# Real-Time Java on JOP

Martin Schöberl

# Overview

- RTSJ – why not
- Simple RT profile
- Scheduler implementation
- User defined scheduling

# Real-Time Specification for Java

- Real-time extension definition
- Sun JSR - *standard*
- Still not completely finished
- Implementations
  - Timesys RI
  - Purdue OVM

# RTSJ Issues

- Large and complex specification
  - Implementation
  - Verification
- Scoped memory cumbersome
- Expensive longs (64 bit) for time values
- J2SE library
  - Heap usage not documented
  - OS functions can cause blocking

# RTSJ Subset

- Ravenscar Java
  - Name from Ravenscar Ada
  - Based in Puschner & Wellings paper
- Profile for high integrity applications
- RTSJ compatible
- No dynamic thread creation
- Only NHRTT
- Simplified scoped memory
- Implementation?

# Real-Time Profile

- Hard real-time profile
  - See Puschner paper
- Easy to implement
- Low runtime overhead
- No RTSJ compatibility

# Real-Time Profile

- Schedulable objects
  - Periodic activities
  - Asynchronous sporadic activities
    - Hardware interrupt or software event
    - Bound to a thread
- Application
  - Initialization
  - Mission

# Application Structure

- Initialization phase
  - Fixed number of threads
  - Thread creation
  - Shared objects in *immortal* memory
- Mission
  - Runs forever
  - Communication via shared objects
  - Scoped memory for temporary data

# Schedulable Objects

- Three types:
  - RtThread, HwEvent and SwEvent
- Fixed priority
- Period or minimum interarrival time
- Scoped memory per thread
- Dispatched after mission start

```
public class RtThread {
    public RtThread(int priority, int period)
    ...
    public RtThread(int priority, int period,
                    int offset, Memory mem)

    public void enterMemory()
    public void exitMemory()

    public void run()
    public boolean waitForNextPeriod()

    public static void startMission()
}

public class HwEvent extends RtThread {
    public HwEvent(int priority, int minTime,
                   Memory mem, int number)
    public void handle()
}

public class SwEvent extends RtThread {
    public SwEvent(int priority, int minTime,
                   Memory mem)
    public final void fire()
    public void handle()
}
```

# Scheduling

- Fixed priority with strict monotonic order
- Priority ceiling emulation protocol
  - Top priority for unassigned objects
- Interrupts under scheduler control
  - Priority for device drivers
  - No additional blocking time
  - Integration in schedulability analysis

# Memory

- No GC: Heap becomes immortal memory
- Scoped memory
  - Bound to one thread at creation
  - Constant allocation time
    - Cleared on creation and on exit
  - Simple enter/exit syntax

# Restrictions of Java

- Only WCET analyzable language constructs
- No static class initializer
  - Use a static init() function
- No finalization
  - Objects in immortal memory live *forever*
  - Finalization complicates WCET analysis of exit from scoped memory
- No dynamic class loading

# Implementation

- Scheduler for a Java real-time profile
  - Periodic and sporadic threads
  - Preemptive
  - Fixed priority
- Microcode
- Java

# Low-level Functions

- Access to JVM internals
- Exposed as special bytecodes
- In Java declared as native methods
- Translation
- Avoids non-standard class files

# Interrupts in JOP

- Translation of JVM bytecodes to microcode
- Interrupts are special bytecodes
- Inserted in the translation stage
- Call of JVM internal Java method

# Dispatching

- Scheduler is a Java method
- Context of task is on the stack
- Exchange stack
- Set stack pointer
- Simple return

```
private static int newSp;

public static void schedule() {

    Native.wr(0, IO_INT_ENA);

    RtThread th = tasks[active];
    th.sp = Native.getSP();
    Native.int2extMem(...);

    // find ready thread and
    // new timer value

    newSp = tasks[ready].sp;
    Native.int2extMem(...);

    Native.wr(tim, IO_TIMER);
    Native.setSP(newSp);
    Native.wr(1, IO_INT_ENA);
}
```

# Implementation Results

- Scheduler and Dispatch in Java
- Only one function in microcode
- Test JVM in C
  - JOP compatible JVM
  - Implements timer with timestamp counter
  - Scheduling in Java
  - No OS needed, just a 32-bit C compiler

# User-Defined Scheduler

- Java is a safe OO Language
  - No pointers
  - Type-safety
- No kernel user space distinction
- Hooks for scheduling
- Scheduler in Java extended to a framework
  - Class Scheduler
  - Class Task

# Schedule Events

- Timer interrupt
- HW interrupt
- Monitor
- Thread blocking
- SW Event

# Interrupts

- Hook for HW interrupts
- Timer interrupt results in scheduler call
- Access to timer interrupt
- Generate interrupt for blocking
- SW Event is not part of the framework

# Synchronization

- Part of the language
- Each object can be a monitor
- JVM instruction or method declaration

```
synchronized void foo() {
    ...
}
```

```
synchronized(o) {
    ...
}
```

# Synchronization cont.

- Called by framework:
  - monitorEnter(Object o)
  - monitorExit(Object o)
- Attach user data to an object:
  - attachData(Object obj, Object data)
  - getAttachedData(Object obj)

# Services for the Scheduler

- Dispatch
- Time
- Timer
- Interrupts

# Class Scheduler

- Extended for a user-defined scheduler
- User provides:
  - schedule()
  - Monitor handling
- Framework supplies:
  - Software interrupt for blocking
  - Dispatch function
  - Current time
  - Timer interrupt

# Class Task

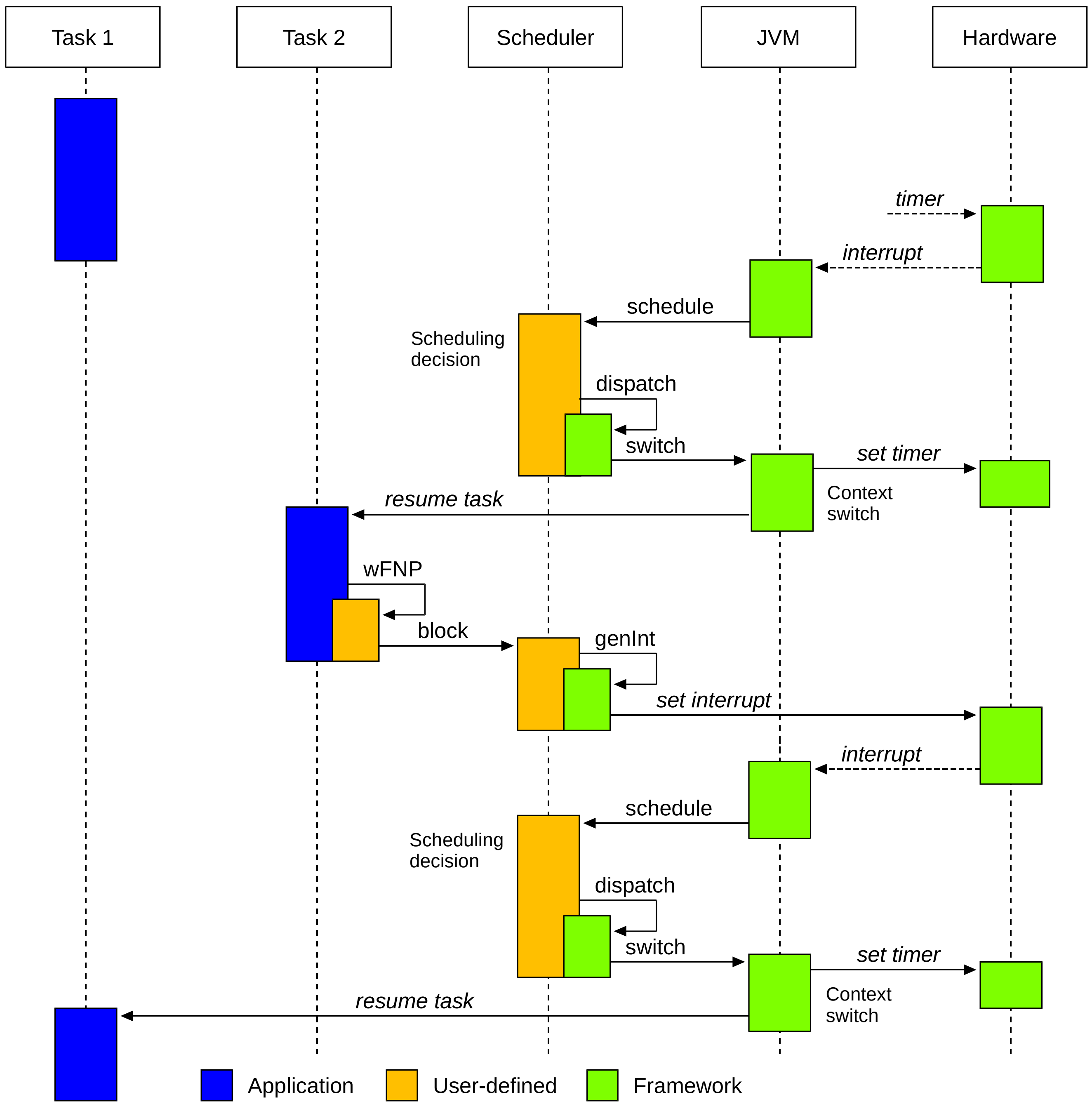
- Minimal (not j.l.Thread)
- Provides list of tasks
- Scoped memory
- Usually extended

# A Simple Example

```
class Work extends Task {

       private int c;
       Work(int ch) {
           c = ch;
       }

       public void run() {

           for (;;) {
               Dbg.wr(c); // debug output
               int ts = Scheduler.getNow() + 3000;
               while (ts-Scheduler.getNow()>0)
                   ;
           }
       }
}
```

# A Simple Example cont.

```
public class RoundRobin extends Scheduler {

    public void schedule() {
        Task t = getRunningTask().getNext();
        if (t==null) t = Task.getFirstTask();
        dispatch(t, getNow()+10000);
    }

    public static void main(String[] args) {
        new Work(‚a');
        new Work(‚b');
        RoundRobin rr = new RoundRobin();
        rr.start();
    }
}
```


Task 1
Task 2
Scheduler
JVM
Hardware
timer
interrupt
schedule
Scheduling decision
dispatch
switch
set timer
Context switch
resume task
wFNP
block
genInt
set interrupt
interrupt
schedule
Scheduling decision
dispatch
switch
set timer
Context switch
resume task
Application
User-defined
Framework

# Summary

- RTSJ is too complex
- System code in Java is possible
- No extra memory protection needed
- Dispatch is 20% slower in framework
- Missing C++ friend in Java
- JopVm in C

# Garbage Collection?

- An essential part of Java
- Without GC it is a different computing model
- RTSJ does not believe in real-time GC
- Real-time collectors evolve
- Active research area
  - For You?

# Further Reading


- P. Puschner and A. J. Wellings. A Profile for High Integrity Real-Time Java Programs. In *4th IEEE International Symposium on Object-oriented Real-time distributed Computing (ISORC)*, 2001.
- M. Schoeberl, Design Rationale of a Processor Architecture for Predictable Real-Time Execution of Java Programs, In *Proceedings of the 10th International Conference on Real-Time and Embedded Computing Systems and Applications (RTCSA)*, 2004.
- M. Schoeberl, Real-Time Scheduling on a Java Processor, In *Proceedings of the 10th International Conference on Real-Time and Embedded Computing Systems and Applications (RTCSA)*, 2004.