TECHNISCHE UNIVERSITÄT
CAROLO-WILHELMINA
ZU BRAUNSCHWEIG

SymTA/S
Compositional performance analysis

ARTIST Workshop on tool platforms for modeling,
analysis, and validation of embedded systems

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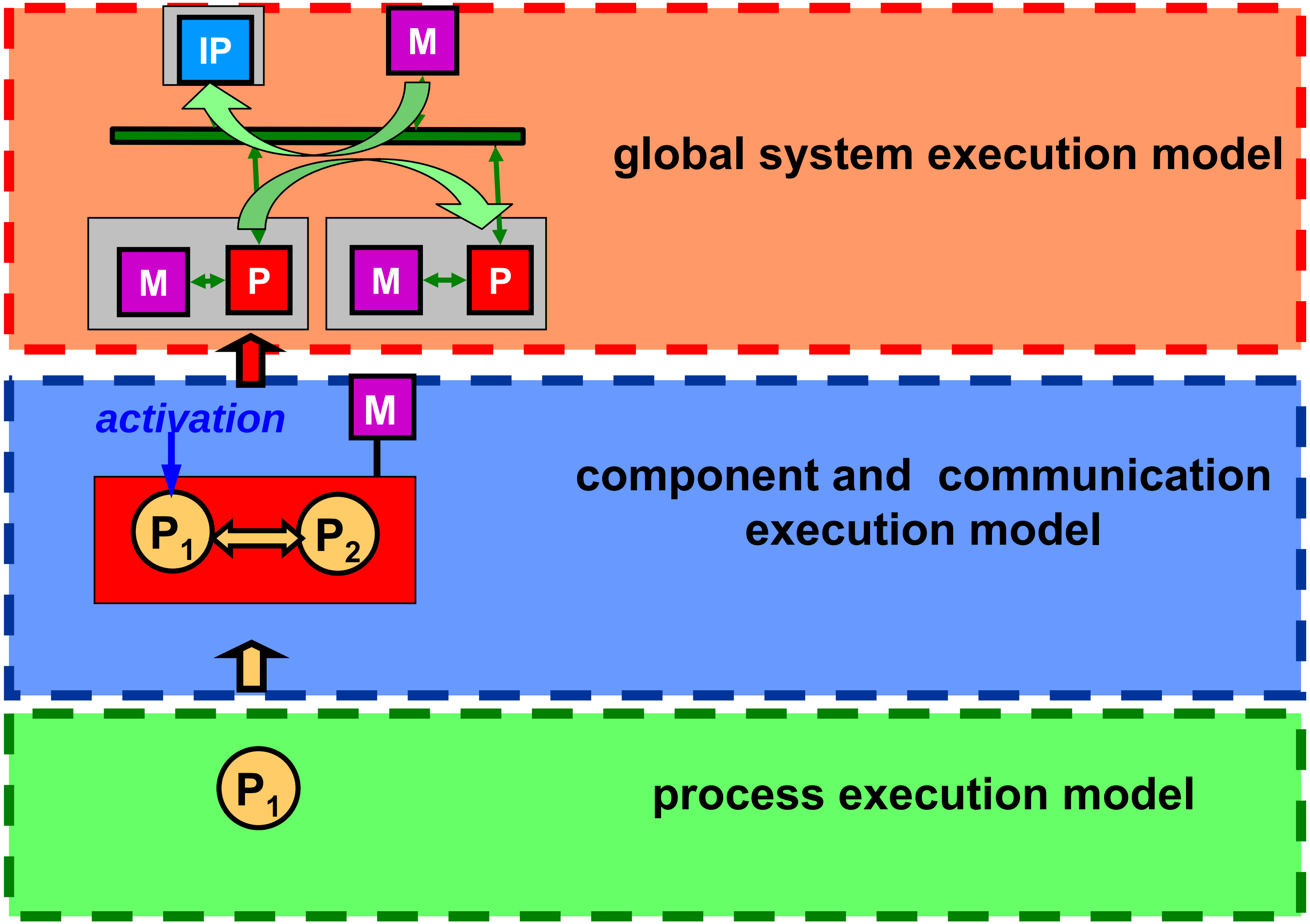
Outline

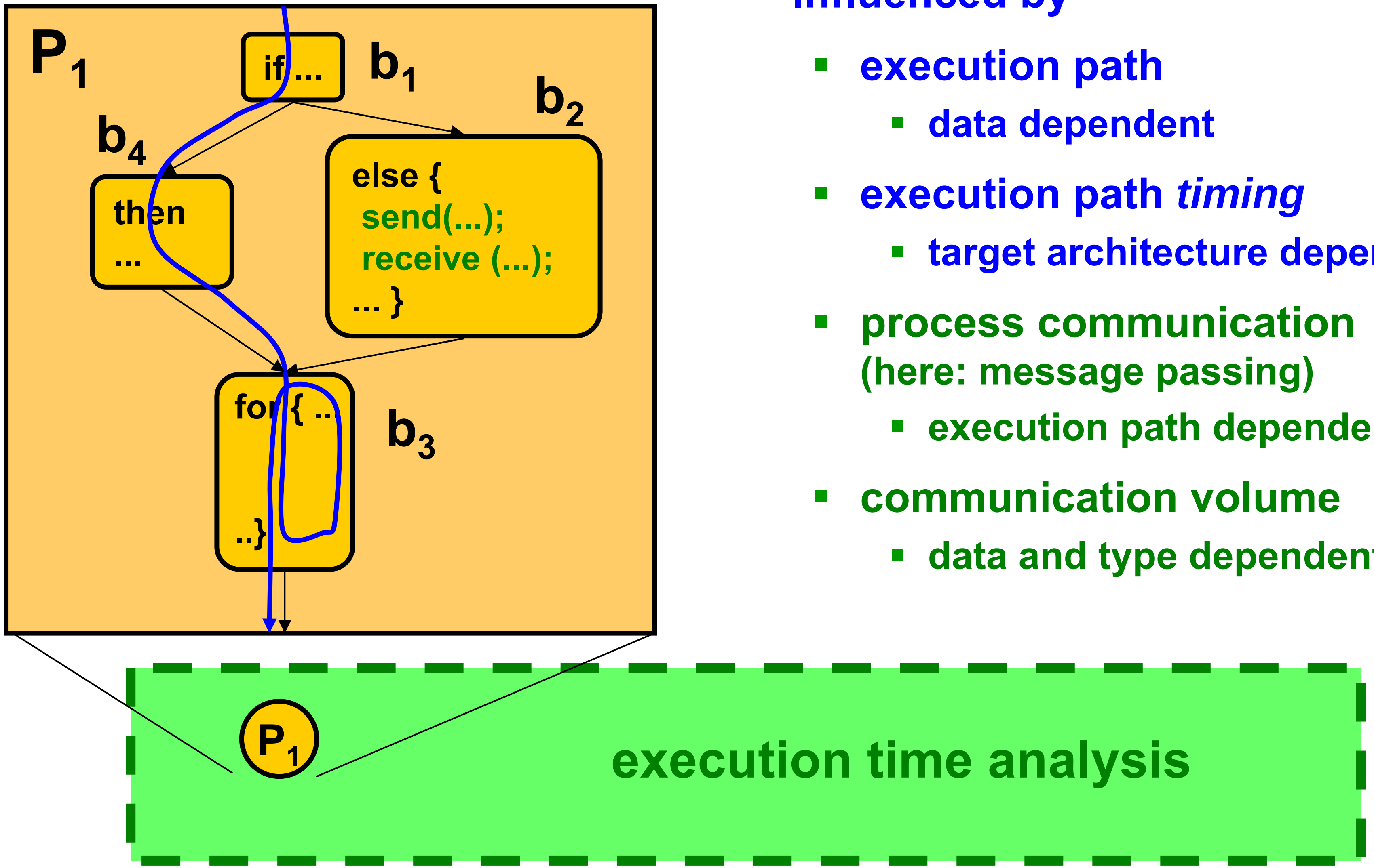
- Performance verification flow
  - Process execution model
  - Component and communication execution model
  - Global system execution model
- Compositional system level analysis
  - Iterative system level analysis approach
  - Considering task dependencies
- The SymTA/S tool
- Conclusion

Performance verification flow

Target architecture performance – general view



Process execution model



- **Influenced by**
  - **execution path**
    - **data dependent**
  - **execution path *timing***
    - **target architecture dependent**
  - **process communication (here: message passing)**
    - **execution path dependent**
  - **communication volume**
    - **data and type dependent**

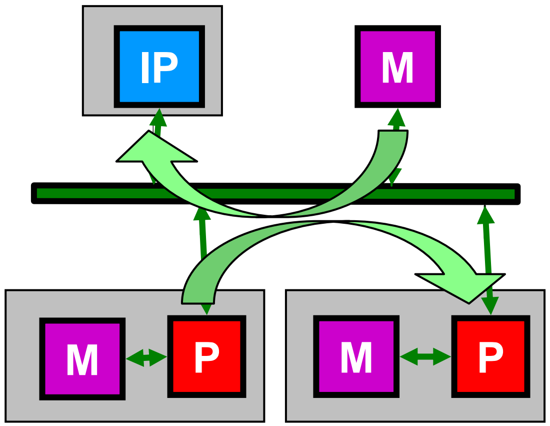
Process timing and communication

- **State of industrial practice - simulation/performance monitoring**
  - **trigger points at process beginning and end**
  - **data dependent execution → upper and lower timing bounds**
- **simulation challenges**
  - **coverage?**
  - **cache and context switch overhead due to run-time scheduling with process preemptions**
- **Alternative - formal analysis of individual process timing**
  - **provides conservative bounds**
  - **serious progress in recent years**

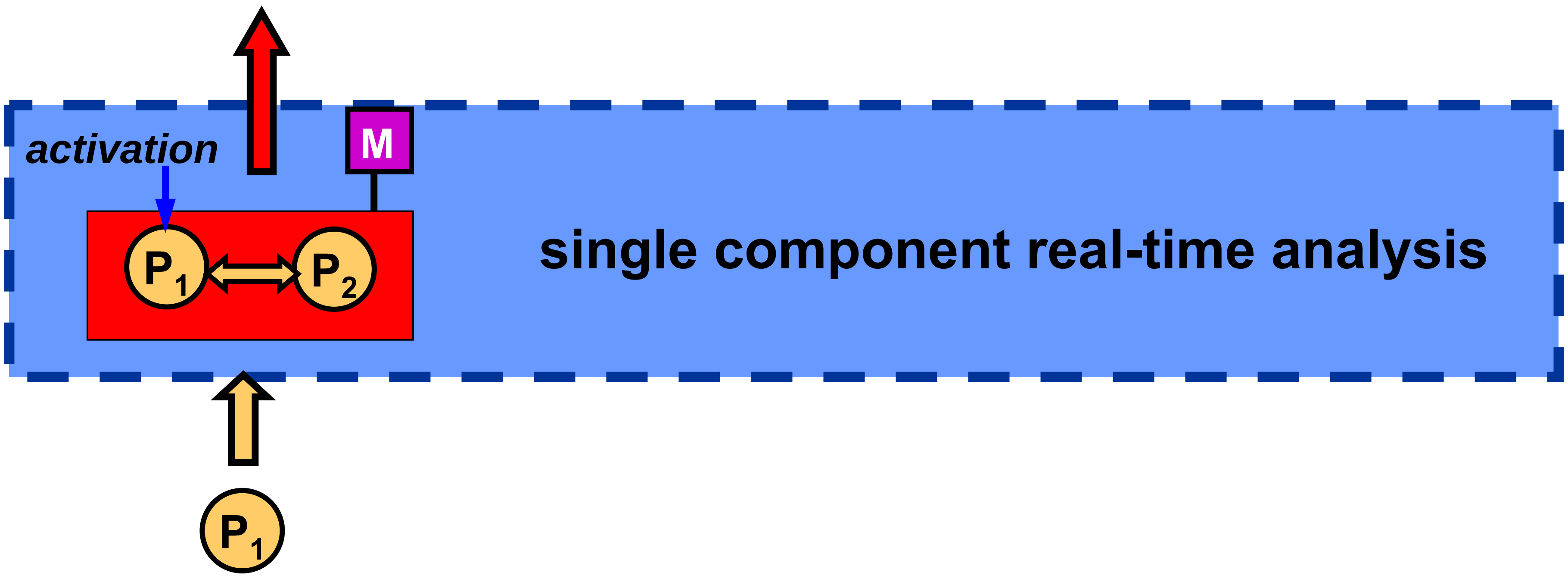
Formal process execution time analysis

- **Active research area with dedicated events (e.g. Euromicro WS)**
- **Formal analysis using simple processor models**
  - **Li/Malik (Princeton) (95): Cinderella**
- **Detailed execution models with abstract interpretation**
  - **Wilhelm/Ferdinand (97 ff.): commercial tool AbsInt**
- **Combinations with simulation/measurement of program segments**
  - **Staschulat/Ernst (99 ff.): SymTA/P**
- **All tools provide (conservative) upper execution time bounds (WCET) or time intervals (WCET/BCET)**

Component and communication execution model



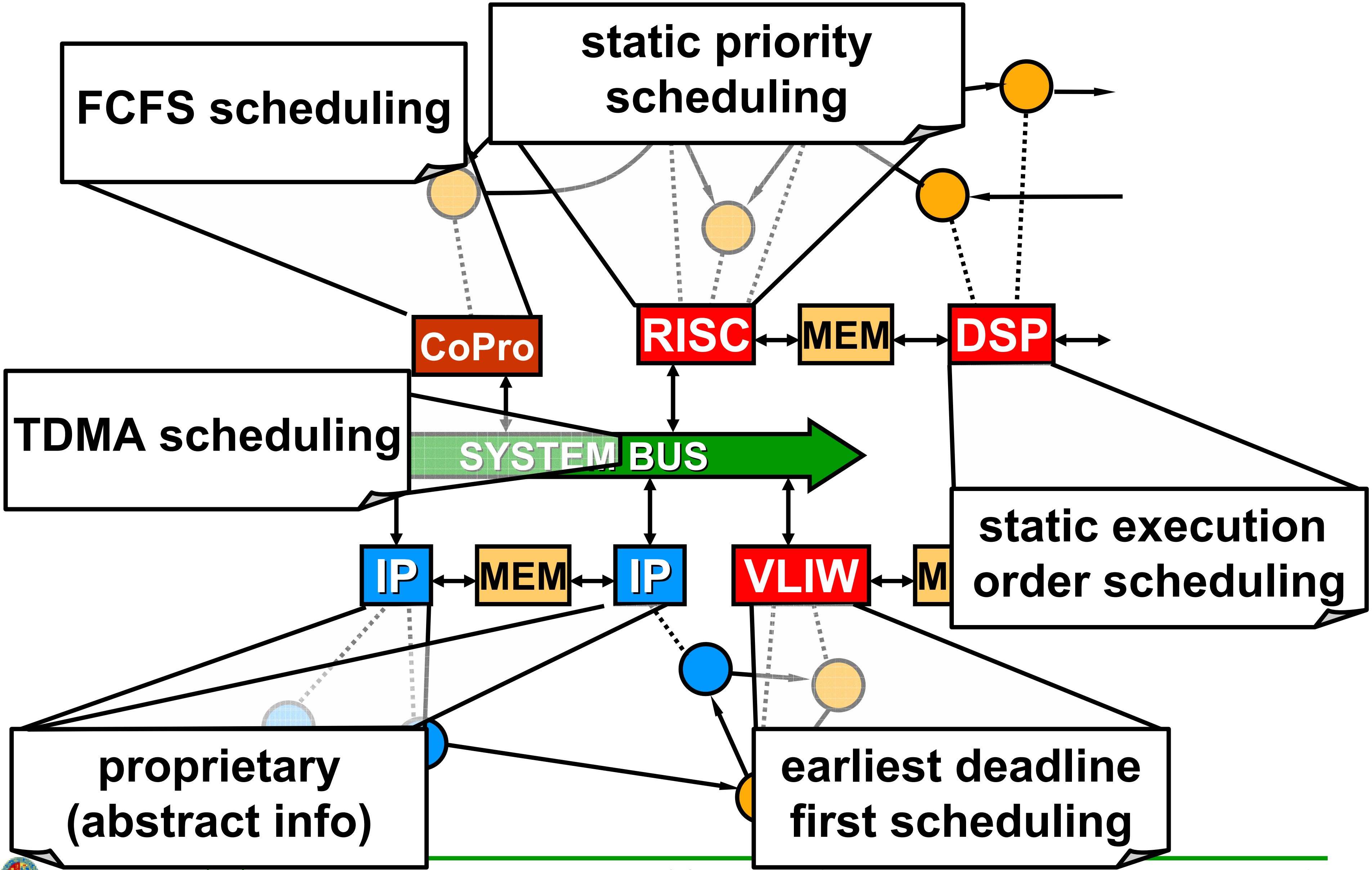
- Influenced by
  - resource sharing strategy
  - process activation



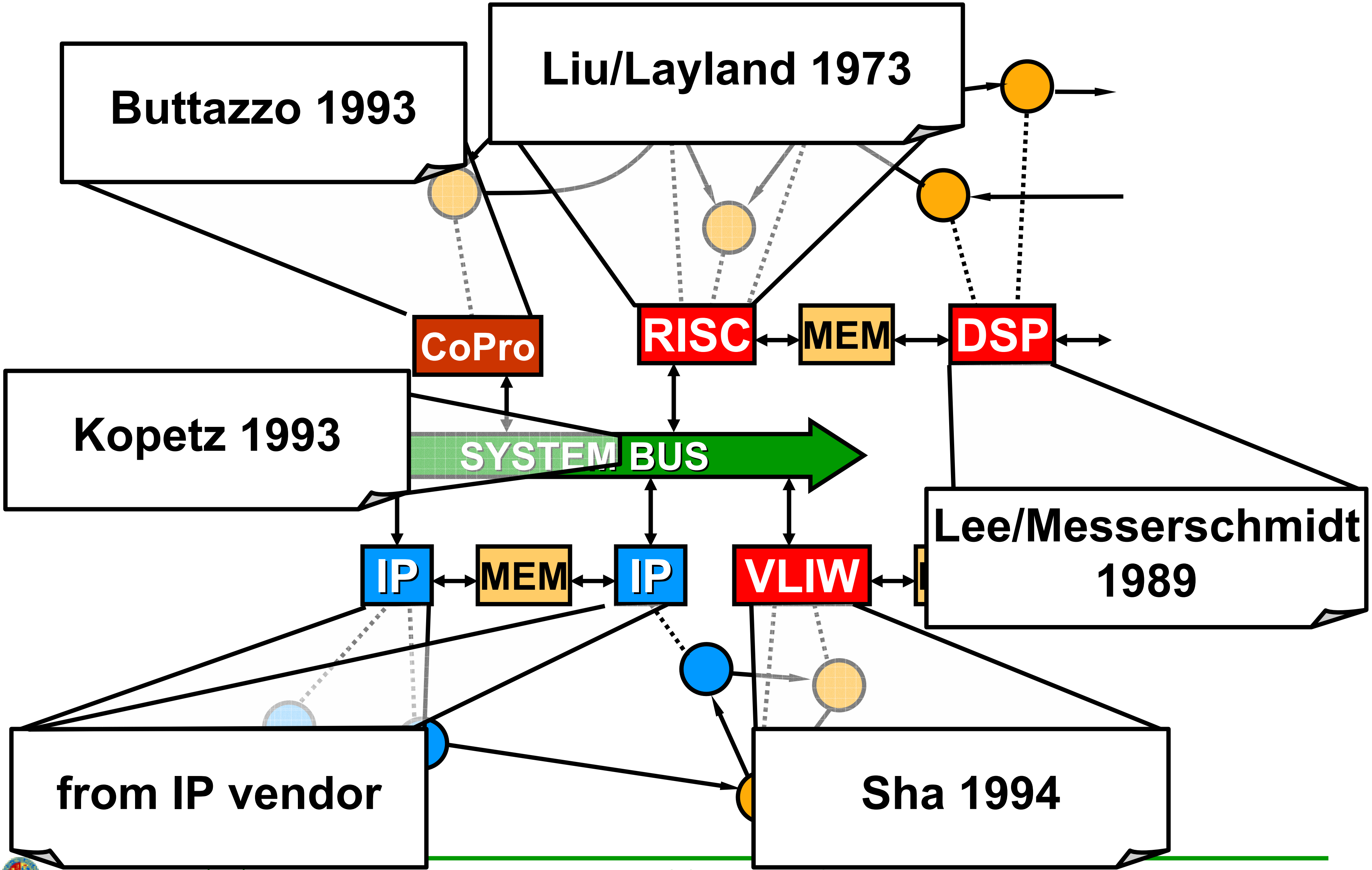
Component and communication execution model

- Resource sharing strategy
- Process and communication scheduling
  - static execution order
  - time driven scheduling
    - fixed: TDMA
    - dynamic: Round-Robin
  - priority driven scheduling
    - static priority assignment: RMS, SPP
    - dynamic priority assignment: EDF
- Timing depends on environment model
  - determines frequency of process activations or communication

Multiple Scheduling Strategies



Scheduling Analysis Techniques

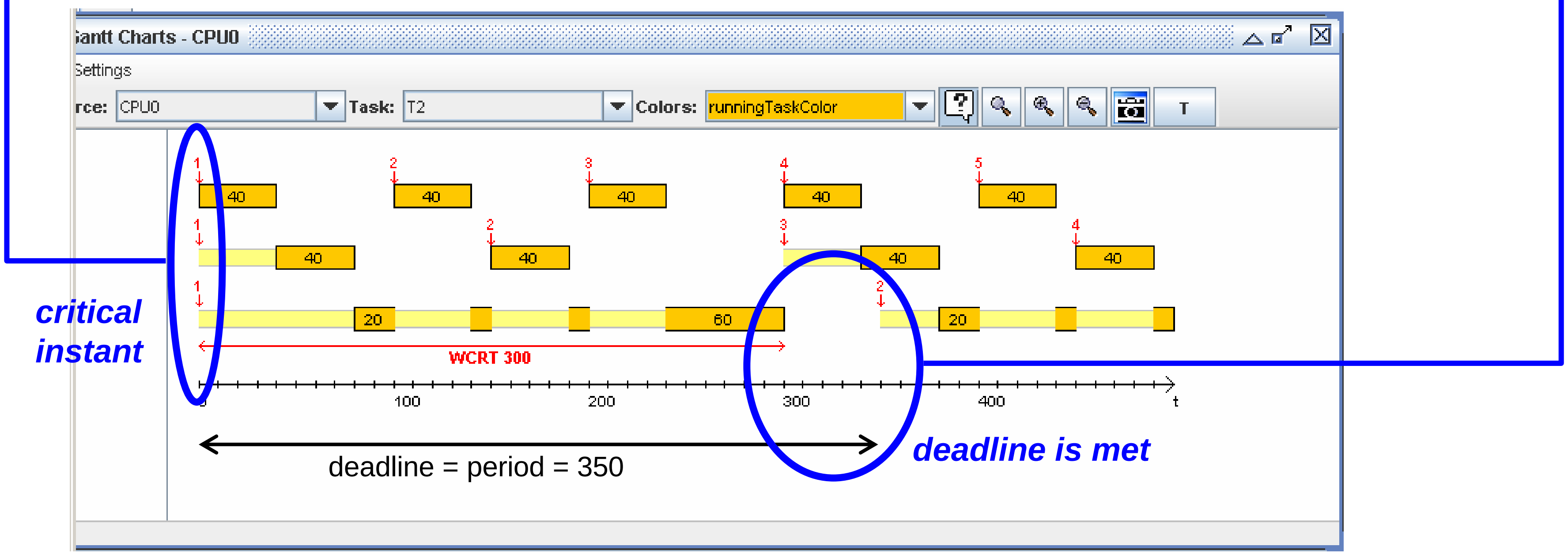


Example: Rate Monotonic Scheduling (RMS)

- Very simple system model
  - periodic tasks with deadlines equal to periods
  - fixed priorities according to task periods
  - no communication between tasks
  - (theoretically) optimal solution for single processors
  - several practical limitations but good starting point
- Schedulability tests for RMS guarantee correct timing behavior
  - processor utilization (load) approach
  - response time approach (basis for many extensions)

RMS Theory – The response time approach

- **Critical instant:**
  all tasks start at t=0 („synchronous assumption“ to ensure maximum interference in the beginning of task execution)
- **when each task meets its first deadline, it will meet all other future deadlines (proof exists!)**
- **test by „unrolling the schedule“ (symbolic simulation)**



RMS Theory – The response time formula

fix-point problem

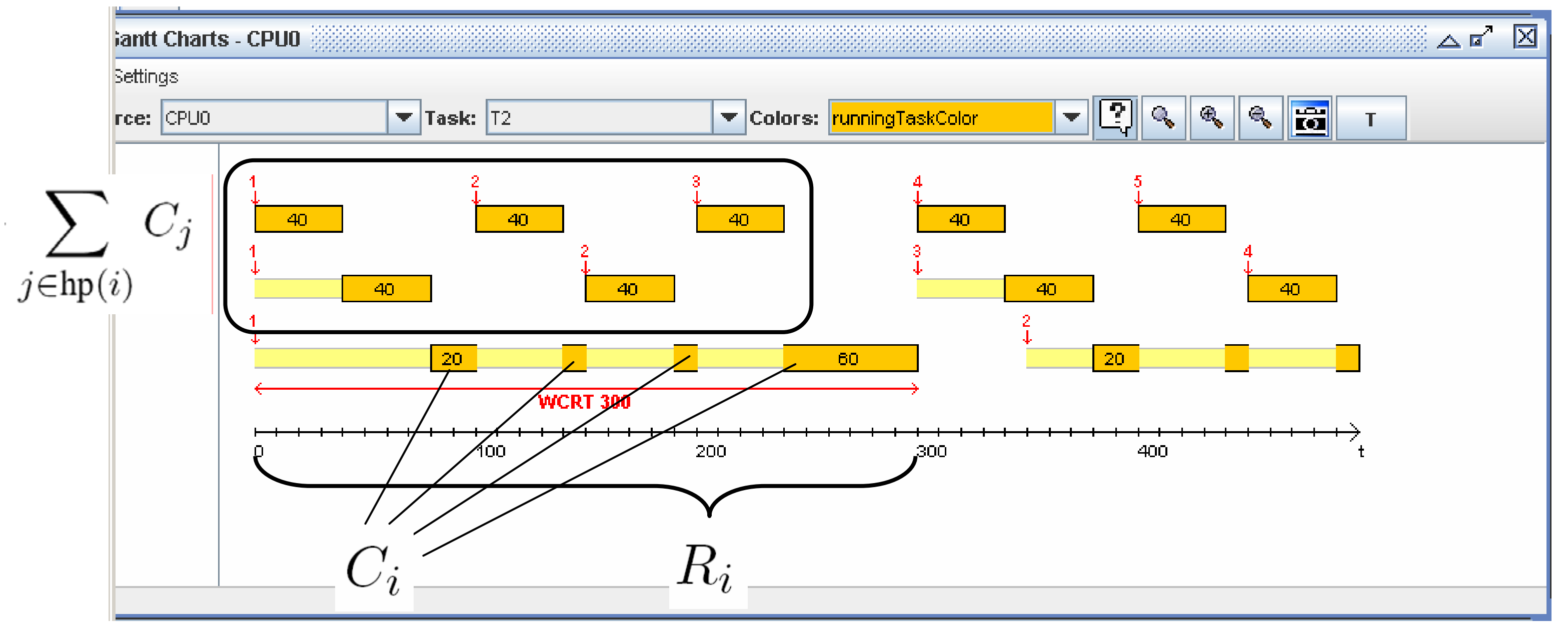
$$R_i = C_i + \sum_{j \in \mathrm{hp}(i)} C_j \left\lceil \frac{R_i}{T_j} \right\rceil \leq D_i = T_i$$

response time

core execution time

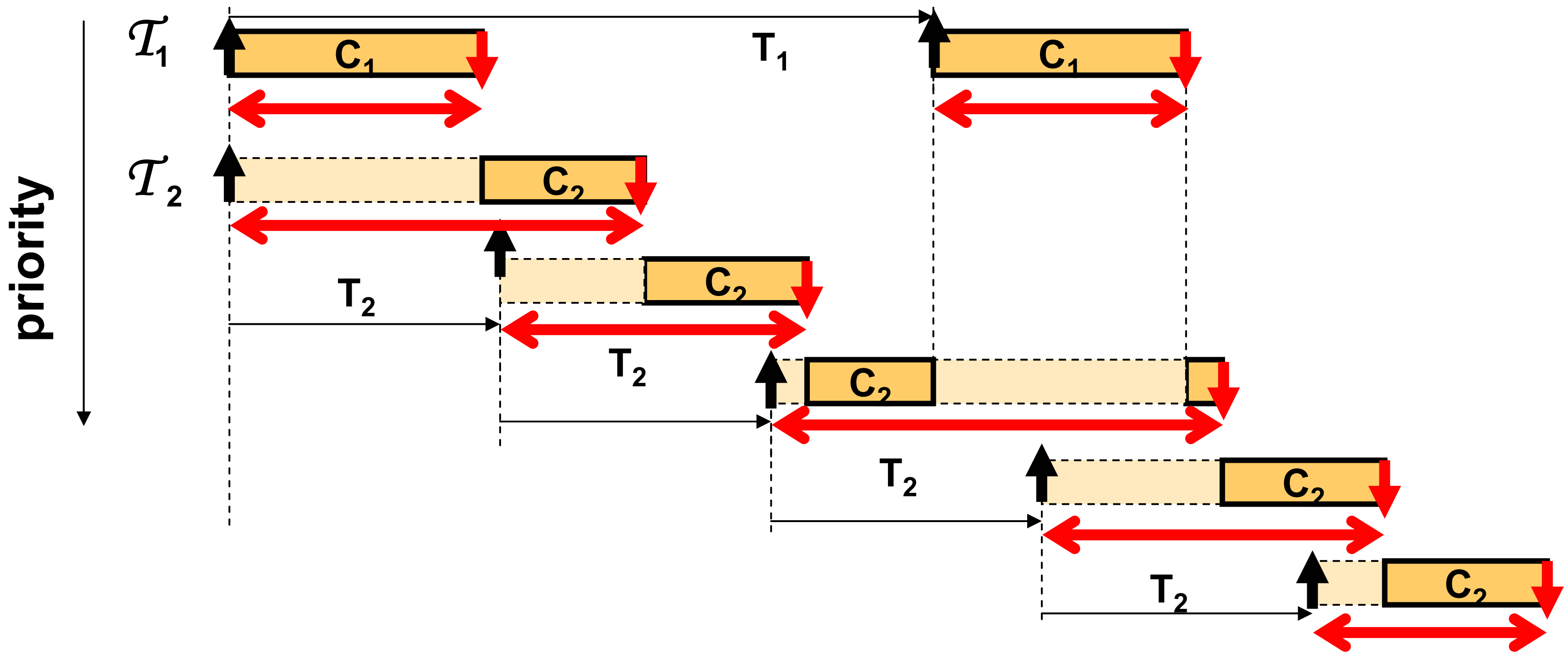
# of preemptions

interference term I_i

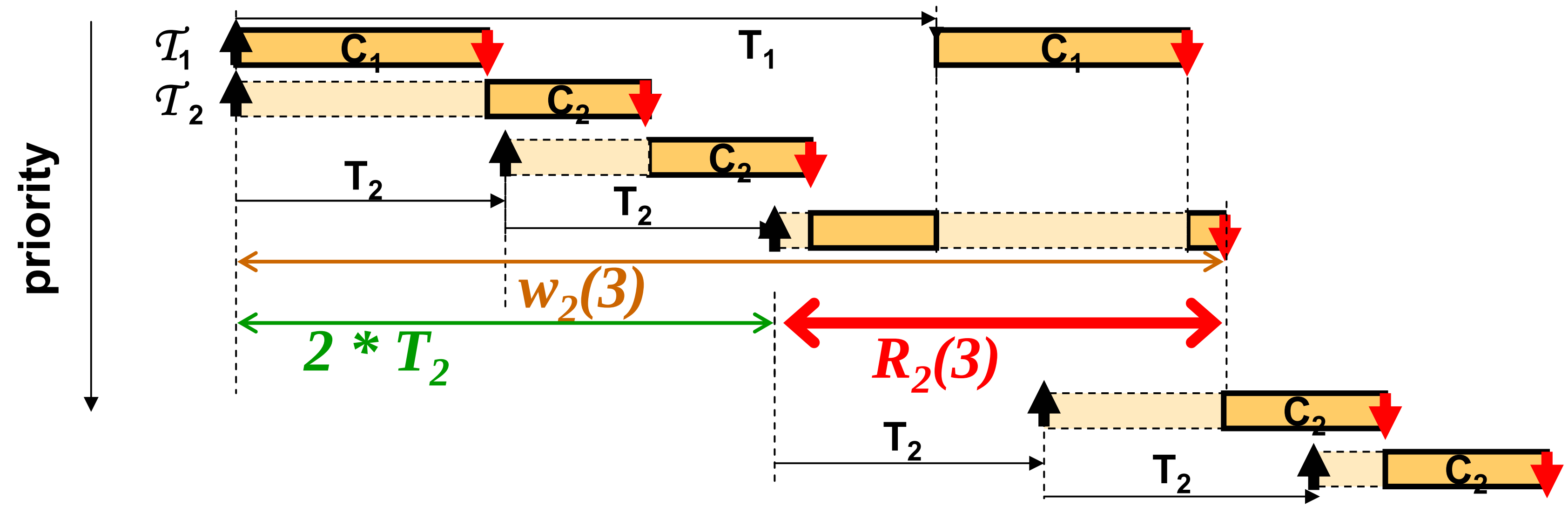


Example: Static priority w/ arbitrary deadlines

- Assumption:
  - tasks with periods T, worst-case execution times C
  - static priorities
  - deadlines (arbitrary) larger than the period



Analysis uses “Busy Window” approach (Lehoczky)



$$w_i(q) = q\,C_i + \sum_{j \in \mathrm{hp}(i)} C_j \left\lceil \frac{w_i(q)}{T_j} \right\rceil$$

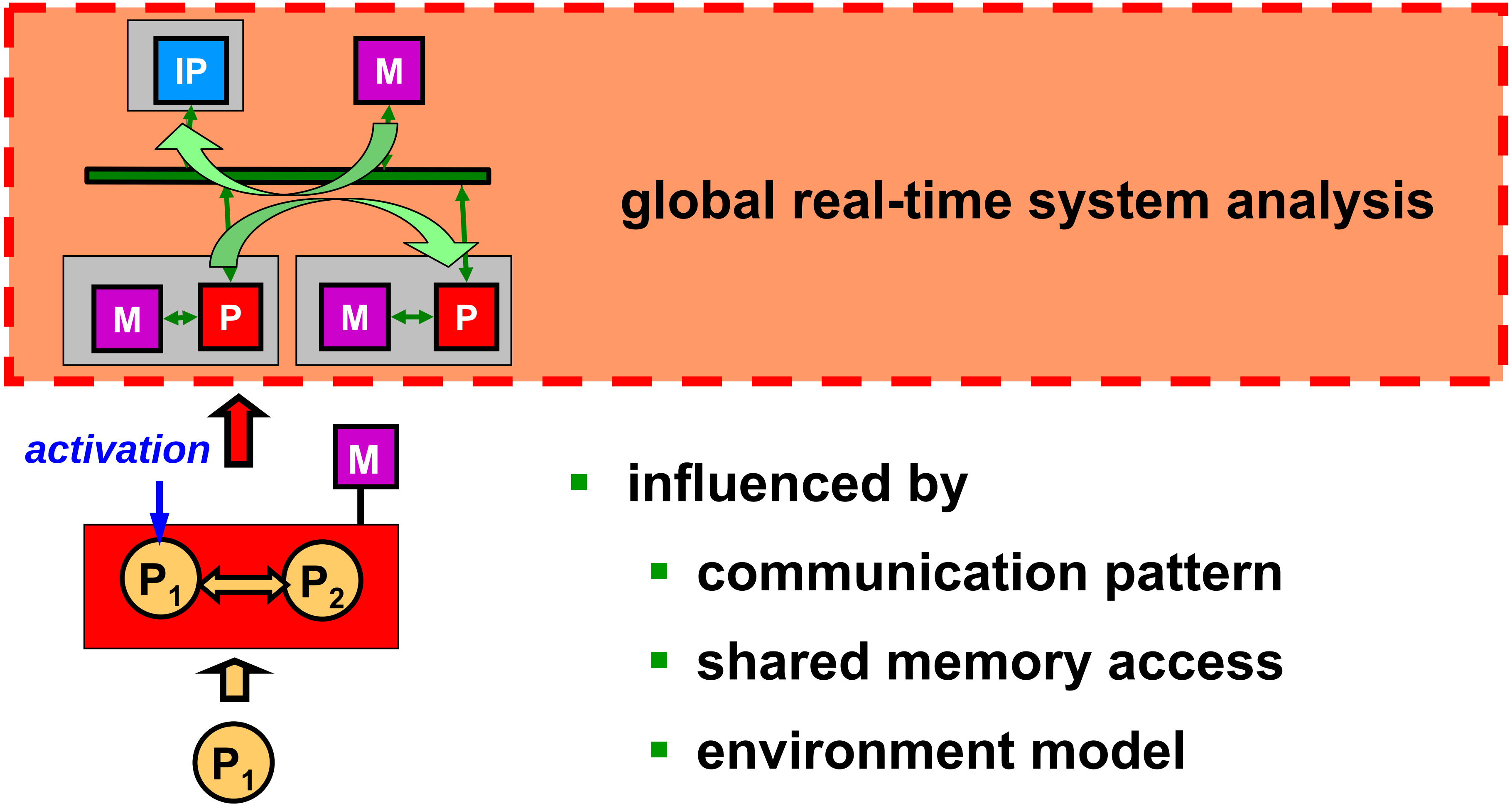
$$R_i(q) = w_i(q) - (q-1)\,T_i$$

find fix point where equations hold!

Other Extensions in Literature

- **Jitter and burst activation**
- **Static and dynamic offsets between task activations**
- **Different task modes**
- **Execution scenarios**
- **Blocking and non-preemptiveness**
- **Scheduling overhead → context switch time**
- **etc...**

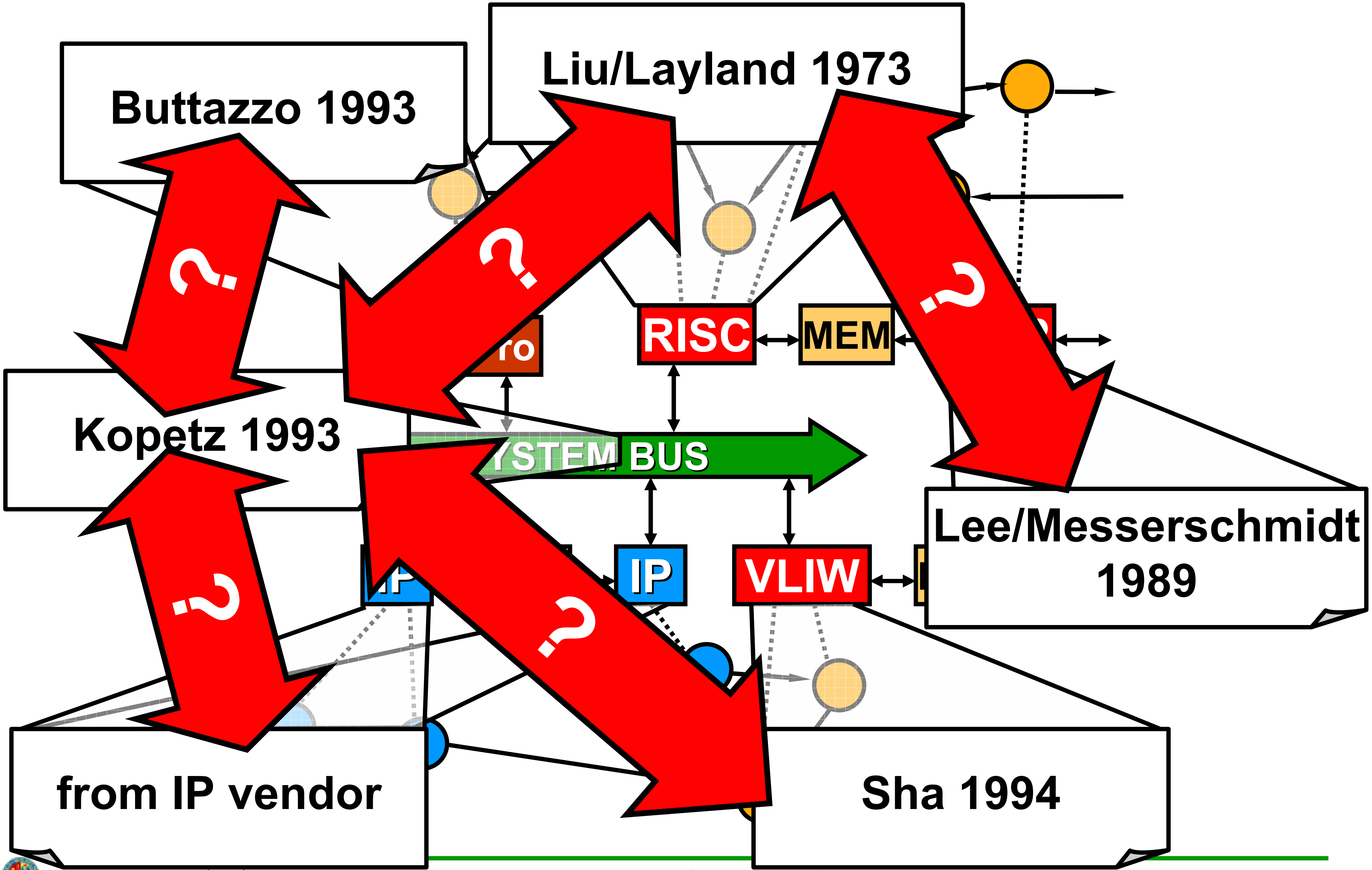
Global system execution model



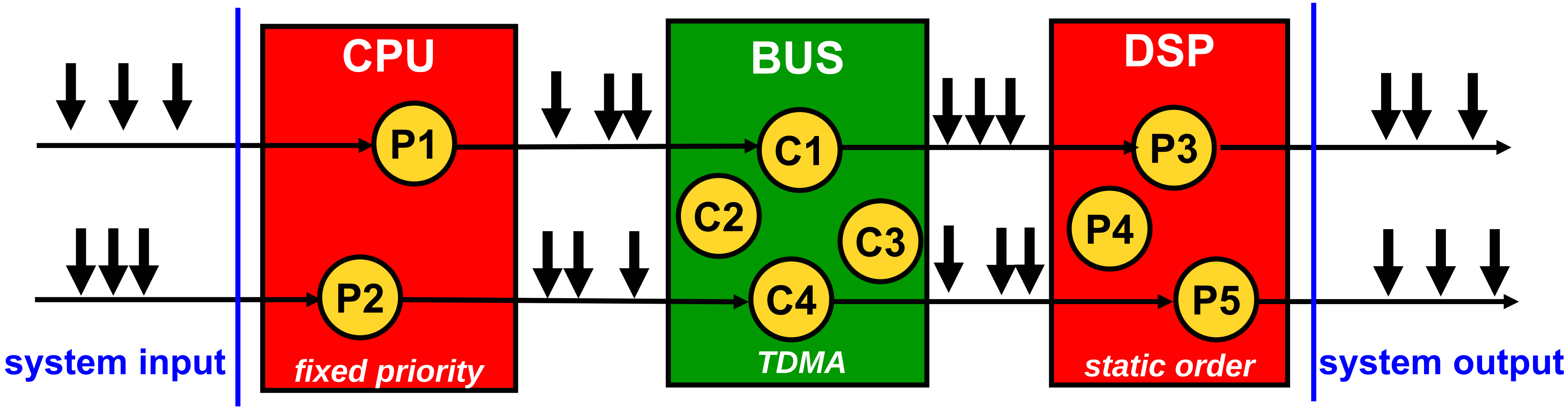
- influenced by
  - communication pattern
  - shared memory access
  - environment model

Compositional performance analysis

Integration ???



Compositional approach



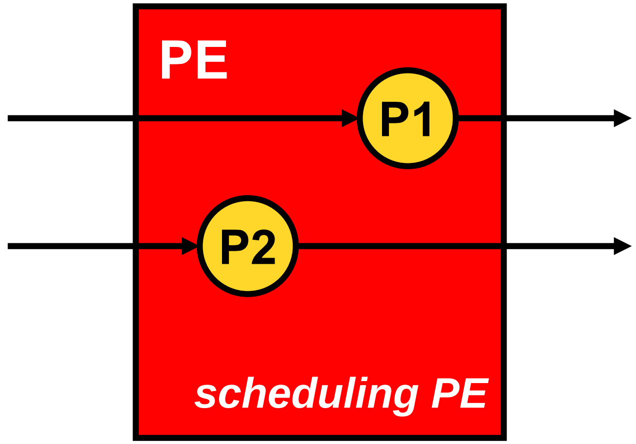
- Tasks are coupled by event sequences
- Composition by means of event stream propagation
  - apply local scheduling techniques at resource level
  - determine the behavior of the output stream
  - propagate to the next component

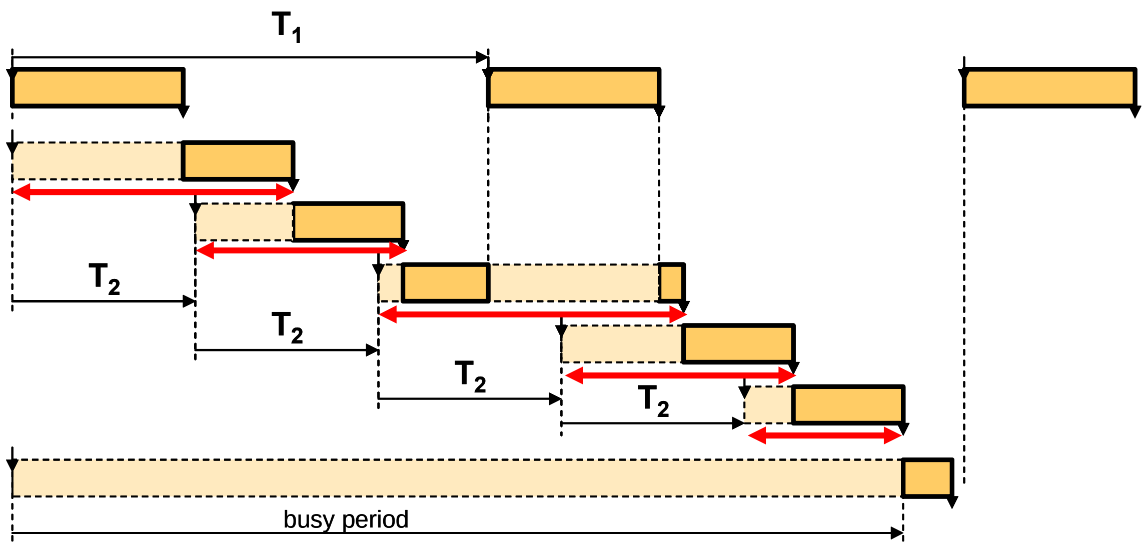
Idea

- Use stream model describing the distribution of activating events as intermediate mathematical formalism
- E.g. arrival curve functions of network calculus
  - $\eta^{+}(\Delta t)$ maximum number of activating events occuring in time window Δt
  - $\eta^{-}(\Delta t)$ minimum number of activating events occuring in time window Δt
  - d^{-} minimum event distance - limits burst density

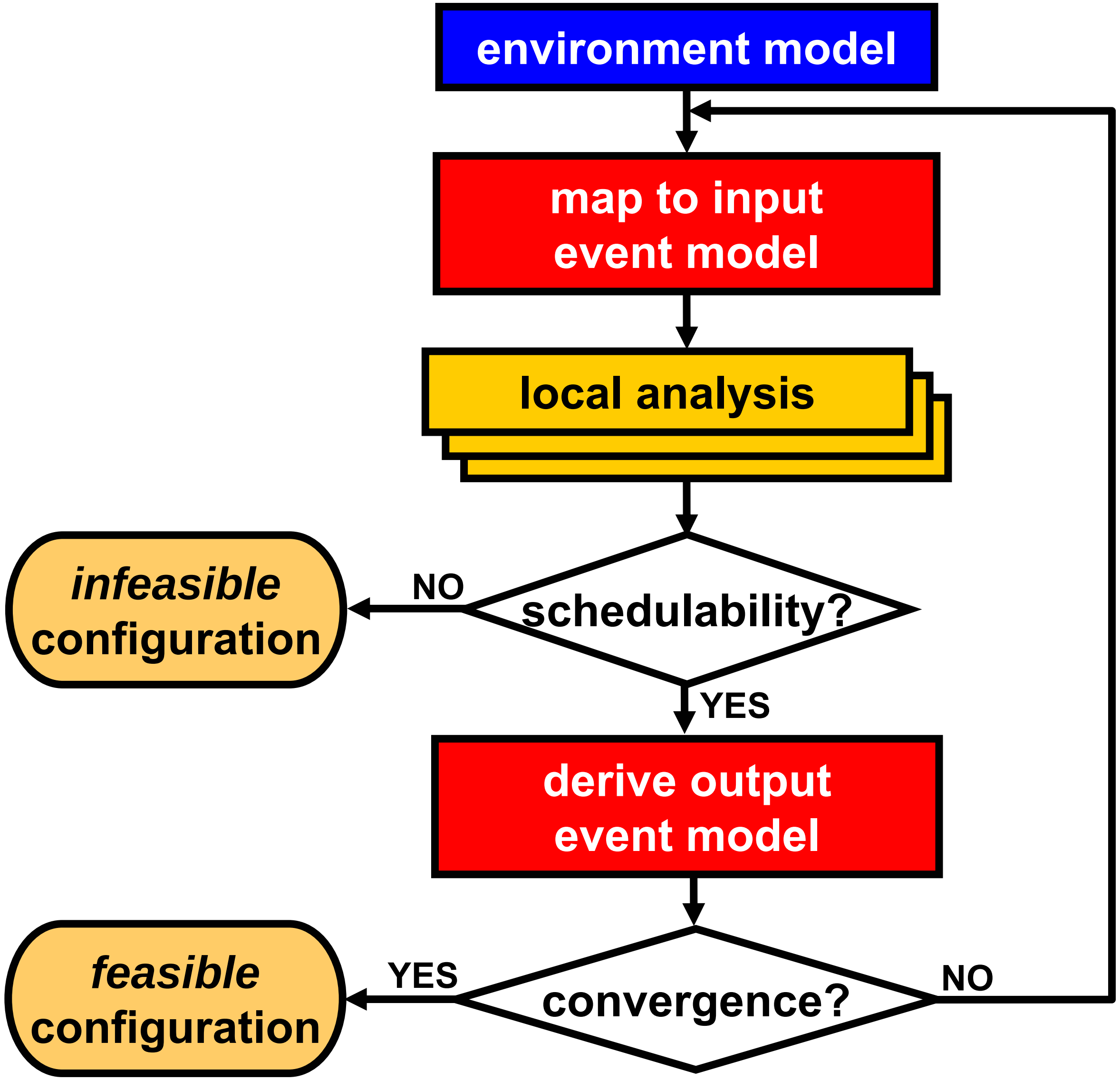
Input – output event model relation

- **Any scheduling increases jitter**
- **Jitter grows along functional path**
- **Increasing jitter leads to**
  - **burst and transient overloads**
  - **higher memory requirements**
  - **power peaks**





System analysis loop

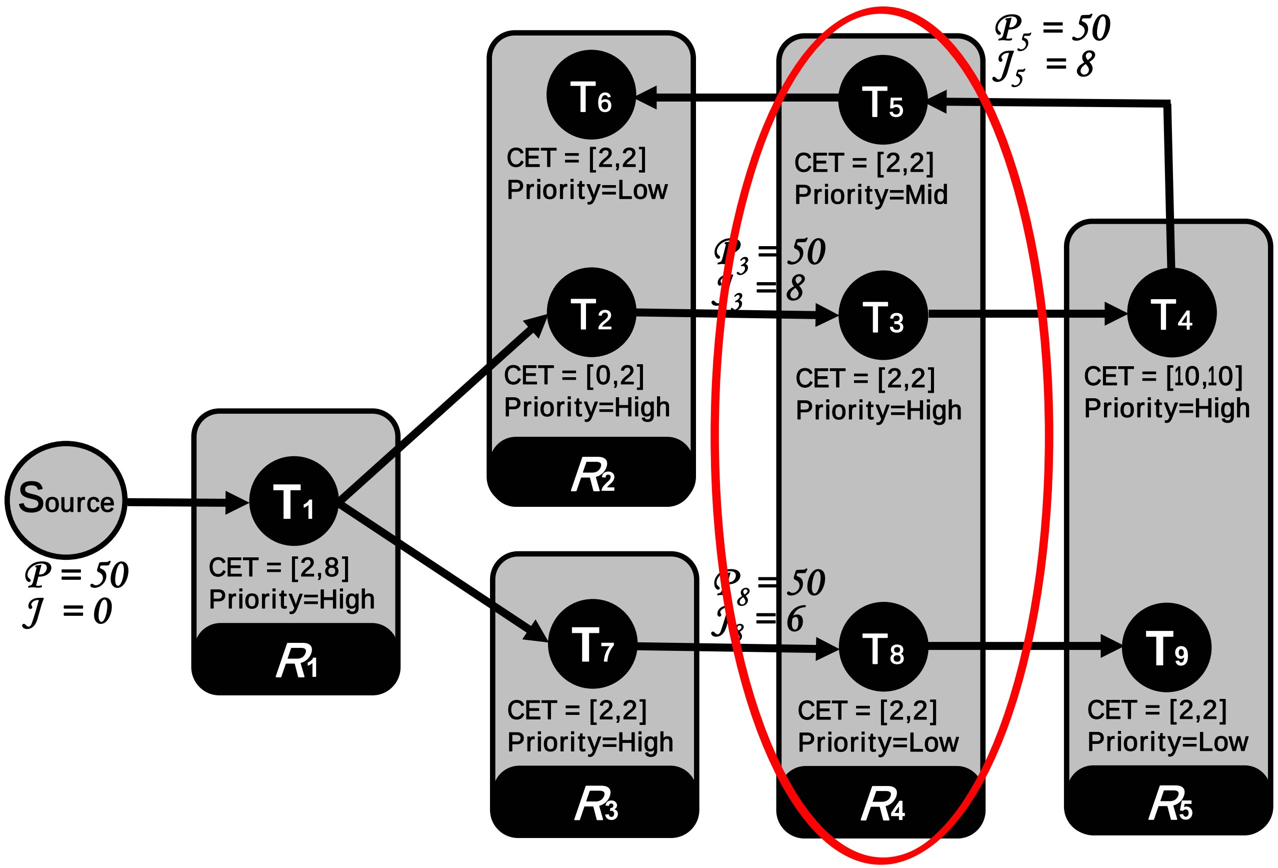


Considering task dependencies

Taking global dependencies into account

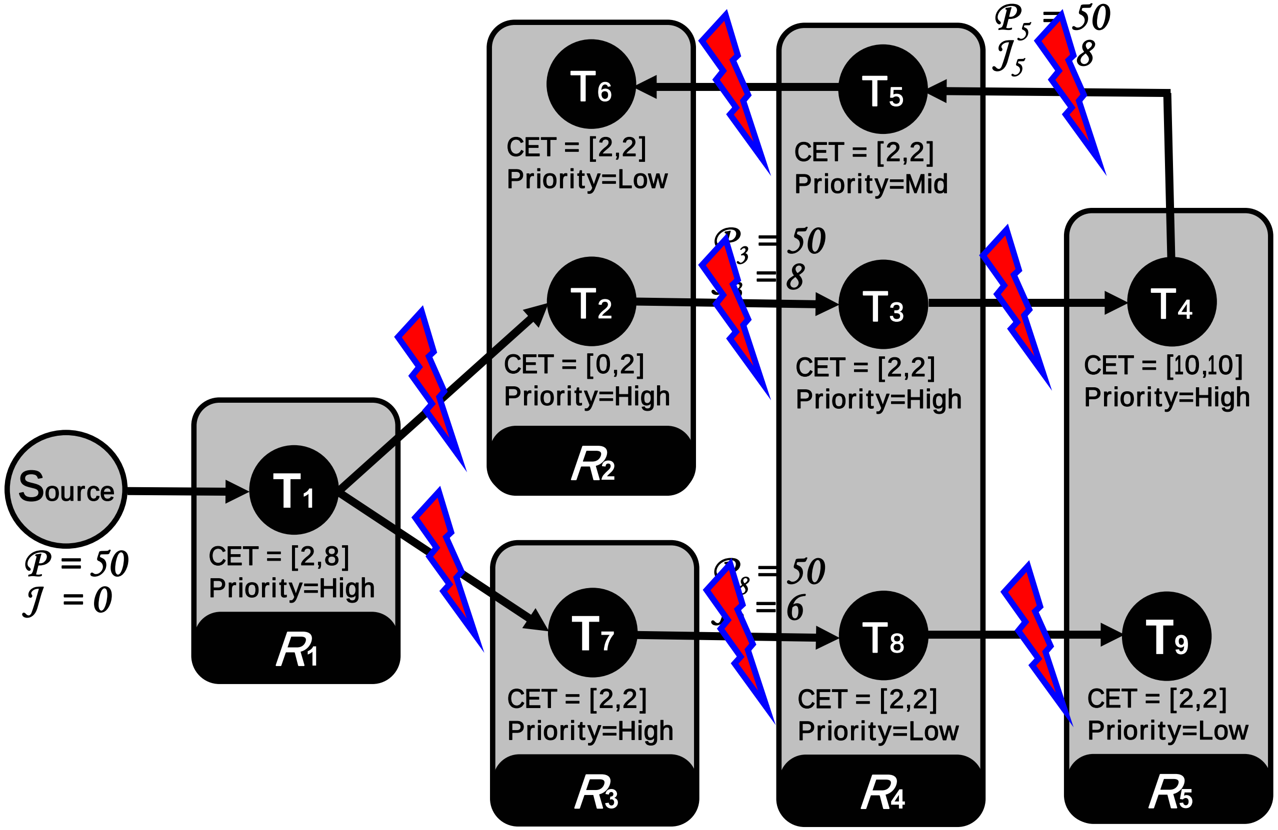
- Utilized stream model is state-less
- Classical critical instance assumption is save but often overly conservative
  - Reason: activating events in different event streams are often time-correlated which rules out the simultaneous activation of all tasks
- Solution: consider „inter-context“ dependencies between tasks to tighten analysis results
  - Idea: propagate offset information along event streams

Motivating Example



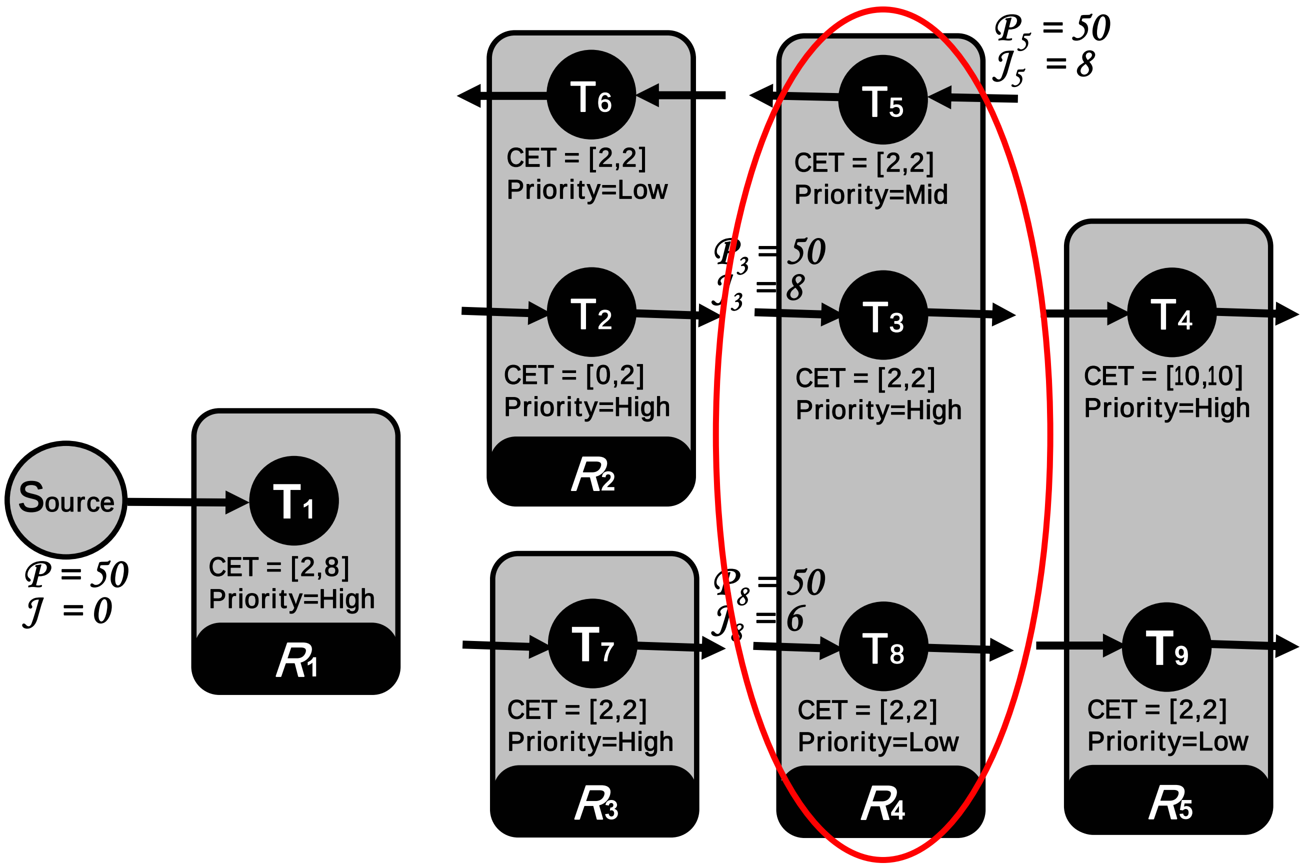
- **Static priority preemptive scheduling on all resources**
- **Compositional performance analysis approach**

Lehoczky (1990)



- **Ignore correlation between tasks!**

Lehoczky (1990)



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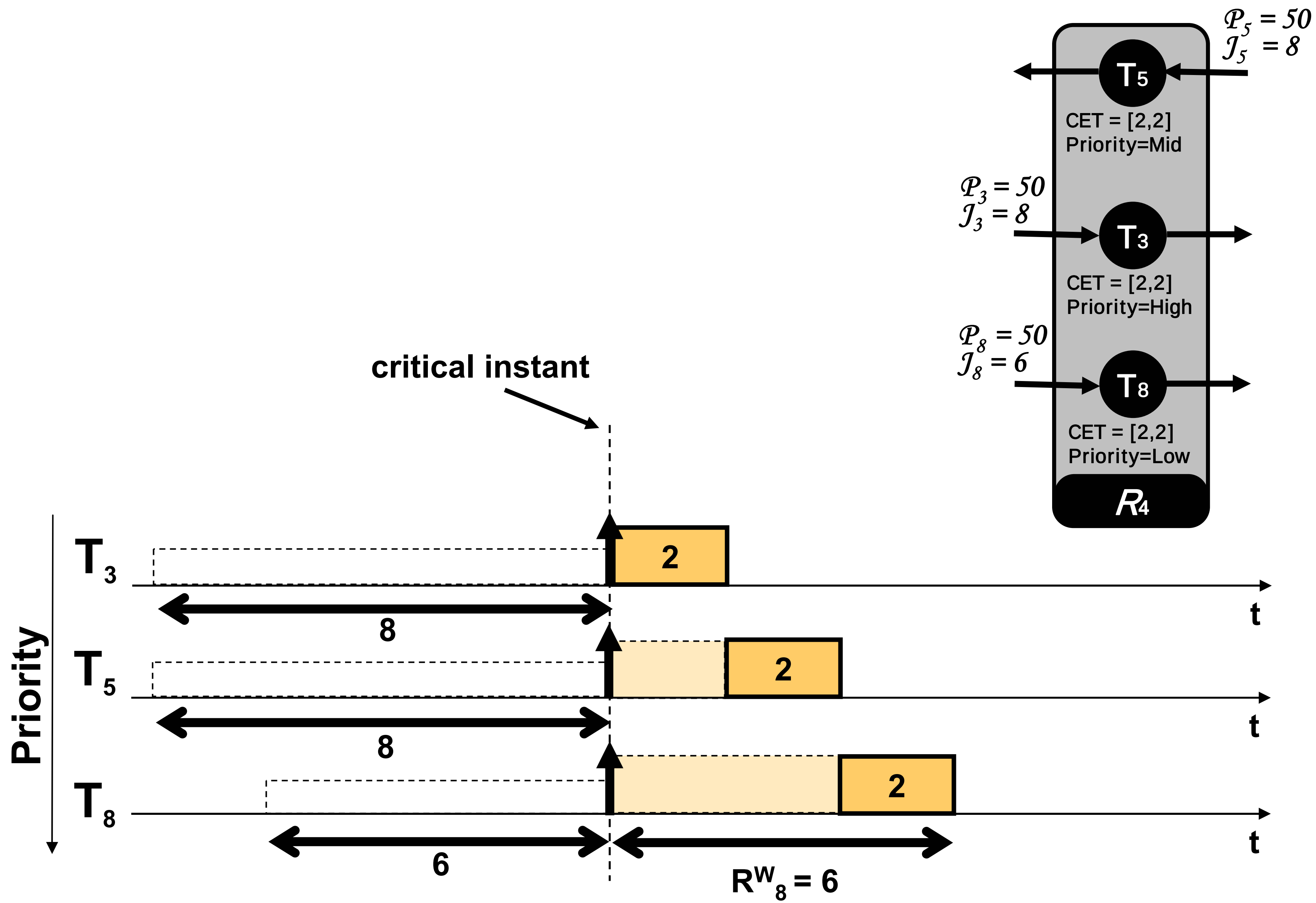
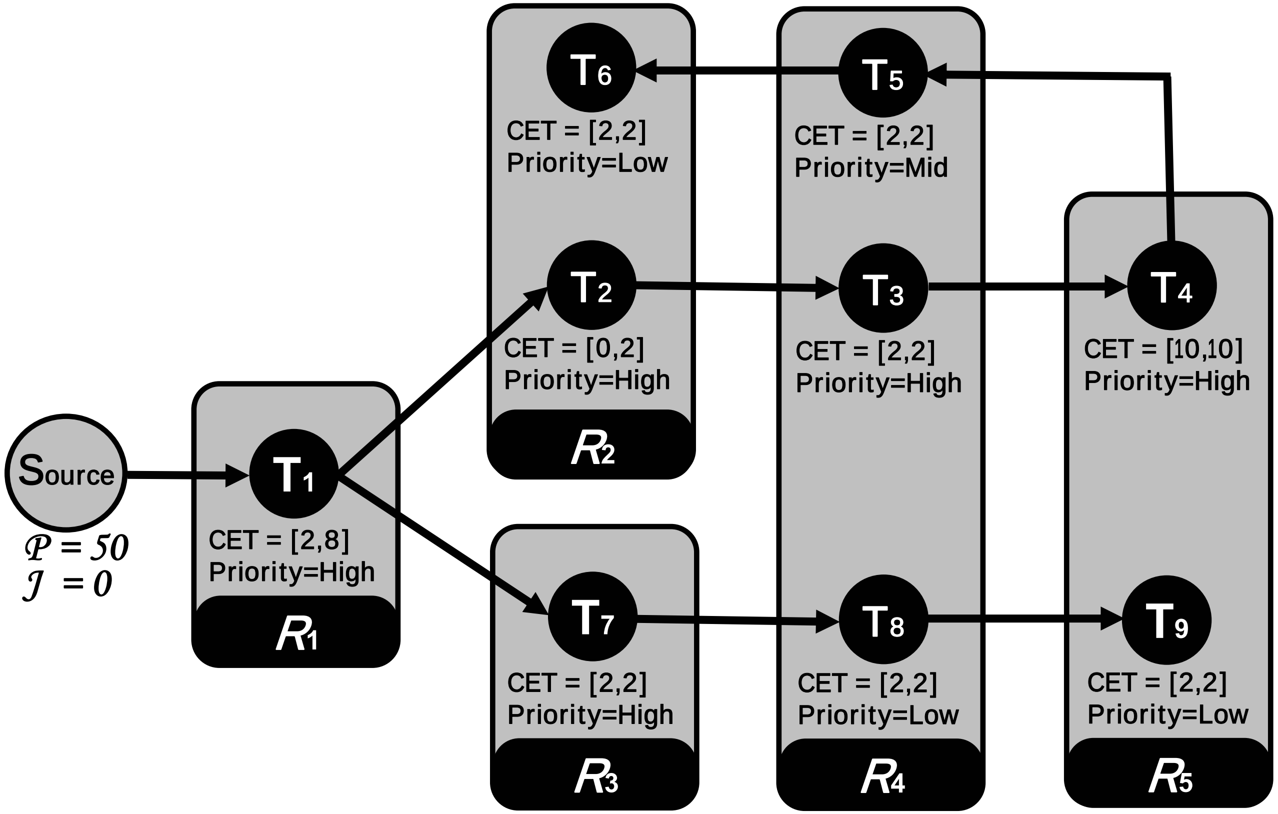
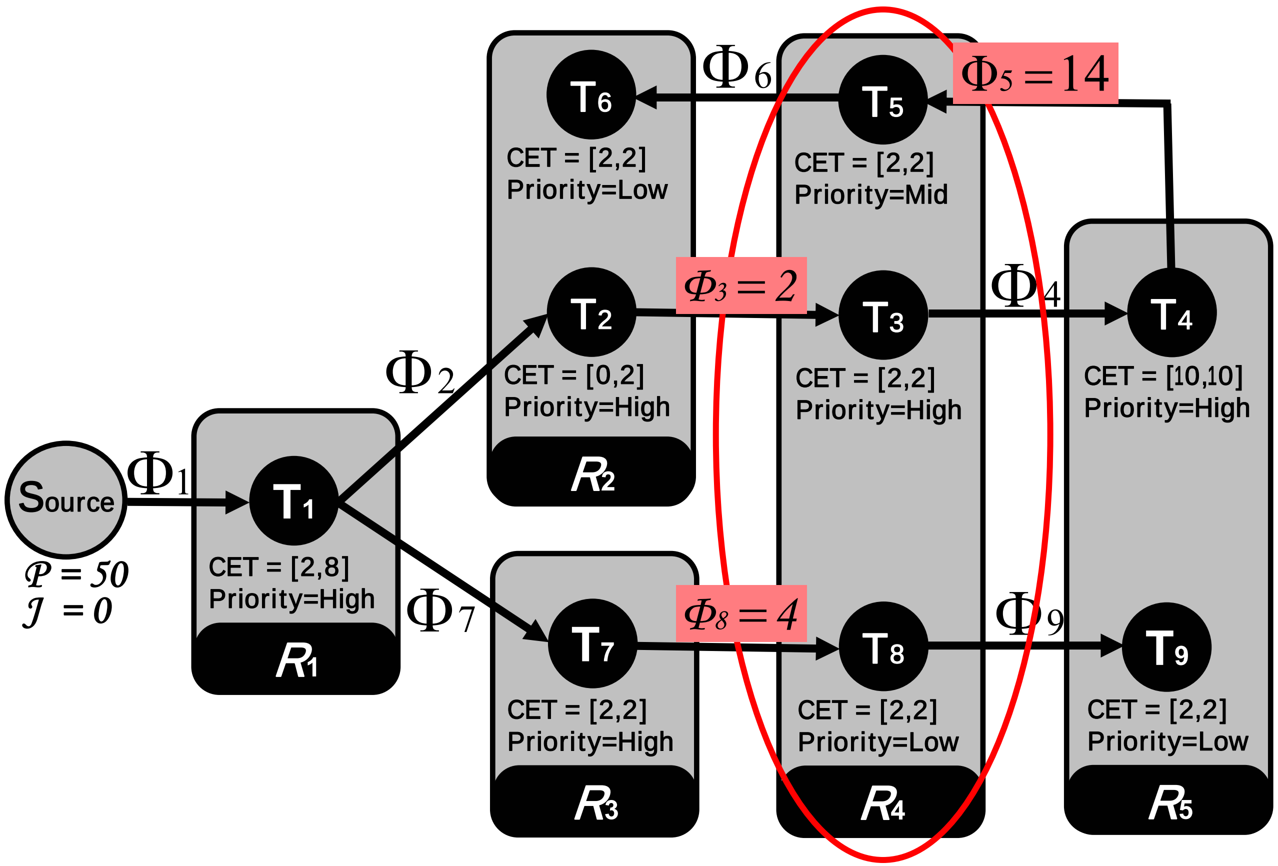


Tindell (1994)



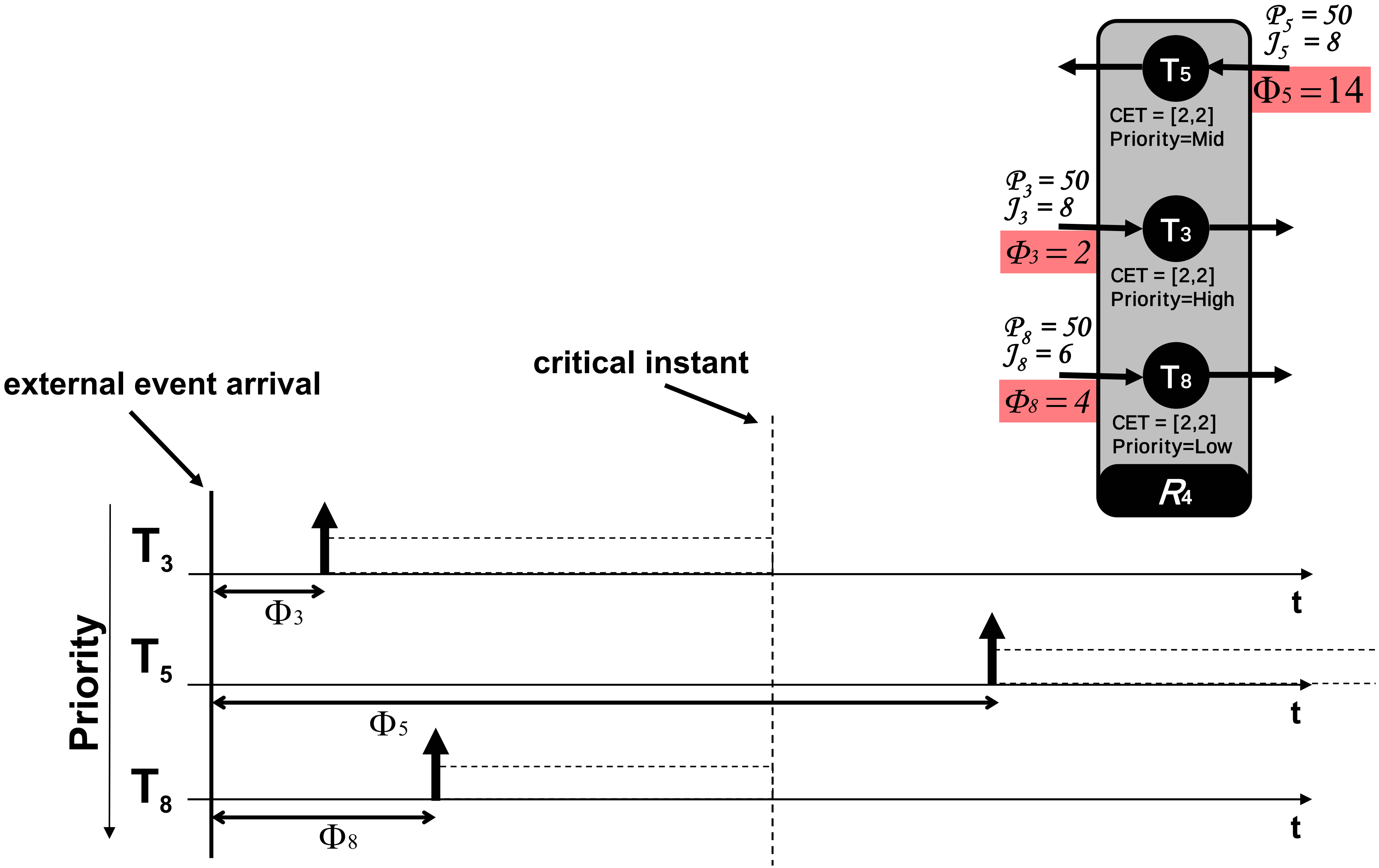
- **Periodic arrival of events at system inputs as timing-reference**

Tindell (1994)



Global Offset Φ_i = **earliest activation time of T_i relative to the periodical arrival of an external event at the system input**

Tindell (1994)



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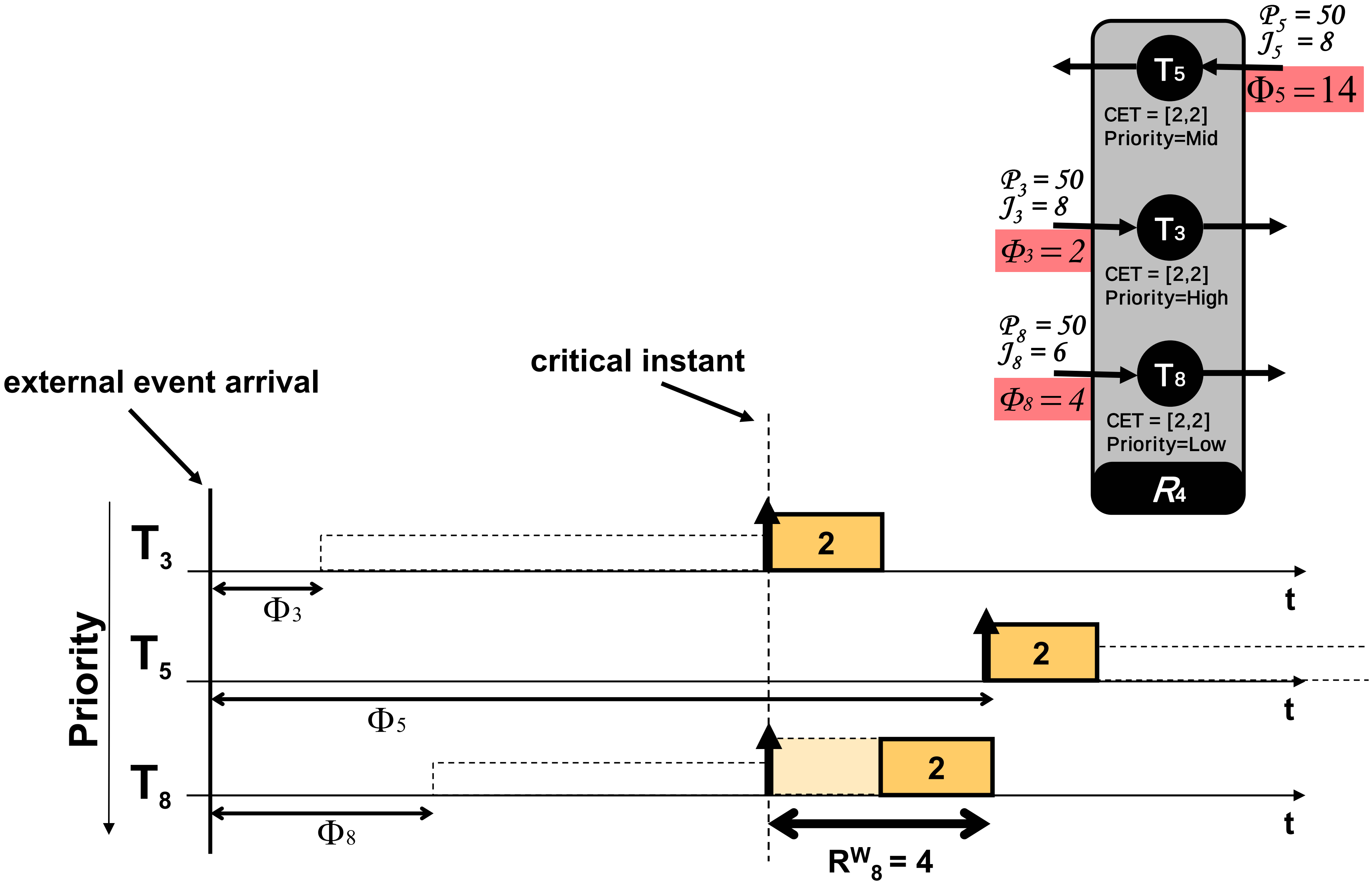


Further Techniques

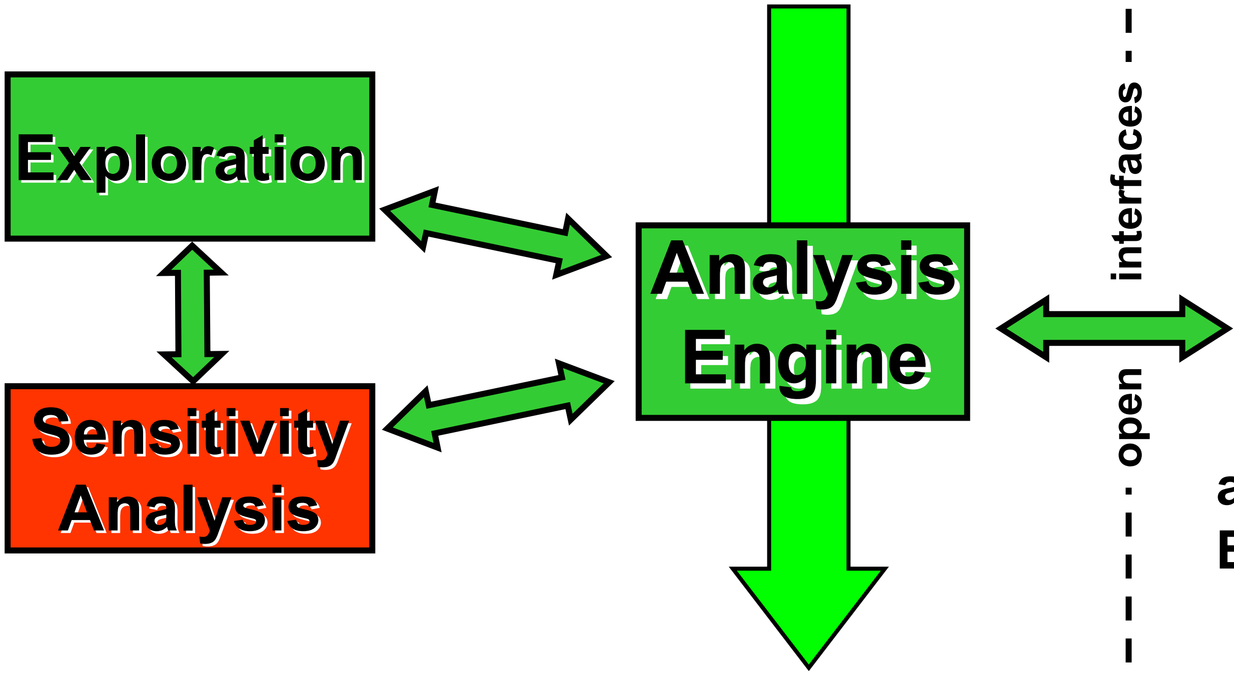
- Relative offsets and relative jitter (Henia et al.)
  - Extends idea of global offsets
  - Describes the earliest activation time of a task relative to a timing-reference *ref*
  - Reference is not necessarily a periodic external event
  - Enables tighter response time calculation
- Precedence relations
  - Explicitly considers precedence relations between tasks (i.e. task i cannot start until task j has finished execution)
  - Orthogonal to offset based techniques

Conclusion

- Abstract stream models enable early system performance analysis …
- … requiring only key performance data
- Advantage: very fast analysis …
  - 10s of tasks: order of milliseconds
  - 100s of tasks: order of seconds
- … allows the application of advanced analysis features
  - System sensitivity analysis
  - System exploration including robustness optimization
- Presented formalisms implemented in a tool called SymTA/S
- Tool commercialized by Symtavision

SymTA/S Tool Suite

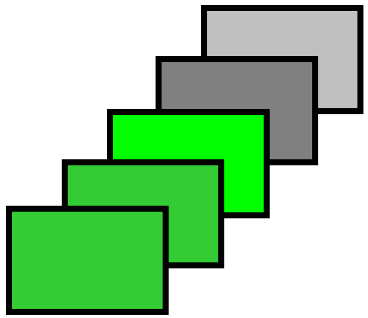
idea, specification,
sketch, existing system



verified system

flow integration:
- data bases
- tools

3rd party



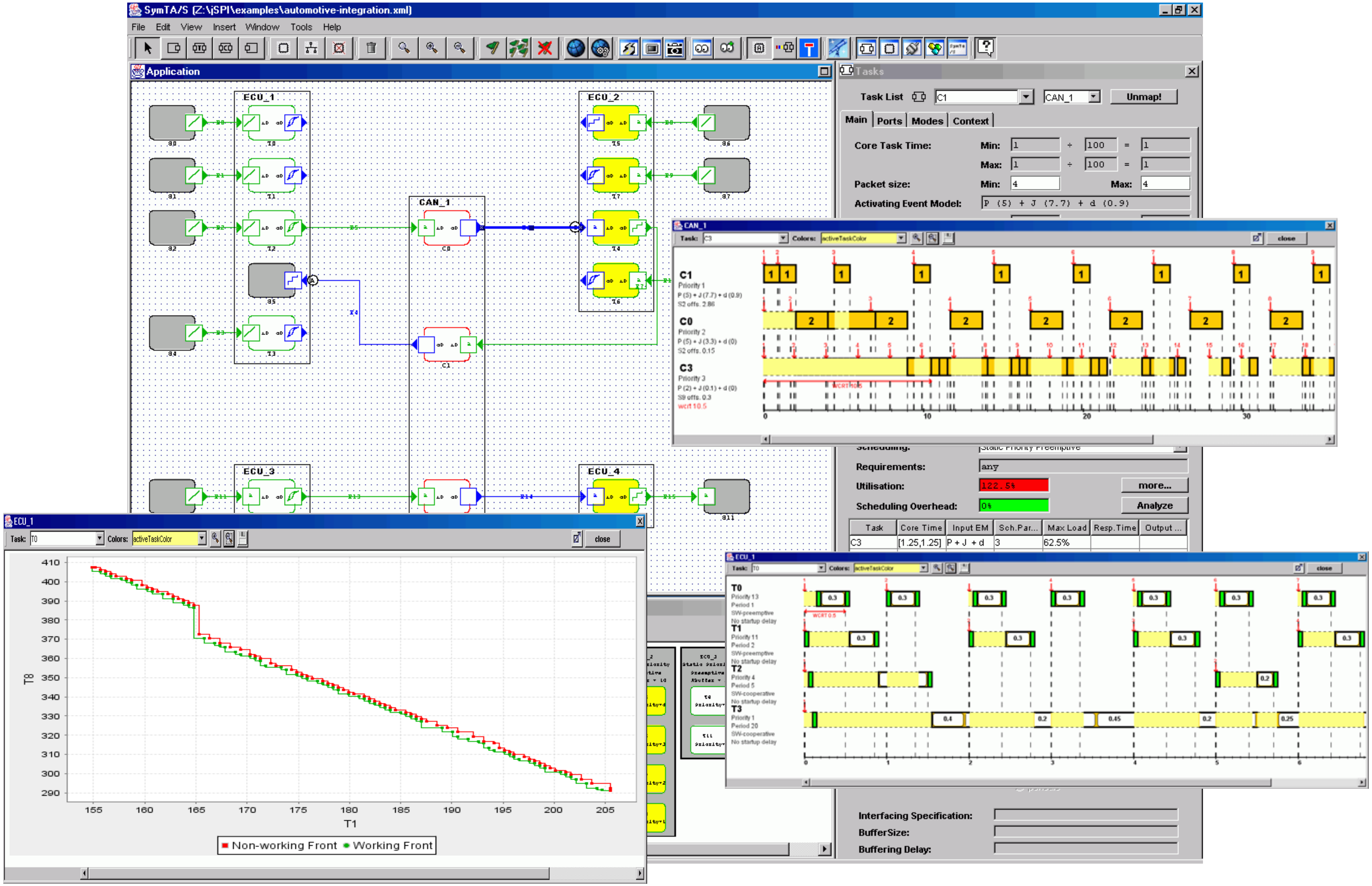
analysis libraries for ECUs, buses, etc ...

- SPP/DMA/RMA
- EDF
- TDMA
- RR

Industry related:

- OSEK flavours
- CAN

SymTA/S screenshot



Thank you for your attention !!!