Model-Based Scheduler Analysis

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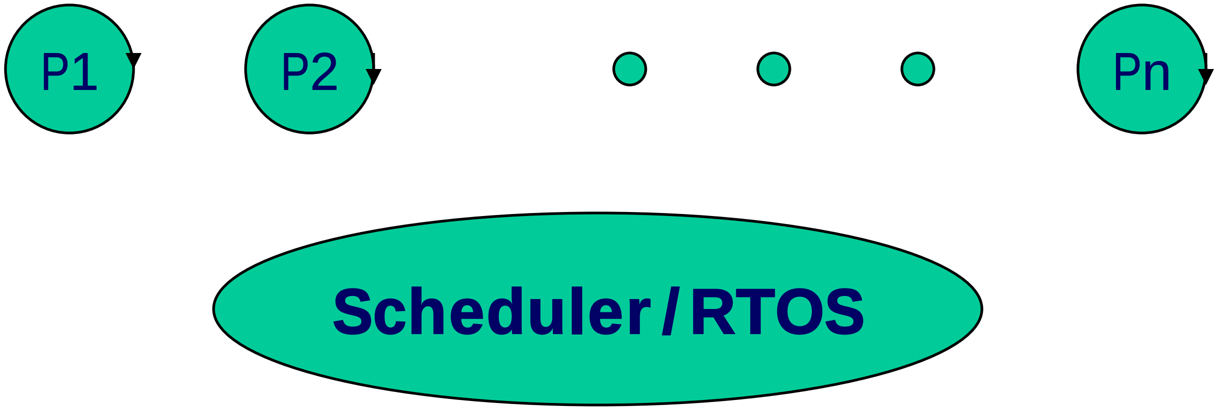
OUTLINE

Scheduler analysis as Model Checking of Timed Systems

- A Unified Model for Timed Systems
  - Timed automata with tasks
- Scheduling Analysis by Model Checking of Timed Systems (w. UPPAAL)
  - Additional trick to handle preemption
  - Limits to decidability
- TIMES tool
- Preliminary ideas on achieving modularity

Classical approach to Real Time Scheduling

- Controller = a set of periodic tasks + a scheduler



- Well-developed techniques, e.g., Rate-Monotonic Scheduling

The Periodic Task Model

+ Simple to analyze (Rate-Monotonic Analysis)

- Assumption too simplistic for many systems
  - May give too pessimistic analysis results
  - ”Real” systems have
    - Shared resources, process synchronization, communication, precedence constraints, complex timing (modes, jitter, ...)
  - Adding these features complicates the model, and leads to an explosion in ”special cases”

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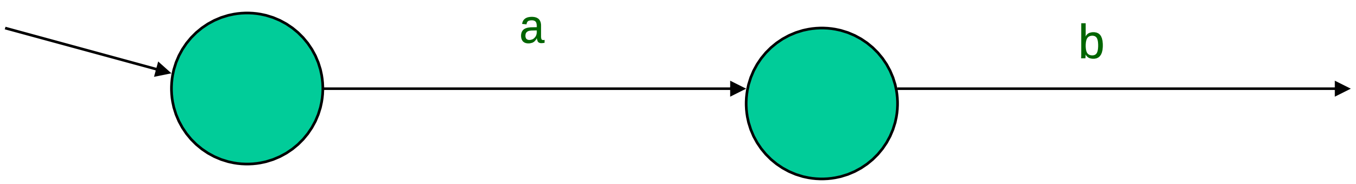
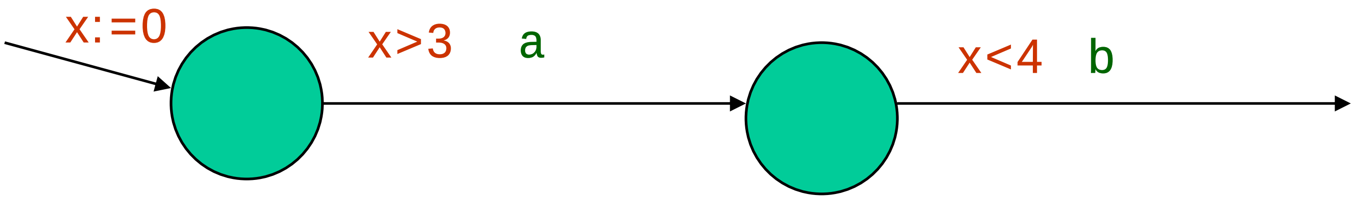
- Wanted: uniform framework to model a variety of patterns in timed systems.
- Proposal: Timed Automata

Timed Automata



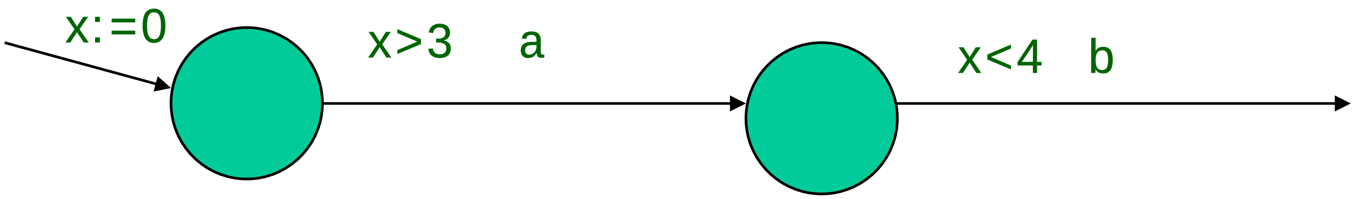
- Based on standard automata

Timed Automata



- Based on standard automata
- Clocks give upper and lower bounds on distance in time between occurrences of symbols.
- Temporal properties of Timed Automata (reachability, LTL, ...) can be model-checked (PSPACE-complete)
- Implemented in tools (UPPAAL, IF/Kronos)

Timed Traces of TA



(3.3, a) (3.4, b),

(6.5, a),

(3.6, a) (3.9, b),

(3.14, a) (3.14159, b)

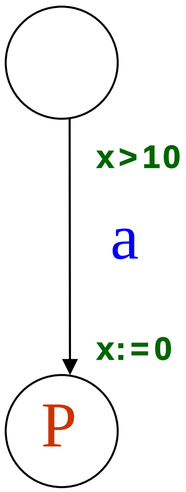
… …

Using Timed Automata to model Real Time Systems

- Arrival pattern of tasks modeled by Timed Automata
  - Extend TA with task spawning
- Computation time of tasks modeled by clock
  - Assume no preemption for now
- Deadlines modeled by clocks
  - Expiration leads to ”error state”
- Include processor and task queue in the analysis
- Precedence, ..., can be modeled by additional synchronizations

Timed Automata with Tasks

- Events
  - synchronization
  - interrupts,
  - passing of time
- Timing constraints
  - specifying event arrivals
  - e.g., periodic and sporadic
- Tasks (executable programs)
  - Internal computation (need not be modeled)
  - Released by a TA transition, and scheduled in the ready queue of RTOS

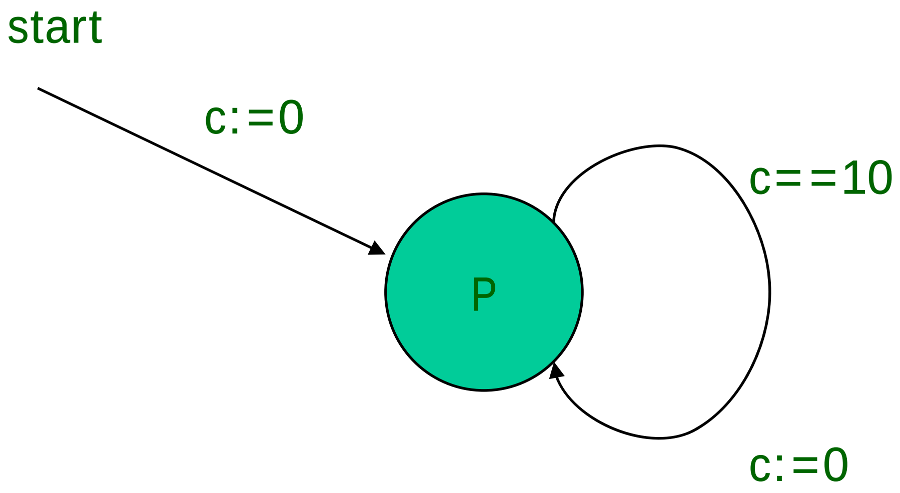


Timed Automaton

+ tasks

- Tasks have parameters:
  - C: WCET
  - D: Relative deadline
  - (other parameters for scheduling, e.g., priority)

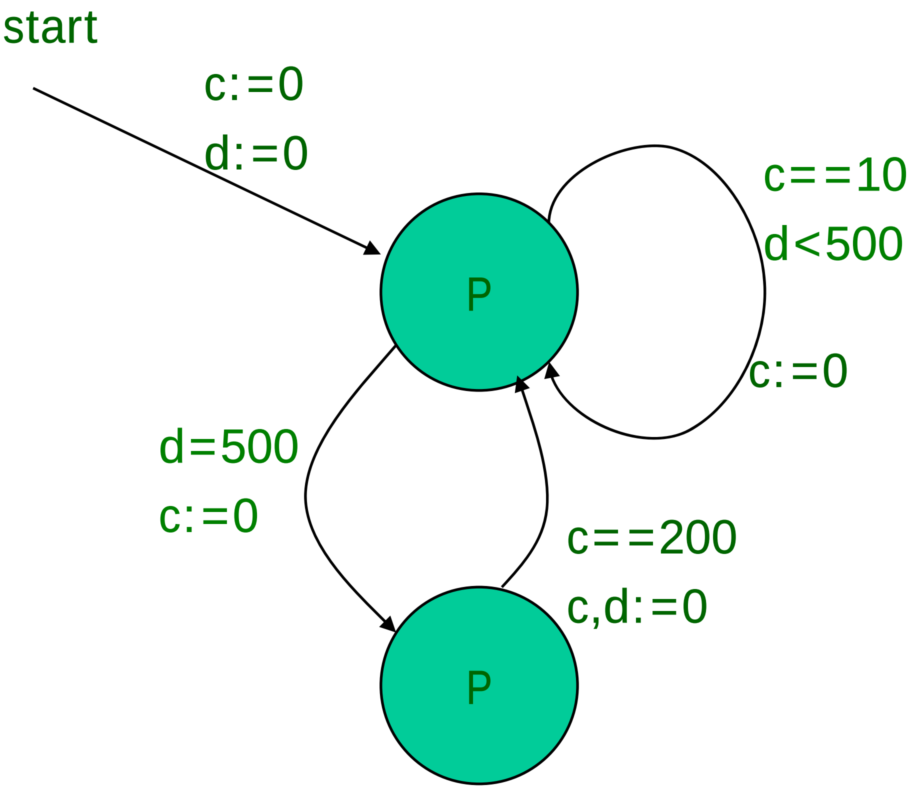
Example: periodic task



c: clock

P: task

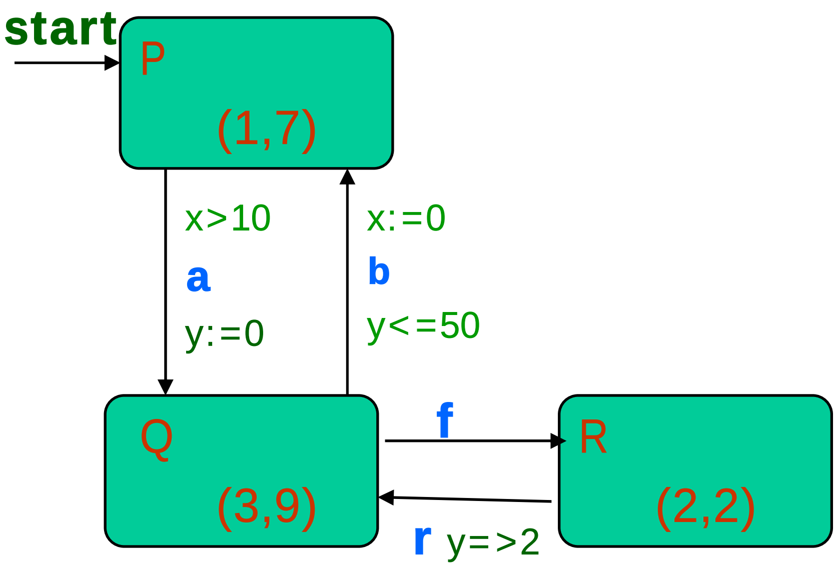
Example: periodic task with modes



c,d: clocks

P: task

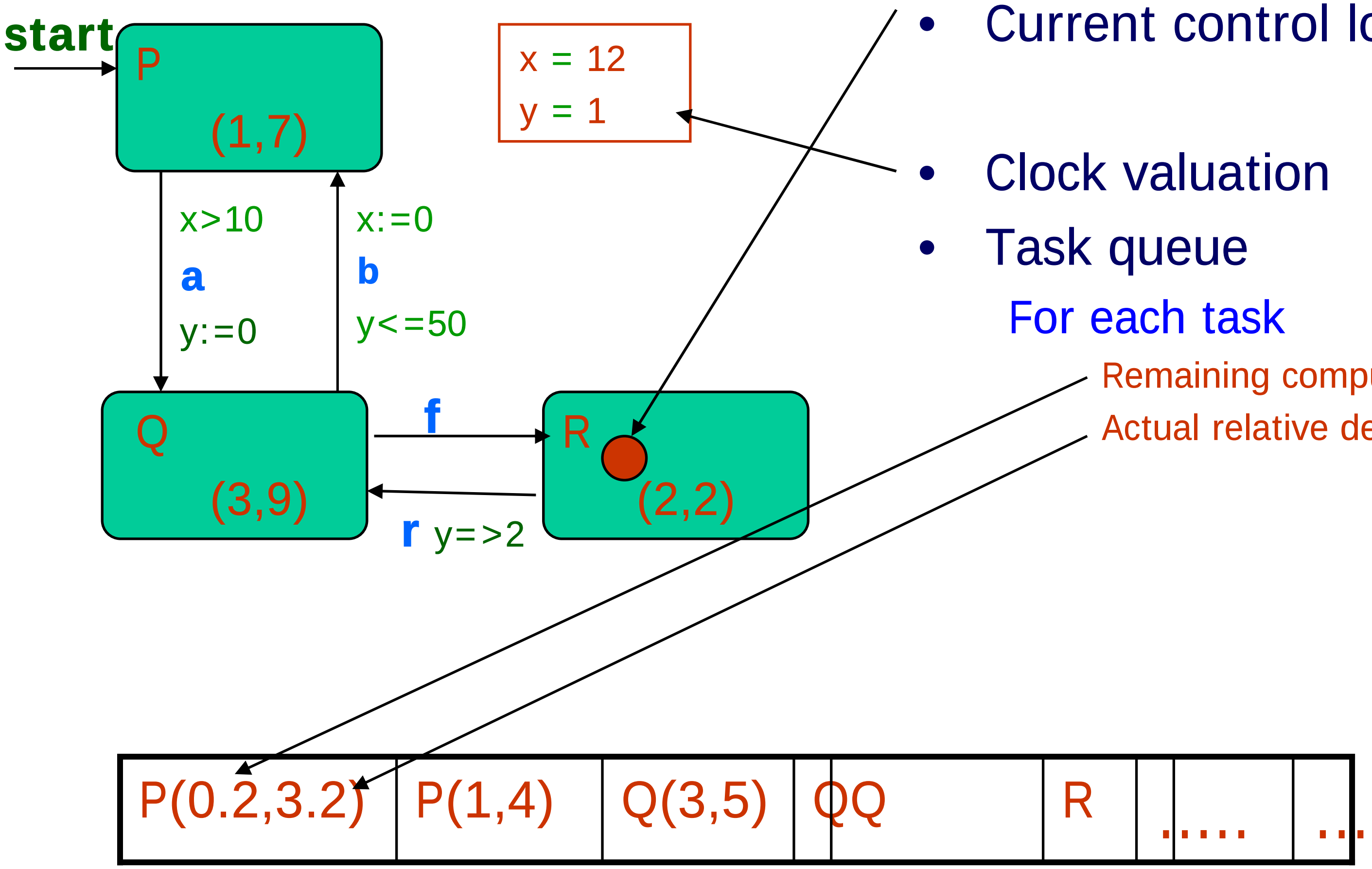
Timed Automata with Tasks (Structure of Operation)



- "Processor" 1 (task generator)
  - Initially, P is released
  - Forever, do
    - Whenever **a** is available and x>10, Q is released
    - Then
      - Whenever **b** is available and y<=50, P is released
      - Whenever **f** appears, it releases R
- "Processor" 2 (task handler)
  - Scheduling and Computing tasks in the queue

P	P	Q	Q	Q	R	...	...	...

States/Configurations of Model



P(0.2,3.2)	P(1,4)	Q(3,5)	QQ	R	.....	...

- Current control location
- Clock valuation
- Task queue

For each task

Remaining computation time

Actual relative deadline

Operations to Model Scheduling

- The scheduling algorithm (EDF, FP, FIFO, ...) is modeled by sorting policy on the task queue
- Task processing modeled by decreasing remaining computation times and relative deadlines

Example:

$$[Q(4, 7), P(2, 10)] \xrightarrow{\text{wait}(0.5)} [Q(3.5, 6.5), P(2, 9.5)]$$

SCHEDULING ANALYSIS

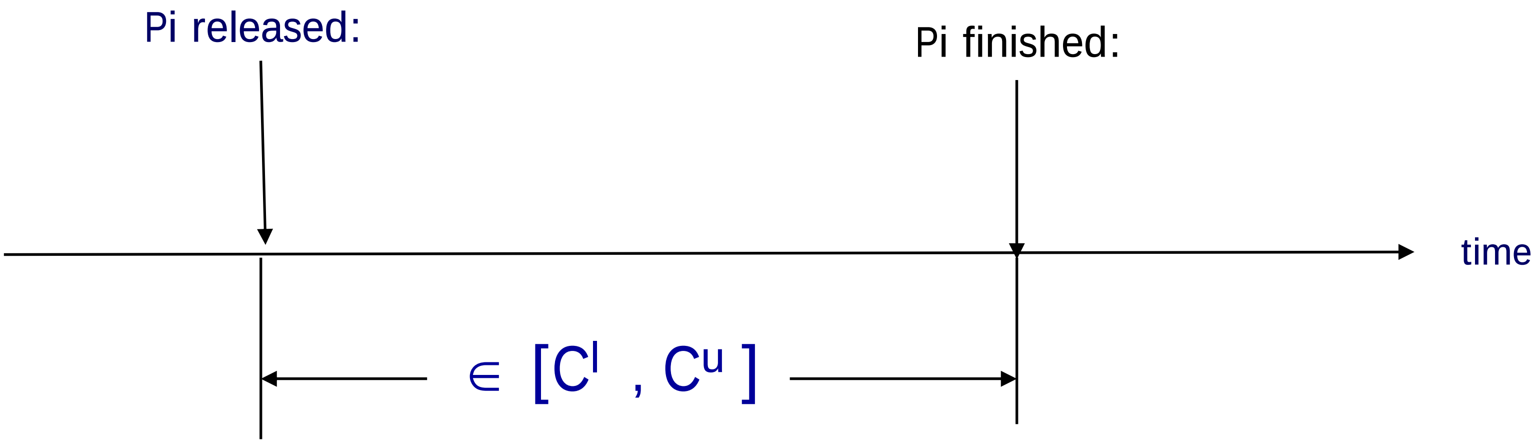
Schedulability by model checking

Assume a scheduling policy Sch:

- A configuration is schedulable with Sch if it is possible to meet all relative deadlines (simple calculation on occuring c_i d_i in task queue)
- An automaton is schedulable with Sch if all its reachable states are schedulable
- Schedulability checking == reachability analysis
  - set of schedulable configurations is bounded (modulo clocks)

Handling preemption

- Assume Pj preempts Pi
- Assume computation time of Pi between C^l and C^u



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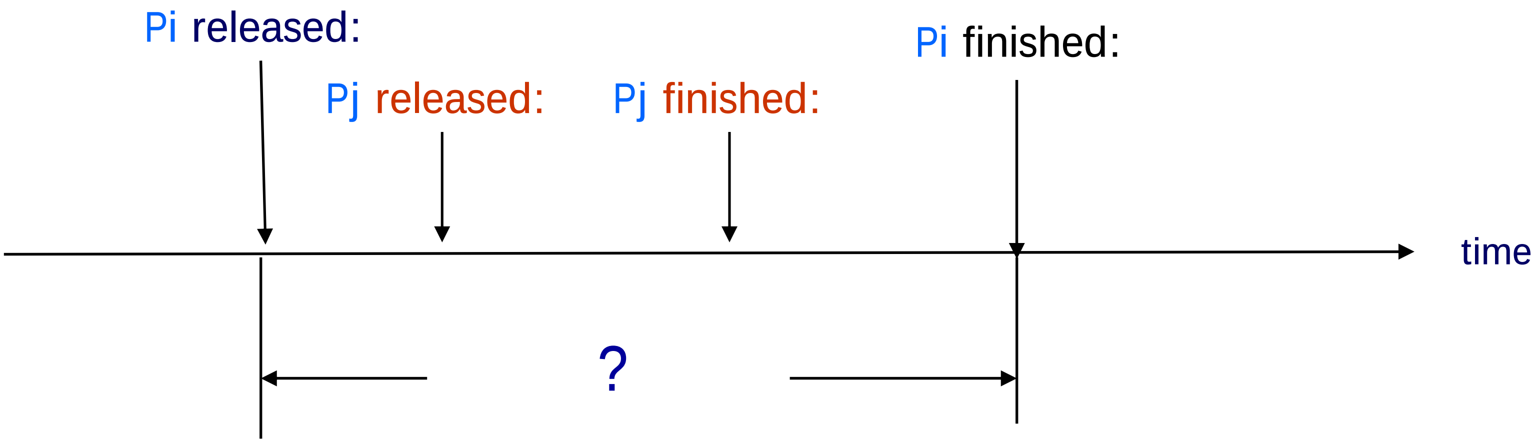

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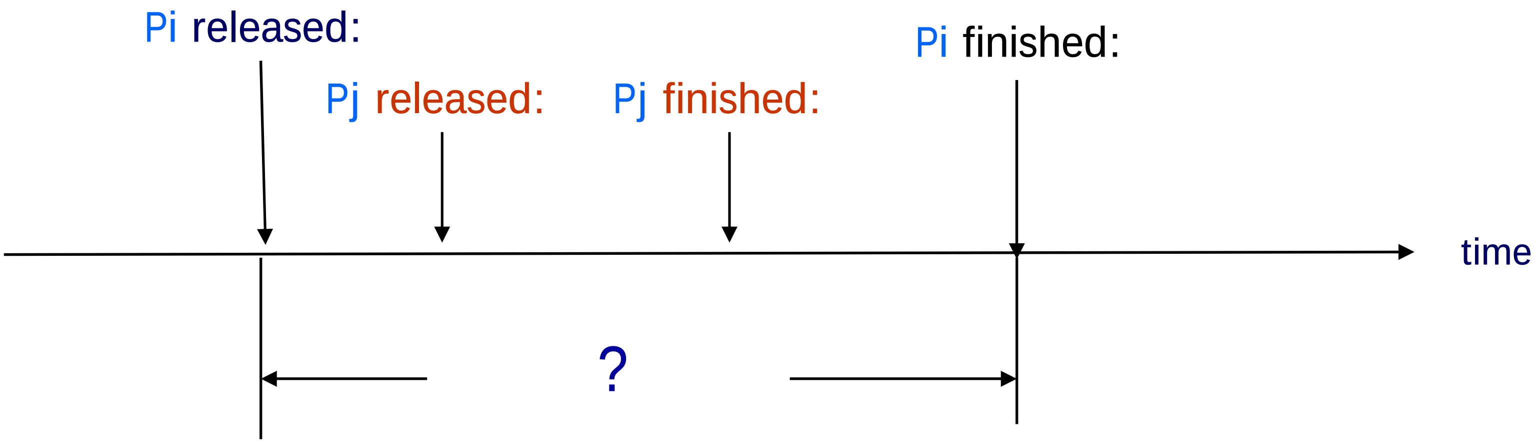

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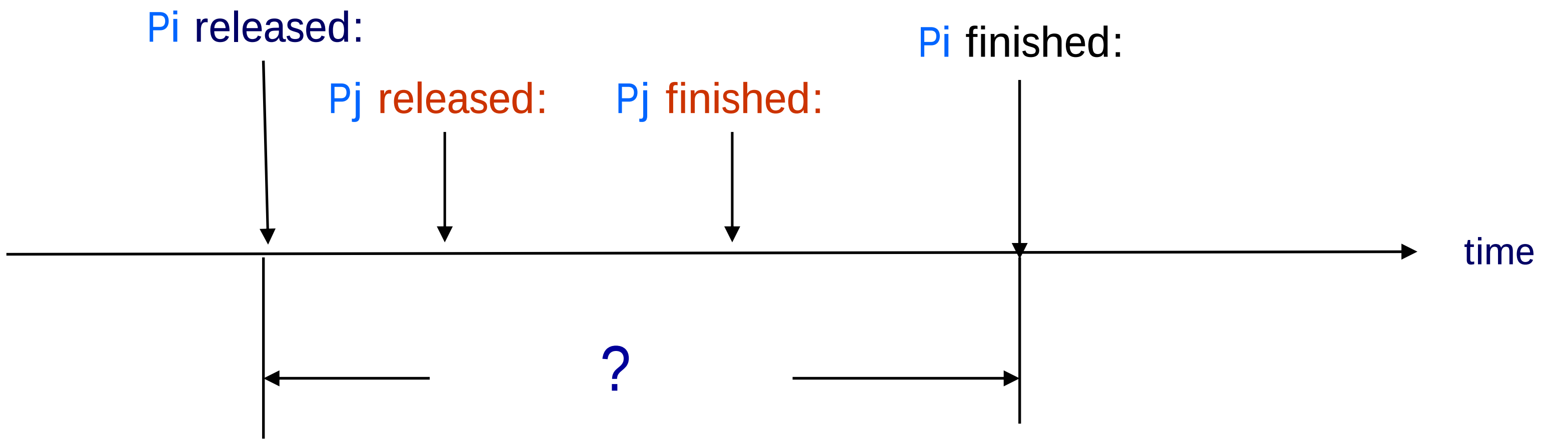

- ? Is an interval if computation time of Pj is known & constant
- if computation time of Pj may vary, timing properties cannot be precisely modeled with timed automata

Decidability results (summary)

- For Non-preemptive scheduling, scheduling can be analyzed by model checking TAs. [Ericsson,Wall,Yi 98]
- For preemptive scheduling, the problem can be solved using BSA (Bounded Substraction Automata) [Fersman,Pettersson,Yi, TACAS02]
  - (#extra clocks needed is 2 x #instances = $2 \sum_i \lceil Di/Ci \rceil$)
- For fixed-priority scheduling, the problem can be solved using TA with only 2 extra clocks – similar to the classic RMA technique (Rate-Monotonic Analysis) [Fersman,Mokrushin, Pettersson,Yi, TACAS03]
- Problem becomes undecidable with preemption if both
  - the execution times of tasks are intervals,
  - task completion times influence task release times [Krcal,Yi, TACAS 04]