Real Time Programming with Ada

Part 2: Real time facilities

Real Time Programming: we need support for

- Concurrency (Ada tasking)
- Communication & synchronization (Ada Rendezvous)
- Consistency in data sharing (Ada protected data type)
- Real time facilities (Ada real time packages and delay statements)
  - accessing system time so that the passage of time can be measured
  - delaying processes until some future time
  - Timeouts: waiting for or running some action for a given time period

System Time

A timer circuit programmed to interrupt the processor at fixed rate.
- To approximate the universal time
- For distributed systems, we need clock synchronization

Each time interrupt is called a system tick (time resolution):

- Normally, the tick can vary 1-50ms, even microseconds in RTOS
  - LegOS: 1ms
  - Linux 2.4, 10ms (100HZ), Linux 2.6, 1ms (1000HZ)

- The tick may be selected by the user
- All time parameters for tasks should be the multiple of the tick
- System time = 32 bits
  - One tick = 1ms: your system can run 50 days
  - One tick = 20ms: your system can run 1000 days = 2.5 years
  - One tick = 50ms: your system can run 2500 days= 7 years
- In Ada95, it is required that the system time should last at least 50 years

Real-Time Support in Ada

- Two pre-defined packages to access the system clock
  - Ada.Calendar and Ada.Real_Rime
  - Both based on the same hardware clock
- There are two delay-statements
  - Delay *time_expression* (in seconds)
  - Delay until *time_expression*
- The delay statements can be used together with select to program timeouts, timed entry etc.

Package calendar in Ada: specification

```
package Ada.Calendar is
  type Time is private;
      --- time is pre-defined based on the system clock
  subtype Year_Number  is Integer range 1901 .. 2099;
  subtype Month_Number is Integer range 1 .. 12;
  subtype Day_Number   is Integer range 1 .. 31;
  subtype Day_Duration is Duration range 0.0 .. 86_400.0;
      --- Duration is pre-defined type (length of interval,
      --- expressed in sec's) declared in the package: Standard
  function Clock return Time;
  function Year    (Date : Time) return Year_Number;
  function Month   (Date : Time) return Month_Number;
  function Day     (Date : Time) return Day_Number;
  function Seconds (Date : Time) return Day_Duration;
  procedure Split  (Date    : in Time;
                    Year    : out Year_Number;
                    Month   : out Month_Number;
                    Day     : out Day_Number;
                    Seconds : out Day_Duration);
```

Package calendar in Ada: specification (ctn.)

```
 function Time_Of(Year    : Year_Number;
                  Month   : Month_Number;
                  Day     : Day_Number;
                  Seconds : Day_Duration := 0.0)
 return Time;

 function "+" (Left : Time;    Right : Duration) return Time;
 function "+" (Left : Duration; Right : Time) return Time;
 function "-" (Left : Time;    Right : Duration) return Time;
 function "-" (Left : Time;    Right : Time) return Duration;
 function "<" (Left, Right : Time) return Boolean;
 function "<="(Left, Right : Time) return Boolean;
 function ">" (Left, Right : Time) return Boolean;
 function ">="(Left, Right : Time) return Boolean;
 Time_Error : exception;
private
   -- not specified by the language
   -- implementation dependent
end Ada.Calendar;
```

Package Real_Time in Ada: specification

```
package Ada.Real_Time is
  type Time is private;
  Time_First : constant Time;
  Time_Last  : constant Time;
  Time_Unit  : constant := implementation-defined-real-number;
  type Time_Span is private;
               --- as Duration, a Time_Span value M representing
                the length of an interval, corresponding to
                the real time duration M*Time_Unit.
  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;
  function Clock return Time;
  function "+"  (Left  : Time; Right  : Time_Span) return Time;
  function "+"  (Left  : Time_Span; Right  : Time) return Time;
  function "-"  (Left  : Time; Right  : Time_Span) return Time;
  function "-"  (Left  : Time; Right  : Time) return Time_Span;
  function "<"  (Left, Right  : Time) return Boolean;
  function "<="(Left, Right  : Time) return Boolean;
  function ">"  (Left, Right  : Time) return Boolean;
  function ">="(Left, Right  : Time) return Boolean;
```

Package Real_Time in Ada: specification (cnt.)

```
  function "+"  (Left, Right : Time_Span) return Time_Span;
  function "-"  (Left, Right : Time_Span) return Time_Span;
  function "-"  (Right : Time_Span) return Time_Span;
  function "*"  (Left : Time_Span; Right : Integer) return Time_Span;
  function "*"  (Left : Integer; Right : Time_Span) return Time_Span;
  function "/"  (Left, Right : Time_Span) return Integer;
  function "/"  (Left : Time_Span; Right : Integer) return Time_Span;
  function "abs"(Right : Time_Span) return Time_Span;
  function "<"  (Left, Right : Time_Span) return Boolean;
  function "<="(Left, Right : Time_Span) return Boolean;
  function ">"  (Left, Right : Time_Span) return Boolean;
  function ">="(Left, Right : Time_Span) return Boolean;
  function To_Duration  (TS : Time_Span) return Duration;
  function To_Time_Span  (D : Duration) return Time_Span;
  function Nanoseconds  (NS : Integer) return Time_Span;
  function Microseconds  (US : Integer) return Time_Span;
  function Milliseconds  (MS : Integer) return Time_Span;
  type Seconds_Count is range implementation-defined;
  procedure Split(T : in Time; SC : out Seconds_Count;
                 TS : out Time_Span);
  function Time_Of(SC : Seconds_Count; TS : Time_Span) return Time;
  private
  ... -- not specified by the language
end Ada.Real_Time;
```

Programming Delays

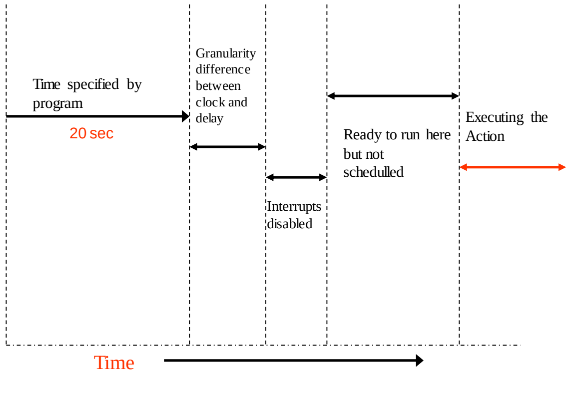
Relative Delays

- **Delay the execution of a task for a given period**
- **Relative delays (using clock access)**

```
Start := Clock;
loop
  exit when (Clock - Start) > 10.0;    -- bust waiting
end loop;
ACTION;
```

- **To avoid busy-waiting, most languages and OS provide some form of delay primitive**
  - In Ada, this is a delay statement `delay 10.0`
  - In UNIX, sleep(10)

Semantics of Delay(20); Action



Absolute Delays

- **To delay the execution of a task to a specified time point (using clock access):**

```
Start := Clock;
FIRST_ACTION;
loop
  exit when Clock > Start+10.0;    -- busy waiting
end loop;
SECOND_ACTION;
```

- To avoid busy-wait (access "clock" all time every tick!):

```
START := Clock;
FIRST_ACTION;
delay until START + 10.0;  (this is by interrupt)
SECOND_ACTION;
```

- As with **delay**, **delay until** is accurate only in its lower bound

Absolute Delays: Example

```
task Ticket_Agent is
  entry Registration(...);
end Ticket_Agent;

task body Ticket_Agent is
  -- declarations
  Shop_Open : Boolean := True;
begin
  while Shop_Open loop
    select
      accept Registration(...) do
        -- log details
      end Registration;
    or
      delay until Closing_Time;
      Shop_Open := False;
    end select;
    -- process registrations
  end loop;
end Ticket_Agent;
```

Periodic Task

```
task body Periodic_T is
    Next_Release : Time;
    ReleaseInterval  : Duration := 10
begin
    Next_Release := Clock + ReleaseInterval;
    loop
        -- Action
        delay until Next_Release;
        Next_Release := Next_Release + ReleaseInterval;
    end loop;
end Periodic T;
```

If Action takes 11 seconds, the delay statement will have no effect

Will run on average every 10 seconds

local drift only

Control Example I

```
with Ada.Real_Time; use Ada.Real_Time;
with Data_Types; use Data_Types;
with IO; use IO;
with Control_Procedures;
use Control_Procedures;


procedure Controller is

  task Temp_Controller;

  task Pressure_Controller;
```

Control Example II

```
task body Temp_Controller is
  TR : Temp_Reading; HS : Heater_Setting;
  Next : Time;
  Interval : Time_Span := Milliseconds(30);
begin
  Next := Clock;  -- start time
  loop
    Read(TR);
    Temp_Convert(TR,HS);
    Write(HS);
    Write(TR);
    Next := Next + Interval;
    delay until Next;
  end loop;
end Temp_Controller;
```

Control Example III

```
  task body Pressure_Controller is
    PR : Pressure_Reading; PS : Pressure_Setting;
    Next : Time;
    Interval : Time_Span := Milliseconds(70);
  begin
    Next := Clock;  -- start time
    loop
      Read(PR);
      Pressure_Convert(PR,PS);
      Write(PS);
      Write(PR);
      Next := Next + Interval;
      delay until Next;
    end loop;
  end Pressure_Controller;
begin
  null;
end Controller;
```

Control Example IIII

```
  task body Pressure_Controller is
    PR : Pressure_Reading; PS : Pressure_Setting;
    Next : Time;
    Interval : Time_Span := Milliseconds(70);
  begin
    Next := Clock;  -- start time
    loop
      Read(PR);
      Pressure_Convert(PR,PS);
      Write(PS);
      Write(PR);
      Next := Next + Interval;
      delay until Next;
    end loop;
  end Pressure_Controller;
begin
  null;
end Controller;
```

Here Temp_Controller & Pressure_Controller start concurrently

Programming Timeouts

Timeout and message passing

```
loop
    select
        accept Call(T : temperature) do
            New_temp:=T;
        end Call;
    or
        delay 10.0;
            --action for timeout
    end select;
    --other actions
end loop;
```

Timeout (by server)

```
task Server is
  entry Call(T : in Temperature);
  -- other entries
end Server;

task body Server is
  -- declarations
begin
  loop
    select
      accept Call(T : in Temperature) do
        New_Temp := T;
      end Call;
    or
      delay 10.0;
      -- action for timeout
    end select;
    -- other actions
  end loop;
end Server;
```

Timeout (by client)

```
loop
  -- get new temperature T
  Server.Call(T);
end loop;

loop
  -- get new temperature T
  select
    Server.Call(T);
  or
    delay 0.5;
    -- other actions
  end select;
end loop;
```

Timeouts on Entries

- The above examples have used timeouts on inter-task communication; it is also possible, within Ada, to do timed (and conditional) entry call on protected objects

```
select
  P.E ; -- E is an entry in protected object P
or
  delay 0.5;
end select;
```

Timeouts on Actions

```
select
  delay 0.1;
then abort
  -- action
end select;
```

- If the action takes too long, the triggering event will be taken and the action will be aborted
- This is clearly an effective way of catching *run-away code* --- *Watchdag*

SUMMARY: Language support for RT Programming

- Concurrency: multi-tasking
- Communication & synchronization
- Consistency in data sharing /protected data types
- Real time facilities
  - Access to system clock/time
  - Delay constructs: Delay(10) and Delay until next-time
  - Timely execution of tasks (run-time system)

The "core" of RT Programming Languages

- Primitive Types
  - Basic Types: e.g. Integers, reals, lists, ...
  - Abstract data type: Semaphore
    - P(S)
    - V(S)
- Assignment: X:= E
- Control Statements: If, While, ..., goto
- Sequential composition: P;P
- Concurrent composition: P|| P
- Communication: a!e, a?x
- Choice: P or P
- Clock reading: Time
- Delays: Delay(n), Delay until n
- Exception: Loop P until B

RT Programming Languages

- "Classic" high-level languages with RT extensions e.g.
  - Ada
  - Real-Time Java, C + RTOS
  - SDL, Soft RT language for telecommunication systems
- Synchronous Programming (from 1980's)
  - **Esterel** (Gerard Berry)
  - Lustre (Caspi and Halbwachs)
  - Signal (le Guernic and Benveniste)
- Design, Modeling, Validation, and Code Generation (from models to code)
  - Giotto (Henzinger et al, not quite synchrnous)
  - UPPAAL/TIMES (Uppsala)
  - Real-Time UML
  - SimuLink

RT Programming Languages

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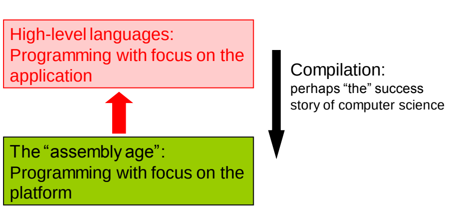
  - SDL, Soft RT language for telecommunication systems
- Synchronous Programming
  - **Esterel** (Gerard Berry)
  - Lustre (Caspi and Halbwachs)
  - Signal (le Guernic and Benveniste)
- Towards Real Real-Time Programming (mostly in research):
  - Giotto (Henzinger et al, not quite synchrnous)
  - TIMES (Uppsala)

The History of Computer Science: Lifting the Level of Abstraction



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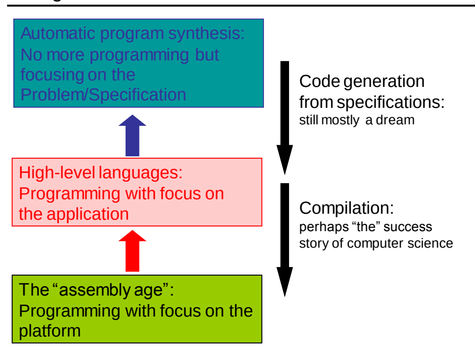

Future Goal in Real-Time Software Development