } catch (InterruptedException e) {
                System.out.println("age=" + age() + ", " + serverName
                    +   " interrupted out of rendezvous"); return; } } }



    public static void main(String args[]) {
        String serverName = Transact.SERVER_NAME; String serverMachine =
        Transact.SERVER_MACHINE; int serverPort = Transact.SERVER_PORT;
        int runTime = Transact.RUN_TIME; // seconds try {


            serverPort = Integer.parseInt(args[0]); runTime = Integer.parseInt(args[1]); } catch
          (Exception e) { /* use defaults */ } System.out.println("Server: serverMachine=" +
          serverMachine
```

```
            +   ", serverName=" + serverName + ", serverPort="
            +   serverPort + ", runTime=" + runTime); try {

            TransactServer server = new TransactServer(serverName, serverPort); } catch (Exception e) {

            System.err.println(serverName + " exception " + e);
            e.printStackTrace();
          System.exit(1); }

        System.out.println("age=" + age() + ", " + serverName
            +   " has been created and bound in the registry"); try {

            Thread.sleep((runTime+10)*1000);
        } catch (InterruptedException e) { /* ignored */ } System.out.println("age=" + age() +
        ", " + serverName
            +   ", time to terminate and exit"); System.exit(0); } }


class Client extends SugarRE implements Runnable {
    private String name = null; private int id =
    -1;
    private RemoteRendezvousClient rend = null; private int napTime =
    0; private Thread me = null;

    private Client(int id, RemoteRendezvousClient rend, int napTime) {
        this.name = "Client " + id; this.id = id; this.rend =
       rend; this.napTime = napTime; (me = new
       Thread(this)).start(); }



    public void timeToQuit() { me.interrupt(); } public void pauseTilDone() throws
    InterruptedException
        { me.join(); } public void
    run() {
        int napping; Request r =
        null;
        if (Thread.currentThread() != me) return; while (true) {

            if (Thread.interrupted()) {
                System.out.println("age=" + age() + ", " + name
                    +   " interrupted"); return; }


            napping = 1 + (int) random(napTime); try {

                Thread.sleep(napping); } catch
            (InterruptedException e) {
                System.out.println("age=" + age() + ", " + name
                    +   " interrupted out of sleep"); return; }


            r = new Request(name, napTime); System.out.println("age=" +
            age() + ", "
                +   name + " sending to server request:" + r); try {

                r = (Request) rend.clientTransactServer(r); } catch (Exception e) {

                System.err.println("Client exception " + e);
                e.printStackTrace(); return; }


            System.out.println("age=" + age() + ", "
                +   name + " received from server reply:" + r);
```

```
        }
    }
    public static void main(String[] args) {
        String serverName = Transact.SERVER_NAME; String serverMachine =
        Transact.SERVER_MACHINE; int serverPort = Transact.SERVER_PORT;
        int numClients = 3; int napTime = 4;

                                                                // both in
        int runTime = Transact.RUN_TIME; // seconds try {

            serverMachine = args[0]; serverName
            = args[1];
            serverPort = Integer.parseInt(args[2]); numClients = Integer.parseInt(args[3]); napTime =
           Integer.parseInt(args[4]); runTime = Integer.parseInt(args[5]); } catch (Exception e) { /* use
           defaults */ } System.out.println("Client: serverMachine=" + serverMachine



            +   ", serverName=" + serverName + ", serverPort=" + serverPort
            +   "\n numClients=" + numClients + ", napTime=" + napTime
            +   ", runTime=" + runTime);
        RemoteRendezvousClient rend = null; try {

            rend = new RemoteRendezvousClient(serverName,
                serverMachine, serverPort); } catch
        (Exception e) {
            System.err.println("Client exception " + e);
            e.printStackTrace();
          System.exit(1); }

        Client[] c = new Client[numClients]; for (int i = 0; i <
        numClients; i++)
            c[i] = new Client(i, rend, 1000*napTime); System.out.println("All Client
        threads started"); // let the Clients run for a while try {


            Thread.sleep(runTime*1000);
            System.out.println("age=" + age()
                +   ", time to terminate the Clients and exit"); for (int i = 0; i < numClients;
            i++)
                c[i].timeToQuit();
            Thread.sleep(1000);
            for (int i = 0; i < numClients; i++)
                c[i].pauseTilDone();
        } catch (InterruptedException e) { /* ignored */ } System.out.println("age=" +
        age()
            +   ", all Clients are done"); System.exit(0); }
    }


/* ..... To run: machineA% javac Transact.java
machineA% rmic RemoteRendezvousServer machineA%
java TransactServer &

machineA% rsh machineB "java Client machineA"
* /
```

Sample run of Transact.java server

```
% javac Transact.java % rmic
RemoteRendezvousServer
```

```
% java TransactServer &
Server: serverMachine=localhost, serverName=TransactServer, serverPort=8989, runTime=20 RemoteRendezvousServer: calling
createRegistry(8989) RemoteRendezvousServer: createRegistry(8989) called RemoteRendezvousServer: calling bind(TransactServer)
RemoteRendezvousServer: bind(TransactServer) called age=247, TransactServer has been created and bound in the registry age=11737,
performing: Client 1, 4000, 0 age=13946, performed: Client 1, 4000, 2194 age=13948, performing: Client 0, 4000, 0 age=16815, performed:
Client 0, 4000, 2852 age=16816, performing: Client 2, 4000, 0 age=19025, performed: Client 2, 4000, 2193 age=19026, performing: Client 1,
4000, 0 age=21025, performed: Client 1, 4000, 1983 age=21026, performing: Client 0, 4000, 0 age=22675, performed: Client 0, 4000, 1637
age=22676, performing: Client 2, 4000, 0 age=25345, performed: Client 2, 4000, 2658 age=25346, performing: Client 1, 4000, 0 age=26055,
performed: Client 1, 4000, 700 age=26211, performing: Client 2, 4000, 0 age=26607, performed: Client 2, 4000, 367 age=26619, performing
Client 0, 4000, 0 age=29055, performed: Client 0, 4000, 2427 age=29201, performing: Client 1, 4000, 0

age=30255, TransactServer, time to terminate and exit
```

Sample run of Transact.java clients

```
% java Client
Client: serverMachine=localhost, serverName=TransactServer, serverPort=8989 numClients=3, napTime=4,
  runTime=20
RemoteRendezvousClient: calling getRegistry(localhost,8989) RemoteRendezvousClient:
getRegistry(localhost,8989) called RemoteRendezvousClient: calling lookup(TransactServer)
RemoteRendezvousClient: lookup(TransactServer) called All Client threads started


age=1654, Client 1 sending to server request: Client 1, 4000, 0

age=1850, Client 2 sending to server request: Client 2, 4000, 0
```

```
age=2832, Client 0 sending to server request: Client 0, 4000, 0

age=3908, Client 1 received from server reply: Client 1, 4000, 2194

age=6121, Client 1 sending to server request: Client 1, 4000, 0

age=6776, Client 0 received from server reply: Client 0, 4000, 2852

age=8986, Client 2 received from server reply: Client 2, 4000, 2193

age=9101, Client 0 sending to server request: Client 0, 4000, 0

age=10860, Client 2 sending to server request: Client 2, 4000, 0

age=10986, Client 1 received from server reply: Client 1, 4000, 1983

age=12636, Client 0 received from server reply: Client 0, 4000, 1637

age=13310, Client 1 sending to server request: Client 1, 4000, 0

age=15306, Client 2 received from server reply: Client 2, 4000, 2658

age=16015, Client 1 received from server reply: Client 1, 4000, 700

age=16160, Client 2 sending to server request: Client 2, 4000, 0

age=16430, Client 0 sending to server request: Client 0, 4000, 0

age=16570, Client 2 received from server reply: Client 2, 4000, 367

age=19015, Client 0 received from server reply: Client 0, 4000, 2427

age=19150, Client 1 sending to server request: Client 1, 4000, 0

age=20080, Client 2 sending to server request: Client 2, 4000, 0

age=20290, Client 0 sending to server request: Client 0, 4000, 0

age=20730, time to terminate the Clients and exit age=21740, all Clients are
done
```

Example Ring.java

```
import java.io.Serializable; import java.rmi.*;
public class Ring {

    public static final String RING_NAME = "RingMember"; public static final String
  RING_MACHINE = "localhost"; }

class Token implements Serializable {
    private int value = 0; private String owner =
    null;
    public Token(String o, int v) { owner = o; value = v; } public String getOwner() { return
    owner; } public int getValue() { return value; } public void setOwner(String o) { owner = o;
    } public void setValue(int v) { value = v; } public String toString() {


        return "\n Token: owner=" + owner + ", value=" + value; } }
```

```
class RingMember extends SugarRE implements Runnable {
    private RemoteRendezvousServer channel = null; private String name =
    null; private int id = 0;

    private RemoteRendezvousClient successor = null; private String
    successorMachine = null; private String successorName = null; private int
    napTime = 0;
                                                    // seconds
    private Thread me = null;
    public RingMember(int d, String i, String m, String n, int t)
            throws AlreadyBoundException, AccessException, RemoteException { id = d; name = i;


        successorMachine = m;
        successorName = n; napTime = t;

        channel = new RemoteRendezvousServer(name); }

    private void start() { (me = new Thread(this)).start(); } public void timeToQuit() {
    me.interrupt(); } public void pauseTilDone() throws InterruptedException

        { me.join(); } public void
    run() {
        Token t = null;
        if (Thread.currentThread() != me) return;
        System.out.println("age=" + age() + ", " + name + " go!"); if (id == 0) {

            // Special case: create the token and pause // for all other ring
            members to initialize // and register themselves. try {


                Thread.sleep(5000); // Yes, this is a kludge! } catch (InterruptedException
            e) { } try {

                successor =
                    new RemoteRendezvousClient(successorName, successorMachine);
                System.out.println("age=" + age() + ", " + name
                    +   ", successor looked up"); } catch
            (Exception e) {
                System.err.println("age=" + age() + ", " + name
                    +   ", successor exception " + e);
                e.printStackTrace(); return; }


            t = new Token(name, 1000);
            System.out.println("age=" + age() + ", " + name
                +   " creating initial token" + t); try {

                send(successor, t); } catch
            (Exception e) {
                System.err.println("age=" + age() + ", " + name
                    +   ", initial token exception " + e);
                e.printStackTrace(); return; }


            System.out.println("age=" + age() + ", " + name
                +   " passed initial token to successor " + successorName); while (true) {

                if (Thread.interrupted()) {
                    System.out.println("age=" + age() + ", " + name
                        +   " interrupted in run"); return; }


                t = null; try {
```

```
            t = (Token) receive(channel); } catch
        (RemoteException e) {
            System.out.println("age=" + age() + ", " + name
                +   " rendezvous remote exception");
            e.printStackTrace();
        } catch (InterruptedException e) {
            System.out.println("age=" + age() + ", " + name
                +   " interrupted in receive"); return; }


        int napping = 1 + (int) (Math.random()*1000*napTime); System.out.println("age=" +
        age() + ", " + name
            +   " sleeping for " + napping
            +   " ms after receiving token" + t); try {

            Thread.sleep(napping); } catch
        (InterruptedException e) {
            System.out.println("age=" + age() + ", " + name
                +   " interrupted in sleep"); return; }


        t.setOwner(name); t.setValue(t.getValue()+1); System.out.println("age=" +
        age() + ", " + name
            +   " passing token" + t); try {

            send(successor, t); } catch
        (Exception e) {
            System.err.println("age=" + age() + ", " + name
                +   ", pass exception " + e);
            e.printStackTrace(); return; }


        System.out.println("age=" + age() + ", " + name
            +   " token passed to successor " + successorName); } } else {


    // Everybody else waits to get the token before passing it on. while (true) {

        if (Thread.interrupted()) {
            System.out.println("age=" + age() + ", " + name
                +   " interrupted in run"); return; }


        t = null; try {

            t = (Token) receive(channel); } catch
        (RemoteException e) {
            System.out.println("age=" + age() + ", " + name
                +   ", rendezvous remote exception");
            e.printStackTrace();
        } catch (InterruptedException e) {
            System.out.println("age=" + age() + ", " + name
                +   " interrupted in receive"); return; }


        int napping = 1 + (int) (Math.random()*1000*napTime); System.out.println("age=" +
        age() + ", " + name
            +   " sleeping for " + napping
            +   " ms after receiving token" + t); try {

            Thread.sleep(napping); } catch
        (InterruptedException e) {
            System.out.println("age=" + age() + ", " + name
                +   " interrupted in sleep"); return;
```

```
                }
                t.setOwner(name); t.setValue(t.getValue()+1); System.out.println("age=" +
                age() + ", " + name
                    +   " passing token" + t); if (successor
                == null) {
                    // Don't do this until you get the token from // your predecessor to make
                    sure your successor // is registered try {


                        successor = new
                            RemoteRendezvousClient(successorName, successorMachine);
                        System.out.println("age=" + age() + ", " + name
                            +   ", successor looked up"); } catch
                    (Exception e) {
                        System.err.println("age=" + age() + ", " + name
                            +   ", successor exception " + e);
                        e.printStackTrace(); return; } }
                   try {



                    send(successor, t); } catch
                (Exception e) {
                    System.err.println("age=" + age() + ", " + name
                        +   ", pass exception " + e);
                    e.printStackTrace(); return; }


                System.out.println("age=" + age() + ", " + name
                    +   " token passed to successor " + successorName); } } }



public static void main(String args[]) {
    int id = 0;
    int successorId = 1;
    String successorMachine = Ring.RING_MACHINE; String myMachine
    = Ring.RING_MACHINE; int napTime = 4;
                                        // both in
    int runTime = 30;                   // seconds
    try {
        id = Integer.parseInt(args[0]); successorId =
        Integer.parseInt(args[1]); successorMachine = args[2];
        myMachine = args[3];

        napTime = Integer.parseInt(args[4]); runTime =
      Integer.parseInt(args[5]); } catch (Exception e) { /* use defaults */ }
      String name = Ring.RING_NAME + id;

    String successorName = Ring.RING_NAME + successorId;
    System.out.println("age=" + age() + ", " + name
        +   "\n id = " + id
        +   "\n successor machine = " + successorMachine
        +   "\n successor name = " + successorName); RingMember
    member = null; try {

        member = new RingMember(id, name, successorMachine,
            successorName, napTime); } catch
    (Exception e) {
        System.err.println("age=" + age() + ", " + name
            +   ", exception " + e);
        e.printStackTrace();
       System.exit(1); }

    System.out.println("age=" + age() + ", " + name
```

```
            +   " has been created and bound in the registry"); member.start(); try {


            Thread.sleep(1000*runTime);
            System.out.println("age=" + age() + ", " + name
                    +   ", time to terminate and exit");
            member.timeToQuit(); Thread.sleep(1000);
            member.pauseTilDone();

        } catch (InterruptedException e) { /* ignored */ } System.exit(0); } }



/* ..... To run: machineA% javac
Ring.java
machineA% rmic RemoteRendezvousServer machineA%
rsh machineC "rmiregistry &"
machineA% rsh machineC "java RingMember 2 0 machineA &" machineA% rsh
machineB "rmiregistry &"
machineA% rsh machineB "java RingMember 1 2 machineC &" machineA% rmiregistry
&
machineA% java RingMember 0 1 machineB &
* /
```

Sample run of Ring.java ring member 0

```
% javac Ring.java
% rmic RemoteRendezvousServer % java
RingMember 0 1 age=10, RingMember0

    id = 0
    successor machine = localhost successor
    name = RingMember1
RemoteRendezvousServer: calling createRegistry(0) RemoteRendezvousServer: createRegistry(0)
called RemoteRendezvousServer: calling bind(RingMember0) RemoteRendezvousServer:
bind(RingMember0) called age=600, RingMember0 has been created and bound in the registry
age=610, RingMember0 go!


RemoteRendezvousClient: calling getRegistry(localhost,0) RemoteRendezvousClient:
getRegistry(localhost,0) called RemoteRendezvousClient: calling lookup(RingMember1)
RemoteRendezvousClient: lookup(RingMember1) called age=5655, RingMember0,
successor looked up age=5658, RingMember0 creating initial token


      Token: owner=RingMember0, value=1000
age=5694, RingMember0 passed initial token to successor RingMember1 age=9451, RingMember0
sleeping for 21 ms after receiving token
      Token: owner=RingMember2, value=1002 age=9486,
RingMember0 passing token
      Token: owner=RingMember0, value=1003
age=9493, RingMember0 token passed to successor RingMember1 age=13681, RingMember0
sleeping for 490 ms after receiving token
      Token: owner=RingMember2, value=1005 age=14175,
RingMember0 passing token
      Token: owner=RingMember0, value=1006
age=14182, RingMember0 token passed to successor RingMember1 age=20491, RingMember0
sleeping for 321 ms after receiving token
      Token: owner=RingMember2, value=1008 age=20825,
RingMember0 passing token
      Token: owner=RingMember0, value=1009
```

```
age=20832, RingMember0 token passed to successor RingMember1 age=24211, RingMember0
sleeping for 2132 ms after receiving token
      Token: owner=RingMember2, value=1011 age=26355,
RingMember0 passing token
      Token: owner=RingMember0, value=1012
age=26362, RingMember0 token passed to successor RingMember1 age=29581, RingMember0
sleeping for 3991 ms after receiving token
      Token: owner=RingMember2, value=1014 age=30615, RingMember0, time
to terminate and exit age=30618, RingMember0 interrupted in sleep
```

Sample run of Ring.java ring member 1

```
% java RingMember 1 2 & age=10,
RingMember1
    id = 1
    successor machine = localhost successor
    name = RingMember2
RemoteRendezvousServer: calling createRegistry(0) ExportException: A
regsitry already exists. RemoteRendezvousServer: calling getRegistry(0)
RemoteRendezvousServer: getRegistry(0) called RemoteRendezvousServer:
calling bind(RingMember1) RemoteRendezvousServer: bind(RingMember1)
called

age=1838, RingMember1 has been created and bound in the registry age=1844, RingMember1 go!

age=5782, RingMember1 sleeping for 2703 ms after receiving token
      Token: owner=RingMember0, value=1000 age=8502,
RingMember1 passing token
      Token: owner=RingMember1, value=1001
RemoteRendezvousClient: calling getRegistry(localhost,0) RemoteRendezvousClient:
getRegistry(localhost,0) called RemoteRendezvousClient: calling lookup(RingMember2)
RemoteRendezvousClient: lookup(RingMember2) called age=8709, RingMember1,
successor looked up

age=8747, RingMember1 token passed to successor RingMember2 age=9571, RingMember1
sleeping for 183 ms after receiving token
      Token: owner=RingMember0, value=1003 age=9771,
RingMember1 passing token
      Token: owner=RingMember1, value=1004
age=9783, RingMember1 token passed to successor RingMember2 age=14258, RingMember1 sleeping
for 3099 ms after receiving token
      Token: owner=RingMember0, value=1006 age=17370,
RingMember1 passing token
      Token: owner=RingMember1, value=1007
age=17379, RingMember1 token passed to successor RingMember2 age=20908, RingMember1
sleeping for 1294 ms after receiving token
      Token: owner=RingMember0, value=1009 age=22210,
RingMember1 passing token
      Token: owner=RingMember1, value=1010
age=22219, RingMember1 token passed to successor RingMember2 age=26438, RingMember1
sleeping for 1491 ms after receiving token
      Token: owner=RingMember0, value=1012 age=27950,
RingMember1 passing token
      Token: owner=RingMember1, value=1013
age=27958, RingMember1 token passed to successor RingMember2 age=31850, RingMember1,
time to terminate and exit age=31857, RingMember1 interrupted in receive
```

Sample run of Ring.java ring member 2

```
% java RingMember 2 0 & age=10,
RingMember2
    id = 2
    successor machine = localhost successor
    name = RingMember0
RemoteRendezvousServer: calling createRegistry(0) ExportException: A
regsitry already exists. RemoteRendezvousServer: calling getRegistry(0)
RemoteRendezvousServer: getRegistry(0) called RemoteRendezvousServer:
calling bind(RingMember2) RemoteRendezvousServer: bind(RingMember2)
called

age=1964, RingMember2 has been created and bound in the registry age=2024, RingMember2 go!

age=8926, RingMember2 sleeping for 474 ms after receiving token
      Token: owner=RingMember1, value=1001 age=9413,
RingMember2 passing token
      Token: owner=RingMember2, value=1002
RemoteRendezvousClient: calling getRegistry(localhost,0) RemoteRendezvousClient:
getRegistry(localhost,0) called RemoteRendezvousClient: calling lookup(RingMember0)
RemoteRendezvousClient: lookup(RingMember0) called age=9689, RingMember2,
successor looked up

age=9712, RingMember2 token passed to successor RingMember0 age=9963, RingMember2 sleeping
for 3952 ms after receiving token
      Token: owner=RingMember1, value=1004 age=13933,
RingMember2 passing token
      Token: owner=RingMember2, value=1005
age=13942, RingMember2 token passed to successor RingMember0 age=17559, RingMember2
sleeping for 3179 ms after receiving token
      Token: owner=RingMember1, value=1007 age=20743,
RingMember2 passing token
      Token: owner=RingMember2, value=1008
age=20752, RingMember2 token passed to successor RingMember0 age=22400, RingMember2
sleeping for 2053 ms after receiving token
      Token: owner=RingMember1, value=1010 age=24463,
RingMember2 passing token
      Token: owner=RingMember2, value=1011
age=24472, RingMember2 token passed to successor RingMember0 age=28139, RingMember2
sleeping for 1687 ms after receiving token
      Token: owner=RingMember1, value=1013 age=29833,
RingMember2 passing token
      Token: owner=RingMember2, value=1014
age=29842, RingMember2 token passed to successor RingMember0 age=32035, RingMember2,
time to terminate and exit age=32038, RingMember2 interrupted in receive
```

Section 13. Wrapup

Tutorial summary

In this tutorial, we examined one of the Java language's most important features -- support for multithreaded (concurrent) programming.

One benefit of multithreaded programs is that they can take advantage of the additional CPUs in a shared-memory multiprocessor architecture in order to execute more quickly.

Using multiple threads can also simplify the design of a program, as in the example of a server program in which each incoming client request is handled by a dedicated thread.

Thread synchronization is extremely important, and this tutorial provides many examples to illustrate this concept.

This tutorial has also illustrated the following concepts by providing definitions, examples, resources, and sample code: Starting Java threads; thread states, priorities, and methods; volatile modifiers; race conditions; synchronized blocks; monitors; semaphores; message passing; rendezvous; and Remote Method Invocation.

Resources

Download code.zip , a zip file containing all example Java programs used in this tutorial.

The following online and print resources will help you follow up on the material presented in this tutorial:

* All example Java programs in this tutorial have been executed on a PC running ***Red Hat's version 7.0 of Linux*** , using the ***IBM Java software developer kit version 1.3.0 for Linux*** .

* In " ***Writing multithreaded Java applications*** " (developerWorks, March 2001), Alex Roetter explains the Java Thread API, outlines issues involved in multithreading, and offers solutions to common problems.

* Multithreaded programming expert Brian Goetz can help you understand the tricks and traps of the Java threading model in this developerWorks forum, " ***Multithreaded Java programming*** ."

* Brian Goetz also offers ***Threading lightly*** -- a series on threaded programming.

    * The first installment, " ***Synchronization is not the enemy*** " (developerWorks, July 2001), explains when you have to synchronize and how expensive it is.

    * The second article, " ***Reducing contention*** " (developerWorks, September 2001), explores several techniques for reducing contention to improve scalability in programs.

    * The third article, "*Sometimes it's best not to share*" (developerWorks, October 2001), gives tips on exploiting the power of ThreadLocal.

* In "*Writing efficient thread-safe classes*" (developerWorks, April 2000), Neel V. Kumar uses programming examples to explain how language-level support for locking objects and for inter-thread signaling makes writing thread-safe classes easy.

* Andrew D. Birrell's "*An Introduction to Programming with Threads*" (1989; a DEC research report) provides excellent guidance on threading.

* Doug Lea's *Java concurrent programming package* provides standardized, efficient versions of utility classes commonly encountered in concurrent Java programming. The author also explains how to use the Java platform's threading model more precisely by illuminating the patterns and trade-offs associated with concurrent programming in his book, *Concurrent Programming in Java: Design Principles and Patterns*, second edition (Addison Wesley, 2000).

* *JCSP* is a Java class library providing a base range of CSP primitives found at the University of Kent, Canterbury, UK. (CSP, or Communicating Sequential Processes, is a mathematical theory for specifying and verifying complex patterns of behavior arising from interactions between concurrent objects.)

* JavaPP introduces the CSP model into Java threads, enabling Java active processes to communicate and synchronize via CSP synchronization primitives, helping to eliminate race hazards, deadlock, livelock, and starvation. Two good JavaPP sites exist -- at the *University of Bristol* and the *University of Twente*.

* This Bill Venners' article, "*Design for thread safety*" (JavaWorld, August 1998), offers design guidelines for thread safety and provides a background on the concept of thread safety with several examples of objects -- both thread safe and not thread safe; it also delivers guidelines to help determine when thread safety is appropriate and how best to achieve it.

message passing, remote procedure calls, and the rendezvous for thread synchronization and communication.

* Allen Holub's "*Programming Java threads in the real world, Parts 1 through 9*" (JavaWorld, September 1998 - June 1999), is a series that purports to deliver everything you need to know to effectively program threads in real-world applications and situations.

* *Concurrent Programming: Principles and Practice* by Gregory R. Andrews (Benjamin/Cummings, 1991) provides an in-depth overview of principles and practical techniques that can be used to design concurrent programs.

* *Foundations of Multithreaded, Parallel, and Distributed Programming* by Gregory R. Andrews (Addison Wesley, 2000) covers such current programming techniques as semaphores, locks, barriers, monitors, message passing, and remote invocation, providing examples with complete programs, both shared and distributed.

* Stephen Hartley's book, *Concurrent Programming: The Java Programming Language* (Oxford University Press, 1998) shows readers how to use the Java language to code semaphores, monitors,

* ***Java Thread Programming*** by Paul Hyde (Sams, 1999) demonstrates how to leverage Java's thread facilities to increase program efficiency and to avoid common mistakes.

* ***Concurrency: State Models and Java Programs*** by Jeff Magee and Jeff Kramer (John Wiley & Sons, 1999) provides a systematic and practical approach to designing, analyzing, and implementing concurrent programs.

* Other, more generic books on operating-system and Java-language programming that have expanded sections on multithreading and concurrent programming include:

    * ***Operating Systems: Internals and Design Principles*** , fourth edition, by William Stallings (Prentice Hall, 2001) reflects ongoing changes in thread and process management and concurrency.

    * ***Modern Operating Systems*** , second edition, by Andrew Tanenbaum (Prentice Hall, 2001) has expanded its coverage of process management, threads, and security issues.

    * ***The Java Language Specification*** by James Gosling, Bill Joy, and Guy Steele (Addison-Wesley, 1996) covers all aspects of the Java execution model, including exceptions, threads, and binary compatibility.

    * ***Core Java 2, Volume II: Advanced Features*** , fifth edition, by Cay Horstmann and Gary Cornell (Prentice Hall, 2002), which starts with a chapter on multithreading, is fully updated for Sun's JDK 2 Version 1.3 and 1.4.

Your feedback

Please let us know whether this tutorial was helpful to you and how we could make it better. We'd also like to hear about other tutorial topics you'd like to see covered. Thanks!

Colophon

This tutorial was written entirely in XML, using the developerWorks Toot-O-Matic tutorial generator. The open source Toot-O-Matic tool is an XSLT stylesheet and several XSLT extension functions that convert an XML file into a number of HTML pages, a zip file, JPEG heading graphics, and two PDF files. Our ability to generate multiple text and binary formats from a single source file illustrates the power and flexibility of XML. (It also saves our production team a great deal of time and effort.)

You can get the source code for the Toot-O-Matic at www6.software.ibm.com/dl/devworks/dw-tootomatic-p . The tutorial Building tutorials with the Toot-O-Matic demonstrates how to use the Toot-O-Matic to create your own tutorials. developerWorks also hosts a forum devoted to the Toot-O-Matic; it's available at www-105.ibm.com/developerworks/xml_df.nsf/AllViewTemplate?OpenForm&RestrictToCategory=11 . We'd love to know what you