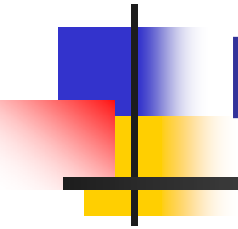
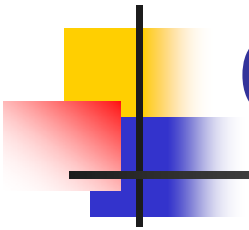


Real-Time Java

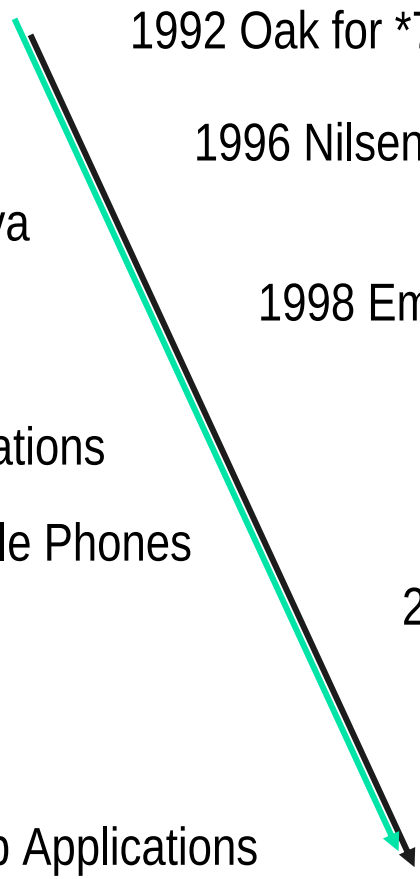
Martin Schöberl



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

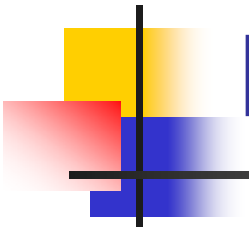
2000 J2ME: Java for Mobile Phones

2002 RTSJ Final Release

2003 JTime

Java for Desktop Applications

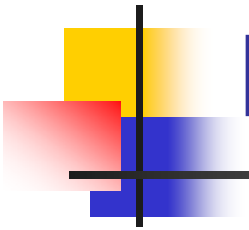
Embedded Systems?



Real-Time Systems

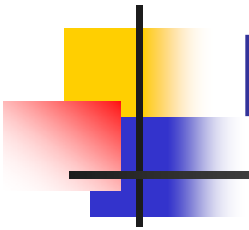
- A definition by John A. Stankovic:

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.



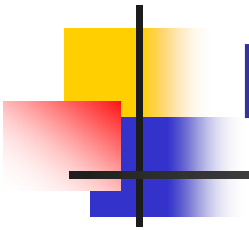
Real-Time Threads

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



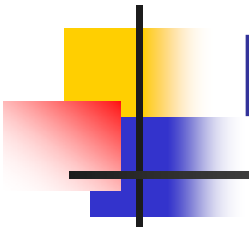
Priority

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



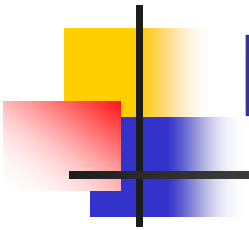
Real-Time Specification for Java

- RTSJ for short
- First JSR request
- Still not completely finished
- Implementations
  - Timesys RI
  - Purdue OVM



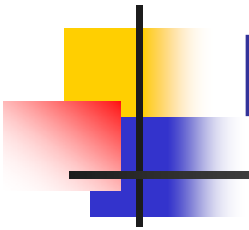
RTSJ Guiding Principles

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



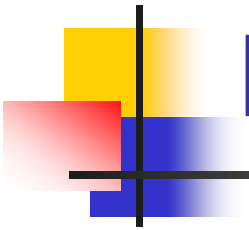
RTSJ Overview

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



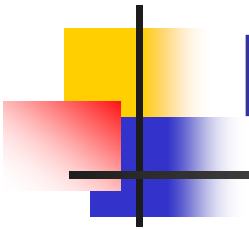
RTSJ: Scheduling

- 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



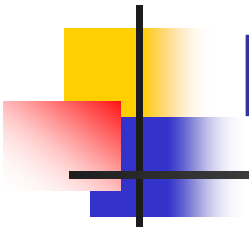
RTSJ: Memory Areas

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



RTSJ: Thread Types

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



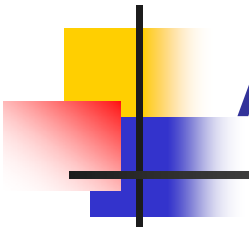
RTSJ: Synchronization

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

RTSJ: Scoped Memory

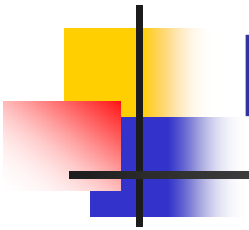
- Cumbersome programming style
- New class for each code part

```
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);
}
```



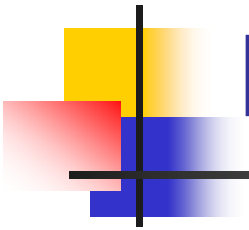
Asynchronous Event Handler

- 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



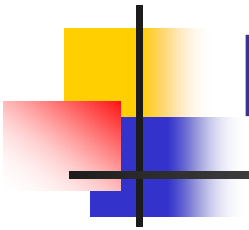
RTSJ Issues

- 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



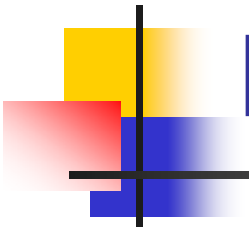
RTSJ Subset

- 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?



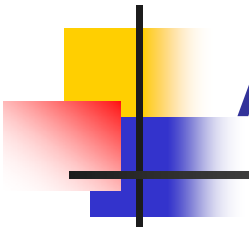
Real-Time Profile

- 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



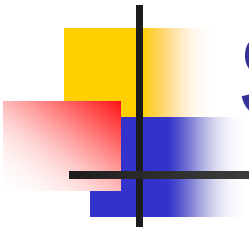
Application Structure

- 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

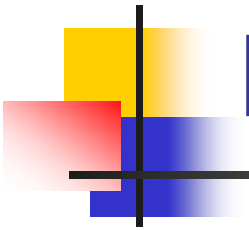
- Three types:
  - RtThread, HwEvent and SwEvent
- Fixed priority
- Period or minimum interarrival time
- Scoped memory per thread
- Dispatched after mission start

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



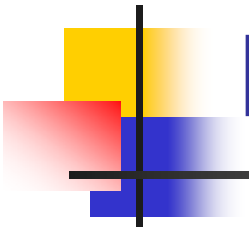
Scheduling

- 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

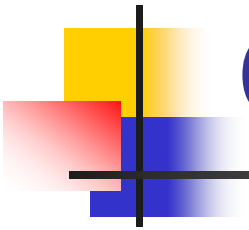
RtThread Example

```
public class Worker extends RtThread {

    private SwEvent event;

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

        super(p, t,
            // create a scoped
            // memory area
            new Memory(10000)
        );
        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

            // some work in
            // scoped memory
            enterMemory();
            workWithMem();
            exitMemory();

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

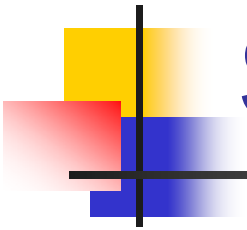
Application Start

```
// 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
  - For You?



Summary

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