TIMED AUTOMATA APPROACH TO DISTRIBUTED AND FAULT TOLERANT SYSTEM VERIFICATION

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Typical Control Application

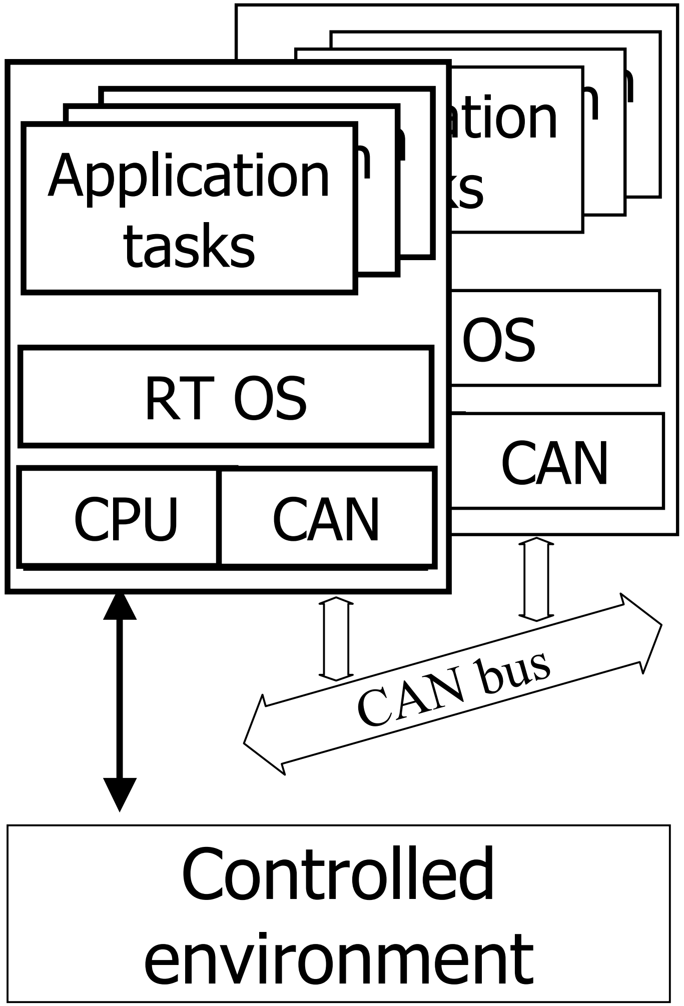
Objective:

to verify the system with respect to its specification

(unsafe state is avoided, end2end response times,…)

Approach:

- •Create fine grain model (timed automata),
- •Formalize specification (subset of temporal logic),
- •Use a Model Checking tool (UPPAAL)



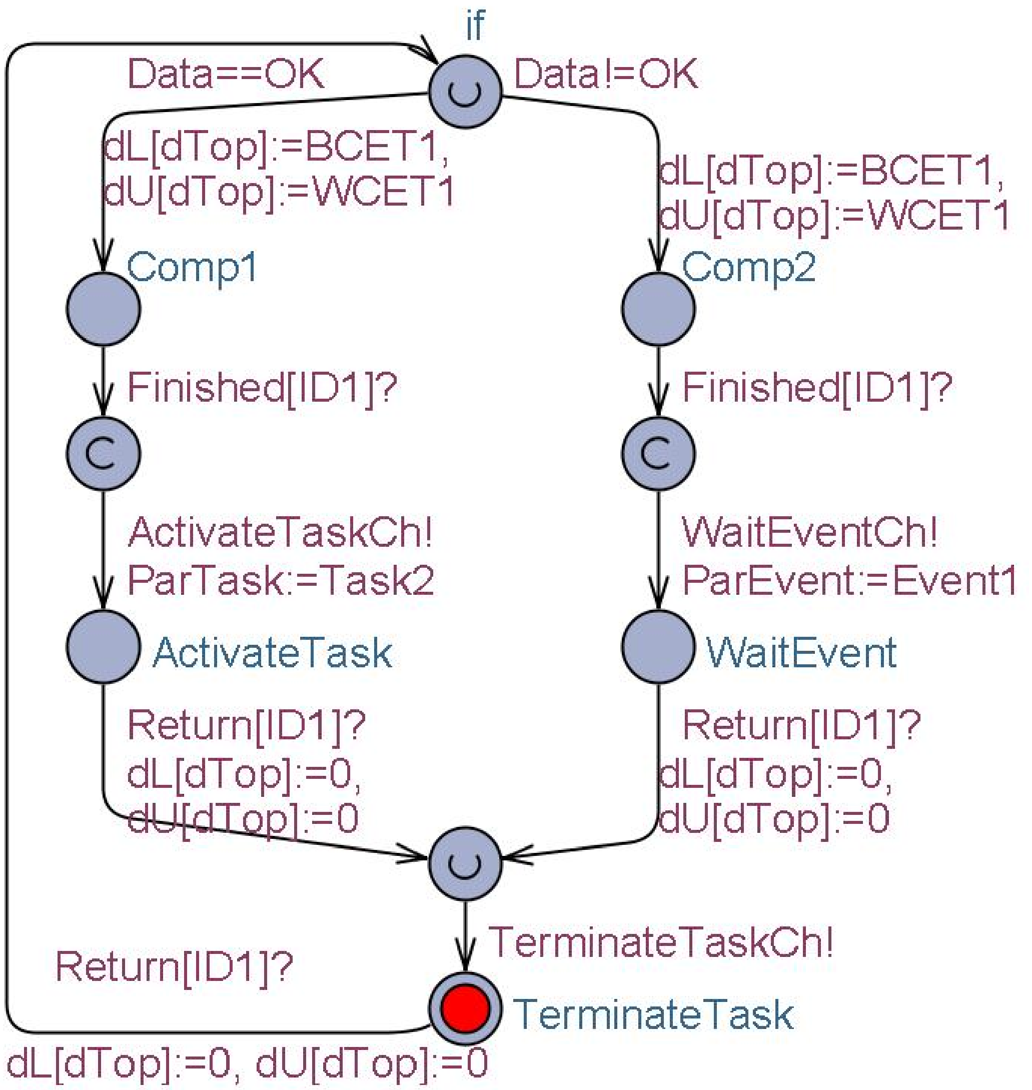
Fine Grain Model:

- ➢Tasks and ISR internal structure
- ➢OS services
- ➢Scheduling policy
- ➢Communication layer
- ➢Controlled environment

Example of Task Internal Structure

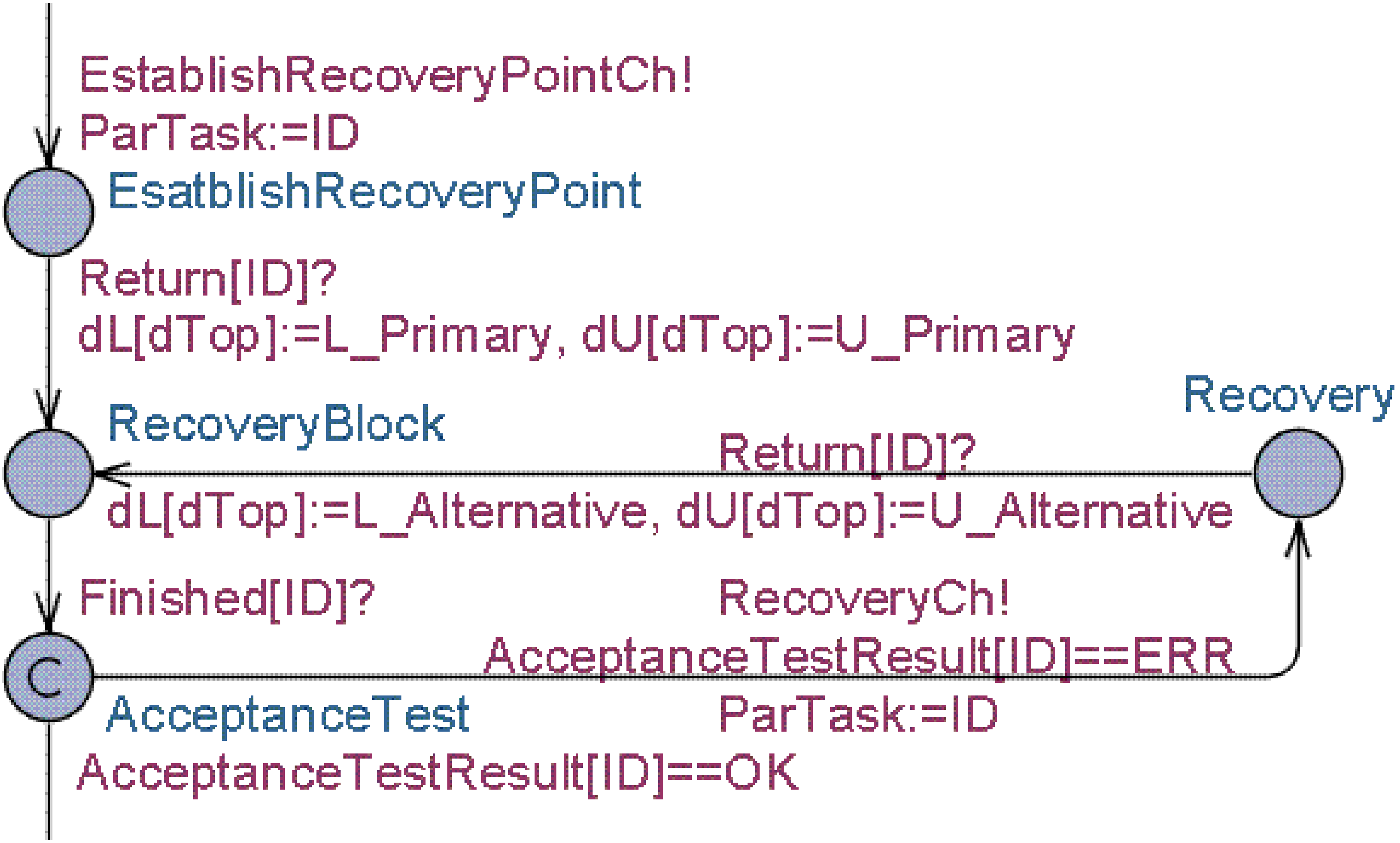
```
Task1()
{
 if (Data==OK)
   {
     Comp1;    // C∈⟨BCET1, WCET1⟩
     ActivateTask(Task2);
   }
 else
   {
     Comp2;    // C∈⟨BCET2, WCET2⟩
     WaitEvent(Event1);
   };
 TerminateTask();
}
```

Controlled environment



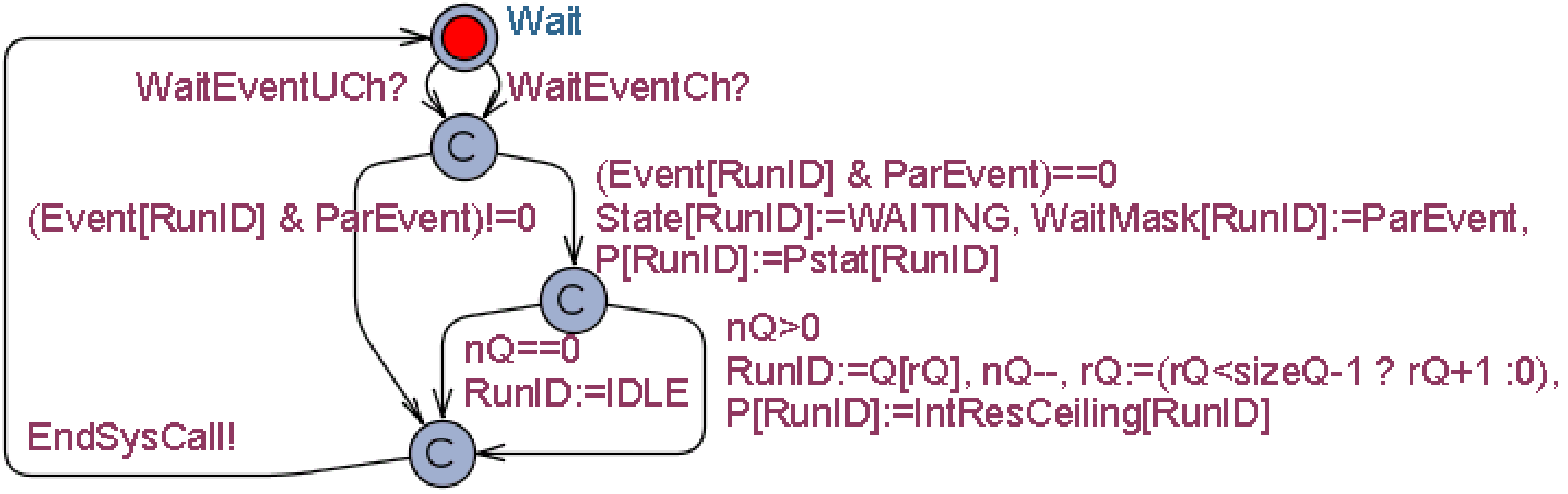
Example of Fault Tolerant Task – Recovery Blocks

```
Ensure (AcceptanceTestResult==OK)
by
   PrimaryBlock;
else by
   AlternativeBlock;
else Err;
```


EstablishRecoveryPointCh!
ParTask:=ID
EsatblishRecoveryPoint
Return[ID]?
dL[dTop]:=L_Primary, dU[dTop]:=U_Primary
RecoveryBlock
Recovery
Return[ID]?
dL[dTop]:=L_Alternative, dU[dTop]:=U_Alternative
Finished[ID]?
RecoveryCh!
AcceptanceTestResult[ID]==ERR
C
AcceptanceTest
ParTask:=ID
AcceptanceTestResult[ID]==OK

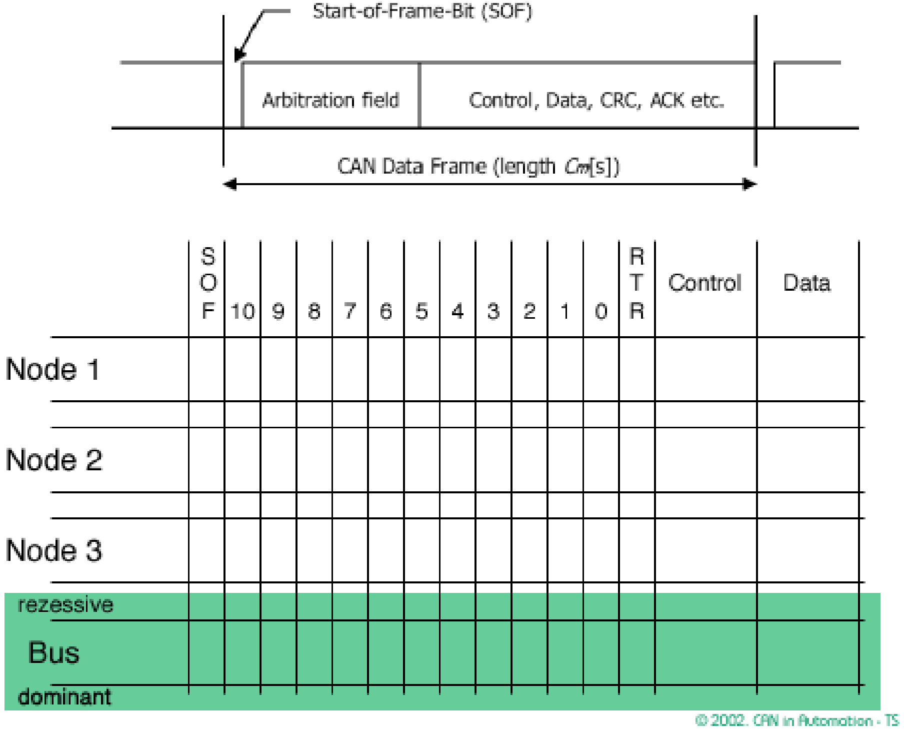
Example of OS Service Model - WaitEvent

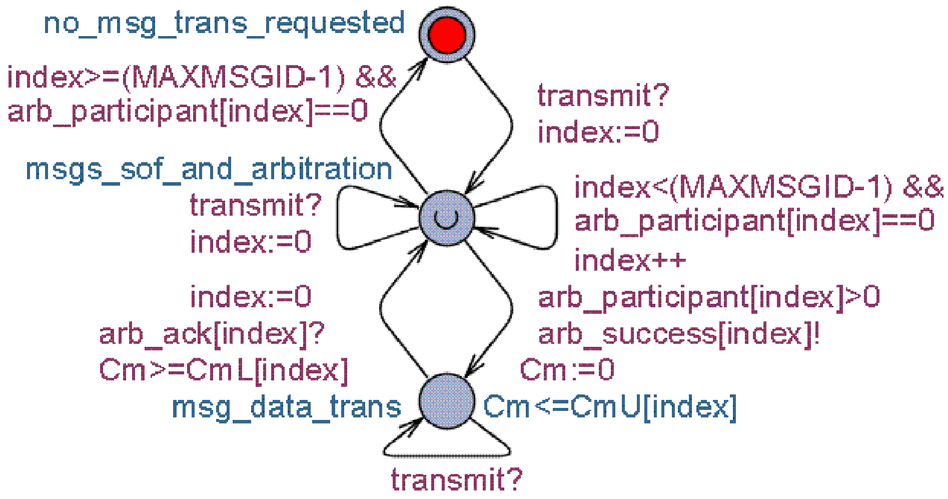
```
WaitEvent (Mask)
{
 if ((Event[RunID] & Mask) == 0)
 {
   State[RunID] := WAITING;
   WaitMask[RunID] := Mask;
   Release Internal Resource;
   RunID := Extract Top of ReadyQ;
   ContextSwitch;
   Get Internal Resource;
   State[RunID] := RUNNING;
 }
 return E_OK;
};
```


Wait
WaitEventUCh?
WaitEventCh?
C
(Event[RunID] & ParEvent)!=0
(Event[RunID] & ParEvent)==0
State[RunID]:=WAITING, WaitMask[RunID]:=ParEvent,
P[RunID]:=Pstat[RunID]
C
nQ==0
RunID:=IDLE
nQ>0
RunID:=Q[rQ], nQ--, rQ:=(rQ<sizeQ-1 ? rQ+1 :0),
P[RunID]:=IntResCeiling[RunID]
EndSysCall!
C

Example of Communication Layer -CAN

Arbitration technique





no_msg_trans_requested

index>=(MAXMSGID-1) &&
arb_participant[index]==0

transmit?
index:=0

msgs_sof_and_arbitration

transmit?
index:=0

index<(MAXMSGID-1) &&
arb_participant[index]==0
index++

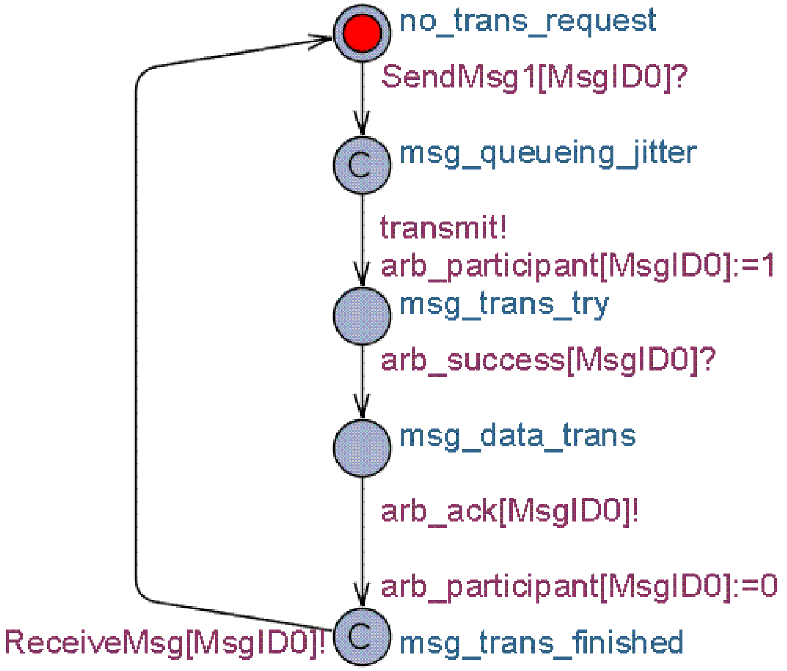
index:=0
arb_ack[index]?
Cm>=CmL[index]

arb_participant[index]>0
arb_success[index]!
Cm:=0

msg_data_trans

Cm<=CmU[index]

transmit?



no_trans_request

SendMsg1[MsgID0]?

msg_queueing_jitter

transmit!
arb_participant[MsgID0]:=1

msg_trans_try

arb_success[MsgID0]?

msg_data_trans

arb_ack[MsgID0]!

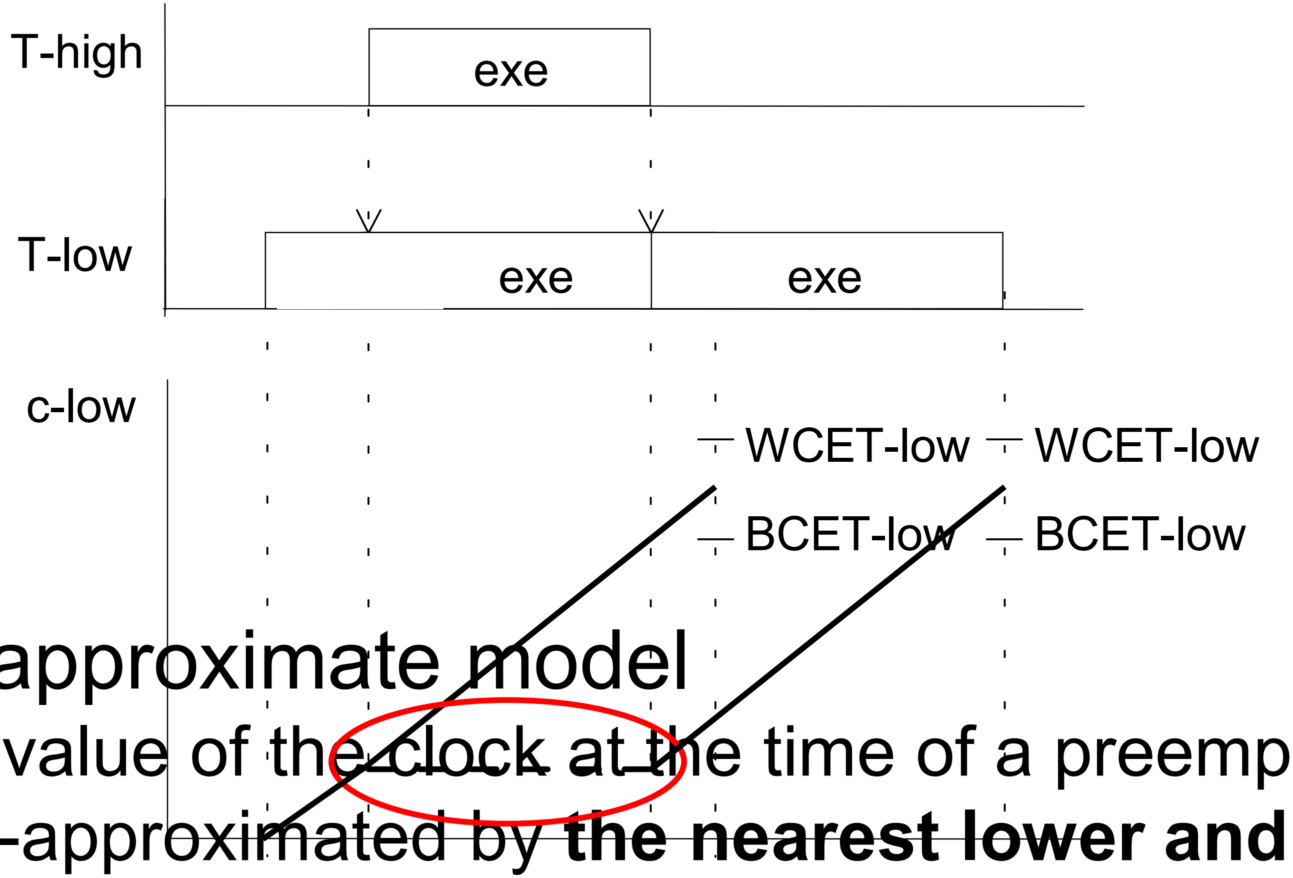
arb_participant[MsgID0]:=0

ReceiveMsg[MsgID0]!

msg_trans_finished

Transmission time
(given by message length and data ra

1st Essential Problem – Preemption



⇨ Over-approximate model

(the value of the clock at the time of a preemption is over-approximated by **the nearest lower and upper integer**)

In Time Automata, **clock variable** measuring process execution time **cannot be stopped** when preemption occurs (price paid for decidability of model checking probem).

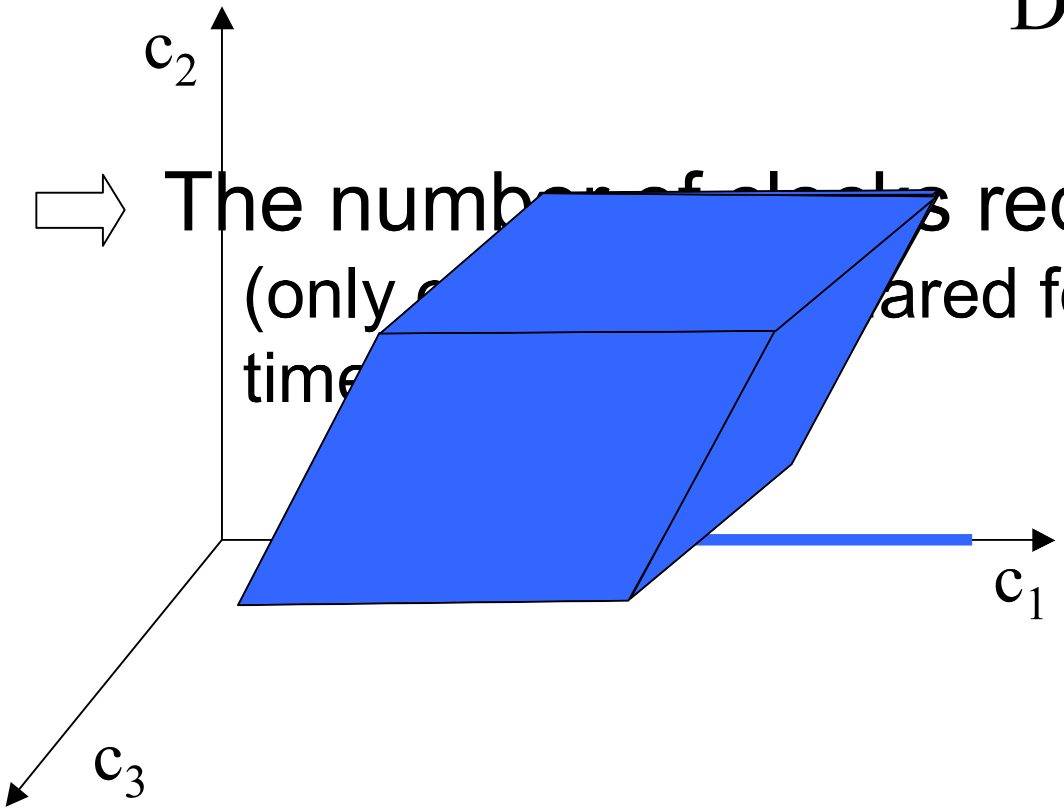
2nd Essential Problem – State-space explosion

The complexity of the model-checking verification **exponentially grows with the number of clocks**

⇨ The numb s reductio

(only c ared for mea on

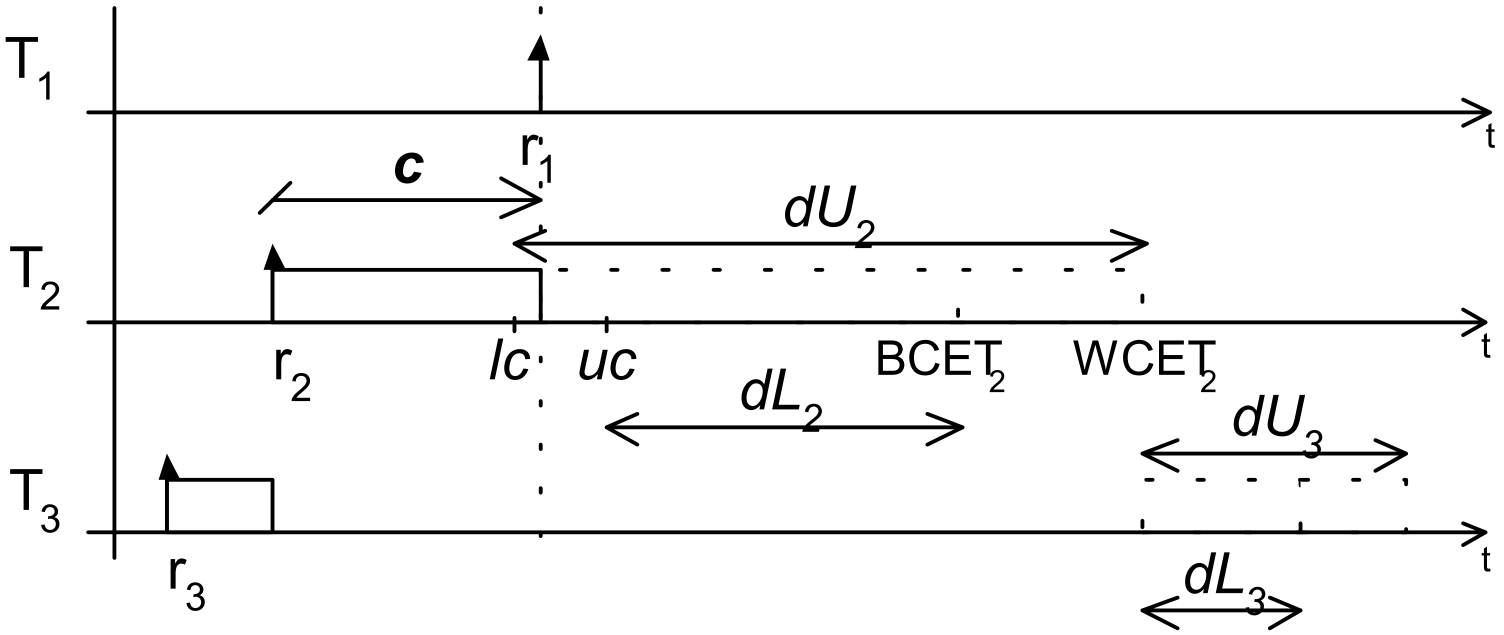
time



DBM

	c_0	c_1	c_2	c_3
c_0				
c_1				
c_2				
c_3				

Implementation



Δ-list

dL	dL_3	$BCET_2$	-	-
dU	dU_3	$WCET_2$	-	-

⇧ *dTop*

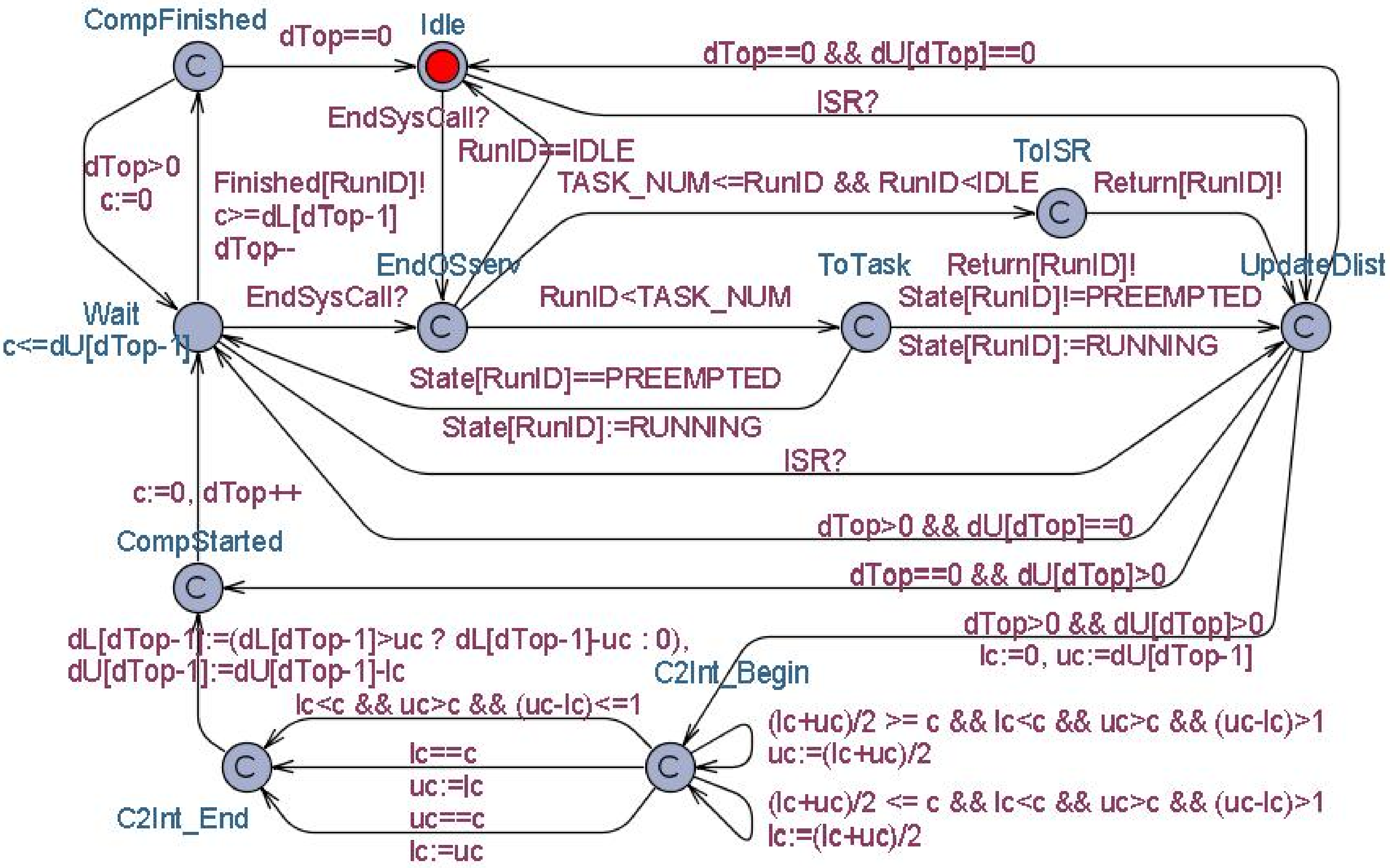
At time r_1 changed to

Δ-list

dL	dL_3	dL_2	$BCET_1$	-
dU	dU_3	dU_2	$WCET_1$	-

⇧ *dTop*

Timed automaton controlling preemption



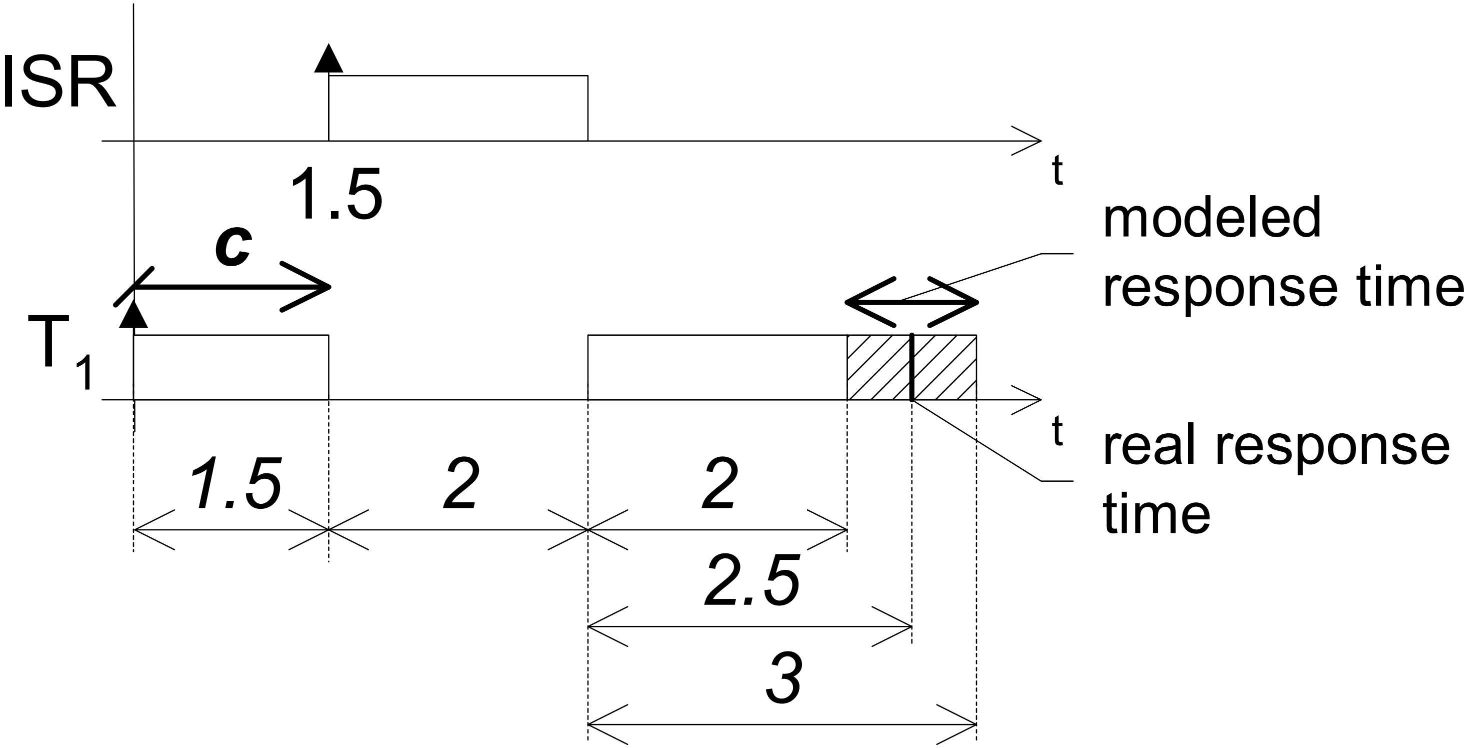
Over-approximation of the model

$IRQ \in (1, 2)$

$C_{ISR} = 2$

$r_{T1} = 0$

$C_1 = 4$

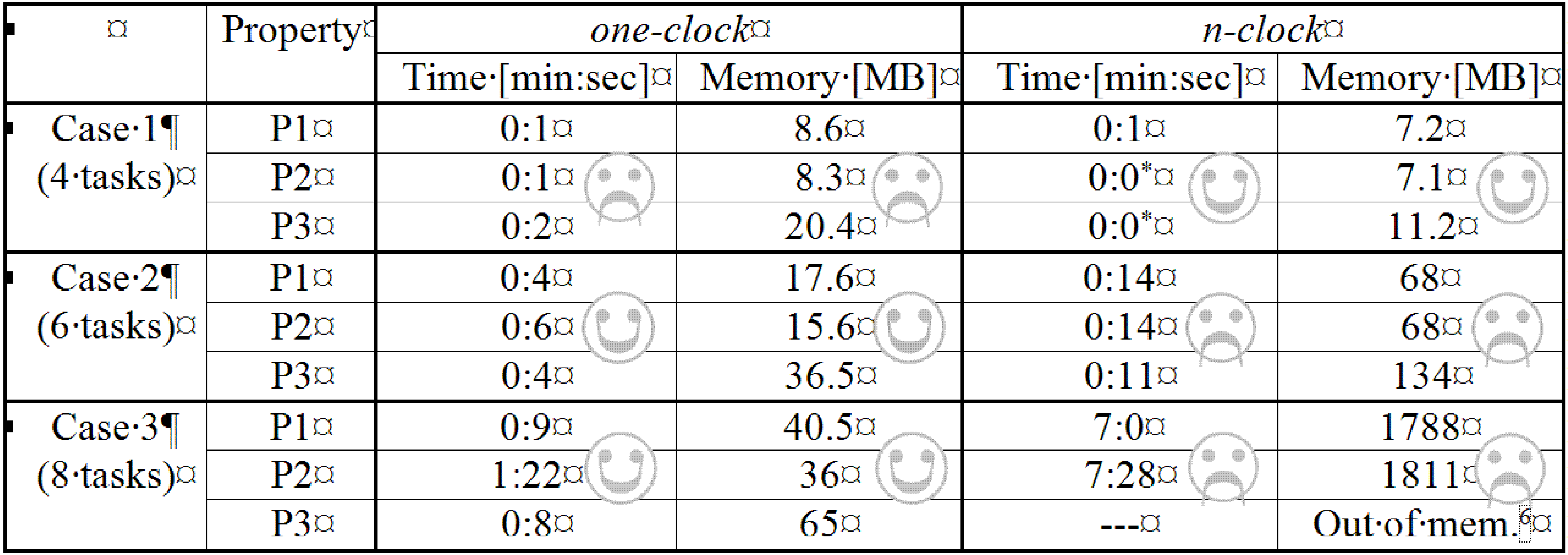


Real behavior $\subseteq$ Modeled behavior

Conclusion

- **model-checking approach** can be
  - used for **verification of distributed RT system** properties (we have designed model of *OSEK OS* services and *CAN*)
  - used for **verification of fault tolerant system** properties (we have developed model of *recovery blocks*)
  - easily changed or extended **by application developer**
- Over-approximation **preserves the most important properties**
  - *Safety properties* (“unsafe state is avoided”)
  - *Bounded liveness properties* (“Desirable state is reached in bounded time”)
- **drawback: high complexity** of model-checking limits size of verified application ()

Complexity



	Property	*one-clock*		*n-clock*	
		Time [min:sec]	Memory [MB]	Time [min:sec]	Memory [MB]
Case 1 (4 tasks)	P1	0:1	8.6	0:1	7.2
	P2	0:1 ☹	8.3 ☹	0:0* ☺	7.1 ☺
	P3	0:2	20.4	0:0*	11.2
Case 2 (6 tasks)	P1	0:4	17.6	0:14	68
	P2	0:6 ☺	15.6 ☺	0:14 ☹	68 ☹
	P3	0:4	36.5	0:11	134
Case 3 (8 tasks)	P1	0:9	40.5	7:0	1788
	P2	1:22 ☺	36 ☺	7:28 ☹	1811 ☹
	P3	0:8	65	---	Out of mem.[6]