Johns Hopkins University Applied Physics Lab

Cybertech Seminar Series

Java Technology Day

The Real-Time Specification for Java™

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Outline

- The Real-Time Specification for Java
  - The Java Community Process
  - JSR-1 expert group
  - Guiding Principles
  - Scheduling
  - Memory Management
  - Synchronization
  - Asynchronous Event Handling
  - Asynchronous Transfer of Control
  - Asynchronous Thread Termination
  - Physical Memory Access

The Java Community Process

- A community-wide, software development method for extending Java APIs
- Java specification request
- Engineers nominated by participating organizations
- Lead participant named
- Specification lead forms expert group
- Specification developed
- Participant review
- Public review
- Reference implementation and test suites

JSR-1 EG Primary Team

- Greg Bollella, Sun Labs (formerly IBM)
- Ben Brosgol, Aonix
- Peter Dibble, Microware
- Steve Furr, QSSL
- James Gosling, Sun Microsystems
- David Hardin, aJile Systems
- Mark Turnbull, Nortel Networks

JSR-1 EG Consultants

- Apogee, Wolfgang Pieb
- Carnegie Mellon, Raj Rajkumar
- Lockheed Martin, Doug Locke
- Lucent, Larry Rau
- MITRE, E. Douglas Jensen
- Mitsubishi Electric, Masahiro Kuroda
- Motorola, Edward Wentworth
- NSICom, Alexander Katz
- NIST, Alden Dima
- Rockwell- Collins, Ray Kaman
- Schneider, Rudy Belliardi
- Thomson- CSF, Jean- Michel Meignien
- Wind River, Currently Unassigned
- Honorary, Russ Richards
- Emeritus, George Malek
- Emeritus, Chris Yurkowski
- Emeritus, Mike Schuette
- Emeritus, Simon Waddington

Guiding Principles

- Temporally Predictable Execution
- Support Current Real-Time Application Development Practice
- Backward Compatibility
  - The RTSJ maps the Java Language Semantics (JLS) semantics to appropriate, required instances
- RTSJ Appropriate for any Java™ Platform
- WOCRAC (like WORA but different)
  - Write Once Carefully Run Anywhere Conditionally
- Support Leading Edge RT Application Development and the Real-Time Scheduling Academic Community
- No Syntactic Extension
- Allow for Implementation Trade-offs
  - Toys to Cruise Missiles
  - Incentive for RTOS vendors

Scheduling

- `Scheduler`
  - Abstract base class
  - Contains methods for feasibility analysis, admission control, dispatching, and asynchronous event handling mechanism
  - Can be considered distinct from the dispatcher
- *`Schedulable`*
  - An Interface
  - Any object implementing *`Schedulable`* is scheduled by a `Scheduler`
  - In the RTSJ `RealtimeThreads` and `AsyncEventHandlers` implement *`Schedulable`*
  - The RTSJ encourages implementations to extend the notion of a schedulable object
  - Each *`Schedulable`* object has a reference to a `Scheduler`

Scheduling

- `PriorityScheduler extends Scheduler`
  - Required scheduler, i.e., this function will be available on all implementations of the RTSJ
  - Actually more like a dispatcher
  - Fixed-priority, preemptive
  - Priority assignment by application logic
  - At least 28 *unique* priority levels for RealtimeThreads
- E.g., `RMAScheduler extends Scheduler`
- E.g., `EDFScheduler extends Scheduler`

Scheduling

- `RealtimeThread extends Thread`
  - Managed by a scheduler
  - May use memory other than the heap
  - Participate in asynchronous transfer of control and thread termination
  - May access physical memory
- `NoHeapRealtimeThread extends RealtimeThread`
  - Not allowed to read or write to objects on the heap
  - Not allowed to manipulate references to objects on the heap
  - Must be created with a scoped memory area
  - May immediately preempt the garbage collector

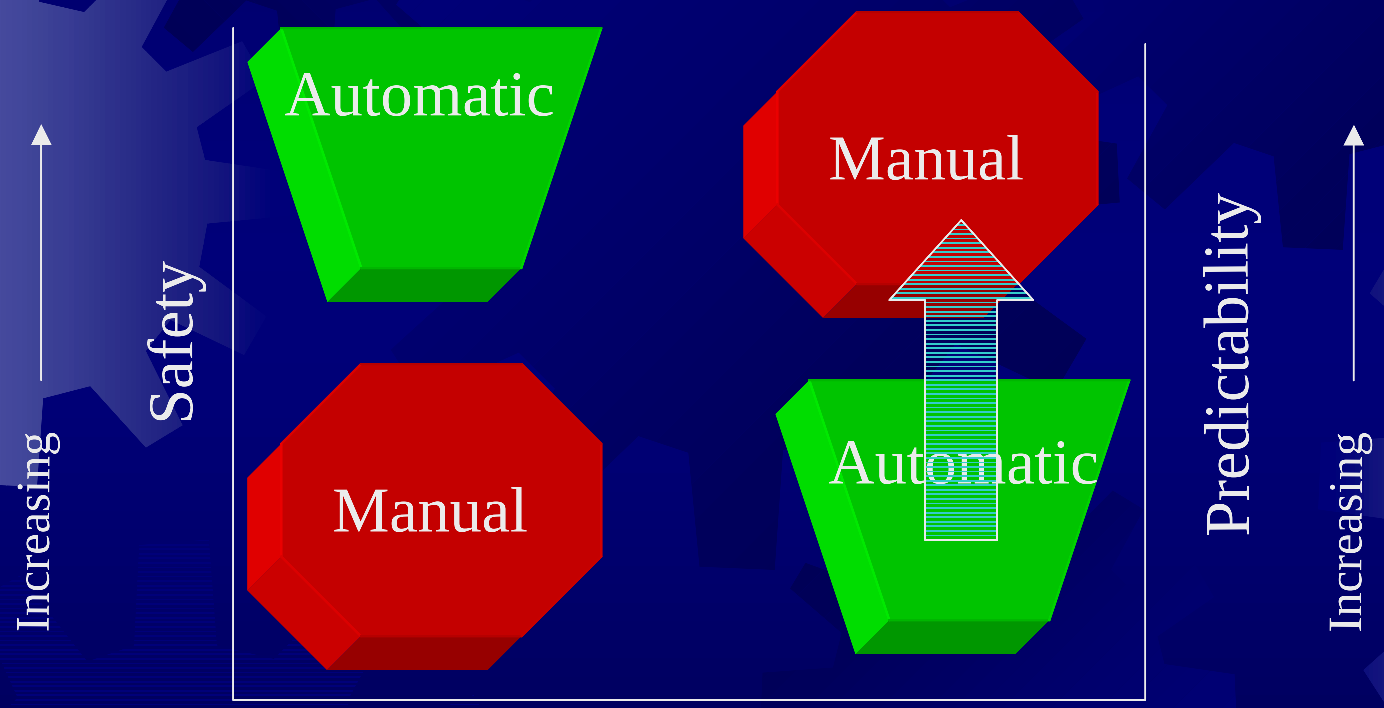
Scheduling

- SchedulingParameters
  - Abstract base class for eligibility metric
  - PriorityParameters
    - Traditional priority
    - ImportanceParameters
      - Importance field for overload situations
- ReleaseParameters
  - Abstract base class for release characteristics
  - PeriodicParameters
  - AperiodicParameters
  - SporadicParameters
- MemoryParameters
  - Defines a schedulable object's memory demands
- ProcessingGroupParameters
  - Used to manage many aperiodic or sporadic threads as a meta-level periodic thread

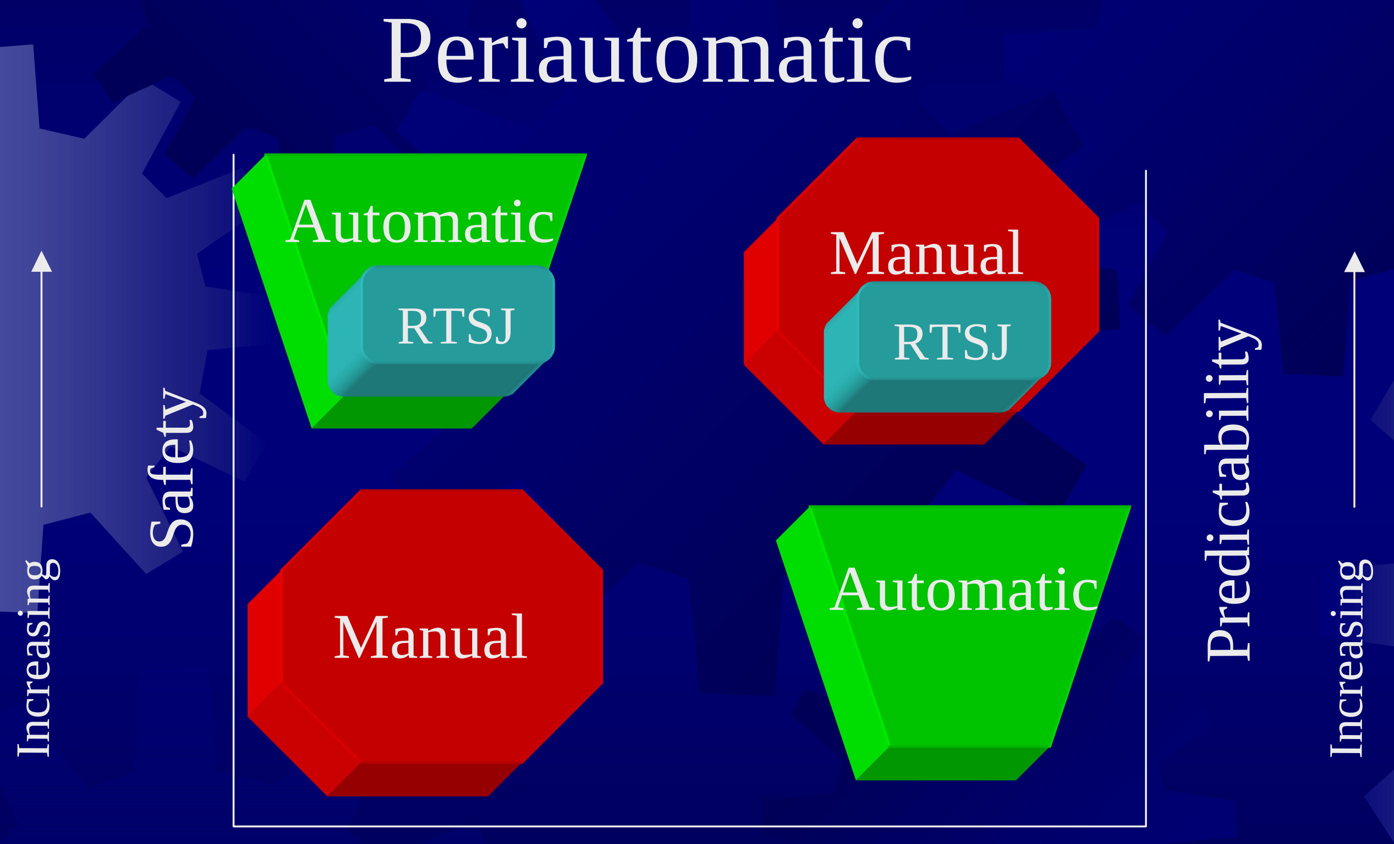
Memory Management

- We note that the JLS is curiously silent on the subject of automatic memory reclamation (aka garbage collection)
- Saying anything about gc seemed to require saying more than the Java™ Programming Language inventors wanted to say
- The JLS allows programmatic allocation of memory (new) but has no programmatic way to deallocate memory
- The RTSJ is also mostly silent on the matter of garbage collection

Memory Management



Memory Management



Memory Management

- RTSJ changes the notion of object lifetime (i.e., when an object is a candidate for collection)
- Manual: Lifetime controlled by program logic
- Automatic: Lifetime controlled by visibility
- RTSJ Memory Types: Lifetime controlled by syntactic scope
  - Objects live until control flows out of scope
  - When control leaves scope finalizers execute and complete before the memory area is accessed

Memory Management

- Memory Areas
  - Objects not managed by collector
- Immortal Memory Area
  - One ImmortalMemory object per JVM™
  - Pre-allocated at JVM start
  - Effective scope is larger than the program, i.e., no control in the program can ever leave the scope of the immortal memory area
  - Used for sharing between real-time threads and sharing between real-time and non-real-time threads

Memory Management

- Scoped Memory Areas
  - Associated with one or more scopes (closure or thread)
  - Scopes may have more than one associated memory area with one primary (where objects are created by default)
  - LTMemory - execution time of new is linear in object size
  - VTMemory - execution time of new is variable

Memory Management

- Assignment Rules, based on object lifetimes
  - Heap ⟺ Heap
  - Heap ⟺ Immortal
    - Collector can traverse immortal area and be safely preempted thus we can allow object in the immortal memory area to hold references to objects in the heap
  - Immortal ⟺ Immortal
  - Scoped ⟹ Immortal
  - Scoped ⟹ Scoped (in outer or same scope)
- Partial static analysis for assignment safety is possible (classfiles so marked)
- Runtime checks necessary for unanalyzed or unanalyzable code

Synchronization

- Priority Inversion Control
- Default behavior of synchronized must be that of the priority inheritance algorithm
- Other priority inversion avoidance algorithms can be set for either all or particular monitors
- Synchronized problematic between regular Java threads and real-time threads
- NoHeapRealtimeThreads have implicit execution priority higher than the collector
  - Correct implementation of any priority inversion avoidance algorithm is impossible if execution priority of NHRT is honored
  - The RTSJ provides three Wait-free Queue classes

Wait-free Queues

- Unidirectional data flow and non-blocking read/write methods
- The `write()` method of the `WaitFreeWriteQueue` is the ‘real-time’ end
- Wait-free write queue
  - Number of entries fixed at creation time
  - Internal objects are allocated from appropriate memory area
  - Real-time writer does not block on queue-full or queue-empty conditions (instead: application logic determines action (toss, overwrite, etc.))

Asynchronous Event Handling

- Real-time and Embedded Systems are typically tightly coupled to the REAL-WORLD
- Events in the real-world are asynchronous to program execution
- Asynchronous events may also arise internally within the JVM™ (i.e., programmatically)
- The RTJS provides a mechanism to bind a schedulable object to the occurrence of an event
- When the event occurs the object's run state changes to ready-to-run and is scheduled wrt its parameter objects
- Mechanism designed for tens of thousands of events and handlers, i.e., very lightweight

Asynchronous Event Handling

- `AsyncEvent`
- `AsyncEventHandler implements Schedulable`
- An instance of `AsyncEvent` represents something that can happen
- An instance of `AsyncEventHandler` has a method (`handleAsyncEvent()`) which contains the logic that should execute when the event occurs
- Handlers are bound to events by
  - `AsyncEvent.addHandler(AsyncEventHandler a);`

Asynchronous Event Handling

- An instance of AsyncEvent may be bound to an external event using
  - `AsyncEvent.bindTo(String s)`
- There are two ways AsyncEvents occur
  - The method `AsyncEvent.fire()` is invoked or
  - an external event occurs
- The execution of handlers is required to be semantically equivalent, wrt scheduling, to instances of `RealtimeThread`

Asynchronous Transfer of Control

- The Real-Time for Java™ Consultants requested the RTSJ include a concept for allowing the asynchronous transfer of the flow of execution to some predetermined, syntactically defined point in the program
- The ATC mechanism is similar to exception handling in the JLS (Java exceptions are synchronous).
- The prime directive for ATC (from ourselves) is:
  - *Code written without a priori knowledge of possible interruption must not be interrupted*
  - How does the RTSJ accomplish the prime directive?

Asynchronous Transfer of Control

- `AsynchronouslyInterruptedException`
  - Only the code within a method with AIE in its throws clause is interruptible
  - `Timed`
- *`Interruptible`* (an interface)
  - Classes which implement can be given to `Timed` constructor

Asynchronous Transfer of Control

- How does logic asynchronously transfer control?
  - `javax.RealtimeThread.interrupt()` has additional semantics
  - when t.interrupt() is executed an AIE is thrown at thread t and then if:
    - control is in any method with AIE in its throws clause then control will transfer to the calling method with an AIE
    - control is in any method without AIE in its throws clause or in any synchronized block/method the method or block will complete normally and the AIE is set to pending

Interruptible I/O Methods

- The consultants required that the RTSJ should allow a mechanism which would preclude indefinitely blocked I/O calls.
- Methods in `java.io.*` now throw IOException, *however,* it's typically not implemented.
- Two cases:
  1. The device (and thus its stream) is no longer needed (or the device no longer exists).
  2. Timed, non-blocking I/O calls (when the device and its associated streams remain viable).

Interruptible I/O Methods

- Case 1: Device no longer needed or gone.
  - Semantics of `stream.close()` and the I/O methods are required to be modified.
    - Blocked I/O calls are *required* to throw appropriate instances of `IOException` when `stream.close()` is called on the stream on which they are blocked.

Interruptible I/O Methods

- Case 2: Timed, non-blocking I/O calls for devices and their streams which remain viable.
  - Programming pattern
    - A simple non-timed, non-blocking I/O call can be easily built from two AsyncEvents and their handlers.

Non-Blocking I/O

```
nonblockingRead () {
//setup, etc.
ae1.fire();
}
```

```
handleAsyncEvent () {
  // handler for ae1
  c = stream.read();
  // handle IOException
  // put c somewhere
  ae2.fire();
}
```

```
handleAsyncEvent () {
  // handler for ae2
  // get c
  // do something with c
}
```

Asynchronous Thread Termination

- To asynchronously terminate a thread is a requirement from the consultants
- Arbitrary thread termination is as unsafe as is arbitrary asynchronous transfer of control thus the same prime directive applies
- ATT typically implies that logic can cause a thread to terminate when some external happening occurs
- The RTSJ allows ATT by use of the asynchronous event handling and asynchronous transfer of control mechanisms

Physical Memory Access

- Requirement by consultants and industry input
- Generalized abstraction of such access is beyond the scope of the charter of the Real-Time for Java Expert Group (RTJEG) (actually, we thought that we did not really know enough about all of the various memory types to create a useful abstraction)
- The RTJEG chose to specify a low-level mechanism useful for building higher-level abstractions

Physical Memory Access

- MemoryArea
  - ImmortalMemory
  - ImmortalPhysicalMemory
  - ScopedMemory
    - LTMemory
    - ScopedPhysicalMemory
    - VTMemory
  - PhysicalMemoryFactory
  - RawMemoryAccess
  - RawMemoryFloatAccess

Physical Memory Access

- Two styles of access
- Ability to set and get bytes of physical memory
  - Useful for device control
  - RawMemoryAccess
  - RawMemoryFloatAccess
- Ability to allocate objects in physical memory
  - Programmer managed object cache
  - ImmortalPhysicalMemory
  - ScopedPhysicalMemory
- Programmers use the physical memory factory to create instances of the three classes

Summary

- The RTSJ addresses seven areas: Scheduling, Memory Management, Synchronization, Asynchronous (Event Handling, Transfer of Control, Thread Termination), and Physical Memory Access
- Current version always available at www.rtj.org
- Comments to: comments@rtj.org
- "The Real-Time Specification for Java", Addison-Wesley, June 2000
- Reference implementation target mid-2001

Code Examples

- RealtimeThread
- PeriodicThread
- Scheduler
- ScopedMemory
- AsyncEvent
- Timer
- AsynchronouslyInterruptedException

RealtimeThread

```
public class ReceiveThread extends RealtimeThread {
        public void run() {
            /* logic for receive thread */}
}
public void example() {
      RealtimeThread rt = new ReceiveThread();
      if (!rt.getScheduler().isFeasible())
            throw new Exception("Whatever...");
      rt.start();
}
```

PeriodicThread

```
public class PeriodicThread extends RealtimeThread {
PeriodicThread(MyPeriodicParameters pp,
              MemoryParameters mp, Runnable r) {
          super(pp.sp, pp, mp, null, null, r);
      }}
```

Periodic Thread

```
public MyPeriodicParameters(RelativeTime period,
                            RelativeTime cost) {
            super(null, /* no start time */
                  period,
                  cost,
                  null, /* deadline == period */
                  null, /* no overrun handler */
                  null); /* no miss handler */
sp = new PriorityParameters(determinePriority());}}
```

PeriodicThread

```
RealtimeThread rt = new PeriodicThread(
       new MyPeriodicParameters(new RelativeTime(50, 0),
                                determineCost()),
       new Runnable() {
         public void run() {
            RealtimeThread t;
               try {
                  t =
              (RealtimeThread)Thread.currentThread();
                  do {
                    /* thread logic. */
                   } while (t.waitForNextPeriod());
                  } catch (ClassCastException e) {}}});
```

Finding a New Scheduler

```
public class SchedulerExample {
public static Scheduler findScheduler(String policy) {
        String className = System.getProperty(
                    "javax.realtime.scheduler." + policy);
        Class clazz;
          try {
            if (className != null
            && (clazz = Class.forName(className)) != null){
                return (Scheduler)clazz.getMethod(
               "instance",null).invoke(null,null);
            }
        } catch (/* lots of exceptions */) {
         return null;
    }
```

Finding a New Scheduler

```
Scheduler scheduler = findScheduler("EDF");
if (scheduler != null) {
    RealtimeThread t1 = new RealtimeThread(null,
                        new PeriodicParameters(
                        null, new RelativeTime(100, 0),
                        new RelativeTime(5, 0),
                        new RelativeTime(50, 0), null,
                        null),
                        null,null,null,null) {
                        public void run() {
                       /* thread processing */
                    }};
         t1.setScheduler(scheduler);
         t1.start();
      }
```

ScopedMemory

```
final ScopedMemory scope = new LTMemory(1024, 16 * 1024);
  scope.enter(new Runnable() {
            public void run() {
              /* Do some time-critical operations */
              try {
                  /* To allocate from the heap */
                  HeapMemory.instance()
                  .newInstance(Class.forName("Foo"));
                  /* Allocate from the previous scope*/
                  scope.getOuterScope()
                  .newInstance(Class.forName("Foo"));
              } catch (ClassNotFoundException e) {
              } catch (IllegalAccessException ia) {
              } catch (InstantiationException ie) {
              }}});
```

ScopedMemory

```
final ScopedMemory scope =
                 new LTMemory(0, 16 * 1024);
RealtimeThread t1 =
   new RealtimeThread(null, null,
   new MemoryParameters(100000, 0), scope, null,
   new Runnable() {
      public void run() {
            /* do some stuff */
           }});
```

AsyncEvent

```
try {
   AsyncEvent inputReady = new AsyncEvent();
   AsyncEventHandler h = new AsyncEventHandler() {
     public void handleAsyncEvent() {
       System.out.print("The first Handler ran!\n");
     }
   };
   inputReady.addHandler(h);
   System.out.print("Test 1\n");
   inputReady.fire();
   Thread.yield();
   System.out.print("Fired the event\n");
```

AsyncEvent

```
SchedulingParameters low = new
         PriorityParameters(PriorityScheduler
            .getMinPriority(null));
    inputReady.setHandler(new AsyncEventHandler(low,
                                   null, null, null, null) {
      public void handleAsyncEvent() {
        System.out.print("The low priority handler
                                         ran!\n");}});
SchedulingParameters high = new
         PriorityParameters(PriorityScheduler
                 .getMaxPriority(null));
    inputReady.addHandler(new AsyncEventHandler(high,
                                   null, null, null, null) {
      public void handleAsyncEvent() {
        System.out.print("The high priority handler
                                               ran!\n");}});
```

AsyncEvent

```
System.out.print("\nTest 2\n");
    inputReady.fire();
    System.out.print("After the fire\n");
    Thread.sleep(100);
    System.out.print("After the sleep\n");
```

AsyncEvent Output

```
Test 1
The first handler ran!
Fired the event
Test 2
The high priority handler ran!
After the fire
The low priority handler ran!
After the sleep
```

Timer

```
public class TimerExample {
    private static final
      SchedulingParameters highPriority = new
        PriorityParameters(PriorityScheduler.getMaxPriority(null));
private static void TestTimer(String title, Timer t) {
       ReleaseParameters rp = t.createReleaseParameters();
       rp.setCost(new RelativeTime(10, 0));
       t.addHandler(new
               AsyncEventHandler(highPriority,rp,null,null,null) {
           public void handleAsyncEvent() {
              System.out.print("  Timer went off at "
              + (System.currentTimeMillis() - T0) + "\n");}});
       t.start();
//USE
TestTimer("One Shot",
     new OneShotTimer(new RelativeTime(100, 0), null))
TestTimer("Periodic",
      new PeriodicTimer(new RelativeTime(100, 0),
       new RelativeTime(100, 0), null));
```

AsynchronouslyInterruptedException

```
public void example() {
  MyInterrupt aie = new MyInterrupt();
  aie.doInterruptible(new Interruptible() {
  public void runNonInterruptible() {
       /* do something that can't be interrupted */
  }
  public void run(AsynchronouslyInterruptedException e)
     throws AsynchronouslyInterruptedException {
     /* This method can be interrupted at any point in time */
      runNonInterruptible();
      e.disable();
      e.enable();
   }
 public void interruptAction(
                       AsynchronouslyInterruptedException e) {
   /* code which executes if run() method interrupted */
 }});
```