## Major Characteristics of RTOS (Last lecture)

- Determinism
  - Deterministic system calls
- Responsiveness (quoted by vendors)
  - Fast process/thread switch
  - Fast interrupt response
- User control over OS policies
  - Mainly scheduling polices
  - Memory allocation
- "Controlled code size
- Support for concurrency and real-time
  - Multi-tasking & Synchronization
  - Time management

## Real time programming

- It is mostly about "Concurrent programming"
- We also need to handle Timing Constraints on concurrent executions of tasks (and maybe other constraints on e.g. energy consumption etc)

However, remember:

- "concurrency" is a way of structuring computer programs
  e.g. three "concurrent modules": task 1, task 2 task 3
- "concurrency" is often implemented by "fast sequential computation"

## RTOS vs. Programming Languages

- Without RTOS support
  - Program your tasks in any programming language (C, Assembly …)
  - Cyclic Execution
- With RTOS support
  - Program your tasks in any programming language
  - Fix the scheduler in OS e.g. static schedule, priority assignment
- With RTOS and RT programming language
  - Program your tasks in a RT languages e.g. RT Java, Ada
  - RTOS is "hidden", a Run-Time kernel for each program

We will consider the RT prog. lang. Ada



## RT programming: the classic approach

- Program your tasks in any sequential language
- Simplest approach: cyclic execution

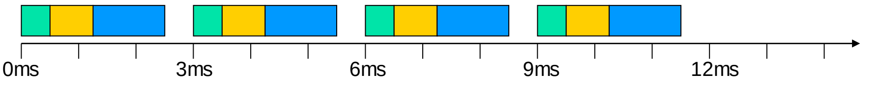
```
loop
  do task 1
  do task 2
  do task 3
end loop
```

Efficient code, deterministic, predictable,
But difficult to make it right, difficult to reuse existing design
In particular extremely difficult for constructing large systems!

## Cyclic Execution : example

| Task | Required sample rate | Processing time |
|---|---|---|
| t1 | 3ms (333Hz) | 0.5ms |
| t2 | 6ms (166Hz) | 0.75ms |
| t3 | 14ms (71Hz) | 1.25ms |

```
void main(void)
{
    do_init();
    while (1)
    {
        t1();
        t2();
        t3();
        delay_until_cycle_start();
    }
}
```





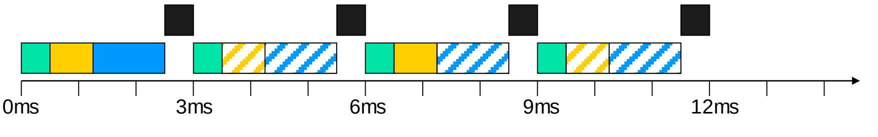

## Cyclic Execution : “overheads”

| Task | Required sample rate | Processing time |
|---|---|---|
| t1 | 3ms (333Hz) | 0.5ms |
| t2 | 6ms (166Hz) | 0.75ms |
| t3 | 14ms (71Hz) | 1.25ms |

t2 requires 12.5% CPU (0.75/6), uses 25% (4*0.75/12)

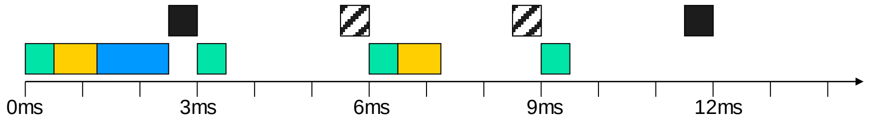
t3 requires 9% CPU (1.25/14), uses 42% (4*1.25/12)

add interrupt I with 0.5ms processing time



## Major/minor cyclic scheduling

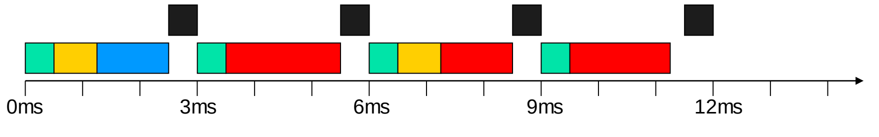
- 12ms major cycle containing 3ms minor cycles
  - t1 every 3ms, t2 every 6ms, t3 every 12ms
- t3 still upsampled (10.4% where 9% needed)
- time is still allocated for I in every cycle
  - will not always be used, but must be reserved






## Fitting tasks to cycles

- add t4 with 14ms rate and 5ms processing time
  - 12ms cycle has 5.25ms free time...
  - ...but t4 has to be artificially partitioned



## Effect of new task at code level

```
void do_task_t4(void)
{
        /* Task functionality */
}
```

```
void do_task_t4_1(void)
{
        /* first bit */
        state_var_1 = x;
        state_var_2 = y;
        ...
}
void do_task_t4_2(void)
{
        x = state_var_1;
        ...
        /* second bit */
        state_var_3 = a;
        state_var_4 = b;
        ...
}
void do_task_t4_3(void)
{
        c = state_var_4;
        ...
        /* third bit */
}
```

```
int state_var_1;
int state_var_2;
int state_var_3;
int state_var_4;
void main(void)
{
        do_init();
        while(1) {
                do_task_t1();
                do_task_t2();
                do_task_t3();
                busy_wait_minor();
                do_task_t1();       /* 3ms */
                do_task_t4_1();
                busy_wait_minor();
                do_task_t1();       /* 6ms */
                do_task_t2();
                do_task_t4_2();
                busy_wait_minor();

                do_task_t1();       /* 9ms */
                do_task_t4_3();
                busy_wait_minor();
        }
}
```



## This is too "ad hoc", though this is often used in industry

- You just don't want to do this for large software systems, say a few hundreds of control tasks
- This was why "Multitasking" came into the picture

## Concurrent programming with multitasking:

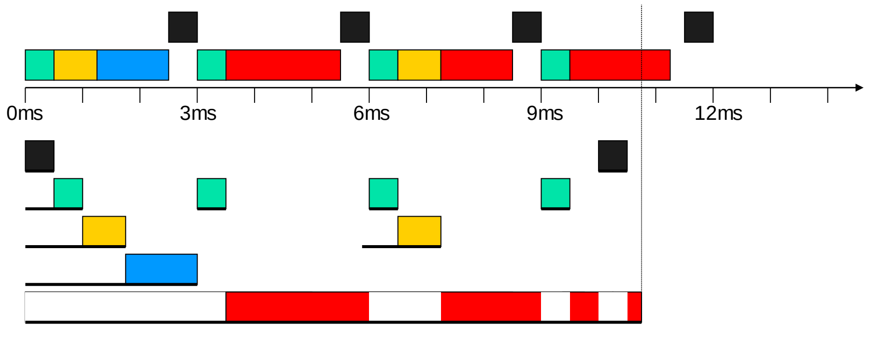
- Program your computation tasks, execute them concurrently with OS support e.g. in LegOS

```
execi(foo1, ..., priority1, ...);
execi(foo2, ..., priority2, ...);
execi(foo3, ..., priority3, ...);
```

Will start three concurrent tasks running foo1, foo2, foo3



## Cyclic Execution vs. Multitasking



# Today's topic:
# Real Time Programming with Ada

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## Ada95

- It is strongly typed OO language, looks like Pascal
- Originally designed by the US DoD as a language for large safety critical systems i.e. Military systems
  - Ada83
  - Ada95 + RT annex + Distributed Systems Annex
  - Ada 2005

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## The basic structures in Ada

- A large part in common with other languages
  - Procedures
  - Functions
  - Basic types: integers, characters, ...
  - Control statements: if, for, ..., case analysis
- Any thing new?
  - Abstract data type: Packages
    - Protected data type
  - Tasking: concurrency
  - Task communication/synchronization: rendezvous
  - Real Time



## Typical structure of programs

Program Foo(...)

Declaration 1 ←----- to introduce identities/variables
and define data structures

Declaration 2 ←----- to define ”operations” : procedures, functions
and/or tasks (concurrent operations)
to manopulate the data structures

Main program
(Program body) ←------ a sequence of statements or ”operations” to
compute the result (output)

## Declarations and statements

- Before each block, you have to declare (define) the variables used, just like any sequential program

```
procedure PM (A : in   INTEGER;
               B:  in out  INTEGER;
                C : out     INTEGER) is
begin
    B := B+A;
    C := B + A;
end PM;
```

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## If, for, case: contrl-statements

```
if TEMP < 15 then
    some smart code;
else
 do something else..;
end if;

case TAL is
    when <2 =>
          PUT_LINE(”one or two”);
    when >4 =>
          PUT_LINE(”greater than 4);
end case;

for I in 1..12 loop
    PUT(”in the loop”);
end loop;
```

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## Types (like in Pascal or any other fancy languages)

```
type LINE_NUMBER is range 1 .. 72
type WEEKDAY is (Monday, Tuesday, Wednesday);
type serie is array (1..10) of FLOAT;

type CAR is
    record
        REG_NUMBER    : STRING(1 .. 6);
        TYPE          : STRING(1 .. 20);
    end record;
```

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## Concurrent (and Real Time) Programming with Ada

- Abstract data types
  - package
  - protected data type
- Concurrency
  - Task creation
  - Task execution
- Communication/synchronization
  - Rendezvous
- Real time:
  - Delay(10)  and  Delay until next-time
  - Scheduling according to timing constraints

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## ”Package”: abstract data type in Ada

- package definition ---- specification
- Package body ---- implementation

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## Package definition -- Specificaiton

- Objects declared in specification is visible externally.

```
package MY_PACKAGE is
    procedure myfirst_procedure;
    procedure mysecond_procedure;
end MY_PACKAGE;
```

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## Package body -- Implementation

- Implements package specification

```
(you probably want to use some other packages here e.g.. )
with TEXT_IO;
use TEXT_IO;

 package body MY_PACKAGE  is
        procedure myfirst_procedure is
        begin
                myfirst_procedure code here;
        end;

        function MAX (X,Y :INTEGER) return INTEGER is
        begin
          … …
        end;

        procedure mysecond_procedure is
        begin
                PUT_LINE("Hello Im Ada Who are U");
                GET();
        end;
end MY_PACKAGE;
```



## Protected data type

```
protected Buffer is
procedure read(x: out integer)
procedure write(x: in integer)
private
   v: integer := 0  /* initial value */

protected body Buffer is
procedure read(x: out integer) is
begin x:=v end
procedure write(x: in integer) is
begin v:= x end
```

(note that you can solve similar problems with semaphores)

## Ada tasking: concurrent programming

- Ada provides at the language level light-weight tasks. These often refered to as threads in some other languages. The basic form is:

```
task T is                        <-------- specification
--- operations/entry or nothing
end T;

task body T is                   <--------- implementation/body
begin
---- processing----
end T;
```



## Example: the sequential case

```
procedure shopping is
begin
buy-meat;
buy-salad;
buy-wine;
end
```

## The concurrent version

```
procedure shopping is

task get-salad;
task body get-salad is
begin
buy-salad;
end  get-salad;
task get-wine;
task body get-wine is
begin
buy-wine;
end  get-wine;
begin
buy-meat;
end
```

buy-salad and buy-wine
will be activated concurrently
here

And then run in parallel with
buy-meat



## Creating Tasks

- Tasks may be declared at any program level
- Created implicitly upon entry to the scope of their declaration.
- Possible to declare task types to start several task instances of the same task type

## example

```
procedure Example1 is
    task type A_Type;
    task B;
    A,C : A_Type;

    task body A_Type is
        --local declarations for task A and C
    begin
        --sequence of statements for task A and C
    end A_Type;

    task body B is
        --local declarations for task B
    begin
        --sequence of statements for task B
    end B;

begin
    --task A,C and B start their executions before the first statement of this procedure.
end Example1;
```

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## Task scheduling

- Allow priorities to be assigned to tasks in task definition
- Allow task dispatching policy to be set (Default: highest priority first)

```
task Controller is
    pragma Priority(10)
end Controller
```

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## Task termination: a task will terminate if:

- It completes execution of its body
- It executes a terminate alternative of a select statement
- It is aborted:
  - abort_statement ::= abort task_name {, task_name};

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## Task communication/synchronization

- Message passing using ”rendezvous”
  - entry and accept
- Shared variables
  - protected objects/variables

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## Rendezvous

```
procedure foo

        task T is
         entry E(...in/out parameter...);
        end;

        task body T is
         begin
              -------
         accept E(... ...) do
              ------- sequence of statements
         end E;

         task user;
         task body user is
         begin
         ---
         T.E(... ...)
         ---
         end
begin
...
end

end foo:
```

T and user will be started concurrently



## Rendezvous

| | |
|---|---|
| task body A is | task body B is |
| begin | begin |
| ... | ... |
| B.Call; | accept Call do |
| ... | .... |
| end A | end Call |
| | ... |
| | end A |

## This is implemented with Entry queues (the compiler takes care of this!)

- Each entry has a queue for tasks waiting to be accepted
  - a call to the entry is inserted in the queue
  - the first task in the queue will be ”accepted” first (like the queue for a semaphore)
- By default, the queuing policy is FIFO
  - it can be different queuing policies

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## An Example: Buffer

```
task buffer is
entry put(X: in integer)
entry get(x: out integer)
end;

task body buffer is
  v: integer;
 begin
 loop accept put(x: in integer) do v:= x end put;
       accpet get(x: out integer) do x:= v end get;
 end loop;
 end buffer;

---
buffer.put(...)     <--------------------------------------------- other tasks (users)!!
Buffer.get(...)
----
```

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## An Example, the Semaphore

- The Idea of a (binary) semaphore
- Two operations, p and v
    - p grabs semaphore or waits if not available
    - v releases the semaphore

## A Semaphore using a Task, RV

- The specification
    - ```
      task type Semaphore is
                 entry p;
                 entry v;
      end Semaphore;
      ```
      ```

## A Semaphore using RV

- The body of semaphore is very simple:
  - task body Semaphore is
    begin
    loop
    accept p;
    accept v;
    end loop;
    end Semaphore;

```
task body Semaphore is
begin
        loop
                accept p;
                accept v;
        end loop;
end Semaphore;
```

## Using the Semaphore Abstraction

- Declare an instance of a semaphore
    - Lock : Semaphore;
  - Now we can use this semaphore to create a monitor, using
    - Lock.P;
      code to be protected in monitor
      Lock.V;

## Choice: Select statement

```
task Server is
      entry S1(...);
      entry S2(...);
end Server;

task body Server is
      ...
begin
      loop
                --prepare for service
                select
                   when <boolean expression> =>
                        accept S1(...) do
                                --code for this service
                        end S1;
                or
                        accept S2(...) do
                                --code for this service
                        end S2;
                or
                       terminate;
                end select;
      --do any house keeping
      end loop;
end Server;
```

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