A Framework accommodating Categorized Multiprocessor Real-time Scheduling in the RTSJ

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1. Backgrounds

• RTSJ and its implementations provide very good environment for real-time Java applications
  – User-implemented schedulers can be applied to make scheduling decisions
  – However, it does not have any multiprocessor related features
    “How can we make it useful for multiprocessor based schedulers?”

• Scheduling on multiprocessor systems is far more difficult than on single processor systems
  – There is no the Almighty solution for this problem yet

• Several operating systems are capable of multiple schedulers within their kernels
1.1 Categorization of Scheduling Algorithms

- In 2004, Carpenter et al. [1] presented a taxonomy for multiprocessor scheduling algorithms in two-dimensional space
  - The complexity of the priority scheme
    - Static
    - Dynamic, but fixed within a job
    - Fully dynamic
  - The degree of migration allowance
    - No migration
    - Migration only at job boundaries
    - Unrestricted migration

<table>
<thead>
<tr>
<th>Unrestricted migration</th>
<th>(1,3)-restricted</th>
<th>(2,3)-restricted</th>
<th>(3,3)-restricted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Restricted migration</td>
<td>(1,2)-restricted</td>
<td>(2,2)-restricted</td>
<td>(3,2)-restricted</td>
</tr>
<tr>
<td>Partitioned</td>
<td>(1,1)-restricted</td>
<td>(2,1)-restricted</td>
<td>(3,1)-restricted</td>
</tr>
<tr>
<td>1: Static</td>
<td>2: Job-level dynamic</td>
<td>3: Fully dynamic</td>
<td></td>
</tr>
</tbody>
</table>

1.1 Categorization of Scheduling Algorithms

- The progenitors of all scheduling algorithms[2] (grouped by priority dynamics)
  - Static: RM
  - Job-level dynamic: EDF
  - Fully dynamic: LLF

- The basic schedulers for each category

<table>
<thead>
<tr>
<th>Migration degree</th>
<th>Global RM</th>
<th>Global EDF</th>
<th>…</th>
</tr>
</thead>
<tbody>
<tr>
<td>Restricted migration RM</td>
<td>Restricted migration EDF</td>
<td>Restricted migration LLF</td>
<td></td>
</tr>
<tr>
<td>Partitioned RM</td>
<td>Partitioned EDF</td>
<td>Partitioned LLF</td>
<td></td>
</tr>
</tbody>
</table>

1.2 Scheduler Frameworks

• Embracing multiple scheduling algorithms
  – Operating system
    • Kernel
      – Linux
      – LITMUS\textsuperscript{RT}
      – ChronOS
    • Kernel/Application
      – RESCH
  – Middleware framework
    • RTSJ implementations
      – JEOPARD
1.3 RTSJ

• The Real-Time Specification for Java
  – Current official spec: 1.0.2
    • Real-time thread scheduling
    • Memory management
    • Resource sharing
    • Asynchronous event handling
  – Recent ‘Alpha’ release: 1.1 Alpha 6
    • Processor affinity for threads and event handlers
    • Minor updates, improvements and bugfixes
1.3 RTSJ

• Implementation of the RTSJ
  e.g) Java Real-Time System (v2.2u1)
  – A real-time virtual machine
    • Java HotSpot Server VM + @ (RT features)
  – RTSJ class libraries
    • RTSJ 1.0.2 (full)
  – Java class libraries
    • Java SE 5
1.3 RTSJ

- Available RTSJ implementations

<table>
<thead>
<tr>
<th>Implementation</th>
<th>RTSJ Ver.</th>
<th>Vendor</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTSJ RI</td>
<td>1.1a6 / 1.0.2(6)</td>
<td></td>
<td>Last released in JAN 2009</td>
</tr>
<tr>
<td>Sun Java RTS</td>
<td>1.0.2</td>
<td>Oracle</td>
<td></td>
</tr>
<tr>
<td>IBM WebSphere RT</td>
<td>1.0.2</td>
<td>IBM</td>
<td></td>
</tr>
<tr>
<td>JEOPARD</td>
<td>1.1 (JSR282)</td>
<td>JEOPARD Consortium</td>
<td>Uses parallel JamaicaVM from aicas GmbH</td>
</tr>
<tr>
<td>Perc Pico</td>
<td>JSR302</td>
<td>aonix</td>
<td>J2ME environment</td>
</tr>
<tr>
<td>OVM</td>
<td>1.0.1</td>
<td>Purdue University</td>
<td>Under BSD License</td>
</tr>
</tbody>
</table>
2. The CMRF

- The Categorized Multiprocessor Real-time scheduling-supporting middleware Framework
  - Goal: To provide functions to embrace the progenitor algorithms of each category
    - With minimum changes on existing system
  - Environment
    - OS: Linux, kernel 2.6.x
      - Native POSIX Thread Library
      - (PREEMPT_RT or equivalent kernel preemption patches)
    - RTSJ version: 1.0.2 (partial implementation)
      - RealtimeThread
      - Time and timers
      - Scheduler and scheduling parameters
2.1 The CMRF - Structures

- **SCHED_FIFO base scheduler**
  - Provided by Linux kernel
  - The first-come thread with the highest priority is served first.
  - Serving PriorityScheduler in the RTSJ

- **Scheduling ‘Schedulables’ of the RTSJ**
  - Only RealtimeThread is currently supported.
  - Direct use of SCHED_FIFO for thread scheduling
    - `sched_setparam`: Priority changes
    - `sched_setaffinity`: Thread migration

- **Timers as sleep functions**
  - The basic timer is implemented using `nanosleep()` function provided by underlying OS via Java Native Interface
2.1 The CMRF - Structures

- The structure blocks of the CMRF
  - Native block
  - Java Runtime Environment
  - Framework and RTSJ block
  - Application schedulers

- Scheduling sequence
  - Scheduling decisions are made by application schedulers
  - Within the decision making, the eligible thread is dispatched through the framework
  - The dispatched thread is scheduled by SCHED_FIFO
2.1 The CMRF - Structures

• Scheduling events
  – Arrival of a new RealtimeThread
  – Release of next period of a RealtimeThread
  – Finishing a job
  – Timer

• Thread scheduling flow
  1) Job arrival
  2) reschedule()
  3) Dispatch()
  4) run() method
  5) ...
  6) waitForNextPeriod()
  7) (go back to 2)
2.2 The CMRF - Evaluation

• Evaluation
  – Task parameters
    • Cost: \( \leq 10\text{ms} \)
    • Deadline: 100ms
    • Period: 100ms
    • Total jobs: 100,000 releases / processor

  – Test system
    • Two Intel Xeon E5506 2.13GHz processors, 4 cores per processor
      – 8 total processors
    • Four AMD Opteron 6176 SE 2.3GHz processors, 12 cores per processor
      – 48 total processors
    • Ubuntu Linux 10.04.4, kernel 2.6.31
      – With PREEMPT_RT patch applied
    • OpenJDK6
      – HotSpot Server VM
2.2 The CMRF - Evaluation

- Deadline-miss ratio test, partitioned
  - RM starts to miss deadlines from utilization of 7.2/33.6 (90%/70%) with miss ratio of 0.95% and 0.31%
  - EDF and LLF starts missing from 7.2/43.2 (90%) with ratio of 0.39%/0.09%(EDF), 0.31%/0.05%(LLF) respectively
2.2 The CMRF - Evaluation

- Deadline-miss ratio test, restricted migration
  - RM starts to miss deadlines from utilization of 6.4 (80%), ratio of 0.5%
  - EDF and LLF starts missing from 6.4/43.2 (80%/90%), 6.4/48(80%/100%) with ratio of about 0.1% and 0.2%
2.2 The CMRF - Evaluation

- Deadline-miss ratio test, unrestricted migration
  - RM starts to miss deadlines from utilization of 6.4/38.4 (80%) with ratio of about 0.7%
  - EDF starts missing at 8/48 (100%), ratio of 0.83%/0.98%
2.2 The CMRF - Evaluation

- Elapsed time of each algorithms
  - Measurement of time taken for each algorithm
  - Partitioned schemes takes from 81~152us
  - Dispatch() call takes 90~100us, however, partitioned algorithms do not use affinity assign features in the call
    - As calling Dispatch() frequently, the algorithm gets slower
  - Restricted migration schemes takes around 454~628us
  - Global migration schemes takes 643~801ms
2.2 The CMRF - Evaluation

- **Jitter test (within single processor)**
  - Measures release overhead
    - Jitter time = [targeted release time – actual release time]
  - **Parameters**
    - Partitioned
    - Utilization: 0.2
    - Total releases: 160,000 jobs / processor

<table>
<thead>
<tr>
<th></th>
<th>Intel Xeon E5506</th>
<th>(in nanosec.)</th>
<th>AMD Opteron 6176SE</th>
<th>(in nanosec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>JRTS</td>
<td>OVM</td>
<td>CMRF</td>
<td>JRTS</td>
</tr>
<tr>
<td>Jitter, Min.</td>
<td>2,438</td>
<td>2,529</td>
<td>2,823</td>
<td>1,457</td>
</tr>
<tr>
<td>Jitter, Max.</td>
<td>144,426</td>
<td>190,048</td>
<td>52,404</td>
<td>2,295,608</td>
</tr>
<tr>
<td>Average jitter</td>
<td>53,546</td>
<td>62,201</td>
<td>52,404</td>
<td>302,836</td>
</tr>
<tr>
<td>Deviation</td>
<td>20,286</td>
<td>23,017</td>
<td>14,053</td>
<td>180,192</td>
</tr>
</tbody>
</table>
3. Conclusion

• Two-dimensional categorization needs:
  – Priority axis: priority parameters
  – Migration axis: affinity setting

• This can be done by using corresponding system calls and SCHED_FIFO policy
  – Thread scheduling using FIFO policy replaces Schedulables scheduling on the RTSJ

• No other specially built JVM is needed to schedule real-time Java threads on a system
Appendix – Issues and Discussions

• Other major issues
  – Memory management and garbage collection
  – Resource sharing and synchronization

  – High precision & accurate timing ( < ms)
    • Current timer is based on nanosleep() call
      – Precise, but not accurate enough to handle (3,3) schedulers

  – Supporting of thread dispatching model:
    • RTSJ 1.1 thread dispatching model by Wellings in [3]
      – More generalized dispatching for non-priority based scheduling

Thank you for your attention

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