User-Defined Clocks in RTSJ

Andy Wellings and Martin Schoelberl

With a little help from our friends in JSR 282 particularly Kelvin Nilsen

Introduction

- RTSJ provides a framework for multiple clocks but only requires a monotonic real-time clock
- An implementation could add new clocks using this framework, but the framework is incomplete if the users wants to add their own clocks
- RTSJ V1.1 provided limited added support

Structure

- Requirements
- The RTSJ Version 1.1 model
- Extending the model
- Implementing the model on JOP
- Conclusions

Requirements: the role of time

- Interfacing with *time*
  - Measuring the passage of time
  - Delaying threads until some future time
  - Programming timeouts
- Representing timing requirements
  - Rates of executions and deadlines
- Satisfying timing requirements
  - Schedulability analysis

Requirements: types of time

- Calendar time
- Simulation time
- Monotonic time
- Execution time
- Atomic time

Time Base

- A time base provides the underlying basis for a particular time type
- For ever time base there is an associated clock
  - The value read from the clock is a transformation of its time base
- E.g, atomic time is measured by a clock which counts the vibration of cesium atoms in response to being exposed to microwaves; counting the corresponding cycles is a measure of time.
  - A single oscillation can be considered as a tick of the clock

Active and Passive Clocks

- Active clocks can support timers
  - Underlying time base can be as simple as a hardware timer chip
- Passive clock only allow the current time to be read
  - Underling time base could be a CPU cycle counter or GPS signal

Relation with `real time'

- Is there a relationship between the user-defined clock's epoch and calendar time?
- Is milliseconds/nanoseconds the most appropriate measure for duration?
  - Consider a crankshaft: full/partial rotation is a tick
  - Length of tick depends on rotation speed
  - Clock is monotonic but not uniform

RTSJ Version 1.1 Model

- Each user-defined active clock should only be responsible for indicating one timing event
- The RTSJ infrastructure should be responsible for maintaining any delay queues

RTSJ V 1.1 API

«interface»
javax.realtime::ClockCallBack

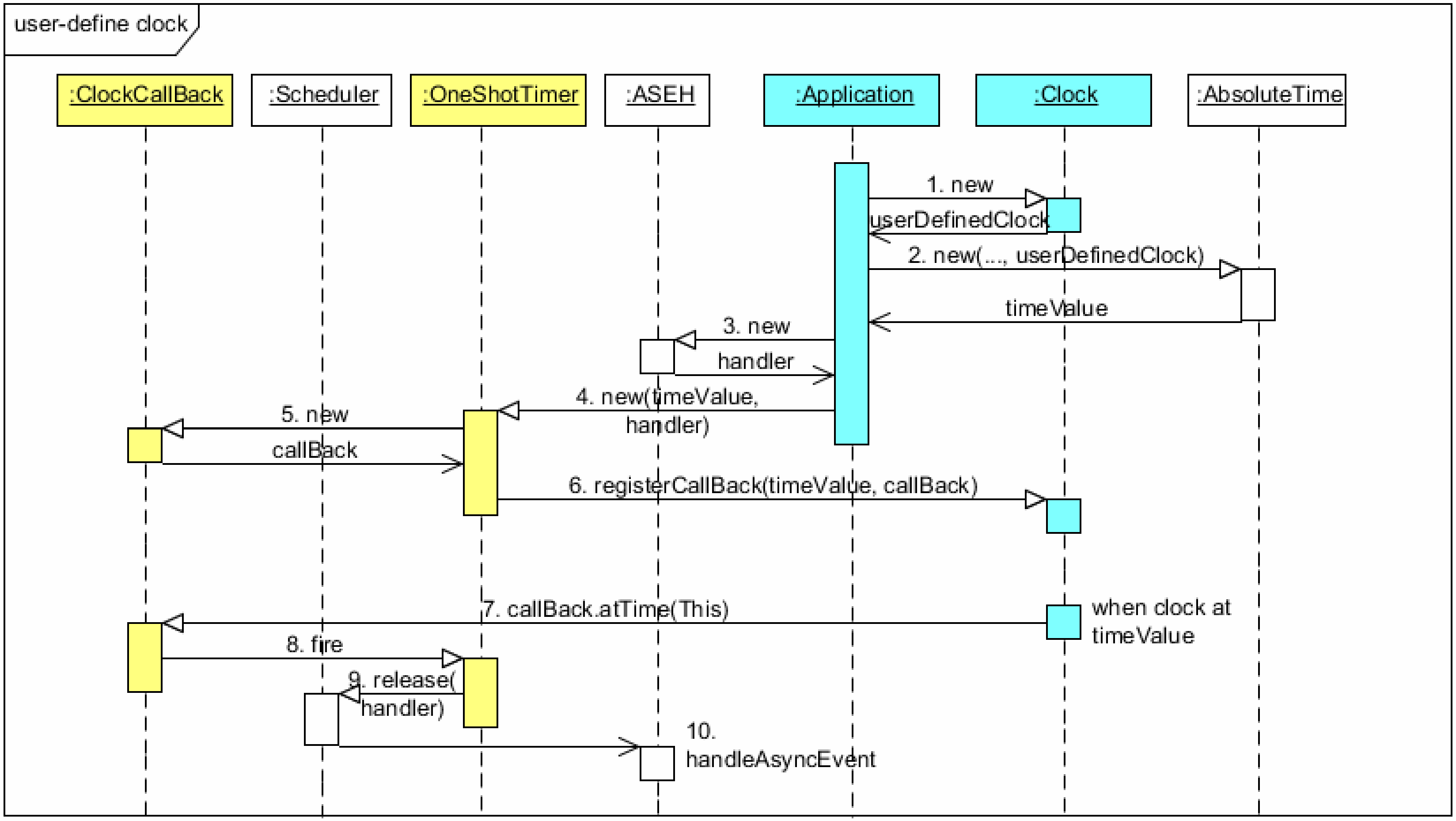
atTime(clock:Clock)
discontinuity(clock:Clock, updatedTime:AbsoluteTime)

javax.realtime::Clock

...

+drivesEvents():boolean
+registerCallBack(time:AbsoluteTime, event:ClockCallBack)
+resetTargetTime(time:AbsoluteTime):boolean

User Case: One shot timer



York

Limitations

- Active user-defined clocks can only be used with the Timer classes
- Reasons
  - To avoid the complexity of linking with OS provided time services (e.g. Timed wait on mutexes)
  - To limit the scope of changes to the RTSJ spec
- Our goal: to explore a more general model

RTS York

Time Bases and Physical Attributes

1. Release a schedulable object from a timer associated with the time base
2. Associate the deadline of some computation with a number of times the physical attribute of the system changes
3. Use the change in the physical attribute as a "timeout" on waiting for another event to occur: e.g. entering into a scope memory area joinAndEnter, a timed Object.wait

Time Bases and Physical Attributes

4. Use it for a minimum inter-arrival “time”; that is, the minimal inter-arrival time of another event should be related to the change in the physical attribute
5. Delay a computation until a certain number of changes have occurred
6. Use “time values” to obtain partial ordering between other events

Motivating Example

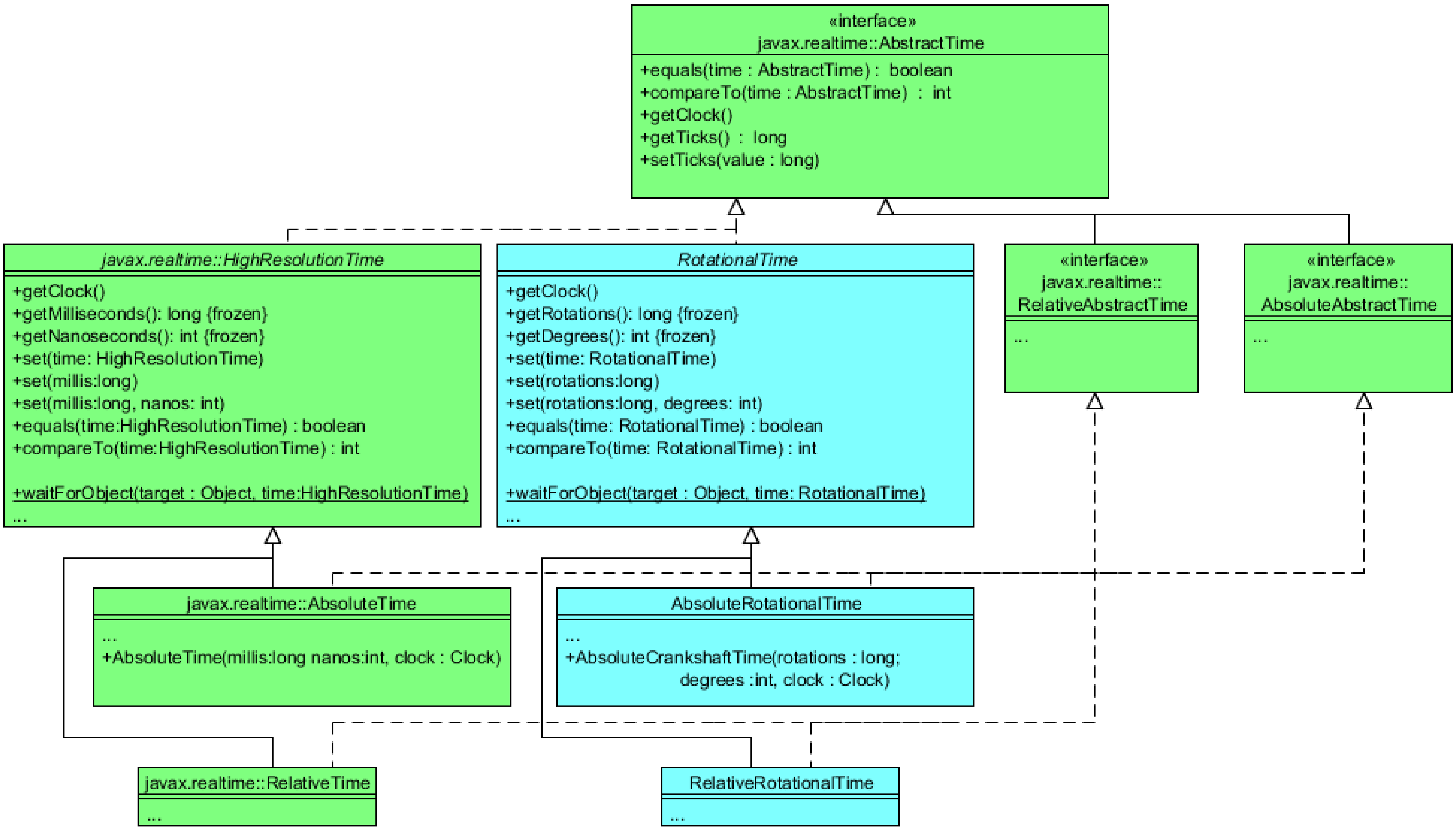
- A time base that is provided by the rotation of a crankshaft
- The full/partial rotation represents the tick of the associated clock
- A tick depends on the speed of rotation
  - absolute time values will not have a direct correlation with wall clock time and milliseconds and nanoseconds is not a relevant measure of relative time
- A tick represents a fraction of the rotation
- Such a clock would be monotonic but not have uniform progress

Alternative Approach

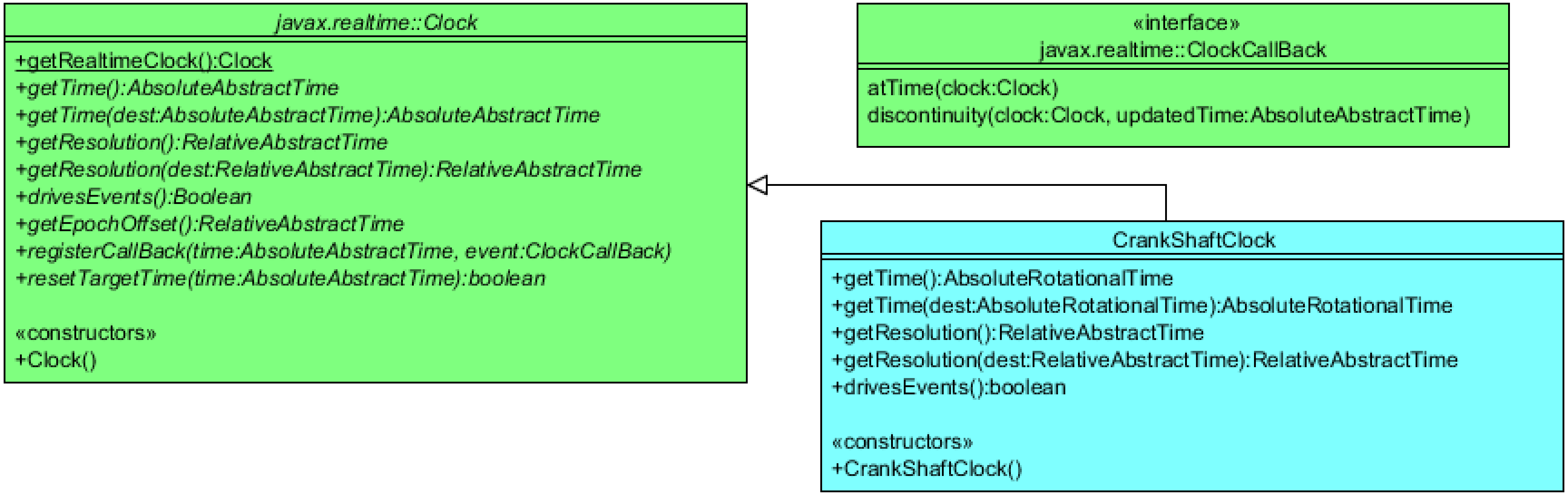
- Treat the “clock” as a device
- Associating asynchronous events with the changes detected by the devices
- Use an event-based programming model rather than a time-based programming model
- Problem: integrating 2, 3, 5 might be difficult

RTS York

API Refactoring I



API Refactoring II



The Crankshaft Clock

```
public class CrankshaftClock extends Clock {
  public CrankshaftClock() { }

  public void tick () {
    now++;  if(now == nextTime) { cback.atTime(this); }
  }
  @Override
  public AbsoluteAbstractTime getTime () {…}
  @Override
  public RelativeAbstractTime getResolution() {…}
  @Override
  protected boolean drivesEvents() {  return true;  }
```

The Crankshaft Clock

```
@Override
protected void registerCallBack (AbsoluteAbstractTime time,
                                           ClockCallBack clockEvent) {
  cback = clockEvent;  nextTime = time.getTicks();
}

@Override
protected boolean resetTargetTime(AbsoluteAbstractTime time) {
  if (now > time.getTicks()) {
    nextTime = time.getTicks();  return true;
  } else return false;
}
...

private long now = 0; private long nextTime = 0;
private ClockCallBack cback;
}
```

Crankshaft Interrupt

```
public class CrankshaftInterruptHandler
        extends InterruptServiceRoutine {
  private CrankshaftClock clock;
  public CrankshaftInterruptHandler(String name,
                                    CrankshaftClock clock) {
    this.clock = clock;
  }
  @Override
  protected synchronized void handle() {
    clock.tick();
  }
}
```

JOP Implementation

- Experiment 1
  - Use CPU cycle counter as a passive clock assuming RTSJ Version 1.1 Model
- Experiment 2:
  - Experiment 1 with the extended model
- Experiment 3
  - Use a simulation of a crankshaft (which generates interrupts) as an active clock
  - Run a periodic thread

Experiement 1

- Implementation trivial
- However:
  1. The counter is 32 bits and overflows after around 43 seconds; this is not catered for in current API but subclass could add a getMaxValue method
  2. Conversion between tick number and RTSJ format needs to operate on longs and requires one division and one remainder operation

Experiment 2

- Introduce two new time types: AbsoluteUserTick and RelativeUserTick
- Now no need for conversions

- Perhaps: base Clock class needs a getMaxValue method?

Experiment 3: Active Clock

- The scheduler must be aware of additional release events
- Current scheduler is highly optimized to avoid unnecessary timer interrupts
  - The ready queue is implicitly encoded in a priority-ordered list of threads

RTS York

Experiment 3

- The algorithm needed to be changed as it is not possible to find the single higher priority thread that will be release next

Conclusions

- The RTSJ version 1.1. add extra capabilities but does not go as far as it could
- User-defined active clocks can only be used with Timers
- We have investigated a more general model
- In the implementation on JOP, these changes are relative moderate
- Supporting scheduling based on user-defined clocks is possible when thread scheduling is implemented by the JVM, but might be almost impossible when the JVM delegates scheduling to the underlying real-time operating system