

RES

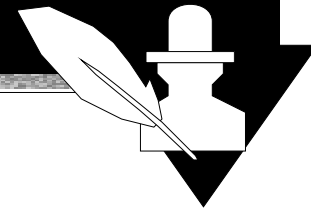


Time & Space

Uwe R. Zimmer – The Australian National University



Real-Time & Embedded Systems



References for this chapter

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all references and links are available on the course page



Real-Time & Embedded Systems



Notions of time and space

The big topics:

What is time? / What is embodiment?

Interfacing with time

Specifying timing requirements

Satisfying timing requirements



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Notions of time and space

What is time?

Do we exist in time, or is time part of our existence?

☞ Is time an intrinsic property of nature? ☞ Platonism

Time is an external phenomenon. Thus simultaneous events happen at the same exact absolute time. There is the underlying assumption that time is progressing, even if no changes can be observed.

☞ Is time a construct which is based on observable events? ☞ Reductionism

Time is the observation of distinguishable events. If the observed events are *'regular'*, a *useful* time-reference can be constructed. If all possible observers detect one event before another one, they are said to be in sequence. If this cannot be assumed for all possible observers, they are said to be simultaneous. Therefore the notion of time is reduced to a **notion of causality**.

☞ Is time 'linear' between observable events?



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Notions of time and space

What is time?

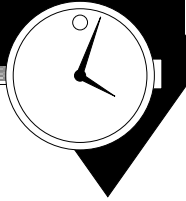
A mathematical notion of time

- Transitivity: $x < y \wedge y < z \Rightarrow x < z$
- Linearity: $x < y \vee x > y \Rightarrow x \neq y$
- Irreflexivity: $\neg(x < x)$
- Density: $x < y \Rightarrow \exists z | x < z \wedge z < y$

☞ Real clocks have **limited** resolutions and are running **asynchronously!**



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Notions of time and space

What is time? – A physical notion of time

- 1676: **Rømer** proves the existence of the speed of light (and measures it).
 - 1687: **Newton's** "Principia Mathematica" assumes an absolute time, independent of space itself and independent of events.
 - 1905: The concept of absolute time is destroyed first by **Einstein** and (a few weeks later) by **Poincaré**.
 - 1915: **Einstein's** general theory of relativity eliminates the independence of time (space) and events in time (space).
- ☞ One principal consequence for measurements of time:

Clocks under higher gravity or in faster observation frames are slower

Practical consequences: clocks in satellites need to be adjusted accordingly



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Notions of time and space

What time is it?

UT0

1884: Mean solar time at Greenwich meridian

UT1

Corrected UT0, ↗ polar motion

UT2

Corrected UT1, ↗ variations in the speed of rotation of the earth

IAT

a caesium 133 atomic clock (current accuracies: one miss in

(International Atomic Time)

10^{13} ticks, e.g. approximately once every 300000 years)

UTC

(Universal Time Coordinated)

a IAT clock, which is synchronized to UT2

(by introducing occasional leap ticks)

– difference between UTC and IAT is < 0.5 s

'1 sec.'

1/86400 of a mean solar day

... or ... 1/31566925.9747 of the tropical year for 1900

(Ephemeris Time defined 1955)

... or ... 9192631770 periods of the radiation corresponding to the transition between two hyperfine levels of the ground state of the caesium 133 atom




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Notions of time and space

What is time?

How real is real-time?

- ‘Real’-time  usually: time as given by *external* sources.

Engineering: it is of no importance how time is defined and understood, as long as an ‘**external reference**’ is given and used as ‘**real-time**’.



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Notions of time and space

What time is it?

Time frames:

Generating a time frame?

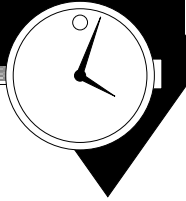
- by a timer generating a regular interrupt
- by employing a RTC-module

Using an existing time-frame?

- by employing time-stamps or sequence numbers of received sensor-readings
- by a radio receiver for UTC or IAT (available in some countries)



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Notions of time and space

What time is it?

☞ Generating a time frame?

- by a timer generating a regular interrupt
- by employing a RTC-module

☞ Using an existing time-frame?

- by employing time-stamps or sequence numbers of received sensor-readings
- by a radio receiver for UTC or IAT (available in some countries)

Common programming languages guarantee

a '**resolution**' and '**accuracy**' of time (in reference to 'a second'),

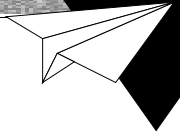
not its origin or meaning.



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Notions of time and space

What is embodiment?



Working hypothesis:

- ☞ Embodied phenomena are those that by their very nature occur in real time and real space.



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Notions of time and space

What is embodiment?

Phenomenology:

- The phenomena of experience as the central aspects and building blocks of understanding.
(rather than: “finding the ‘truth’”)

applied to and trying to combine aspects of

- ☞ **Ontology** (about the nature of being and categories of existence)
- ☞ **Epistemology** (the study of knowledge)



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Notions of time and space – Phenomenology

What is embodiment?

Edmund Husserl (1859-1938, Vienna, Halle, Göttingen, Freiburg):

- Founder of the phenomenological tradition
... as a trial to establish modern science which is firmly grounded on the phenomena of experience (instead of being an abstract mathematical construct).
- Phenomenology originally as a method to examine the nature of intentionality
- Coined the terms
 - **Noema**: the objects of consciousness
 - **Noesis**: the mental experiences of those objects
 - **Lebenswelt** (life-world): the inter-subjective world of everyday-experience

☞ Husserl rejected pure abstract and formalized reasoning



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Notions of time and space – Phenomenology

What is embodiment?

Martin Heidegger (1889-1976, Freiburg):

- Moved phenomenology from a discussion about mental phenomena separated from the physical world (Cartesian dualism)
 - ☞ to a discussion about **connected physical and mental phenomena**.
- Moved the central questions from epistemology to ontology (*'Being and Time'*, 1927)

The meaning is not 'in the head' but in the world!

- Coined terms:
 - **Dasein** (being-in-the-world): 'being as inseparable from the world in which it occurs'
 - ☞ being as always purposeful and active
 - ☞ the world as an unconscious but accessible background
 - **Zuhanden** (ready-to-hand): 'equipment as a part of actual interaction with the world'
 - **Vorhanden** (present-at-hand): 'equipment as a conscious model'



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Notions of time and space – Phenomenology

What is embodiment?

Maurice Merleau-Ponty (1908-1961, Paris (Sorbonne)):

- 'The Phenomenology of Perception' (1945)
- Embodiment has three implications:
 - a body as a physical entity
 - a body as a set of physical skills and situated responses gained from the physical world
 - a body as a set of 'cultural skills' gained from the cultural world in which it is embedded
- Embodied perception as a bi-directional sensation and a basis for empathy (Perception in itself does not exist).

☞ see also: Phenomenology of Jean-Paul Sartre

Recent works in robotics (and insights about biological sensors) blur the line between action and perception even further.



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Notions of time and space

What is embodiment?

back to the working hypothesis:

- Embodied phenomena are those that by their very nature occur in real time and real space.

refinement:

- Embodiment is the property of any engagement with the real world which (may) makes this engagement meaningful.

(Paul Dourish)

- Embodied phenomena are the essence of meaningful interaction

(Real-time and embedded systems are the technical instantiations of embodiment)



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Notions of time and space

What is embodiment?

Implications:

- ☞ There is *no such thing* as
‘intelligence’, ‘autonomy’ or any other cognitive process,
which is *independent of a physical environment*.
- ☞ There is *no such thing* as a
universal system or body (mechanical design, robot, device, ...)
which is *operational in all physical environments*.



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Notions of time and space

What is embodiment?

Meaningfully embedded systems are part of an '*ecological niche*' (Rolf Pfeifer):

- **The operational environment** is supportive and employed by the system
- **The embedded system** is constructed as a part of the operational environment and according to the task
- **The task** is meaningful considering the morphology and cognitive ability of the system as well as the response from the environment

☞ i.e. being *situated, embodied, and self-sufficient*



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Notions of time and space

What is embodiment?

☞ Embodied skills depend on

a tight coupling between perception and action

... up to the level where the distinction between both can become difficult

☞ Tight coupling between perception and action means

to operate under real-time constraints

... and to construct meaningful morphologies



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Notions of time and space

The big topics:

What is time? / What is embodiment?

Interfacing with time

Specifying timing requirements

Satisfying timing requirements



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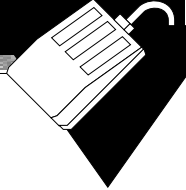
Interfacing with time

What time is it in ...

	Resolution (syntactical)	Range (all time variables)	Requested resolution (clock ticks)	Actual resolution (detectable?)
JAVA	<i>ms</i>	undefined	undefined	no
RT JAVA	<i>ms, ns</i>	undefined	undefined	yes
Ada95	<i>ms, μs, ns</i>	>50 years	<1 <i>ms</i>	yes
POSIX threads	<i>ms, ns</i>	undefined	<20 <i>ms</i>	yes
C	integer (as seconds)	undefined	undefined	no



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Notions of time in Ada

Ada.Real-Time package

```
package Ada.Real_Time is
  type Time is private;
  Time_First : constant Time;
  Time_Last  : constant Time;
  Time_Unit  : constant := 10#1.0#E-9; -- ns

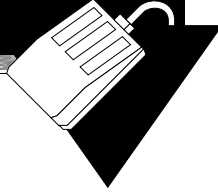
  type Time_Span is private;
  Time_Span_First : constant Time_Span;
  Time_Span_Last  : constant Time_Span;
  Time_Span_Zero  : constant Time_Span;
  Time_Span_Unit  : constant Time_Span;

  Tick : constant Time_Span; -- actual clock resolution < 1 ms
  function Clock return Time;

  (... operations on and conversions with time and time_span ...)
end Ada.Real_time
```



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Notions of time in RT-Java

RT-Java time classes

Time root class:

```
public abstract class HighResolutionTime implements java.lang.Comparable  
    direct known subclasses: AbsoluteTime, RelativeTime, RationalTime
```

- similar to Ada.Real-Time, but no requested accuracy
- adds the concept of frequency ('rational time'), but does not guarantee for equidistant instantiations.

Clock Class:

```
public abstract class Clock  
{  
    public static Clock getRealtimeClock ();  
    public abstract RelativeTime getResolution ();  
    public abstract void setResolution (RelativeTime resolution);  
}
```



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Notions of time in POSIX

Real-time clock interface in POSIX

```
#define CLOCK_REALTIME ...; // clockid_t type
struct timespec {
    time_t tv_sec; /* number of seconds */
    long tv_nsec; /* number of nanoseconds */
};
typedef ... clockid_t;

int clock_gettime (clockid_t clock_id, struct timespec *tp);
int clock_settime (clockid_t clock_id, const struct timespec *tp);
int clock_getres (clockid_t clock_id, struct timespec *res);

int clock_getcpuclockid (pid_t pid, clockid_t *clock_id);
int clock_getcpuclockid (pthread_t_t thread_id, clockid_t *clock_id);

int nanosleep (const struct timespec *rqtp, struct timespec *rmtp);
/* nanosleep return -1 if the sleep is interrupted by a */
/* signal. In this case, rmtp has the remaining sleep time */
```



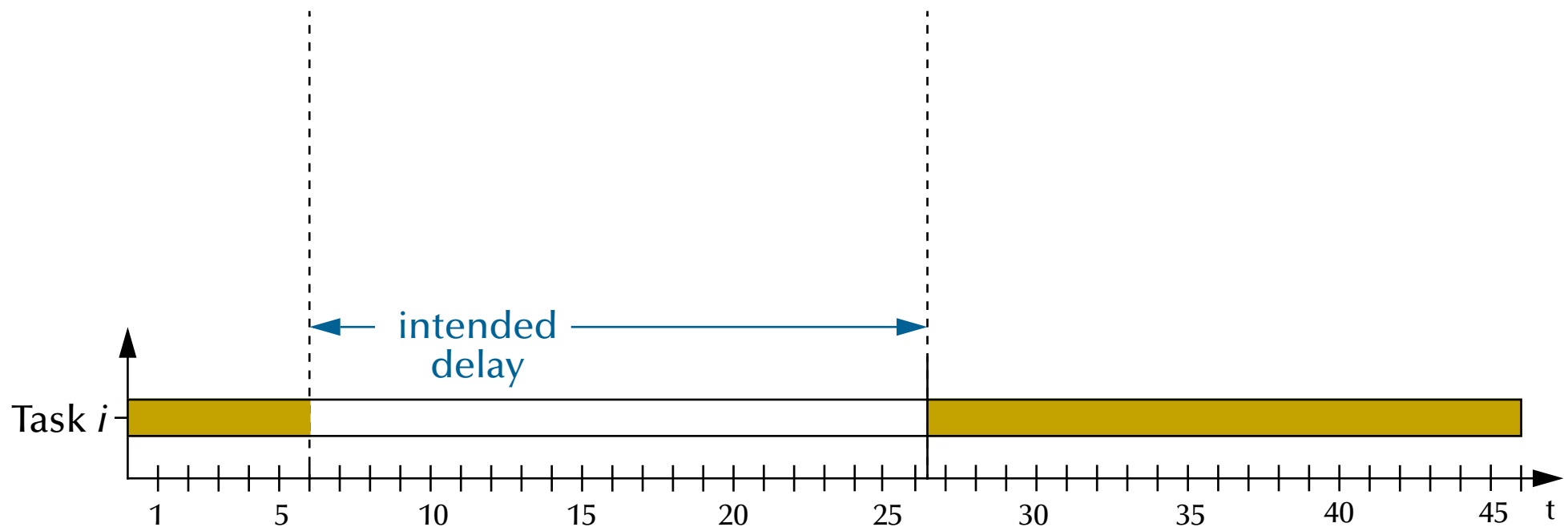
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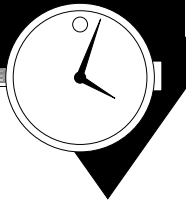


Interfacing with time

Programming primitive 'Delay'

- Alternative for 'busy-wait' and interrupts: Suspend a task for a fixed time

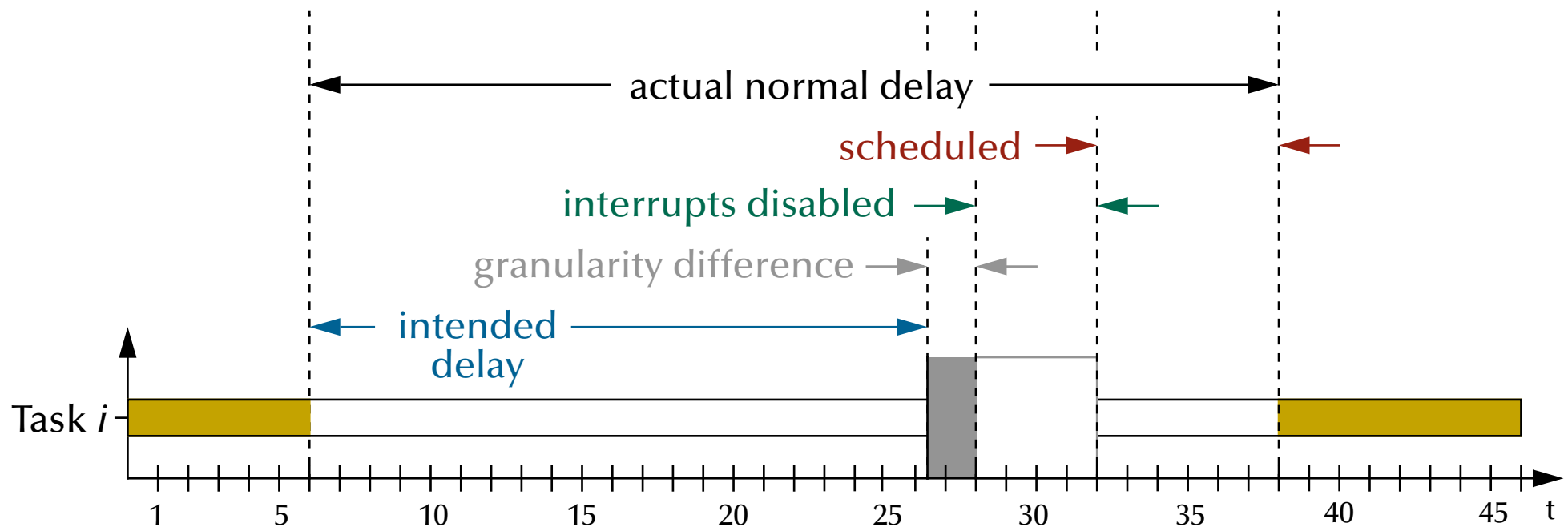




Interfacing with time

Programming primitive 'Delay'

- Alternative for 'busy-wait' and interrupts: Suspend a task for a fixed time
 - **but** all these process or thread delays are precise only in their lower bound!





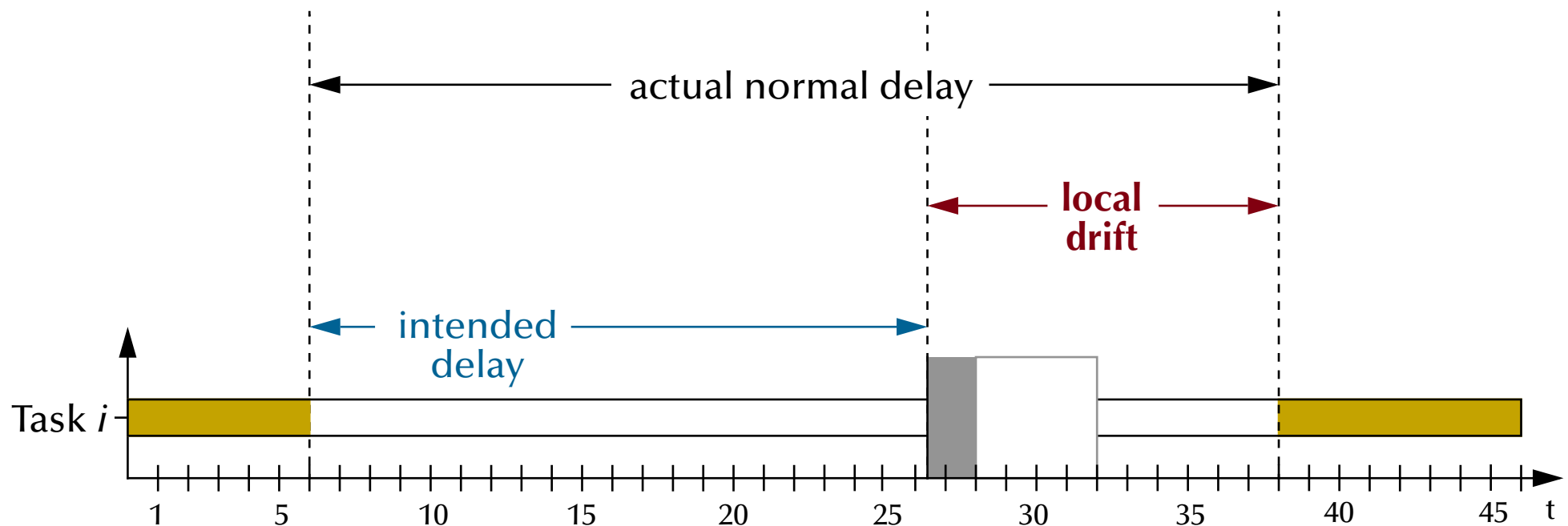
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Interfacing with time

Programming primitive 'Delay'

- Alternative for 'busy-wait' and interrupts: Suspend a task for a fixed time
 - **local drift:** sum of all additional actual delays





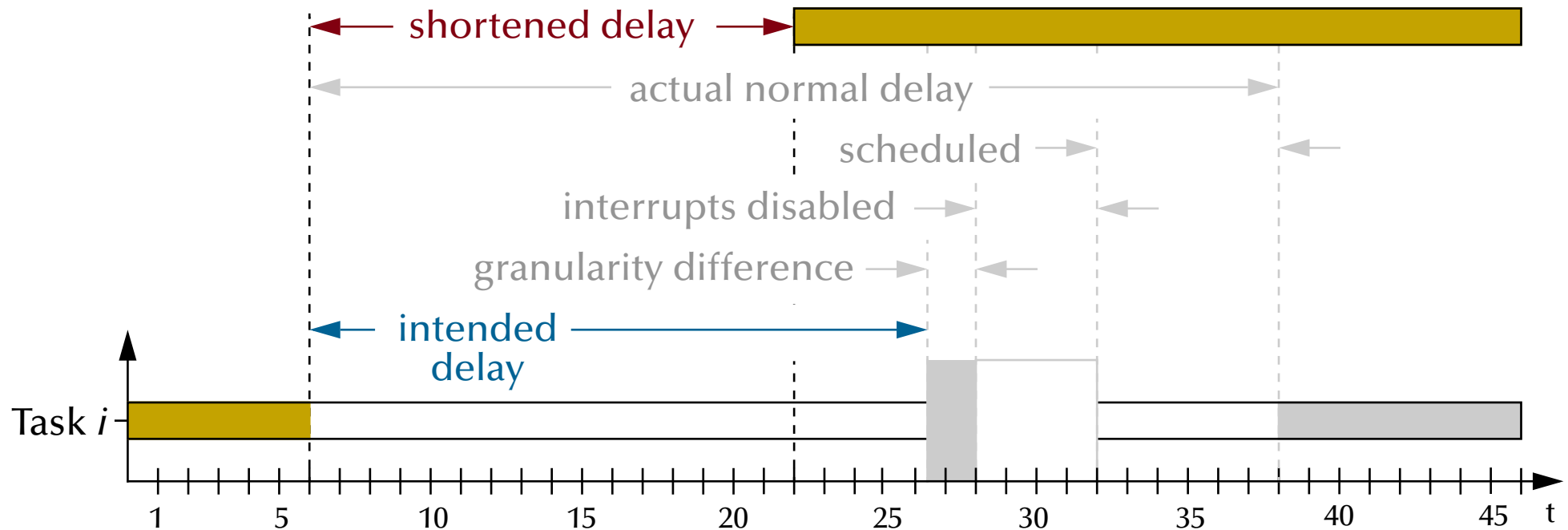
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Interfacing with time

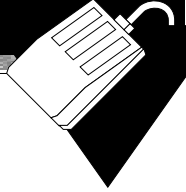
Programming primitive 'Delay'

- Alternative for 'busy-wait' and interrupts: Suspend a task for a fixed time
 - if task i is enabled for interrupts, it can also be activated earlier!





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Interfacing with time

Relative delay

(Ada95)

```
task T;  
task body T is  
begin  
  loop  
    Action;  
    delay 5.0; -- sec.  
  end loop;  
end T;
```

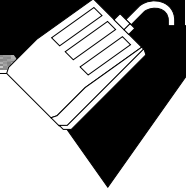
This loop will delay **at least** for 5 seconds:

local and **cumulative** drift effects here!





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Interfacing with time

Relative as absolute delay?

(Ada95)

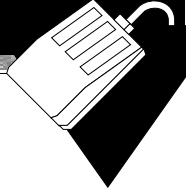
```
task body T is
  Interval: constant Duration:= 5.0; -- sec.
  Start_Time: Time;
begin
  loop
    Start_Time:= Clock;
    Action;
    delay Interval - (Clock - Start_Time);
  end loop;
end T;
```

Delay time calculation
is **not atomic!**





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Interfacing with time

Relative as absolute delay?

(Ada95)

task body T is

```
Interval: constant Duration:= 5.; -- sec.
```

```
Start_Time: Time;
```

```
begin
```

```
  loop
```

```
    Start_Time:= Clock;
```

```
    Action:
```

```
    delay Interval - (Clock - Start_Time);
```

```
  end loop;
```

```
end T;
```

Delay time calculation
is **not atomic!**



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Interfacing with time

Absolute delay

(Ada95)

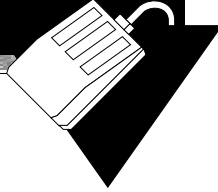
```
task body T is
  Interval: constant Duration:= 5.0; -- sec.
  Next_Time: Time;
begin
  Next_Time:= Clock + Interval;
  loop
    Action;
    delay until Next_Time;
    Next_Time:= Next_Time + Interval;
  end loop;
end T;
```

This loop will delay
on average for 5 seconds:

note that this also holds, if 'Action' is sporadically longer than 5 s



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Interfacing with time

Zero delay?

(Ada95)

task body T is

```
begin
  loop
    Action;
    delay 0.0;
  end loop;
end T;
```

Allow explicitly
for a **task-switch**

- the delay statement does not only suspend the current task, but also potentially activates other tasks
- ☞ may be used to enable other processes on the same priority level



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Interfacing with time

Delays

Absolute & relative delays are available in:

- Real-Time Java, Pearl, Ada95, ... and many other process-oriented languages

Only relative delays are available in some 'low-level' environments:

- POSIX: `nanosleep` (absolute delays need to be constructed employing timers and signals)

Only absolute delays are available in some 'harder' real-time environments:

- Occam2, Ada95 (Ravenscar profile), ...



Interfacing with time

Timeouts

As a third alternative to busy-waiting and infinite blocking, **timeouts** are implemented in:

- **Shared variable** communications
 - Semaphore
 - Conditional critical regions
 - Monitors
 - Protected objects
- **Message passing** between processes
 - Asynchronous and synchronous message transfers
 - Remote procedure calls
 - Remote objects
- **Actions**



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Interfacing with time

Timeouts on semaphore

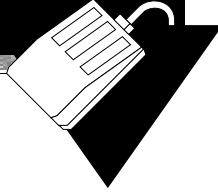
POSIX:

```
if (sem_timedwait (&call, &timeout) < 0) {
    if (errno == ETIMEDOUT) {
        /* timeout occurred, try something else */
    }
    else {
        /* some other error occurred, do something about it */
    }
}
else {
    /* semaphore is locked successfully, go ahead */
};
```

Suspend current process until the semaphore `call` is open or the time-span `timeout` has passed



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Interfacing with time

Timeouts on entry calls

(same for task-entry calls (message passing) and protected object calls (monitors))

```
task body Sensor is
  T : Temperature;
begin
  loop
    -- find temperature T somewhere
  select
    Controller.Call(T);
  or
    delay 0.5; -- sec.
    -- action if temperature could not be delivered in time
  end select;
end loop;
end Sensor;
```

Try calling for
500ms





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Interfacing with time

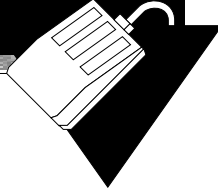
Timeouts on incoming calls

```
task body Controller is
Current_Temp : Temperature;
begin
  loop
    select
      accept Call (T: Temperature) do
        Current_Temp := T;
      end Call;
    or
      delay 1.0; -- sec.
      -- action if the temperature was not available in time
    end select;
    -- normal processing
  end loop;
end Controller;
```

accept calls for a
limited time-span of 1s



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Interfacing with time

Timeouts on incoming calls

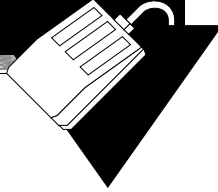
```
task body Controller is
-- declarations
begin
  loop
    select
      accept Call (T: Temperature) do
        Current_Temp:= T;
      end Call;
    or
      delay until Deadline;
      -- no further calls before the deadline
    end select;
    -- normal processing
  end loop;
end Controller;
```

accept any number of calls
until a closing time 'Deadline'
for this entry





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Interfacing with time

No-wait on incoming calls

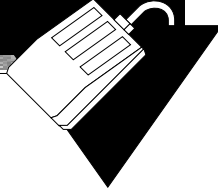
```
task body Controller is
-- declarations
begin
  loop
    select
      accept Shutdown do
        -- termination actions
        exit;
      end Shutdown;
    else
      -- normal operation
    end select;
    -- synchronize
  end loop;
end Controller;
```

synchronous alternative for
an interrupt acceptance





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Interfacing with time

No-wait on entry calls

(same for task-entry calls (message passing) and protected object calls (monitors))

```
task body Sensor is
```

```
T : Temperature;
```

```
begin
```

```
  loop
```

```
    -- measure temperature T
```

```
  select
```

```
    Controller.Call(T);
```

```
  else
```

```
    -- action if temperature can not yet be delivered,
```

```
    -- e.g. further refine the measurement
```

```
  end select;
```

```
end loop;
```

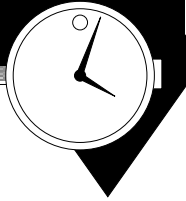
```
end Sensor;
```

Try delivering,
else refine the result further





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Interfacing with time

Timeout on actions

- All above timeouts suspend / activate a process / task / thread at a synchronization point.
- Up to now, there wasn't any abortion of on-going actions, due to a timeout

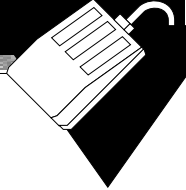
to achieve this there need to be an

☞ **asynchronous change of control flows**

- on the level of code-blocks: ☞ **Timeout on actions**
- on the level of processes / tasks / threads: (investigated later)



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Interfacing with time

Timeout on actions

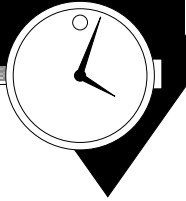
(Ada95)

Monitor a code block:

```
select
  delay until Deadline;
  -- computations did not finish in time: take measures
then abort
  -- hard to predict sequence of computations
end select;
```



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Interfacing with time

Timeout on actions

☞ Common RT-systems concept:

Timeliness is often more important than **Precision**

1. **Get a first approximation** in fixed amount of time and well before the deadline
2. Inspect the deadline and if there is enough spare time:
3. **Improve the result** and keep a record of improvements (while keeping an eye on the deadline)
 - 3-a If the most precise result is delivered before the deadline occurs: ✓
 - 3-b else use the closest approximation so far: ✓

☞ The deadline is fulfilled and there is a result in any case



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Interfacing with time

Timeout on actions

Get a first approximation and employ spare time for refinements:

```
Deadline := ... -- set an absolute deadline for the computations
-- compulsory computations (save first result)
select
  delay until Deadline;
  Precise_Result := False;
then abort
  while Result_Can_Be_Improved loop
    -- optimising computations (save results after each iteration)
  end loop;
  Precise_Result := True;
end select;
-- use result
```

Take a first guess

improve, improve, improve, ...

Continue in time and with the best result possible



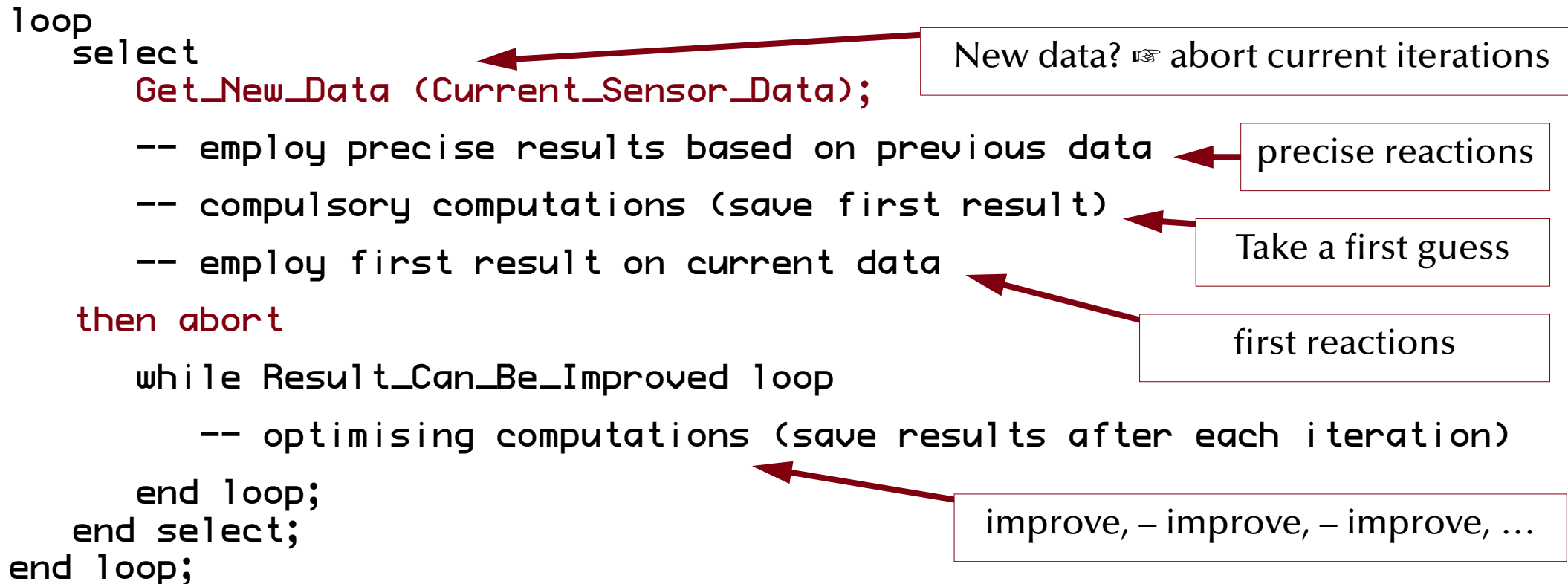
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Interfacing with time

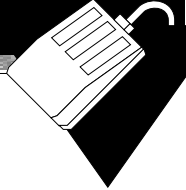
Timeout on actions

Time-base can also be given externally, e.g, via a protected call:





Real-Time & Embedded Systems



Interfacing with time

Timeout on actions

(RT-Java)

Similar methods in RT-Java:

```
public class Timed extends AsynchronouslyInterruptedException
    implements java.io.Serializable
{
    public Timed (HighResolutionTime time) throws IllegalArgumentException;
    public boolean doInterruptible (Interruptible logic);
    public void    resetTime      (HighResolutionTime time);
}
```

☞ see full example of imprecise computations in *RT-Java* in the course textbook.

(timeouts on actions in *POSIX* need to be emulated employing timers and signals)



Real-Time & Embedded Systems



Notions of time and space

The big topics:

What is time? / What is embodiment?

Interfacing with time

Specifying timing requirements

Satisfying timing requirements



Real-Time & Embedded Systems

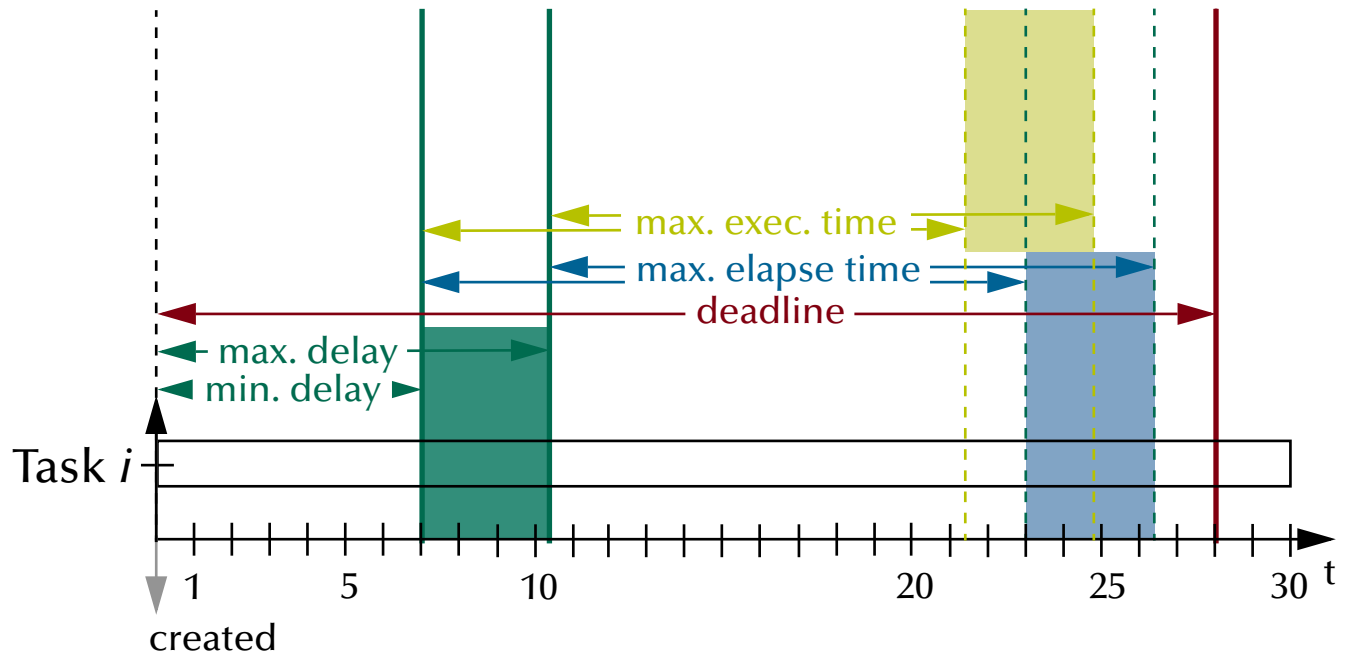


Specifying timing requirements

Temporal scopes

Common attributes:

- Minimal & maximal delay after creation
- Maximal elapsed time
- Maximal execution time
- Absolute deadline





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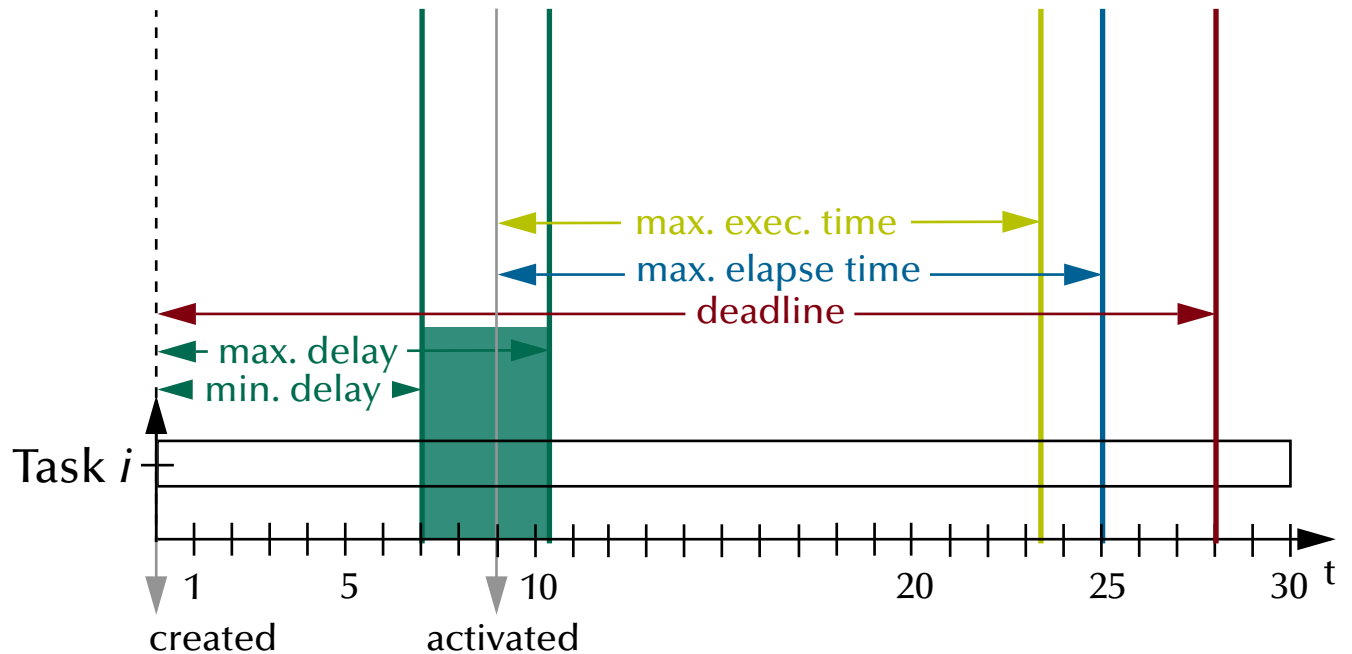


Specifying timing requirements

Temporal scopes

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- Absolute deadline





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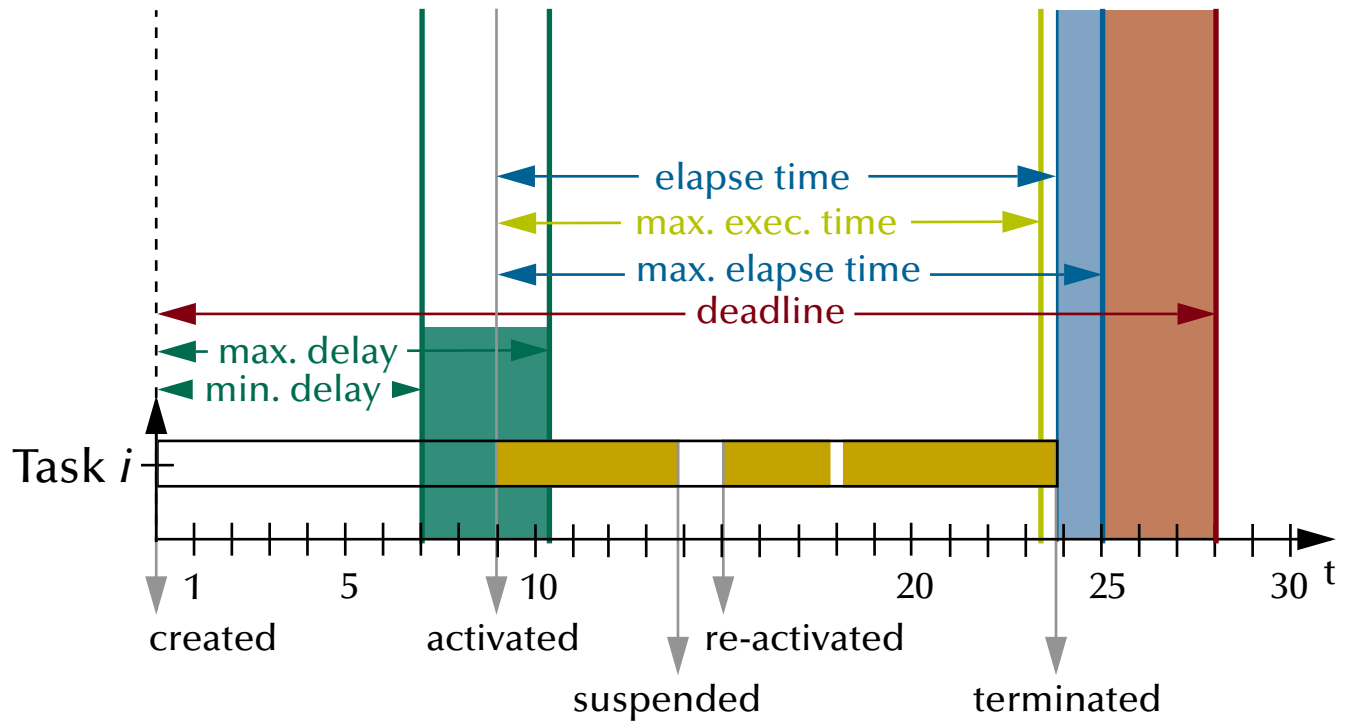


Specifying timing requirements

Temporal scopes

Common attributes:

- Minimal & maximal delay after creation
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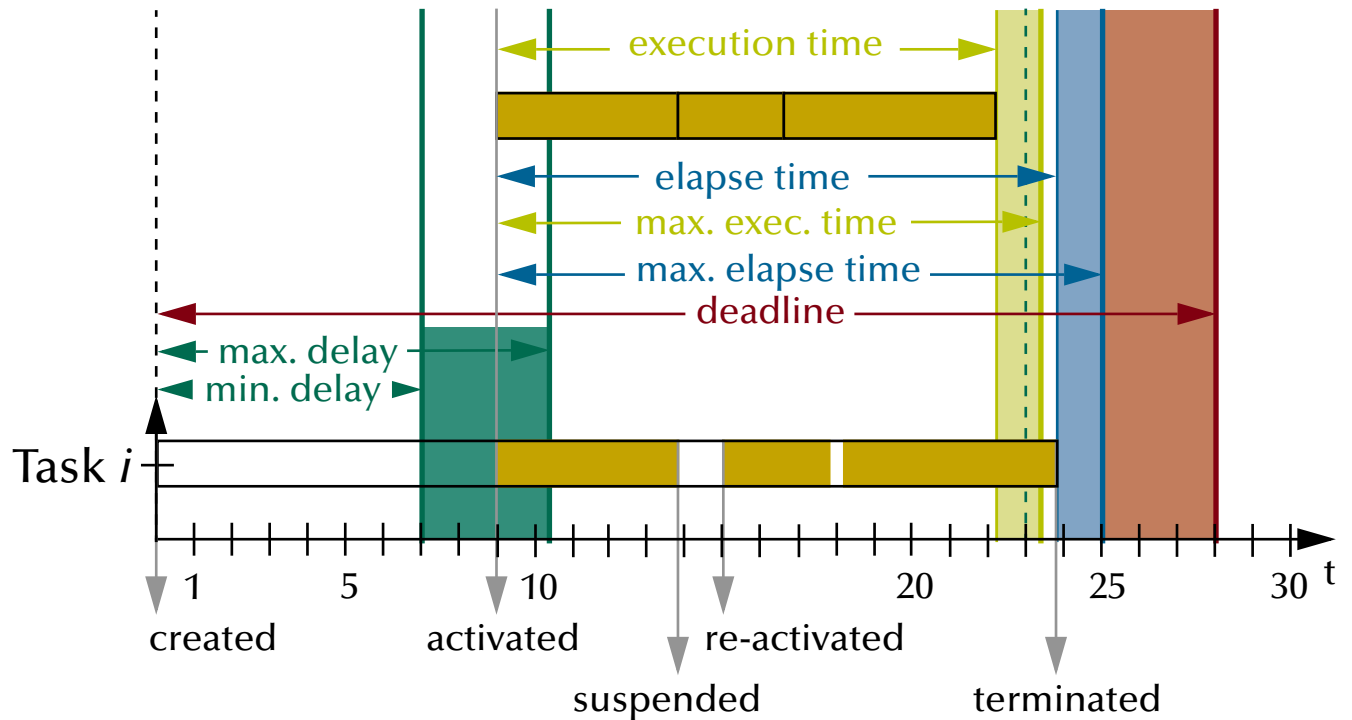


Specifying timing requirements

Temporal scopes

Common attributes:

- Minimal & maximal delay after creation
- Maximal elapsed time
- Maximal execution time
- Absolute deadline





Real-Time & Embedded Systems



Specifying timing requirements

Some common scope attributes

Temporal Scopes can be:

Periodic

– e.g. controllers, samplers, monitors

Aperiodic

– e.g. 'periodic on average' tasks, burst requests

Sporadic / Transient

– e.g. mode changes, occasional services

Deadlines (absolute, elapse, or execution time) can be:

Hard

– single failure leads to severe malfunction

Firm

– results are meaningless after the deadline

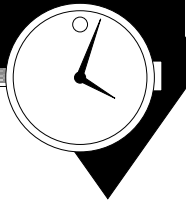
Soft

– only multiple or permanent failures threaten the whole system

– results may still be useful after the deadline



Real-Time & Embedded Systems



Specifying timing requirements

Some common scope attributes

Temporal Scopes can be:

Periodic	– e.g. controllers, samplers, monitors
Aperiodic	– e.g. ‘periodic on average’ tasks, burst requests
Sporadic / Transient	– e.g. mode changes, occasional services

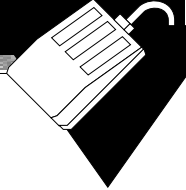
Deadlines (absolute, elapse, or execution time) can be:

Hard	– single failure leads to severe malfunction
Firm	– deadline is threatened but does not threaten the whole system
Soft	– results may still be useful after the deadline

distinction is not so obvious in practical systems



Real-Time & Embedded Systems



Specifying timing requirements

Language support for specifying temporal scopes

Real-time Euclid

DSP

CRL

Pearl

Ada95

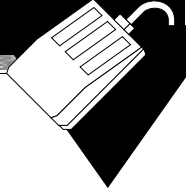
POSIX

Esterel

Real-time Java



Real-Time & Embedded Systems



Specifying timing requirements

Real-time Euclid

Language features:

- Recursions and goto-statements are prohibited.
- Loops are restricted to time bounded loops.
- Processes are static and non-nested.

Time scopes:

- **periodic** <Frameinfo> **first activation** <TimeOrEvent>
- **atEvent** <ConditionalId> <Frameinfo>



Real-Time & Embedded Systems



Specifying timing requirements

Real-time Euclid

Periodic process example:

```
realTimeUnit := 1.0 % = 1 seconds
```

```
var Reactor      : module
```

```
var startMonitoring : activation condition atLocation 16#A10D
```

connect event to an interrupt-address

```
process TempController : periodic
```

```
frame 60
```

```
first activation atTime 600
```

```
or atEvent startMonitoring
```

```
% import list
```

```
%
```

```
% execution part
```

```
%
```

```
end TempController
```

```
end Reactor
```

time-scope specification

no loop! (scheduler activates process)



Real-Time & Embedded Systems



Specifying timing requirements

Real-time Euclid

```
task body Temp_Controller is
  Next_Release : Duration;
begin
  select accept Start_Monitoring;
  or      delay 600.0; -- sec.
  end select;

  Next_Release := Clock + 60.0; -- sec.

  loop
    -- execution part

    delay until Next_Release;
    Next_Release := Next_Release + 60.0; -- sec.
  end loop;
end Temp_Controller;
```

Ada-emulation of the above
RT-Euclid program



Real-Time & Embedded Systems



Specifying timing requirements

Real-time Euclid

```
task body Temp_Controller is
```

```
  Next_Release : Duration;
```

```
begin
```

```
  select accept Start_Monitoring;
```

```
  or      delay for
```

```
  end select;
```

```
  Next_Release :
```

```
  loop
```

```
    -- execution...
```

```
    delay until Next_Release;
```

```
    Next_Release := Next_Release + 60.0; -- sec.
```

```
  end loop;
```

```
end Temp_Controller;
```

Ada-emulation of the above
RT-Euclid program

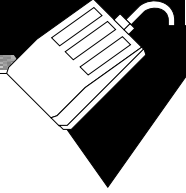
but:

no formal time-scope specification!

→ no schedulability analysis!



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Specifying timing requirements

Real-time Euclid

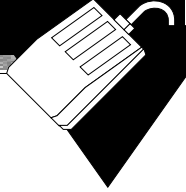
State:

Real-Time Euclid was suggested by Kligerman and Stoyenko in 1986

- ☞ Additional schedulability analysis modules became available
- ☞ Stayed in an academic context, but influenced many more recent RT-systems.



Real-Time & Embedded Systems



Specifying timing requirements

CRL

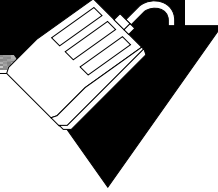
(a language for complex real-time systems)

Ways to handle 'dangerous constructs' (loops, recursions, synchronisations, ...):

- Exclude them
 - ☞ Real-time Euclid
- Expand them to become individually safe
(e.g. by adding mandatory timeout)
- Attribute the code with additional constraints,
enabling a full pre-runtime analysis ☞ **CRL**



Real-Time & Embedded Systems



Specifying timing requirements

CRL

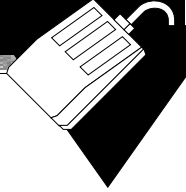
(a language for complex real-time systems)

Constraints in CRL on:

- **Time:**
timeconstraint
 {use | nosoonerthan | nolaterthan <abs_time>} endtimeconstraint
(also relative constraints)
- **Iterations:** assert lower and upper limits for the number of iterations per block
- **Activations:**
activationdeactivationconstraint
 [periodic <Frameinfo> firstactive <TimeOrEvent>
 | atEvent <ConditionalId> <Frameinfo>]
endactivationdeactivationconstraint
- **Direct recursions:** assert lower and upper recursion limits (general recursions are not covered).



Real-Time & Embedded Systems



Specifying timing requirements

CRL

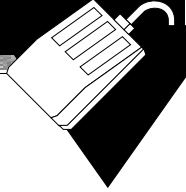
(a language for complex real-time systems)

Evaluation of the constraints and assertions:

- **Timing:**
 - verified at *compile-time*
- **Activation / Deactivation:**
 - checked for schedulability at *compile-time* and enforced by the scheduler at *run-time*.
- **Iterations and recursion:**
 - either verified at *compile-time* or checked at *run-time*.



Real-Time & Embedded Systems



Specifying timing requirements

CRL

(a language for complex real-time systems)

State:

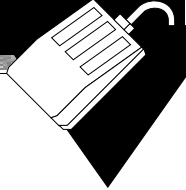
CRL was suggested by Stoyenko, Marlowe and Younis in 1995

- Full featured language
- Compiled to attributed C++

☞ Stayed also in an academic context.



Real-Time & Embedded Systems



Specifying timing requirements

Pearl

Explicit time-scope expressions:

TaskStart ::= [StartCondition] ACTIVATE <task>

StartCondition ::= AT <time> [Frequency] |
AFTER <duration> [Frequency] |
WHEN <interrupt> [AFTER <duration> [Frequency]] |
Frequency

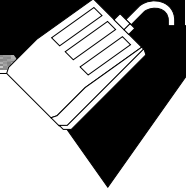
Frequency ::= ALL <duration>
[{UNTIL <time> } |
{DURING <duration>}]

☞ Schedulability analysis (at *compile-time* or *run-time*) possible
(although not defined by the language)

☞ Pearl refinement: a combination of Pearl and Real-time Euclid ☞ **High-Integrity Pearl**



Real-Time & Embedded Systems



Specifying timing requirements

DSP: Distributed Programming System

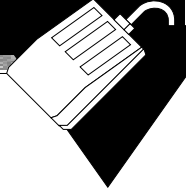
Explicit time-scope expressions at the 'statement level':
e.g. time-scope for a software-engineer:

```
from 11:00 to 19:30 every 45 do
  start elapse 10 do
    setup_coffee_machine
    power_coffee_machine_up
    find_favorite_cup
    put_coffee_in_favorite_cup
    clean_coffee_machine
  end
  start after 3 elapse 25 by 20:00 do
    drink_coffee
  end
end
```

☞ DSP-compiler: breaks the sequences down in processes and schedules



Real-Time & Embedded Systems



Specifying timing requirements

Real-time Java

Real-time Java comes with:

- multiple sets of predefined time-scope parameters
- a scheduler class (with a predefined priority scheduler)
- ☞ Schedulability (feasibility) analysis possible.



Real-Time & Embedded Systems



Specifying timing requirements

Real-time Java

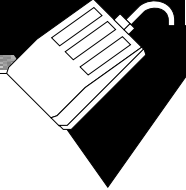
```
public abstract class Scheduler
{
    protected Scheduler ();

    protected abstract boolean addToFeasibility (Schedulable s);
    public abstract void fireSchedulable (Schedulable s);
    public abstract boolean isFeasible ();
    protected abstract boolean removeFromFeasibility (Schedulable s);
    public boolean setIfFeasible (Schedulable s,
                                 ReleaseParameters r,
                                 MemoryParameters m);
    ...
}
```

Formulates an
on-line schedulability analysis!



Real-Time & Embedded Systems



Specifying timing requirements

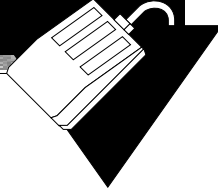
Real-time Java

```
public class PriorityScheduler extends Scheduler
{
    public static final int MAX_PRIORITY;
    public static final int MIN_PRIORITY;
    protected PriorityScheduler ();
    protected boolean addToFeasibility (Schedulable s);
    public void fireSchedulable (Schedulable s);
    public boolean isFeasible ();
    protected boolean removeFromFeasibility (Schedulable s);
    public boolean setIfFeasible (Schedulable s,
                                  ReleaseParameters r,
                                  MemoryParameters m);
    ...
}
```

This PriorityScheduler is the only requested instantiation



Real-Time & Embedded Systems



Specifying timing requirements

Real-time Java

```
public class RealtimeThread extends java.lang.Thread
    implements Schedulable
{
    public RealtimeThread (SchedulingParameters s,
                          ReleaseParameters r,
                          MemoryParameters m,
                          MemoryArea a);

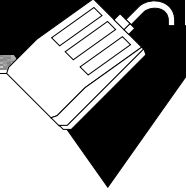
    public synchronized void      addToFeasibility ();
    public synchronized void      addIfFeasible ();
    public static      RealtimeThread currentRealtimeThread () throws ...;
    public synchronized void      schedulePeriodic ();
    public synchronized void      deschedulePeriodic ();
    public              boolean     waitForNextPeriod () throws ...;
    public synchronized void      interrupt ();
    public static      void         sleep (...) throws ...;
    ...
}
```

Priority

Periodic, aperiodic, or sporadic parameters



Real-Time & Embedded Systems



Specifying timing requirements

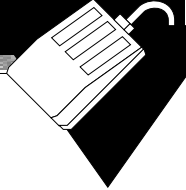
Real-time Java

```
public class NoHeapRealtimeThread extends RealtimeThread
{
    public RealtimeThread (SchedulingParameters s,
                          ReleaseParameters r,
                          MemoryArea a) throws ...;
    ...
}
```

This thread is allowed to interrupt any
garbage collector at any time!
(since it doesn't depend on it itself)



Real-Time & Embedded Systems



Specifying timing requirements

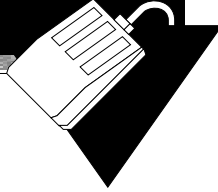
Real-time Java

```
public abstract class SchedulingParameters
{
    public SchedulingParameters ();
}
public class PriorityParameters extends SchedulingParameters
{
    public PriorityParameters (int priority);
    public int getPriority ();
    public void setPriority (int priority) throws ...;
    ...
}
```

'Priority' is the only
default scheduling parameter



Real-Time & Embedded Systems



Specifying timing requirements

Real-time Java

```
public abstract class ReleaseParameters
{
    protected ReleaseParameters
        (RelativeTime cost,
         RelativeTime deadline,
         AsyncEventHandler overrunHandler,
         AsyncEventHandler missHandler);

    public RelativeTime getCost();
    public AsyncEventHandler getCostOverrunHandler();
    public RelativeTime getDeadline();
    public AsyncEventHandler getDeadlineMissHandler();
}
```

Cost is an estimate of the max. execution time

Measuring execution time is *not* requested, i.e. the overrunHandler might never be activated!



Real-Time & Embedded Systems



Specifying timing requirements

Real-time Java

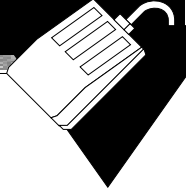
```
public class PeriodicParameters extends ReleaseParameters
{
    public PeriodicParameters
        (HighResolutionTime start,
         RelativeTime period,
         RelativeTime cost,
         RelativeTime deadline,
         AsyncEventHandler overrunHandler,
         AsyncEventHandler missHandler);

    public RelativeTime getPeriod ();
    public HighResolutionTime getStart ();
    public void setPeriod (RelativeTime period);
    public void setStart (HighResolutionTime start);
}
```

most frequently used
release parameters



Real-Time & Embedded Systems



Specifying timing requirements

Real-time Java

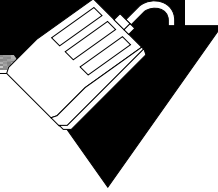
```
public class AperiodicParameters extends ReleaseParameters
{
    public AperiodicParameters
        (RelativeTime cost,
         RelativeTime deadline,
         AsyncEventHandler overrunHandler,
         AsyncEventHandler missHandler);
}
```

these are the minimum
release parameters
(while cost might be used for
feasibility analysis only)

the deadline-missHandler
need to be supplied
in any implementation



Real-Time & Embedded Systems



Specifying timing requirements

Real-time Java

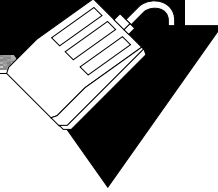
```
public class SporadicParameters extends AperiodicParameters
{
    public SporadicParameters
        (RelativeTime    minInterarrival,
         RelativeTime    cost,
         RelativeTime    deadline,
         AsyncEventHandler overrunHandler,
         AsyncEventHandler missHandler);

    public RelativeTime getMinimumInterarrival ();
    public void         setMinimumInterarrival (RelativeTime minimum);
}
```

Sporadic events are not allowed to come in bursts!



Real-Time & Embedded Systems



Specifying timing requirements

Real-time Java

The minimal required implementation supplies:

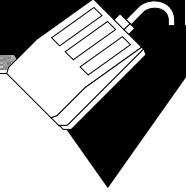
- ☞ Priority scheduling
- ☞ On-line schedulability analysis
- ☞ Deadline violation handlers
- ☞ (max. execution time deadline checks are suggested but not required)
- ☞ a sporadic scheduler is not required (although the sporadic release parameter set is).

Hard real-time environments require the exclusive usage of
'No heap real-time threads'

(synchronization with an 'object-oriented' thread invalidates the feasibility assurances)



Real-Time & Embedded Systems



Specifying timing requirements

Ada95

Ada95 has *no* explicit time-scope expressions at task-level.

Ada95 offers ...

- tasking
- a priority scheduler (the only required scheduler)
- synchronisation and communication primitives
- asynchronous transfer of control, timed calls, timeout on actions etc. pp.
- ... but no hardware timers!

... to create the basis for most kinds of hard real-time-scopes manually.

☞ but no automatic schedulability analysis!



Real-Time & Embedded Systems



Specifying timing requirements

Esterel

Since Esterel is a synchronous language, ...

... all actions and communications take zero time by definition.

- ☞ There is no expression for continuous, non-zero time-scopes.
- ☞ Time is interpreted in the reductionist way as a sequence of events
- ☞ Time-scopes translate to signal-relations and signal-counters

Continuous time scopes need to be taken into account while

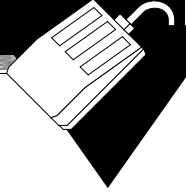
1. **analysing and reducing** the problem to a zero-time atomic system
2. **implementing** the synchronous system on an actual system.

- ☞ Continuous time-scopes for the ...

... validation of the zero-time assumption!



Real-Time & Embedded Systems




Specifying timing requirements

POSIX

the usual:  use timers!

common combination:

 usage of **Ada95** together with **POSIX timers** as a basis for hard-real-time-scopes and schedulers



Real-Time & Embedded Systems



Notions of time and space

The big topics:

What is time? / What is embodiment?

Interfacing with time

Specifying timing requirements

Satisfying timing requirements



Real-Time & Embedded Systems



Satisfying timing requirements

Two paths towards fulfilling rt-requirements:

☞ **Real-time logic** approach

formal, correct in its specifications, & offers calculus for asynchronous, real-time systems

↘ *needs to ignore most real world effects, like jitters, drifts, failures, interferences, etc. pp.*

➤ **gives a correct solution** according to the specification

☞ **Complex systems** oriented approach

deals with existing computer systems, sensors, & offers a set of approximating methods

↘ *not complete or correct in any formal sense*

➤ **deals with real-world systems**, gives 'robust' systems, passes rigorous experiments



Real-Time & Embedded Systems



Satisfying timing requirements

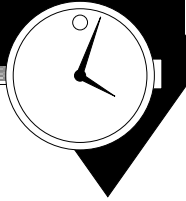
Fulfilling rt-requirements:

Complex systems oriented approach:

- *System identification and compile-time analysis:*
 - Calculate or limit statement durations
 - Calculate or limit iterations and recursions
 - Analyse potential dead- or life-locks ➤ **chapter 8**
 - Calculate schedulability ➤ **chapter 7**
- *Run-time analysis and checks:*
 - Dynamic scheduling schemes: Re-validate schedulability ➤ **chapter 7**
 - Check for all constraints and assertions at run-time ➤ **chapter 9**
- *Supply fault-tolerant behaviours:*
 - Error recoveries, mode changes, ... ➤ **chapter 9**



Real-Time & Embedded Systems



Satisfying timing requirements

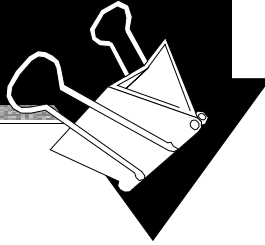
Fulfilling rt-requirements:

Real-time logic approach:

- *Reduce the problem:*
 - Reduce any asynchronous, analogue, dynamical, fractal, jitter-, drift, or failure-affected parts of the system to a fully synchronous and discrete system ➡ **chapters 5 and 6**
 - Formulate the specification on the basis of the reduced synchronous system.
- *Verify the reduced system:*
 - Verify the reduced synchronous against the specifications ➡ *not covered in this course*
- *Compile the reduced system to an actual system:*
 - The resulting actual system will be executable on a real machine and employ real devices
- ➡ *Re-check the actual system (e.g. by means of a complex systems-approach) ➡ ...*



Real-Time & Embedded Systems



Summary

Time & Space

- **What is time? / What is embodiment?**
 - Approaches by different faculties to understand the basis for this course
- **Interfacing with time**
 - Formulating local time-dependent constraints
 - Access time, delay processes, detect timeouts (in different languages)
- **Specifying timing requirements**
 - Formulating global timing-constraints
 - Understanding time-scope parameters (and expressing them in different languages)
- **Satisfying timing requirements**
 - Real-time logic and complex systems approach