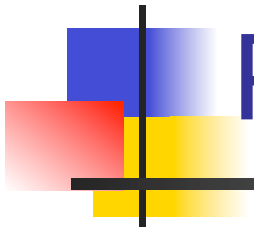
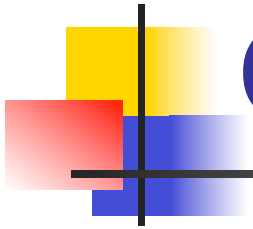


Real-Time Java

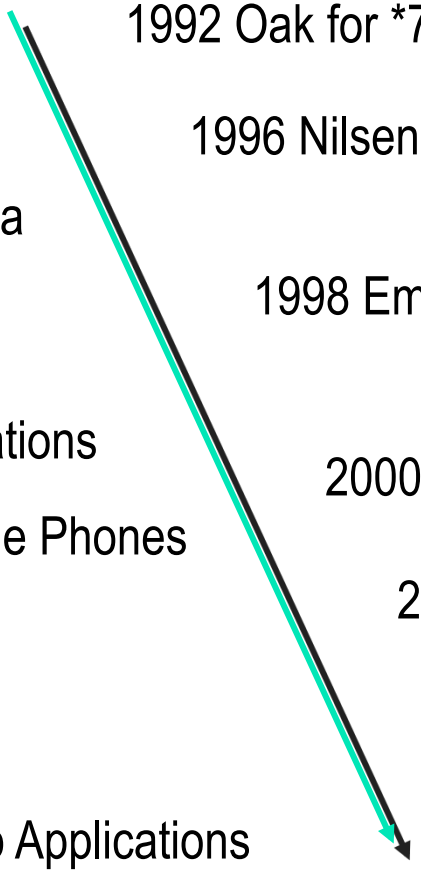
Martin Schöberl



Overview

- What are real-time systems
- Real-time specification for Java
- RTSJ issues, subset
- Real-time profile
- Open question - GC

History of (Real-Time) Java



1992 Oak for *7

1995 Java for the Internet

1996 Nilsen: First Paper on Real-Time Java

1997 picoJava, PersonalJava

1998 EmbeddedJava, RTSJ Start

2000 J2EE: Server Applications

2000 J2ME: Java for Mobile Phones

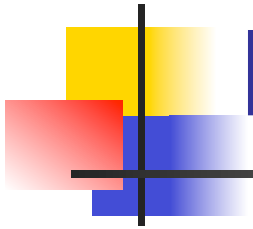
2000 JOP executes first instructions

2002 RTSJ Final Release

2003 JTime

Java for Desktop Applications

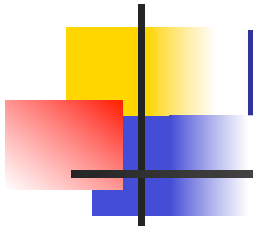
Embedded Systems?



Real-Time Systems

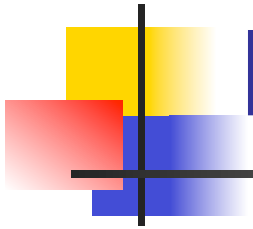
- A definition by John A. Stankovic:

In real-time computing the correctness of the system depends not only on the logical result of the computation but also on the time at which the result is produced.



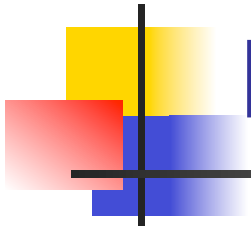
Real-Time Threads

- In real-time systems there are:
  - Periodic threads
  - Event threads/handler
- No continuous running threads
- Fixed Priority driven scheduler
- Threads can starve!



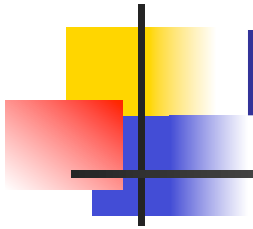
Priority

- Kind of *importance*
- Scheduling theory:
  - Shorter periods – higher priorities
  - RMA: Rate Monotonic Analysis
  - Assignment is optimal
- In (hard) RT forbidden
  - sleep()
  - wait(), notify()



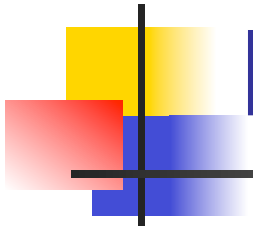
Real-Time Specification for Java

- RTSJ for short
- First JSR request
- Still in flux
- Implementations
  - Timesys RI
  - Purdue OVM
  - Aicas JamaicaVM
  - Sun Mackinac
  - IBM J9



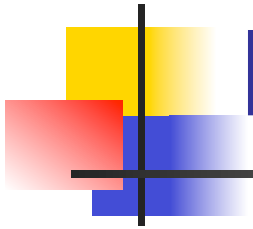
RTSJ Guiding Principles

- Backward compatibility to standard Java
- Write Once, Run Anywhere
- Current real-time practice
- Predictable execution
- No Syntactic extension
- Allow implementation flexibility



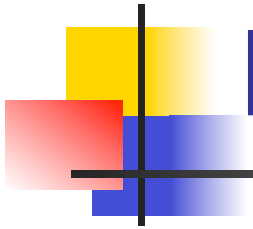
RTSJ Overview

- Clear definition of scheduler
- Priority inheritance protocol
- NoHeapRealtimeThread
- Scoped memory to avoid GC
- Low-level access through raw memory
- High resolution time and timer



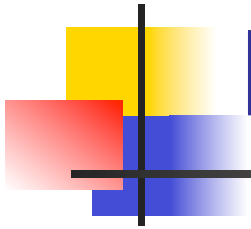
RTSJ: Scheduling

- Standard Java offers no guarantee
  - Even non preemptive JVM possible
- Fixed priority
- FIFO within priorities
- Minimum of 28 unique priority levels
- GC priority level not defined



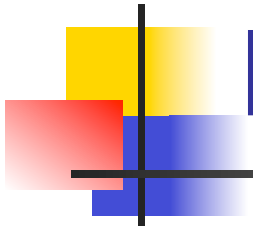
RTSJ: Memory Areas

- GC collected Heap
- Immortal memory
- Scoped memory
  - LTMemory
  - VTMemory
- Physical memory
  - Different time properties
  - Access to HW devices!



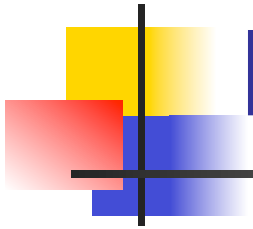
RTSJ: Thread Types

- Extensions of `java.lang.Thread`
  - `RealTimeThread`
  - `NoHeapRealTimeThread`
  - `AsyncEventHandler`
- Scoped and immortal memory for NHRTT
  - Strict assignment rules
  - Not easy to use



RTSJ: Synchronization

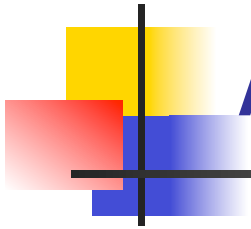
- Use `synchronized`
- Priority inversion possible in standard Java
- Priority inheritance protocol
- Priority ceiling emulation protocol



RTSJ: Scoped Memory

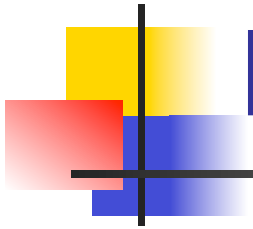
- Cumbersome programming style
- New class for each code part

```
class UseMem implements Runnable {

    public void run() {
        // inside scoped memory
        Integer[] = new Integer[100];
        ...
    }
}

// outside of scoped memory
// in immortal? at initialization?

LTMemory mem = new LTMemory(1024,
    1024);
UseMem um = new UseMem();

// usage
computation() {

    mem.enter(um);
}
```



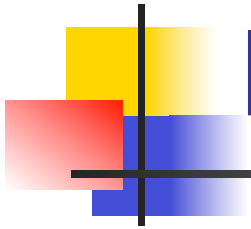
Asynchronous Event Handler

- Difference between bound an unbound
  - Implementation *hint* at application level
  - No functional difference for the application
- Better: only one type
  - Specify a minimum latency at creation
  - Runtime system decides about implementation



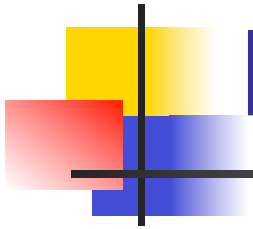
RTSJ Issues

- J2SE library:
  - Heap usage not documented
  - OS functions can cause blocking
- On small systems:
  - Large and complex specification
  - Expensive longs (64 bit) for time values



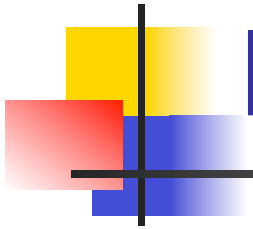
RTSJ Subset

- 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?



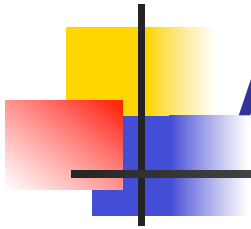
Real-Time Profile

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



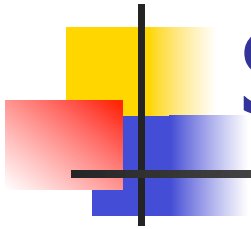
Real-Time Profile

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



Application Structure

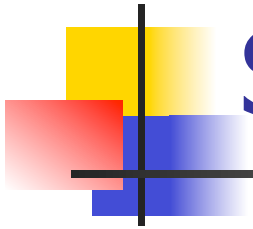
- Initialization phase
  - Fixed number of threads
  - Thread creation
  - Shared objects in *immortal* memory
- Mission
  - Runs forever
  - Communication via shared objects
  - Scoped memory for temporary data



Schedulable Objects

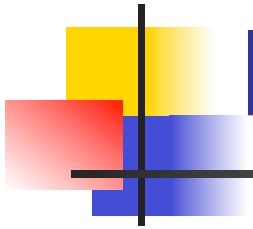
- Three types:
  - RtThread, HwEvent and SwEvent
- Fixed priority
- Period or minimum interarrival time
- Scoped memory per thread
- Dispatched after mission start

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

    public void run()
    public boolean waitForNextPeriod()

    public static void startMission()
}

public class HWEvent extends RtThread {
    public HWEvent(int priority, int minTime,
                   int number)
    public void handle()
}

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



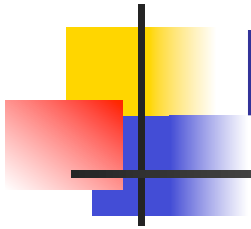
Scheduling

- 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



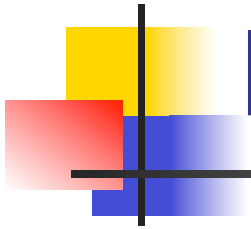
Memory

- 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

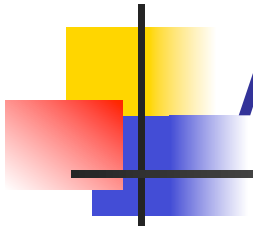
- Only WCET analyzable language constructs
- Static class initializers invoked at JVM start
- No finalization
  - Objects in immortal memory live *forever*
  - Finalization complicates WCET analysis of exit from scoped memory
- No dynamic class loading



RtThread Example

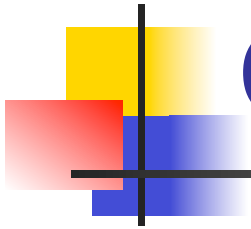
```
public class Worker extends RtThread {

    private SwEvent event;

    public Worker(int p, int t,
                  SwEvent ev) {

        super(p, t);
        event = ev;
        init();
    }

    private void init() {
        // all initialzation stuff
        // has to be placed here
    }
```

```
    public void run() {

        for (;;) {
            work();       // do work
            event.fire(); // and fire
                          // an event

            // wait for next period
            if (!waitForNextPeriod()) {
                missedDeadline();
            }
        }
        // should never reach
        // this point
    }
}
```



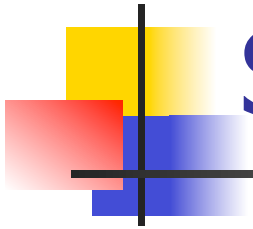
Application Start

```
// create an Event
Handler h = new Handler(3, 1000);

// create two worker threads with
// priorities according to their periods
FastWorker fw = new FastWorker(2, 2000);
Worker w = new Worker(1, 10000, h);

// change to mission phase for all
// periodic threads and event handler
RtThread.startMission();

// do some non real-time work
// and invoke sleep() or yield()
for (;;) {
    watchdogBlink();
    Thread.sleep(500);
}
```



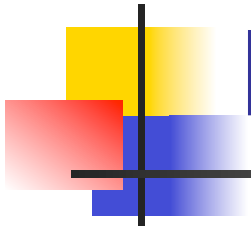
Garbage Collection?

- 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
  - More on Wednesday



Summary

- Real-time Java is emerging
- RTSJ defined by Sun
- Subsets: RJ, JOP-RT
- Real-time GC missing



Project Work

- Meet on Tu 14:00
- Wiki Entry
- 2nd Example
- First Results