Real-Time Java for Latency Critical Banking Applications

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Agenda

• Background
• Benefits of a Real-Time Java Virtual Machine
• Benefits of Real-Time Garbage Collectors
• Q&A
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Banking Trend

• Avoiding latencies (unexpected delays) has always been important

Steve Rubinow (NYSE Group CTO):

“ If you've got some trades going through at 10 milliseconds and some at 1 millisecond, that's a problem. Our customers don't like variance”
Banking Trend

- Physical co-location is removing the external sources of jitter (variation of execution time)
- Application jitter is now much more visible

Dave Cummings (BATS CEO)

“Five years ago we were talking seconds, now we're into the milliseconds. Five years from now we'll probably be measuring latency in microseconds”

Alistair Brown (LIME Brokerage CEO)

“Shortly, we'll be talking micro- versus milliseconds, and at that point speed will probably have less and less relevance”
### Categories of Application Predictability

<table>
<thead>
<tr>
<th>Non real-time</th>
<th>Soft real-time</th>
<th>Hard real-time</th>
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</table>
| - No time-based deadlines  
  > Standard programming logic  
  > Example: UI, web services, algorithmic calculations |  
  - Deadlines may be missed occasionally under well-defined conditions  
  > Mainstream real-time needs  
  > Example: Automated trading system, 3G telco router |  
  - Deadlines cannot be missed  
  > Typically highest priority on system  
  > Example: Robotic motion control and management, Data feed processing |
Traditional Design Choices to Improve Predictability

Use mainstream programming tools and standard platforms

OR

Use customized lower-level tools and proprietary platforms

> Everything is equally important; so try go faster to get everything done
> Guessing game: no guarantee that deadlines will be met – just postponed
> Low infrastructure utilization
> Lack of predictable solution

> Predictable solution, but...
> Expensive – dedicated tools, training, headcount; longer development cycles, complicated maintenance
> Challenging integration of real-time elements with the standard applications
Traditional Real-Time Design Choices: Examples

• Example 1: Global engineering conglomerate needs PLC control elements with hard real-time capabilities for industrial automation
  
  PC-oriented SBC boards cost ~20% of custom boards but have no integrated real-time solution  
  OR  
  Custom boards from a specialized provider are very costly and require more for software/tools

• Example 2: Leading financial services institution needs to scale its market-facing system while meeting Service Level Agreements

  Standard Java applications offer flexibility and scalability but GC pauses threaten SLAs  
  OR  
  Legacy system able to meet current SLAs but no longer viable with regard to maintainability and scalability
Real-Time Design Choices

How about an open standards-based platform that formally deals with real-time challenges?

- Everything is equally important; try go faster to get everything done
- Guessing game – no guarantee that deadlines will be met
- Low infrastructure utilization
- Lack of predictable solution

Use mainstream programming tools and standard platforms

Use customized lower-level tools and proprietary platforms

Predictable solution, but...
- Expensive – dedicated tools, training, headcount, longer development cycles, effort-intensive maintenance
- Challenging integration of real-time elements with the standard applications
Real-Time Specification for Java (RTSJ)

1998
- Real-Time Specification for Java (JSR-001) proposal submitted
- Joint Sun/IBM
- Many others: Ajile, Apogee, Motorola, Nortel, QNX, Thales, TimeSys, WindRiver

2002
- JSR-001 approved by the Java Community Process
- TimeSys Reference Implementation

2005
- RTSJ update proposal submitted (JSR-282)
- Apogee Aphelion
- Sun Java Real-Time System
- IBM’s webSphere RealTime

2007
- RTGC added to Sun Java RTS
- Others companies implementing RTSJ (not yet certified)

2008
- New Sun/IBM JSR

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Use case 1: Send Market Data at a Fixed Rate

Neither too late... nor too often!

• Mainstream Java solution:
  
  ```java
  while (true) do {
    compute_data();
    now = System.currentTimeMillis()
    Thread.sleep(next_period - now);
    send_data();
    next_period += period;
  }
  ```

• Problem:
  > Not guaranteed to wake-up quickly after the sleep call!
RTSJ Benefit 1: Priority Semantic

You must specify the relative importance of the tasks, including with respect to the other processes.

Mainstream "setPriority(10);" is not sufficient!

- RTSJ offers in Java usual real-time scheduling semantics
  - RealtimeThreads preempt non real-time ones
  - Higher priority threads preempt lower priority ones
  - Locks are properly handled (a low priority thread owning a critical resource will be boosted by the thread that requires it)
Use case 1 revisited

• Code executed by a RealtimeThread
  
  ```java
  setPriority(my_RTPriority);
  while (true) do {
    compute_data();
    now = System.currentTimeMillis()
    Thread.sleep(next_period – now);
    send_data();
    next_period += period;
  }
  ```

• Problem:
  > What if a more important RT threads preempts me just before calling sleep?
RTSJ Benefit 2: Rich Real-Time APIs

• RTSJ provides what you will find in most RT Operating Systems
  > Absolute Time Clock, Timers, Non Blocking Queues...

• RTSJ provides an additional layer to make your life simpler
  > Periodic Threads, Asynchronous Event Handlers, RawMemoryAccess, Deadline Miss Monitoring and Management, Asynchronous Transfer of Control...

• RTSJ optionally defines advanced APIs
  > Cost Overflow Monitoring and Management, Feasibility Analysis...
Use case 1, RTSJ version

- Code executed by a `RealtimeThread`
  
  ```java
  setPriority(my_RTPriority);
  setReleaseParameters(myPeriodParam);
  while (true) do {
      compute_data();
      RealtimeThread.waitForNextPeriod();
      send_data();
  }
  ```

  (other variants with Timers, AbsoluteTime wait, ...)

- Problem:
  > Is this sufficient ?
Yes... if optimized for Determinism

- The fastest Garbage Collectors suspend all the threads while they recycle memory.

- The fastest JIT compilers make some assumptions to generate more efficient code and must 'deoptimize' threads if the assumption becomes invalid.

- Solution 1:
  - RTSJ defines additional threads optimized for determinism and isolated for GC jitter.
  - They are as deterministic as C/C++ code!
NoHeapRealtimeThreads

- Code executed by a NoHeapRealtimeThread
  ```java
  setPriority(my_RTPriority);
  setReleaseParameters(myPeriodParam);
  while (true) do {
    compute_data();
    RealtimeThread.waitForNextPeriod();
    send_data();
  }
  ```
- Problem:
  > What about memory allocation since 'isolated' from the GC?
Memory areas for NHRTs

Don't bother if 200 microseconds latencies are OK !!!

- **ImmortalMemory** for non recycled objects
- **ScopedMemory** for recycling
  - Memory areas not subject to the Garbage Collector
  - Per area counters to know how many threads are using an area
  - Objects automatically deleted when the count of their area is 0
  - Dynamic read/write checks to guarantee the safety of this recycling
Use case 1, ScopedMemory version

• Code executed by a NoHeapRealtimeThread
  while (true) do {
    scopedMemory1.enter(runnable);
    // sm1 recycled for the next loop
  }
  void run() {
    compute_data();
    waitForNextPeriod();
    send_data();
  }

• Problem:
  > Is send_data() endorsing read/write constraints?
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Making Java Predictable, RTGC

• Real-Time GC
  > Essentially a “garbage collector with knobs”
  > Large interrupts are avoided at the cost of small, regular, and predictable collections
  > The GC runs often enough to recycle memory on time, depending on allocation and collection rates

• Several models/approaches exist
  > IBM, Aicas, Sun, ...

• Way simpler from a coding point of view
  > Single heap
  > No read/write checks
Overall System Model

Real-Time JVM

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<td><strong>• Standard Java Heap</strong>&lt;br&gt;  &gt; Regular Java threads</td>
<td><strong>• Standard Java Heap or Scoped or Immortal memory</strong>&lt;br&gt;  &gt; Real-Time threads&lt;br&gt;  &gt; Real-Time Garbage Collector</td>
<td><strong>• Scoped/Immortal/Heap</strong>&lt;br&gt;  &gt; NoHeapReal-Time threads&lt;br&gt;  &gt; Real-Time threads&lt;br&gt;  &gt; Hard Real-Time Garbage Collector</td>
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Real-time code and existing, non real-time, code can communicate, share memory, state, and overall environment – something not possible in current real-time solutions.
Sun's RTGC

Apply concept of policy to Henriksson's approach

- Goal: Hard RT latencies for high priority GC'd threads
- Solution: implement GC as real-time threads
  - Running at a priority lower than the hard RT threads
  - And possibly concurrently with the other threads
- Advantages
  - Scalable (no issues with multi-processor support)
  - Flexible
Default RTGC Scheduling Policy

- NHRTs
- Critical RT threads
- Boosted GC Work at GC Max prio
- Soft RT threads
- Start GC Work at low priority

- Thread doing work
- Thread pause – priority interruption
- GC active/running

Priority

Could run concurrently on another CPU

Run-to-block GC

Boosting (Remaining Memory Too Low)

Time
Use case 1 revisited

• Code executed by a **hard** RealtimeThread
  ```java
goodThread:
  while (true) do {
    waitForNextPeriod();
    send_data();
  }
```

• Code executed by a **soft** RealtimeThread
  ```java
softThread:
  while (true) do {
    compute_data();
    waitForNextPeriod();
  }
```

• `softRT.setDeadlineMissHandler(dm)`
Use case 1 Deadline Miss Handler

• **Hard** Real-Time AsynchronousEventHandler

  ```java
  void handleAsyncEvent() {
      quickly_compute_simpler_data();
      softRTThread.schedulePeriodic();
  }
  ```

  or

  ```java
  void handleAsyncEvent() {
      softRTTThread.setPriority(hardPrio);
      softRTThread.schedulePeriodic();
  }
  ```
Use Case 2 : Events Driven Request with Deadlines

• A request is valid:
  > For a limited time
  > When a set of asynchronous input feeds dependent conditions are true

• Proposed design:
  > Use a high priority critical thread for the request
  > If necessary, rely on priority boosting to safely use locks to check the <condition,deadline> pair(s)
  > Use AsynchronousEventHandlers to process the input feeds
    > Potentially at different priorities (hard and/or soft)
    > Use Minimum Inter-arrival Time policies to handle overflows
Use Case 3 : NASDAQ
“Reduce I/O Jitter and Context Switches”

- I/O must not hold other requests
- Implemented Solution:
  > One thread per-CPU
    > One front-end to receive requests and executed non I/O ones
    > I/O requests dispatched to another thread
    > I/O completion can be seen as a new request by the front-end

- Benefits from Java RTS deterministic compilation and memory management but:
  > What if I/O requests can be processed at different rates?
  > Could I handle more non I/O requests?
Use Case 3: Why Care about Context Switches?

This should not be your role!

- **Risk**: under-utilization of resources
- **Scalable Design:**
  - Chosen number of high priority time-critical front-end threads
  - Could even be at different priorities depending on the input stream
  - AsynchronousEventHandler to process I/Os at a lower priority
    - New I/O processing threads will automatically be created by the VM server thread pool to maximize the number of parallel requests
    - Requests started later can complete earlier
    - The server thread automatically grabs a new one... *without context switch*
Sun Java RTS Unique Selling Proposition

Sun's Java Real-Time System – absolute execution predictability with all the benefits of the Java platform

- Truly predictable, sample latency numbers:
  - RTGC: 200 microseconds
  - NHRT: 20 microseconds

- Open
  - Based on open, community-driven standards
Customer Evaluations

- Over 500 companies and universities from more than 60 countries have evaluated Sun Java Real-Time System
- Some data points from them:

Maximum Latency Required

Evaluations by Industry

Source: Evaluation download survey for Sun Java RTS
Key Benefits of RTSJ

TECHNICAL
- Maximize system utilization
- Cross-platform portability
- Leverage standard OS's
- Real-time tools

BUSINESS
- Eliminate latency outliers
  > Save millions of $ lost due to missed market opportunities, productivity losses etc.
- Eliminate risks inherent in custom and proprietary solutions
- Leverage investment in existing Java code, skills
- Increase developer productivity using Java
Key Benefits of RTSJ + RTGC

**TECHNICAL**
- Maximize system utilization
- Cross-platform portability
- Leverage standard OS's
- Real-time tools
- Minimize solution complexity
- Better design / architecture choices

**BUSINESS**
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- Increase developer productivity using Java
Key Benefits of Sun Java RTS

**TECHNICAL**
- Maximize system utilization even more (hard + soft RT)
- Cross-platform portability
- Leverage standard OS's
- Real-time tools (DTrace)
- Minimize solution complexity
- Better design / architecture choices
- Easy integration of hard, soft, and non time-critical design elements

**BUSINESS**
- Eliminate latency outliers
  - Save millions of $ lost due to missed market opportunities, productivity losses etc.
- Eliminate risks inherent in custom and proprietary solutions
- Leverage investment in existing Java code, skills
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Questions?
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