Embedded Systems Programming - PA8001

`http://bit.ly/15mmqf7`

Lecture 9

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Priority assignment

Question

How do we set thread/message priority for the purpose of meeting deadlines?

Static priorities

Assign a fixed priority to each thread and keep it constant until termination.

Dynamic priorities

Determine the priority at run-time from factors such as the time remaining until deadline.

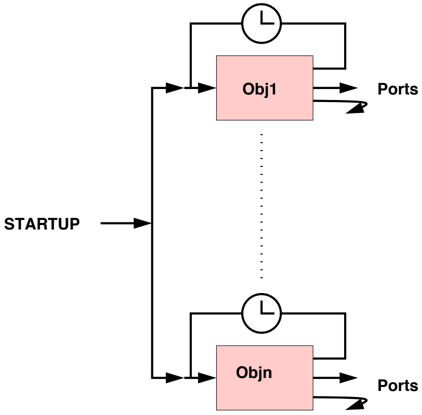
:-(

In neither case a method exists that is both predictable and generally applicable to all programs!

:-)

It is possible to get by if we concentrate on programs of a restricted form.

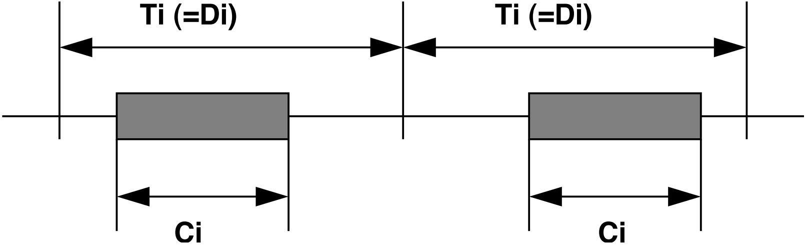
Initial restricted model



- Only periodic reactions
- Fixed periods
- No internal communication
- Known, fixed WCETs
- Deadlines = periods

If time allows, we will discuss how to remove these restrictions.

Notation



Each reactive object obj_i executes a message (thread/task/job) m_i in a periodic fashion.

For each message m_i

- We know its period T_i (given, determines the `AFTER` offset)
- We know its WCET C_i (meassured or analyzed)
- We know its relative deadline D_i (given, equal to T_i for now)

We want to determine its priority P_i!

In concrete code

The application

```
int ignite(APP * self, int nothing){
  BEFORE(D_1, &obj_1, m_1, arg_1);
  BEFORE(D_2, &obj_2, m_2, arg_2);
    ⋮
  BEFORE(D_n, &obj_n, m_n, arg_n);
}


int main(){ return TINYTIMBER(&app,ignite, 0); }
```

In concrete code

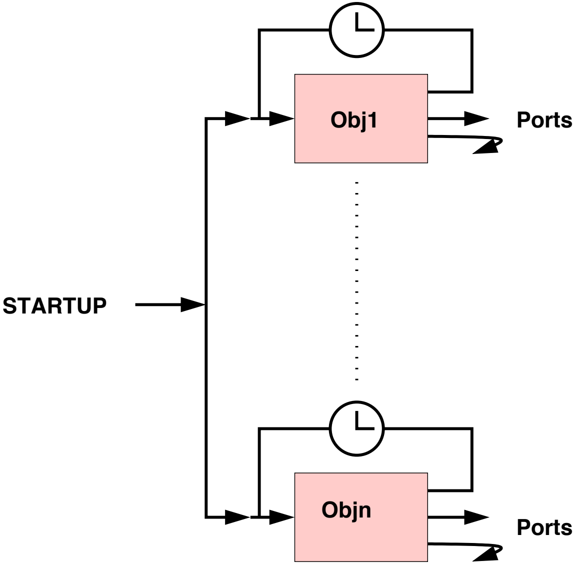
The objects

```
Class_i obj_i = initClass_i();
```

```
int m_i(Class_i *self, int arg){
  // read ports
  // compute
  // update self state
  // write ports
  SEND(T_i, D_i, self, m_i,arg);
}
```

Each $D_i = T_i$

Schematically (again)



Static priorities – method

Rate monotonic (RM)

Under the given assumptions, there exists a static priority assignment rule that is really simple

The shorter the period, the higher the priority

For RM, the actual priority values do not matter, only their relative order.

Because of our inverse priority scale, we can simply implement RM by letting $P_i = D_i$ $(= T_i)$

RM example

Given a set of periodic tasks with periods

T1 = 25ms
T2 = 60ms
T3 = 45ms

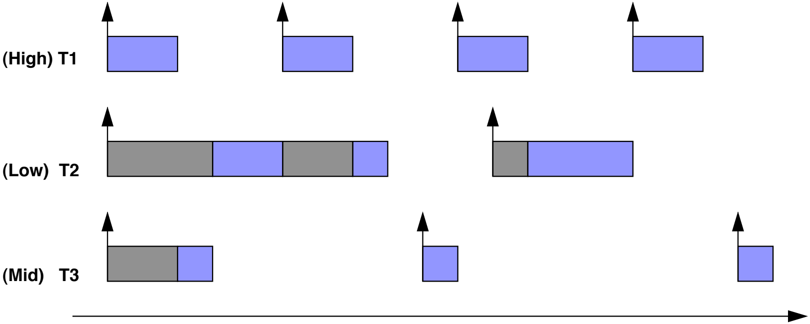
Valid priority assignments

P1 = 10
P2 = 19
P3 = 12

P1 = 1
P2 = 3
P3 = 2

P1 = 25
P2 = 60
P2 = 45

RM example



Period = Deadline. Arrows mark start of period.
Blue: running. Gray: waiting.

Dynamic priorities – method

Earliest Deadline First – EDF

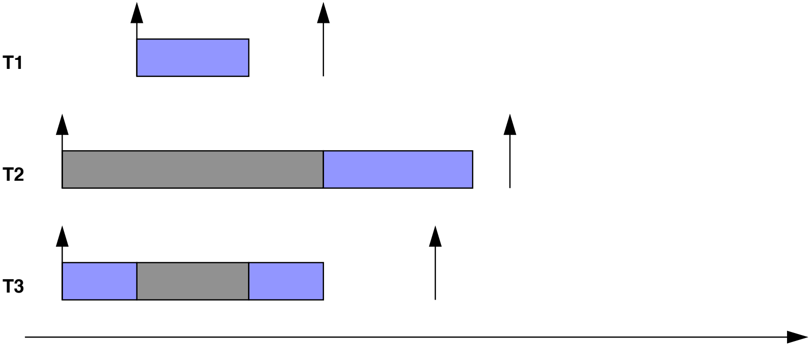
Dynamic priority assignment rule:

> The shorter the time remaining until deadline, the higher the priority

To use absolute deadlines: priorities = remaining clock cycles (before missing the deadline)

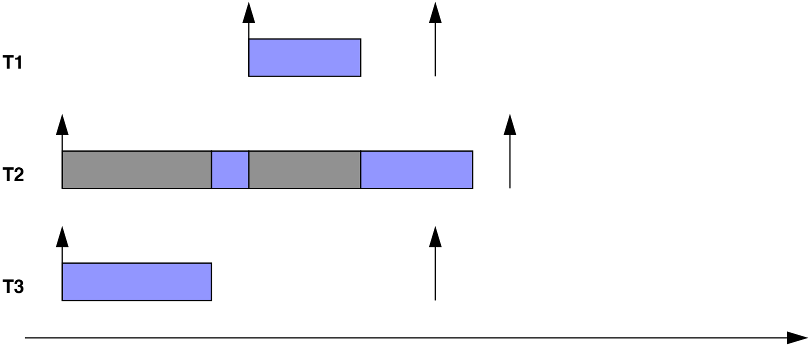
Under EDF, each activation n of periodic task i will receive a new priority: $\mathsf{P_{i(n)} = baseline_{i(n)} + D_i}$

EDF example



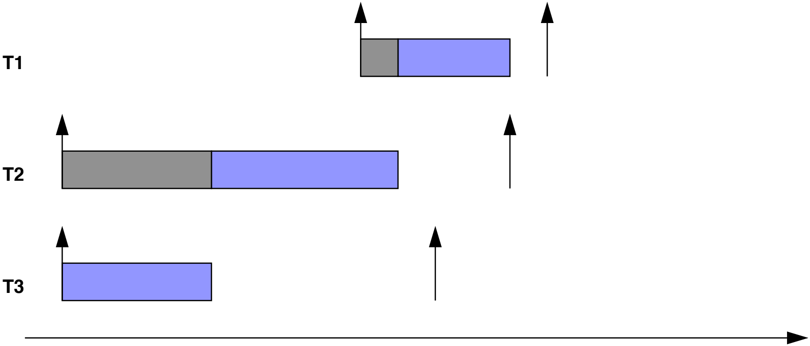
T1 arrives later, but its deadline is earlier than both T2's and T3's absolute deadlines!

EDF example



Deadline of T1 < Deadline of T2

EDF example



(absolute) Deadline of T1 > (absolute) Deadline of T2

Optimality

Multiple ways assigning priorities to meet deadlines

Optimal: a method which fails only if every other method fails

- RM is optimal among static assignment methods
- EDF is optimal among dynamic methods

Schedulability

An optimal method may also fail
A set of task may not be schedulable at all

Example

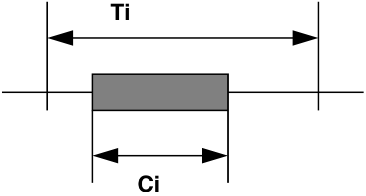
The shortest path from A to B is 200km (the optimal scheduling).
We have only one hour to reach the destination and the maximum speed is 120 km/h (deadline and platform constraints).
Can we be there on time (schedulability analysis)

Schedulability

To determine whether task set is at all schedulable (with optimal methods)

Schedulability must take the WCETs of tasks into account.

Utilization-based analysis



For a periodic task set, an important measure is how big a fraction of each turn a task is actually using the CPU.

That is, the CPU utilization of a periodic task i is the ratio $\frac{C_i}{T_i}$, where C_i is the WCET and T_i is the period.

Note

Any task for which $C_i = T_i$ will effectively need exclusive access to the CPU!

Utilization-based analysis (RM)

Given a set of simple periodic tasks, scheduling with priorities according to RM will succeed if

$$U \equiv \sum_{i=1}^{N} \frac{C_i}{T_i} \leq N(2^{1/N} - 1)$$

where N is the number of threads.

That is, the sum of all CPU utilizations must be less than a certain bound that depends on N.

Utilization bounds

N	Utilization bound
1	100.0 %
2	82.8 %
3	78.0 %
4	75.7 %
5	74.3 %
10	71.8 %

Approaches 69.3% asymptotically

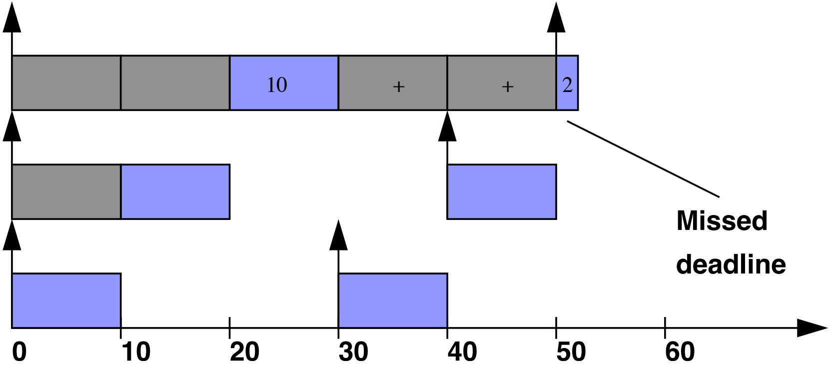
Example A

Task	Period	WCET	Utilization
i	T_i	C_i	U_i
1	50	12	24%
2	40	10	25%
3	30	10	33%

The combined utilization U is 82%, which is above the bound for 3 threads (78%).

The task set fails the utilization test.

Time-line for example A



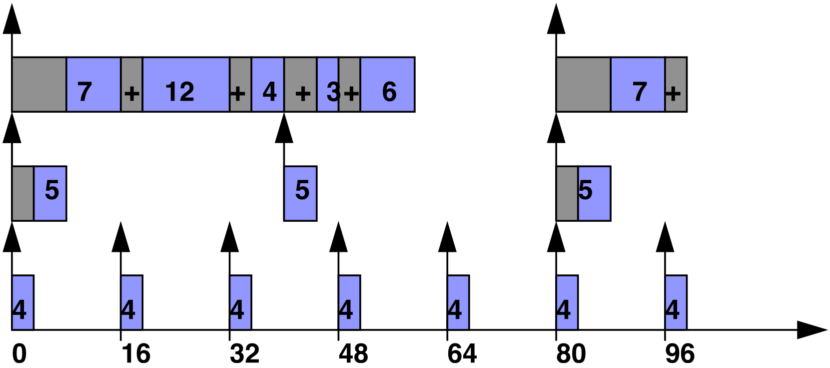
Example B

Task	Period	WCET	Utilization
i	T_i	C_i	U_i
1	80	32	40%
2	40	5	12.5%
3	16	4	25%

The combined utilization U is 77.5%, which is below the bound for 3 threads (78%).

The task set will meet all its deadlines!

Time-line for example B



Example C

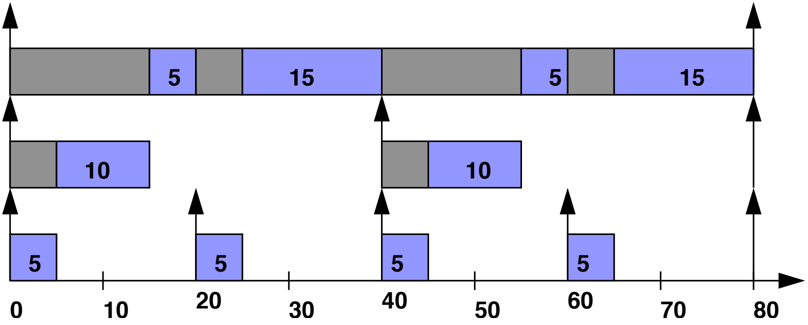
Task	Period	WCET	Utilization
i	T_i	C_i	U_i
1	80	40	50%
2	40	10	25%
3	20	5	25%

The combined utilization U is 100%, which is well above the bound for 3 threads (78%).

However, this task set still meets all its deadlines!

How can this be??

Time-line for example C



Characteristics

The utilization-based test

- Is sufficient (pass the test and you are OK)
- Is not necessary (fail, and you might still have a chance)

Why bother with such a test?

- Because it is so simple!
- Because only very specific sets of tasks fail the test and still meet their deadlines!

Utilization-based analysis (EDF)

Given a set of simple periodic tasks, scheduling with priorities according to EDF will succeed if

$$U \equiv \sum_{i=1}^{N} \frac{C_i}{T_i} \leq 1$$

That is, the sum of all CPU utilizations must be less than or equal 100%, independent of the number of tasks.

Unlike the case for RM, the utilization-based test for EDF is both sufficient and necessary (demand more than 100% of the CPU and you are bound to fail!)

EDF vs RM

Similarities

- Both algorithms are optimal within their class
- Both are easy to implement in terms of priority queues
- Both have simple utilization-based schedulability tests
- Both can be extended in similar ways

Advantages of EDF

- Close relation to terminology of real-time specifications
- Directly applicable to sporadic, interrupt-driven tasks
- superior CPU utilization

EDF vs RM

Drawbacks of EDF

- It exhibits random behaviour under transient overload (but so does RM, in fact, in a different way)
- RM predictably skips low priority tasks under constant overload (but EDF rescales task priorities instead)
- Utilization-based test becomes more elaborate for EDF when $D_i \leq T_i$ (but is still feasible)
- Operating systems generally don't support it (priority scales lack granularity, no automatic time-stamping)
- Few languages allow for natural deadline constraints

However, for reactive objects, EDF fits nice as an alternative to RM

Implementation (RM)

In `TinyTimber.c`

```
struct msg_block{
  ...
  Time baseline;
  Time priority;
  ...
};

void async(Time offset, Time prio,
           OBJECT *to, METHOD meth, int arg){
   ...
   m->baseline=MAX(TIMERGET(),
                   current->baseline+offset);
   m->priority = prio;
   ...
}
```

Implementation (EDF)

In `TinyTimber.c`

```
struct msg_block{
  ...
  Time baseline;
  Time deadline;
  ...
};

void async(Time BL, Time DL,
           OBJECT *to, METHOD meth, int arg){
   ...
   m->baseline=MAX(TIMERGET(),
                   current->baseline+BL);
   m->deadline = m->baseline+DL;
   ...
}
```

Loosening the assumptions

Sporadic Tasks

Sporadic tasks: no fixed period (interrupt handlers), urgent deadlines

Characteristics needed for schedulability analysis

Characteristics

Minimum inter-arrival time: minimum time between two events causing sporadic tasks (e.g., key strokes, signal updates)

Period T interpreted as inter-arrival time

For sporadic tasks: $D < T$

Scheduling Sporadic Tasks

Deferrable Servers

A task with period T and the highest priority

Fixed capacity C

Scheduling

Sporadic events scheduled in the server when there is capacity left

Capacity is replenished every T units

Bonus question

Name an alternative to deferrable servers. Compare it with deferrable servers.

Send in your answers before 08:30 tomorrow.

More on real-time

Other analysis

Response-time analysis: more powerful technique than utilization based

More on this in specialized courses on real-time (such as distributed real time systems)