Russian Academy of Sciences
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A Forth-Simulator of Real-Time Multi-Task Applications

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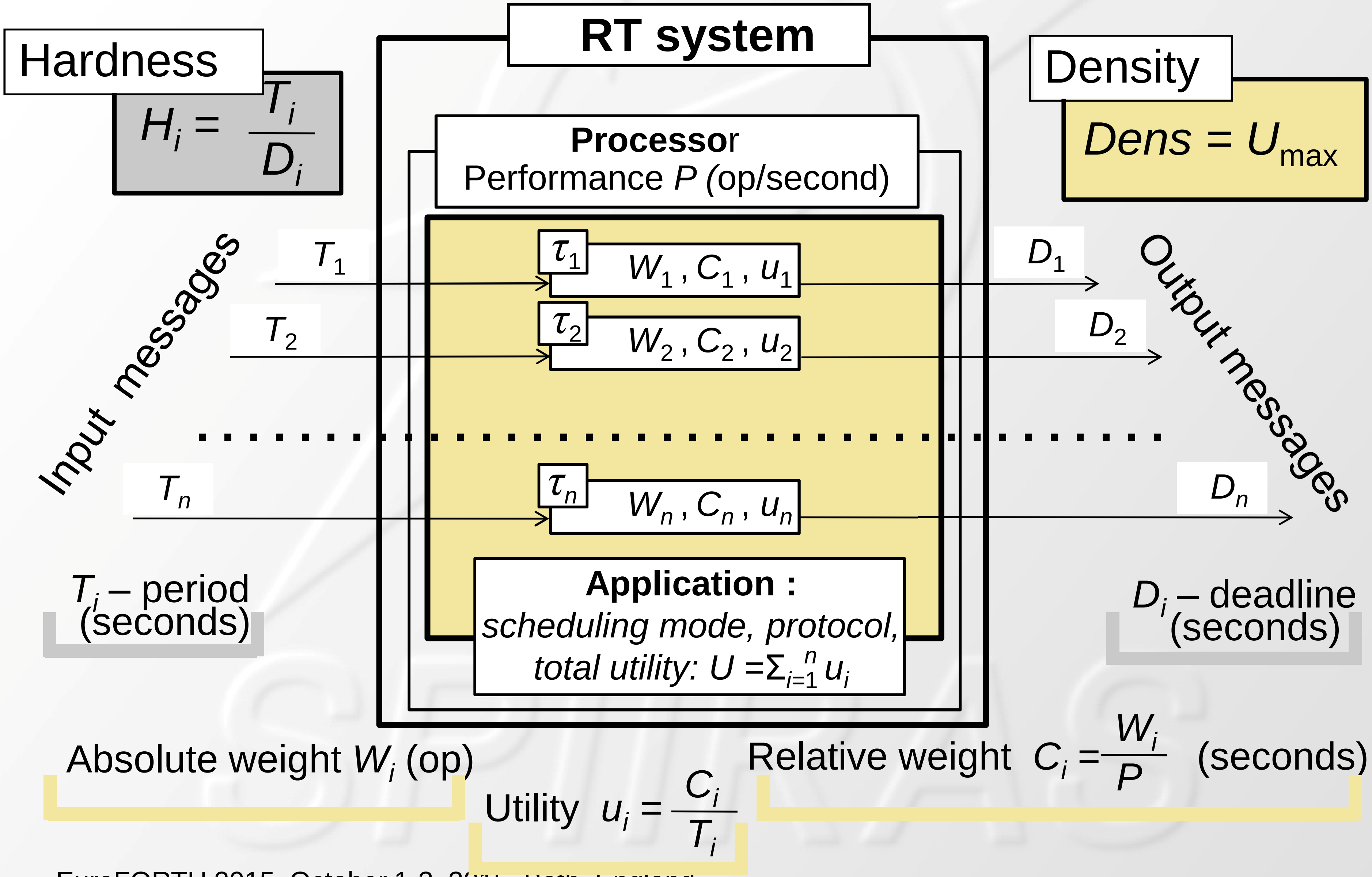
Real-Time Systems



Utility Depends on CPU Performance

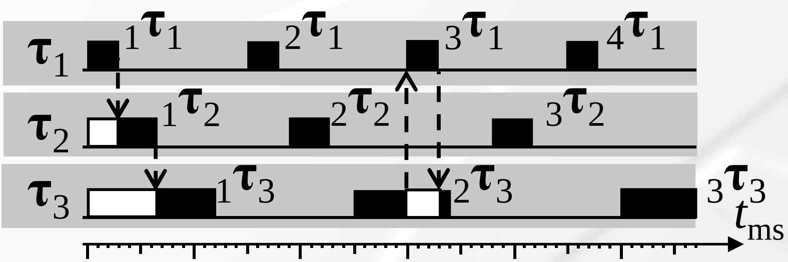
Application

τ_1: T = 15ms, $W = 4\times10^6$op

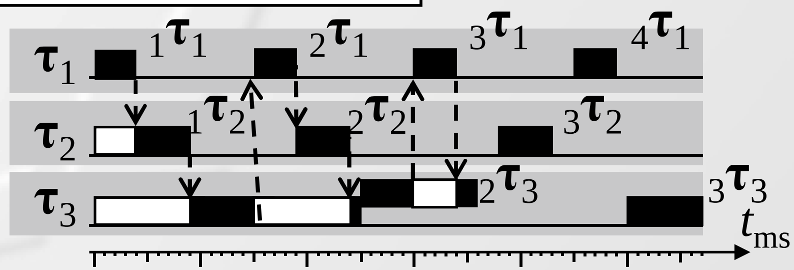
τ_2: T = 19ms, $W = 5\times10^6$op

τ_3: T = 25ms, $W = 7\times10^6$op

Rate-monotonic scheduling $H_i = 1$: *Dens* = 0,81

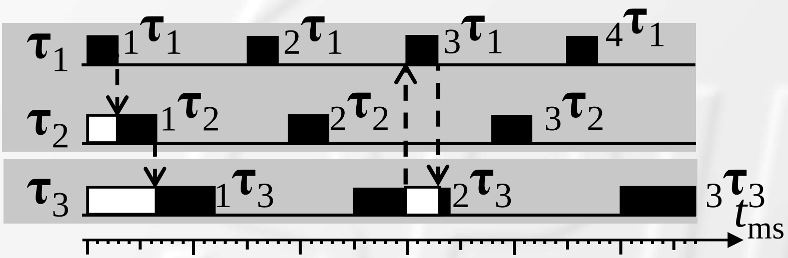


$P = 1.3\times10^6$op/ms U = 0,62

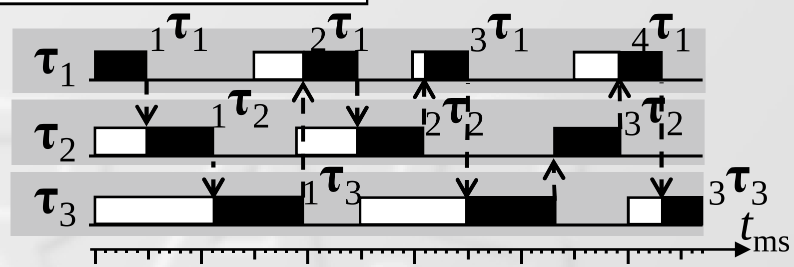


$P = 1.0\times10^6$op/ms U_{max} = 0,81

Early deadline first scheduling $H_i = 1$: *Dens* = 1

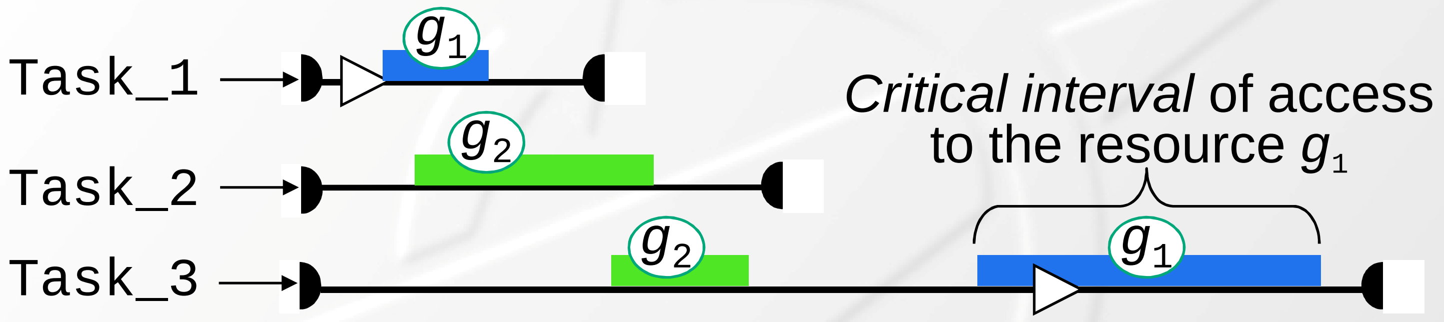


$P = 1.3\times10^6$op/ms U = 0,62



$P = 0.81\times10^6$op/ms U_{max} = 1,0

Protocols for Access to Resources



The simplest protocol (no priority inheritance)

Condition to entry a critical interval:	**the resource is unlocked**
Action at entering a critical interval:	**lock the resource**
Action at exiting a critical interval:	**unlock the resource**

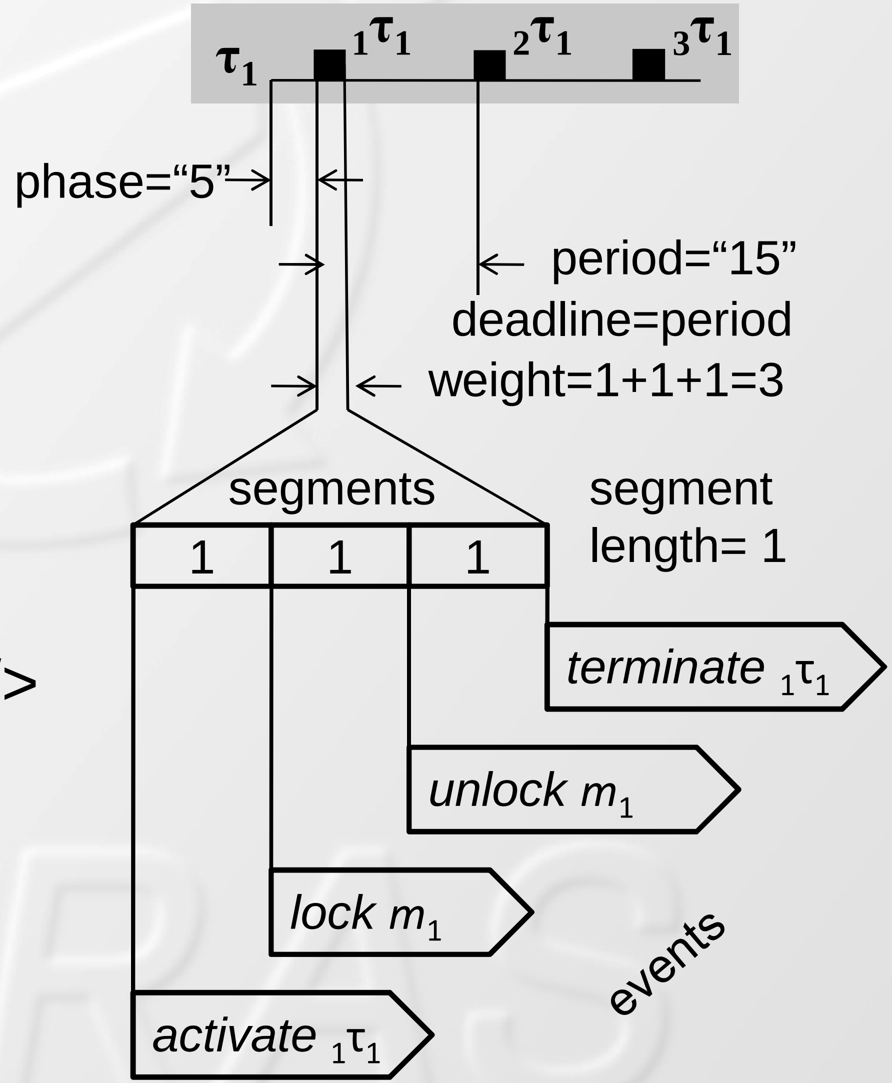
Other protocols (basic/transitional priority inheritance)

When entering a critical interval:
check additional conditions, perform additional actions

When exiting a critical intervial:
perform additional actions

Specifying Task Structure

<task name=“t_1”
phase=“5” period=“15” >
<segment length=“1”
interface=“m_1”
op_type=“lock”/>
<segment length=“1”
interface=“m_1”
op_type=“unlock”/>
<segment length=“1”
op_type=“end”/>
</task>

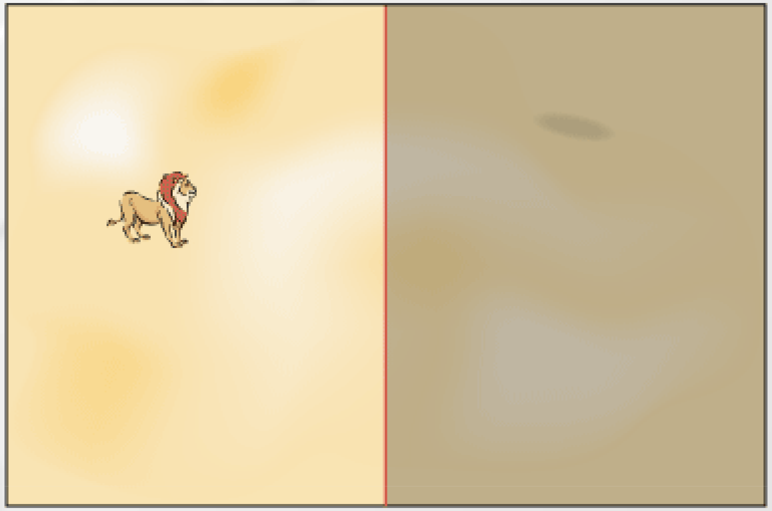


Creating a Resource

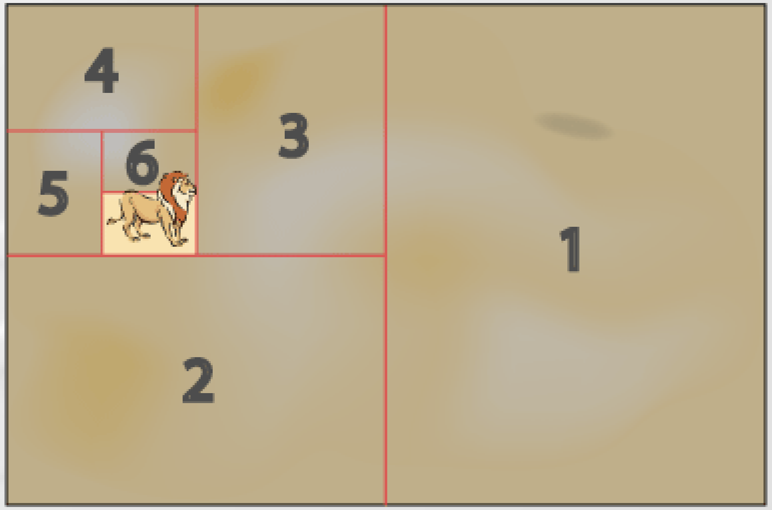
```
: CreateResource ( n--resource-addr) \ Create a new resource with the ID=n
    ResourcePool CELL+ ( n, Pool-addr)
    BEGIN
        DUP @ 0=
        IF  \ Add a new resource to the pool
            #Resources 1+!
            #Resources @ Max#Resources > ABORT" ResourcePool overflow!"
        ( n, pool-addr,)
            2DUP !                          \ -1 Store the resource number
            CELL+ ( n, new-res-addr)
            DUP 0!                          \ 0 Resource priority
            DUP CELL+ ( n, new-res-addr, res-status-addr)
            DUP 0!                          \ 1 Resource status
            CELL+    ( n, new-res-addr, res-queue-addr)
            NULL OVER !    \ 2 Resource queue of jobs waiting for this resource
            CELL+  ( n, new-res-addr, res-#elems-addr)
….
```

Finding the Scaling Factor

```
ScaleInf 0!
Sf @ DUP * Utility /Round  ScaleSup !
     BEGIN
           ScaleSup @ ScaleInf @ - 1 >
     WHILE
           ScaleInf @ ScaleSup @ + 2/ ScaleMed !
           #Violations 0!
           Simul
\ checking that all deadlines were met
           ScaleMed @  #Violations @ 0=
           IF
              ScaleInf
           ELSE
              ScaleSup
           THEN
           !
   REPEAT
```



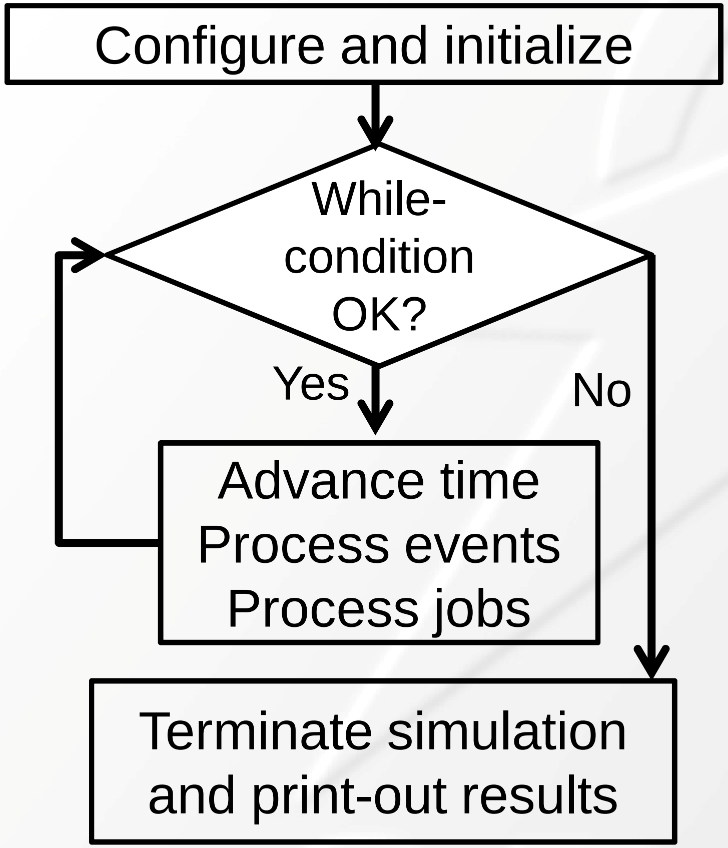
Catching a Lion in a Desert

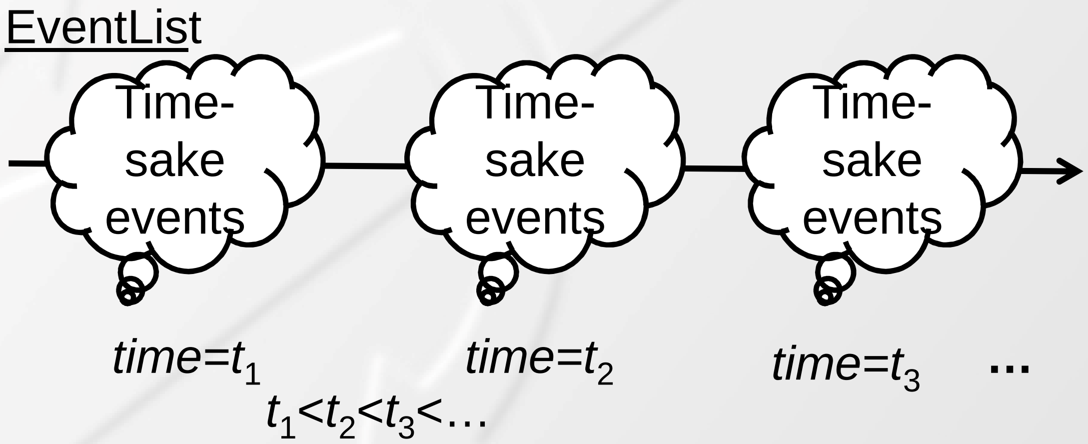


Working through Ordered Lists

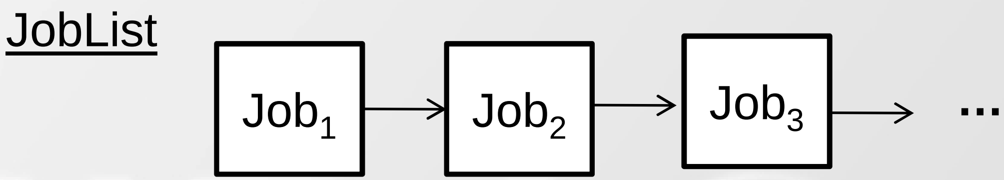
```
: List ( list-element-size, max-list-length -- ) \ Define a list
    CREATE
        NULL ,          \ The "Next" field
        0 ,             \ The current number of elements in the list
        ,               \ The maximal number of list elements
    DOES> ( -- list addr) ;
20 List TaskList        \ Ordered by their static priorities
120 List EventList      \ Ordered by their time to occur
10000 List JobList      \ Ordered by their dynamic (current) priorities
: >List ( new-elem-addr, list-addr -- )  \ Place a new element into the ordered list

: List@ ( list-addr-- elem-addr) \ Get the first (heading) element of the list

: List> ( list-addr-- elem-addr) \ Delete the first element from the list

: List>> ( ordering-value, list-addr--) \ Find and delete a list element
```

The Simulator





Events: Activate a task (create a new job)
Lock a resource
Unlock a resource
Terminate a job



$Prio(Job_1) \geq Prio(Job_2) \geq Prio(Job_3) \geq \ldots$

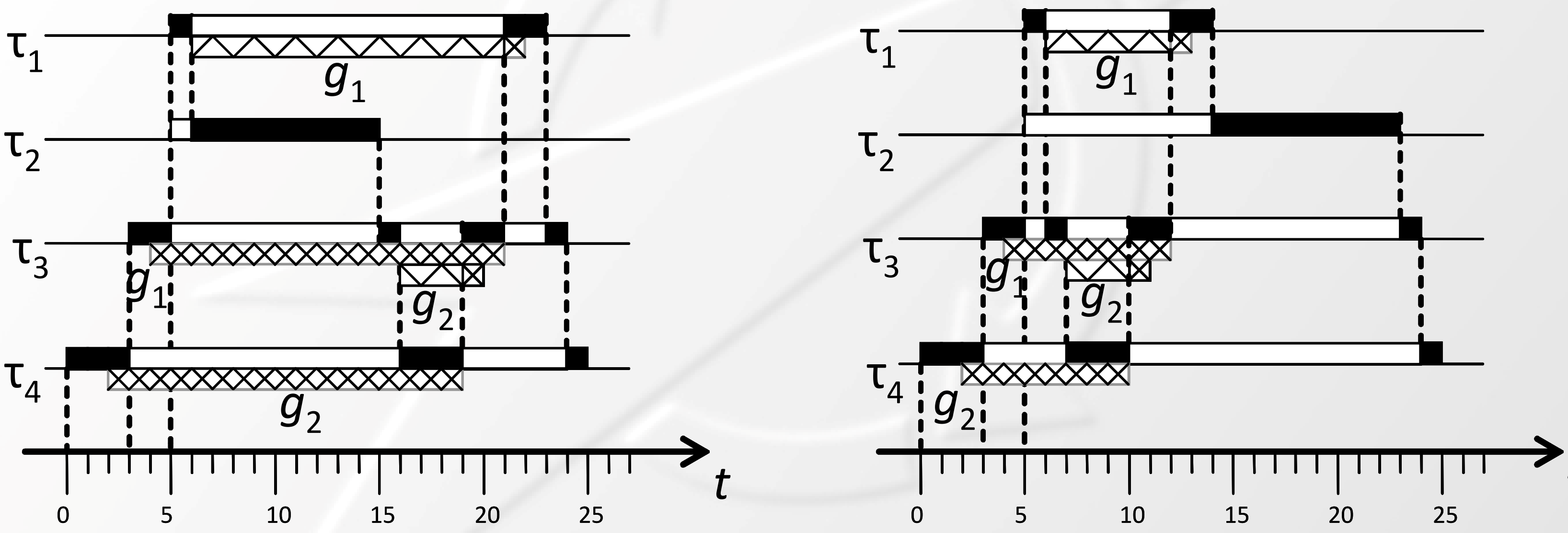
While-condition: (Time < TimeLimit) ∧ (#Jobs < JobLimit) ∧ (#Violations < ViolationsLimit)

Job: Consume processor time by task segment and add a new event to the EventList

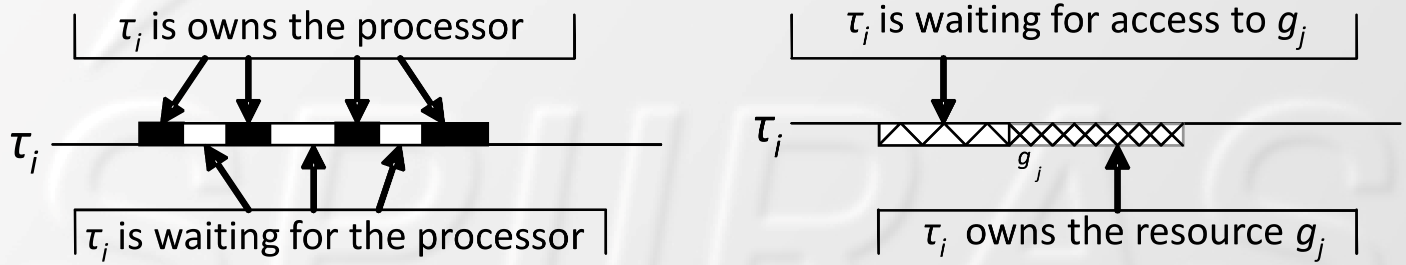
Logs of Two Simulation Sessions

TimeLimit=25 JobLimit=0 ViolationLimit=1	TimeLimit=25 JobLimit=0 ViolationLimit=1
SchedulingMode=RM InheritanceMode=NI	SchedulingMode=RM InheritanceMode=BI
Configuration file name: c:\MPE\App_4t2r.txt	Configuration file name: c:\MPE\App_4t2r.txt
Time=0 Proc=0 for 0 A 4.1	Time=0 Proc=0 for 0 A 4.1
Time=2 Proc=4.1 for 2 L 4.1 of 2	Time=2 Proc=4.1 for 2 L 4.1 of 2
Time=3 Proc=4.1 for 1 A 3.2	Time=3 Proc=4.1 for 1 A 3.2
Time=4 Proc=3.2 for 1 L 3.2 of 1	Time=4 Proc=3.2 for 1 L 3.2 of 1
Time=5 Proc=3.2 for 1 A 1.3 A 2.4	Time=5 Proc=3.2 for 1 A 1.3 A 2.4
Time=6 Proc=1.3 for 1 W 1.3 of 1	Time=6 Proc=1.3 for 1 W 1.3 of 1
Time=15 Proc=2.4 for 9 E 2.4	Time=7 Proc=3.2 for 1 W 3.2 of 2
Time=16 Proc=3.2 for 1 W 3.2 of 2	Time=10 Proc=4.1 for 3 U 4.1 of 2 L 3.2 of 2
Time=19 Proc=4.1 for 3 U 4.1 of 2 L 3.2 of 2	Time=11 Proc=3.2 for 1 U 3.2 of 2
Time=20 Proc=3.2 for 1 U 3.2 of 2	Time=12 Proc=3.2 for 1 U 3.2 of 1 L 1.3 of 1
Time=21 Proc=3.2 for 1 U 3.2 of 1 L 1.3 of 1	Time=13 Proc=1.3 for 1 U 1.3 of 1
Time=22 Proc=1.3 for 1 U 1.3 of 1	Time=14 Proc=1.3 for 1 E 1.3
Time=23 Proc=1.3 for 1 E 1.3	Time=23 Proc=2.4 for 9 E 2.4
Time=24 Proc=3.2 for 1 E 3.2	Time=24 Proc=3.2 for 1 E 3.2
Time=25 Proc=4.1 for 1 E 4.1	Time=25 Proc=4.1 for 1 E 4.1
Time=25 Hardness=1,0000	Time=25 Hardness=1,0000
1/Hardness=1,0000 Density=0,6056	1/Hardness=1,0000 Density=0,6056
ScalingFactor=1,0000	ScalingFactor=1,0000 ok
ERROR: Deadline violation in Task 1 ok	

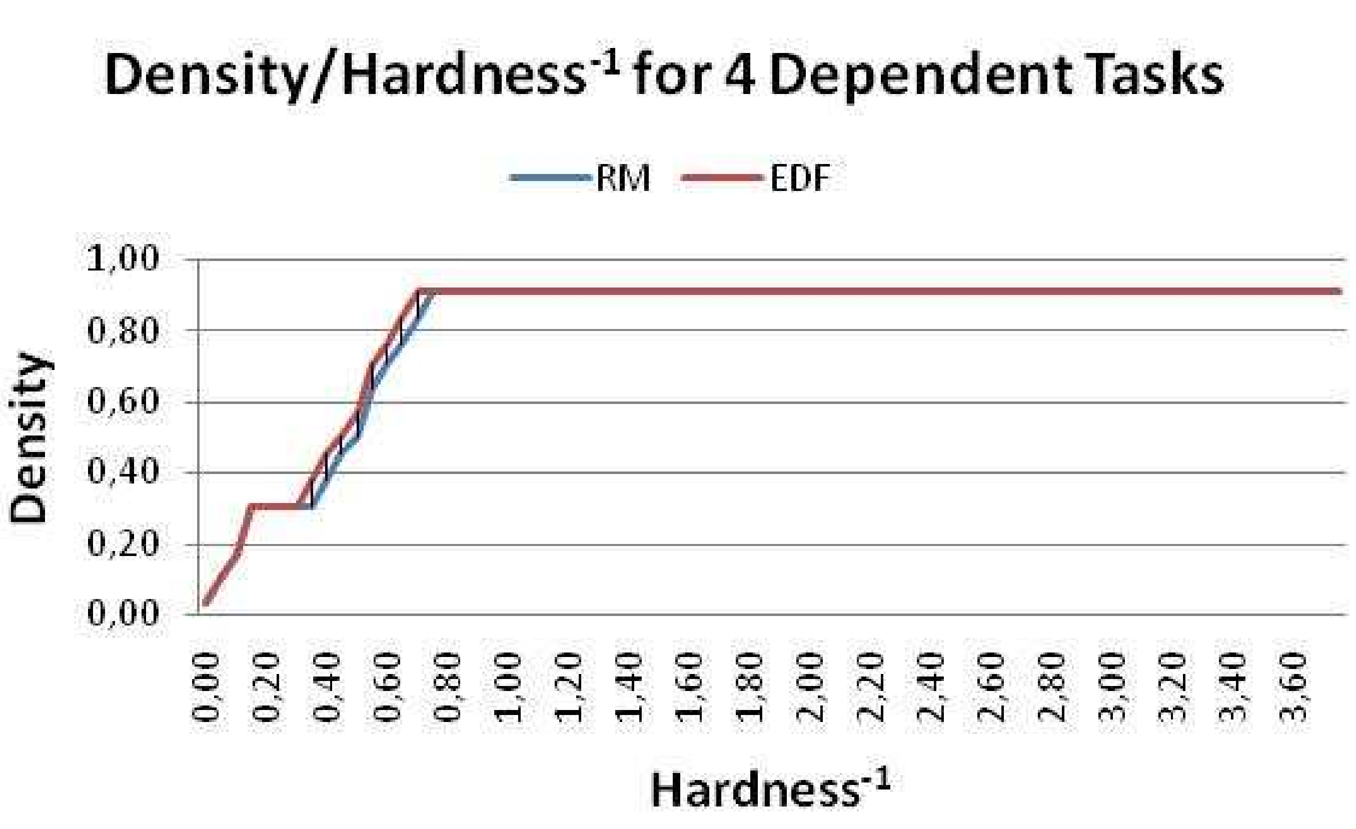
Simulation of 4 Tasks with 2 Resources



a) NI – deadline violation in τ_1 b) BI – no violations



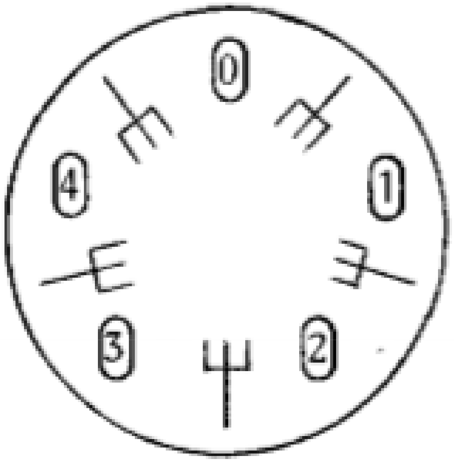
RM vs. EDF in the Same Application



1/H	RM	EDF
0.00	0.0336	0.0336
0.05	0.1009	0.1009
0.10	0.1682	0.1682
0.15	0.3028	0.3028
0.20	0.3028	0.3028
0.25	0.3028	0.3028
0.30	0.3028	0.3028
0.35	0.3028	0.3784
0.40	0.3784	0.4541
0.45	0.4541	0.5046
0.50	0.5046	0.5719
0.55	0.6392	0.7065
0.60	0.7065	0.7568
0.65	0.7568	0.8326
0.70	0.8326	0.9083
0.75	0.9083	0.9083

Four (Five) Dining Philosophers

…Five philosophers, numbered from 0 through 4 are living in a house where the table laid for them, each philosopher having his own place at the table:



Their only problem - besides those of philosophy - is that the dish served is a very difficult kind of spaghetti, that has to be eaten with two forks. There are two forks next to each plate, so that presents no difficulty: as a consequence, however, no two neighbours may be eating simultaneously. …

– Dijkstra E.W. Hierarchical ordering of sequential processes. Acta Informatica 1(2), 1971. – P.115-138.

Configuration Data for 4 Philosophers

<task name=“t_1” phase=”10” period=”1000”>
<segment length=2 interface=”r_1” op_type=”lock”/>
<segment length=4 interface=”r_2” op_type=”lock”/>
<segment length=20 interface=”r_1” op_type=”unlock”/>
<segment length=68 interface=”r_2” op_type=”unlock”/>
<segment length=2 op_type=”end”/> </task>
<task name=“t_2” phase=”7” period=”1000”>
<segment length=2 interface=”r_2” op_type=”lock”/>
<segment length=4 interface=”r_3” op_type=”lock”/>
<segment length=20 interface=”r_2” op_type=”unlock”/>
<segment length=73 interface=”r_3” op_type=”unlock”/>
<segment length=2 op_type=”end”/> </task>
<task name=“t_3” phase=”4” period=”1000”>
<segment length=2 interface=”r_3” op_type=”lock”/>
<segment length=4 interface=”r_4” op_type=”lock”/>
<segment length=20 interface=”r_3” op_type=”unlock”/>
<segment length=79 interface=”r_4” op_type=”unlock”/>
<segment length=2 op_type=”end”/> </task>
<task name=“t_4” phase=”1” period=”1000”>
<segment length=2 interface=”r_4” op_type=”lock”/>
<segment length=4 interface=”r_1” op_type=”lock”/>
<segment length=20 interface=”r_4” op_type=”unlock”/>
<segment length=85 interface=”r_1” op_type=”unlock”/>
<segment length=2 op_type=”end”/> </task>

Log for the 4 Philosophers Puzzle

System Log	Interpretation/Comments
TimeLimit=1000000 JobLimit=0	
ViolationLimit=0 SchedulingMode=RM	Rate Monotonic with Priority Inheritance
InheritanceMode=PI	
Time=1 Proc=0 for 1 A 4.1	Task 4 (job 4.1) is activated at time=1
Time=3 Proc=4.1 for 2 L 4.1 of 4	Task 4 (job 4.1) locks resource 4 at time=3
Time=4 Proc=4.1 for 1 A 3.2	Task 3 (job 3.2) is activated at time=4
Time=6 Proc=3.2 for 2 L 3.2 of 3	Task 3 (job 3.2) locks resource 3 at time=6
Time=7 Proc=3.2 for 1 A 2.3	Task 2 (job 2.3) is activated at time=7
Time=9 Proc=2.3 for 2 L 2.3 of 2	Task 2 (job 2.3) locks resource 2 at time=9
Time=10 Proc=2.3 for 1 A 1.4	Task 1 (job 1.4) is activated at time=10
Time=12 Proc=1.4 for 2 L 1.4 of 1	Task 1 (job 1.4) locks resource 1 at time=12
Time=16 Proc=1.4 for 4 W 1.4 of 2	Task 1 (job 1.4) waits for resource 2 at time=16
Time=19 Proc=2.3 for 3 W 2.3 of 3	Task 2 (job 2.3) waits for resource 3 at time=19
Time=22 Proc=3.2 for 3 W 3.2 of 4	Task 3 (job 3.2) waits for resource 4 at time=22
Time=25 Proc=4.1 for 3	Clinch detected for task 4 (job 4.1) when it tried
Mutual clinch for job 4.1 on resource 1 ok	to lock resource 1 at time=25

Resource_1 Prio=0 Status=Job 1.4 JobsWaiting=NULL
Resource_2 Prio=0 Status=Job 2.3 JobsWaiting=Job 1.4
Resource_3 Prio=0 Status=Job 3.2 JobsWaiting=Job 2.3
Resource_4 Prio=0 Status=Job 4.1 JobsWaiting=Job 3.2

Conclusions

- VFX Forth for Windows, version 4.70
- Only 985 lines of code in Forth
- Only fixed-point arithmetic used
- Special memory allocation to avoid overflow
- Future plans:
  - Improve user's interface
  - More access protocols
  - More scheduling modes
  - Multi-core processors simulation

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Thank you for your attention!