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Programming with Non-Heap Memory in the Real Time Specification for Java

Daniel Dvorak, Ph.D.
Information Technologies and Software Systems Division
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Daniel.Dvorak@jpl.nasa.gov

Outline

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- Background on real-time applications
- Real-Time Specification for Java (RTSJ)
- Effect of RTSJ on normal Java style
- Scoped Memory Scratchpads
- Ending thoughts

Real-Time Systems

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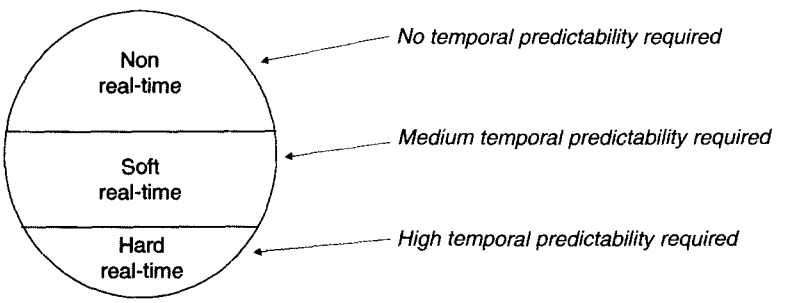
Most real-time systems are a mixture of hard, soft, and non-real-time



A single RTSJ-compliant VM supports all three kinds of activities

Real-Time Control Systems

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Rocky 7 rover in the JPL Mars Yard with camera mast raised

Control of a Mars rover involves:

- coordinating 6 driving motors and 2 steering motors
- reading from a 3-axis accelerometer and a 1-axis gyroscope
- taking pictures with 3 stereo cameras
- controlling a camera mast
- controlling the instrument arm

Java for Real-Time ???

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Java Technology was not intended for real-time systems because:

- Requires run-time garbage collection
- Supports threads, but no scheduling control
- Synchronization delays unpredictable
- Very coarse timer support
- No event processing
- No safe asynchronous transfer of control

RTSJ Guiding Principles (partial)

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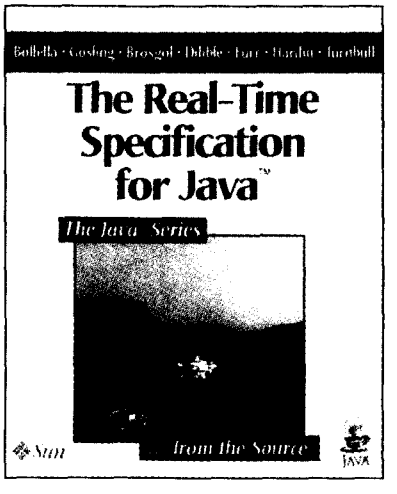
- **Predictable Execution**
  - "hold predictable execution as first priority in all tradeoffs"
- **Backward Compatibility**
  - Existing Java programs run on RTSJ implementations
- **No Syntactic Extensions**
  - No new keywords or other extensions to Java language
- **Leading-Edge Scheduling**
  - Priorities considered harmful



Definitions

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Real-time ≠ "real fast"

- **Real-time** (system or code): A system (or code) which requires that computation have temporal correctness criteria in addition to functional correctness criteria
- **Hard real-time**: A real-time system which requires that the temporal correctness criteria are *always* met (often, incorrectly defined as 'less than n time-units latency')
- **Soft real-time**: A real-time system which requires that the temporal correctness criteria are *almost always* met (often, incorrectly defined as 'more than n time-units latency')

RTSJ Features

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- Full Java capability
- Threads (RealtimeThread, NoHeapRealtimeThread)
- Asynchronous Event handling
- High resolution time
- Precise Timer support
- Asynchronous Transfer of Control
- Flexible memory management
  - *Makes using Java heap optional*
  - *Can avoid interference from garbage collector*
- Raw memory access (e.g., memory-mapped I/O)

Memory Areas

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Java

Heap

- Normal Java heap
- Accessible by all threads
- Subject to garbage collecting
- **Prone to execution latencies due to GC**

RTSJ

- Fixed size memory area that lives until end of app
- Accessible by all threads
- Immortal objects continue to exist exist even when there are no references
- **Never subject to garbage collecting**

Scoped

- Limited size, limited lifetime memory areas
- Scope emptied when all threads exit the area
- Requires designer to consider memory management
- **Never subject to garbage collecting**

Threads

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Java

Thread

- Normal Java thread
- No scheduling control
- Cannot be asynchronously interrupted

RealtimeThread

- Temporal demands specified (deadline, period)
- Processor demands specified (CPU & memory costs)
- Can run as a periodic, aperiodic, or sporadic
- Can allow for asynchronous interrupts

RTSJ

NoHeapRealtimeThread

- Cannot allocate or reference objects in heap memory
- **Can *always* execute in preference to GC**

Java Programming Style

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- Use 'new' to allocate objects (in heap)
- Freely pass references around
- Let GC reclaim unused objects
  - Don't worry about memory management

RTSJ Changes to Style

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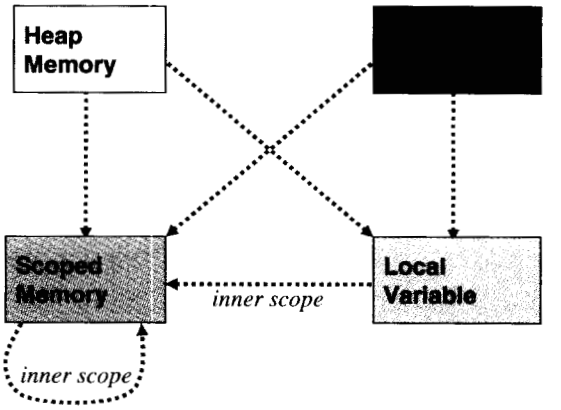
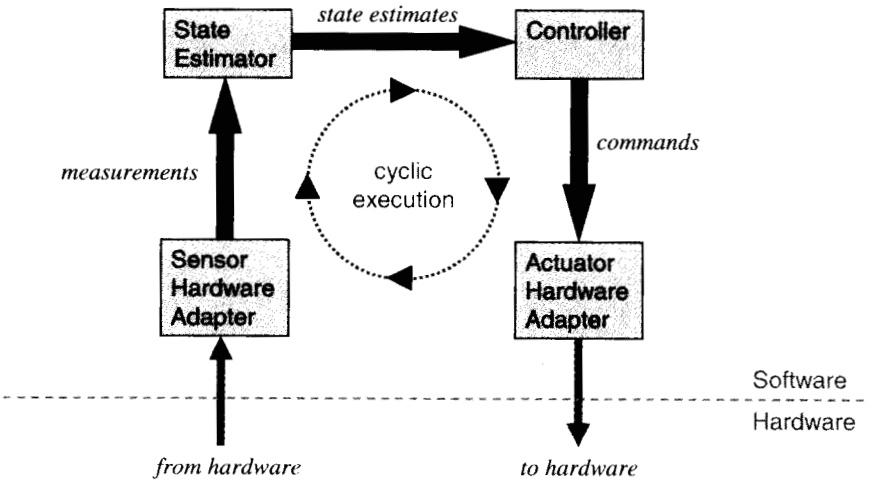
- *Do* worry about memory management
  - NHRT cannot allocate or access heap objects
  - java.lang.Thread cannot allocate Scoped Memory objects
  - Must obey memory area assignment rules

Memory Area Assignment Rules



Legend: X ⇢ Y means that object in X can *NOT* be assigned a reference to an object in Y because Y can disappear before X

Real-Time Control Loop



Memory Management

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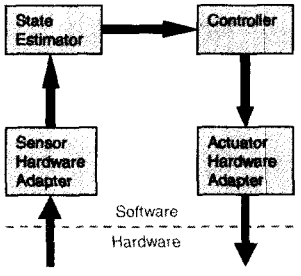
Each component must:
- manage its mutable state in a persistent manner
- manage transient objects allocated during its execution



- How do you manage memory in a way that …
  - supports hard real-time?
  - is natural for Java?
  - minimizes need for programmer discipline?
  - is verifiable w.r.t. memory errors?

Scoped Memory Scratchpad

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- Component enters a scoped memory area
- Subsequent 'new's allocate from scoped, whether in own code or inside called methods
- Transient objects (for current cycle only) will disappear upon scoped memory exit
- Persistent data (across cycles) must be kept in a private memory pool (requires copying)
- Required programmer discipline:
  - Called components must not hold references to arguments
  - Calling components must not hold references to returned objects

Comparison

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- Scoped Memory Scratchpad:
  - Supports natural *new*-based creation of objects
  - Runs hard real-time components in Scoped Memory
  - Scope emptying automatically discards transient data
  - Works with 3rd-party libraries that do *new*
  - Framework software can shield application developers from type of thread and type of memory area
- Shared Memory Pool (an alternative):
  - Get unused objects from a pool in Immortal Memory, release when no longer used (manual memory management)
  - Pass references from one component to another
  - Avoids copying of data (more efficient)
  - Vulnerable to memory leaks and double-usage

Ending Thoughts

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- RTSJ supports hard, soft, and non real-time applications on a single VM having *any* GC ...
- ... but users encounter a conflict between Java's OO style and RTSJ's rules
- The design trade-space includes efficiency, programmer discipline, verifiability, and style
- The approach of "scoped memory scratchpads" favors verifiability and style
- Real-time garbage collectors can alleviate the conflict for apps where the latency is acceptable
  - But GC avoidance enables *very* predictable execution
  - And that's important in control systems

Golden Gate Team

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- **Sun Microsystems**
  - Greg Bollella and James Gosling
- **Carnegie Mellon University**
  - Virgil Champlin and Brian Giovannoni

- **Jet Propulsion Laboratory**
  - Tim Canham, Vanessa Carson, Dan Dvorak, Mark Indictor, Kenny Meyer, Alex Murray, Kirk Reinholtz