# Scheduling for Time-Triggered Network Communication

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14. Juni 2012

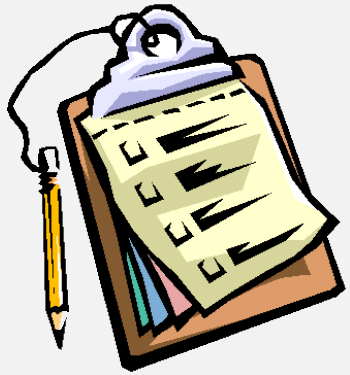
# Agenda

**(1) Rückblick**

(2) Verwandte Arbeiten

- Heuristiken
- Model Checking (SPIN)
- Model Checking (UPPAAL)

(3) Ausblick



# Rückblick: AW1

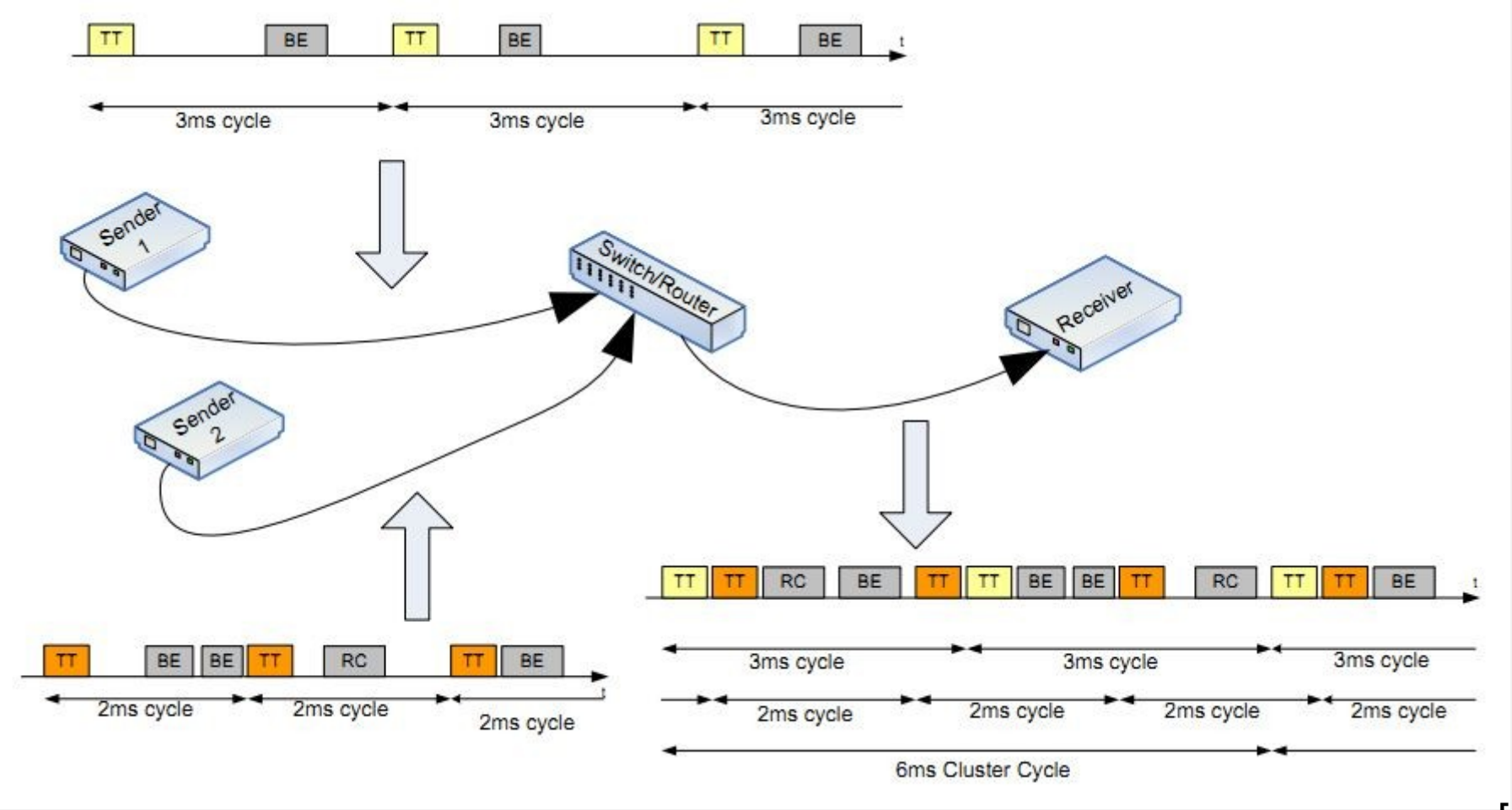
- Time-Triggered Ethernet (TTTech)
- Echtzeiterweiterung
- Switched bussystem

- Schedulingproblem: NP-vollständig
- Preemptive und non-preemptive
- Statisch und dynamisch

# Rückblick: TT-Ethernet

- **Time Triggered**
  - Zeitkritischer Netzwerkverkehr
  - Höchste Priorität
  - Minimum an Latenz und Jitter
- **Rate-constrained**
  - Ereignisbasierter Nachrichtentyp
  - Unterliegt keinem festen Scheduling
  - Werden von TT-Nachrichten verdrängt
- **Best-efford**
  - Standard Ethernet Netzwerkverkehr

# Rückblick: TTE-Schedule

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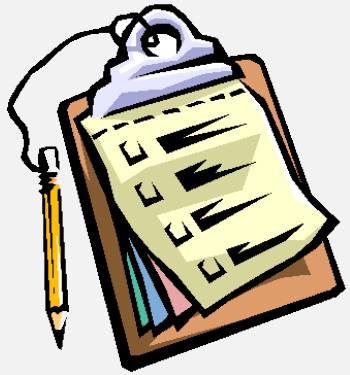

# Heuristiken

## Scheduling with Bus Access Optimization for Distributed Embedded Systems

- Mehrere programmierbare und Hardware Prozessoren
- TTP Bussystem
- Netzwerk-Tasks als normale Prozess-Tasks
- Kontroll- und Datenabhängigkeiten

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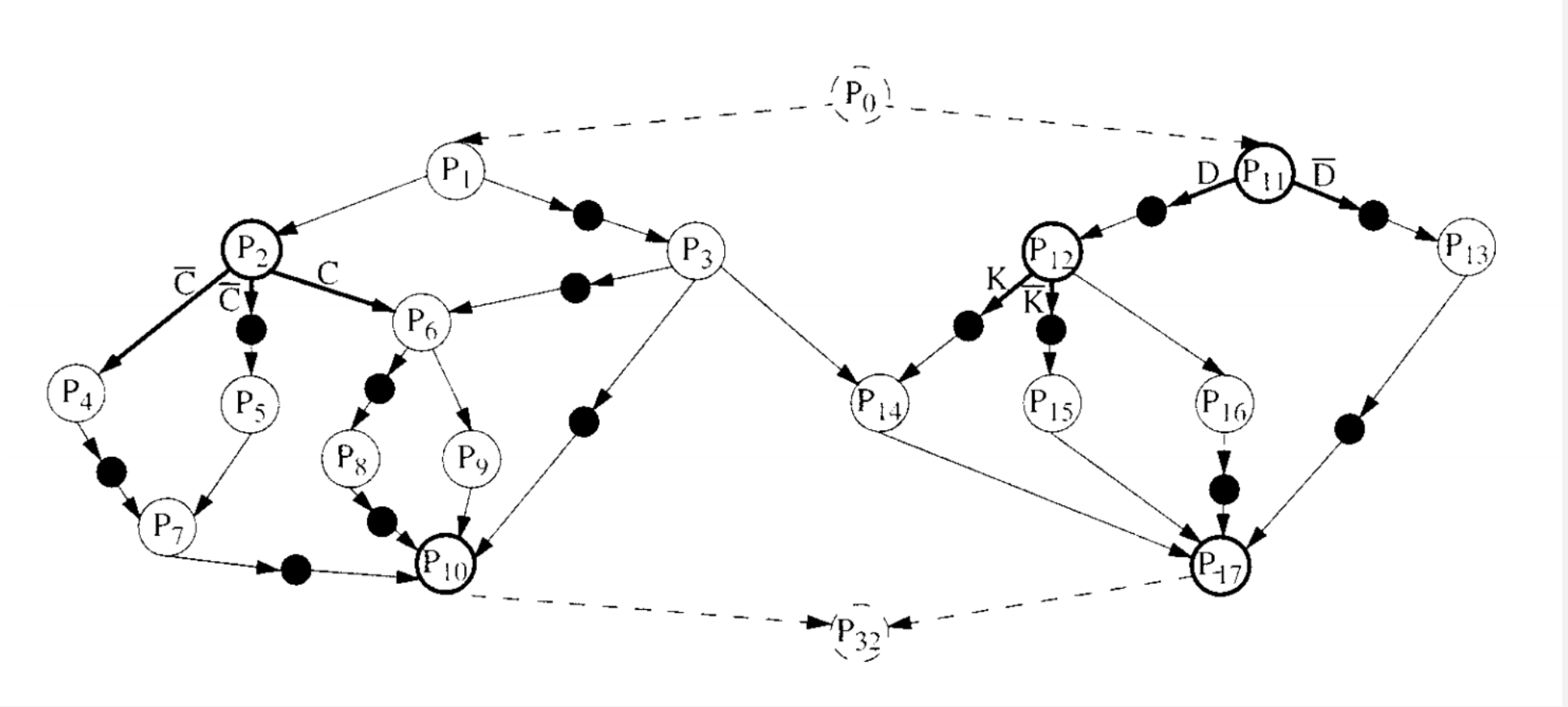
Paul Pop
Linköping University

Petru Eles
Linköping University

Zebo Peng
University of Cincinnati

# Heuristiken: CPG




[2]

Conditional Process Graph

G = (V, Es, Ec)

# Heuristiken: List Schedule

```
List_schedule ()
  for each processing element pe_i, i=1,2, ..., N_pe, do
    free_pei=0
  end for;
  schedule P_0 at t=0; initialize ready process list Ls_Ready
  with direct successors of P_0;        -- P_0 is the source node
  while Ls_Ready is not empty do
    p=Head(Ls_Ready);
    if M(p)∈ HP then                    -- hardware supports several
        schedule p at t=p.t_ready       -- processes at a time;
    else
        p=Select(Ls_Ready, M(p));
        schedule p at t=max(p.t_ready, free_M(p));
        free_M(p)=t+t_p
    end if;
    delete p from Ls_Ready;
    Ls_Ready = Ls_Ready + processes which become
                          ready after p is executed
  end while
end List_schedule;
```

[2]

Basic list scheduling algorithm

# Heuristiken: Schedule Table

| | *true* | $D$ | $D \wedge C$ | $D \wedge C \wedge \overline{K}$ | $D \wedge C \wedge K$ | $D \wedge \overline{C}$ | $D \wedge \overline{C} \wedge \overline{K}$ | $D \wedge \overline{C} \wedge K$ | $\overline{D}$ | $\overline{D} \wedge C$ | $\overline{D} \wedge \overline{C}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $P_1$ | 0 | | | | | | | | | | |
| $P_2$ | 3 | | | | | | | | | | |
| $P_3$ | | 6 | | | | | | | 6 | | |
| $P_4$ | | | | | | 7 | | | | | 7 |
| $P_5$ | | | | | | | 18 | 18 | | | 18 |
| $P_6$ | | | | 21 | 20 | | | | | 20 | |
| $P_7$ | | | | | | | 21 | 21 | | | 21 |
| $P_8$ | | | | 29 | 28 | | | | | 28 | |
| $P_9$ | | | | 26 | 25 | | | | | 25 | |
| $P_{10}$ | | | | 35 | 34 | | 27 | 26 | | 34 | 26 |
| $P_{11}$ | 0 | | | | | | | | | | |
| $P_{12}$ | | | 9 | | | 9 | | | | | |
| $P_{13}$ | | | | | | | | | | 10 | 13 |
| $P_{14}$ | | | | | 18 | | | 24 | | | |
| $P_{15}$ | | | | 19 | | | 24 | | | | |
| $P_{16}$ | | | | 15 | 15 | | 15 | 15 | | | |
| $P_{17}$ | | | | 25 | 24 | | 30 | 26 | | 24 | 24 |
| $P_{18}$ (1→3) | 3 | | | | | | | | | | |
| $P_{19}$ (2→5) | | | | | | 9 | | | | | 8 |
| $P_{20}$ (3→10) | | | | 21 | 20 | | 21 | 20 | | 20 | 20 |
| $P_{21}$ (3→6) | | | | 19 | 18 | | | | | 18 | |
| $P_{22}$ (4→7) | | | | | | 12 | | | | | 13 |
| $P_{23}$ (6→8) | | | | 26 | 25 | | | | | 25 | |
| $P_{24}$ (7→10) | | | | | | | 25 | 24 | | | 24 |
| $P_{25}$ (8→10) | | | | 33 | 32 | | | | | 32 | |
| $P_{26}$ (11→13) | | | | | | | | | | 8 | 11 |
| $P_{27}$ (11→12) | | | 8 | | | 8 | | | | | |
| $P_{28}$ (12→14) | | | | | 16 | | | 16 | | | |
| $P_{29}$ (12→15) | | | | 16 | | | 16 | | | | |
| $P_{30}$ (13→17) | | | | | | | | | | 22 | 22 |
| $P_{31}$ (16→17) | | | | 23 | 22 | | 23 | 22 | | | |
| D | 6 | | | | | | | | | | |
| C | | 7 | | | | | | | 7 | | |
| K | | | 15 | | | 15 | | | | | |

[2]

# Heuristiken: Ergebnis

- TTP ist kein TTE
- Keine Betrachtung von Nachrichtenklassen
- Kein reines statisches Scheduling
- Starker Fokus auf Conditions

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- Model Checking (UPPAAL)

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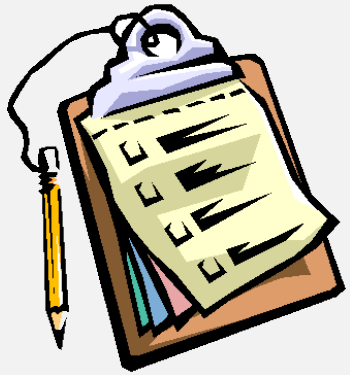
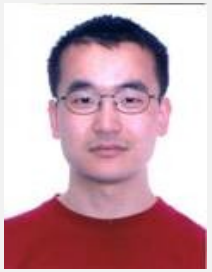


# Model-Checking

## Optimization of Static Task and Bus Access Schedules for Time-Triggered Distributed Embedded Systems with Model-Checking

- Programmierbare Prozessoren
- TTP Bussystem
- Software Tasks und Network Messages in statischer Lookup Table
- Process Graph G = (V, E)



Zonghua Gu

Xiuqiang He

Mingxuan Yuan

Hong Kong University

# Model-Checking: SPIN

- Gerard J. Holzmann – Bell Labs
- Tool zum verifizieren von verteilten Software Modellen
- Promela (Process Meta Language)
- Linear Temporal Logic (LTL)
- Generiert Problem spezifische Model-Checker

# Model-Checking: Promela

```
proctype Task(byte i) {
{Block until precedence relations are satisfied.}
/*Block until CPU is free.*/
atomic{CPU[Task[i].cpuID].status==FREE->
  Task[i].status=RUNNING;
  Task[i].finTime=time+Task[i].et;
  CPU[Task[i].cpuID].status=BUSY;}
/*Block until time advances to its finish time*/
atomic{time==Task[i].finTime->
  Task[i].status=DONE;
  CPU[Task[i].cpuID].status=FREE;
  {Send messages to remote receiver tasks.}
```

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Model of a non-preemptive Task

# Model-Checking: Ergebnis

- TTP ist kein TTE
- Liefert bessere Ergebnisse als die vorherige Heuristik
- Betrachtet work- und non work-conserving Scheduling
- Ressourcenintensiv
- State space explosion

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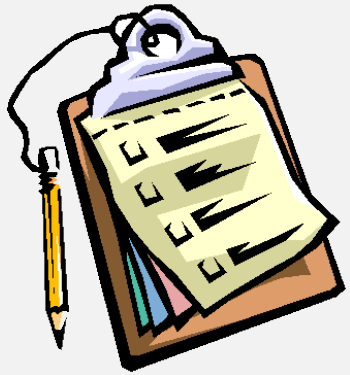
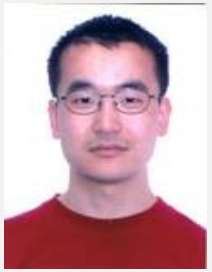


# Model-Checking

## Optimal Static Task Scheduling on Reconfigurable Hardware Devices using Model-Checking

- Re-konfigurierbare FPGAs
- Kein verteiltes System
- Schedulingproblem ähnlich
- Parallelität
- UPPAAL



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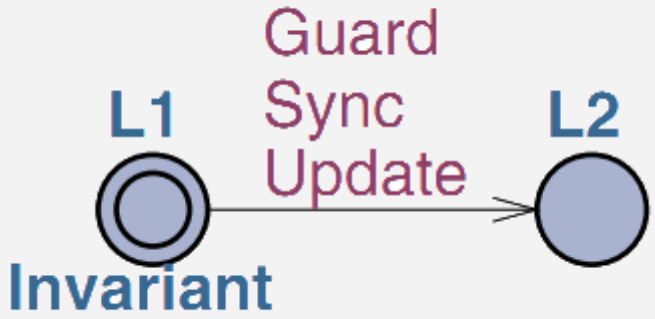
# Model Checking: UPPAAL

- Entwickelt von der Uppsala und Aalborg Universität
- Timed Automata
- Synchronisationskanäle
- Integer Variablen
- Timed Computational Tree Logic (TCTL)
- Execution Trace to final reachable state

# Model-Checking: UPPAAL

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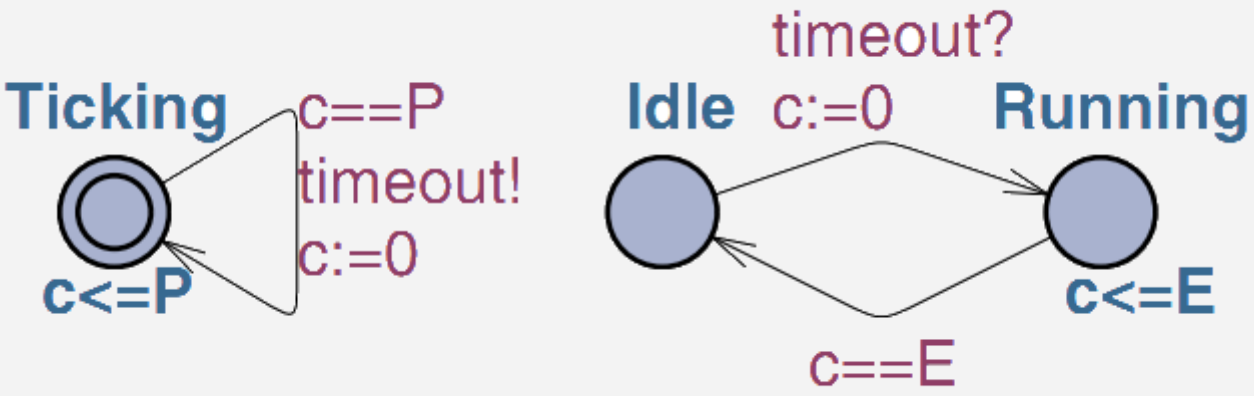
Basis Syntax

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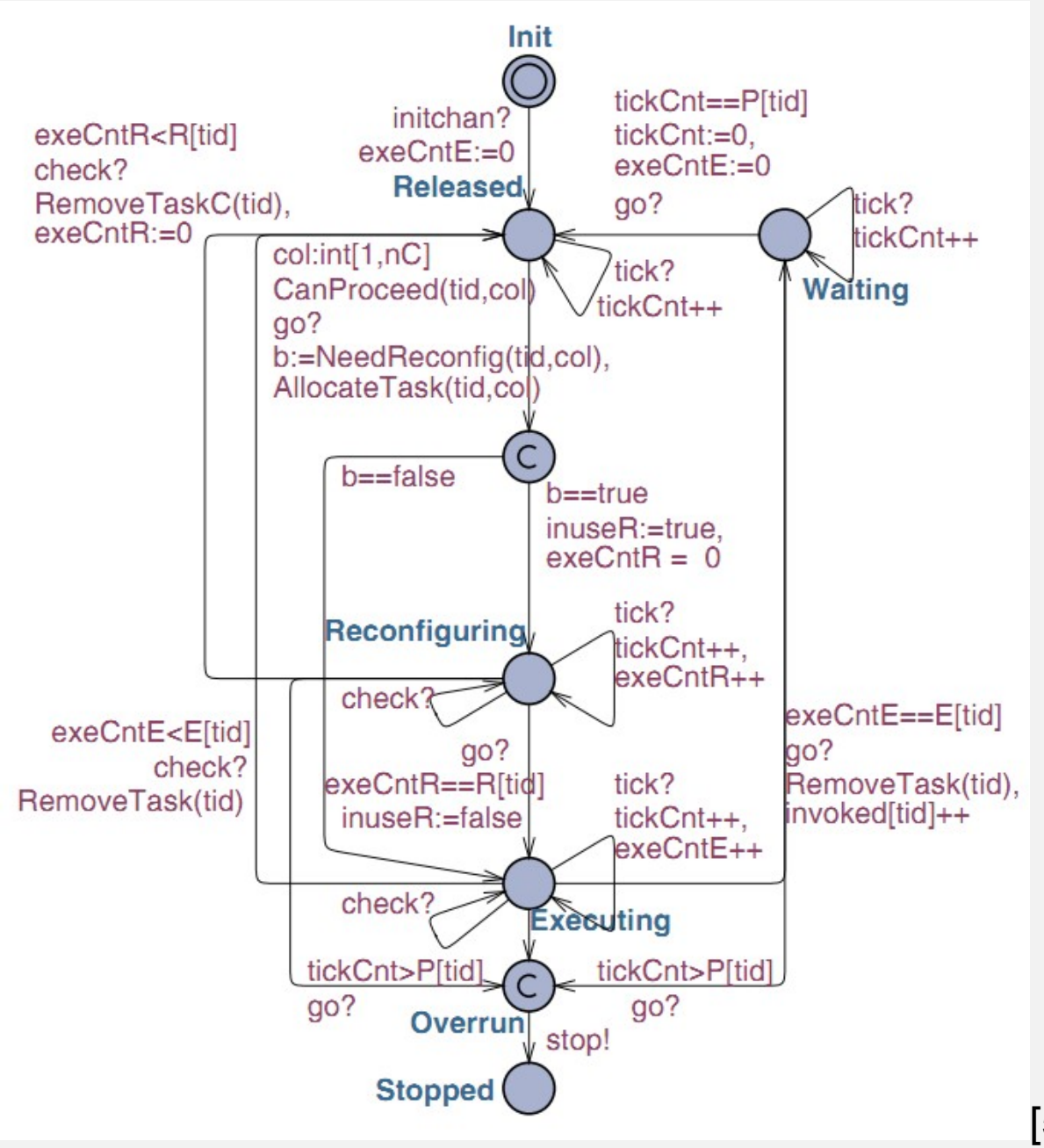
Periodic Task System

# Model-Checking: UPPAAL

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# Model-Checking: Ergebnis

- Timed Automata alternativer Ansatz
- Static Scheduling of real-time tasks
- Parallelität
- Kein verteiltes System
- Kommunikationsprotokoll?
- Nachrichtenklassen?

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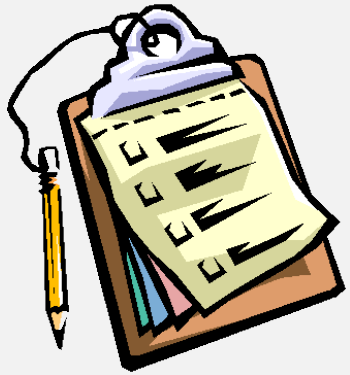

# Ausblick: Projekt

- Basis-Tool entwickeln für TTE-Scheduling
- Heuristik oder Model-Checking?
- Wie lassen sich die TTE-Eigenschaften und Nachrichtenklassen integrieren?
- Bisherige Arbeiten beachten nur TTP

# Vielen Dank...

für die

Aufmerksamkeit!

# Referenzen


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