Schedulability Analysis for Systems with Data and Control Dependencies

Paul Pop, Petru Eles, Zebo Peng

Department of Computer and Information Science
Linköpings universitet
Sweden

- Motivation
- System Model
- Problem Formulation
- Schedulability Analysis
- Experimental Results
- Conclusions

Performance estimation:

- Based on schedulability analysis.

Schedulability analysis:

- Worst case response time of each process.
- Models in the literature:

  Independent processes;

  Data dependencies: *release jitter*, *offsets*, *phases*;

  Control dependencies: *modes*, *periods*, *recurring tasks*.

Characteristics and Message

Characteristics:

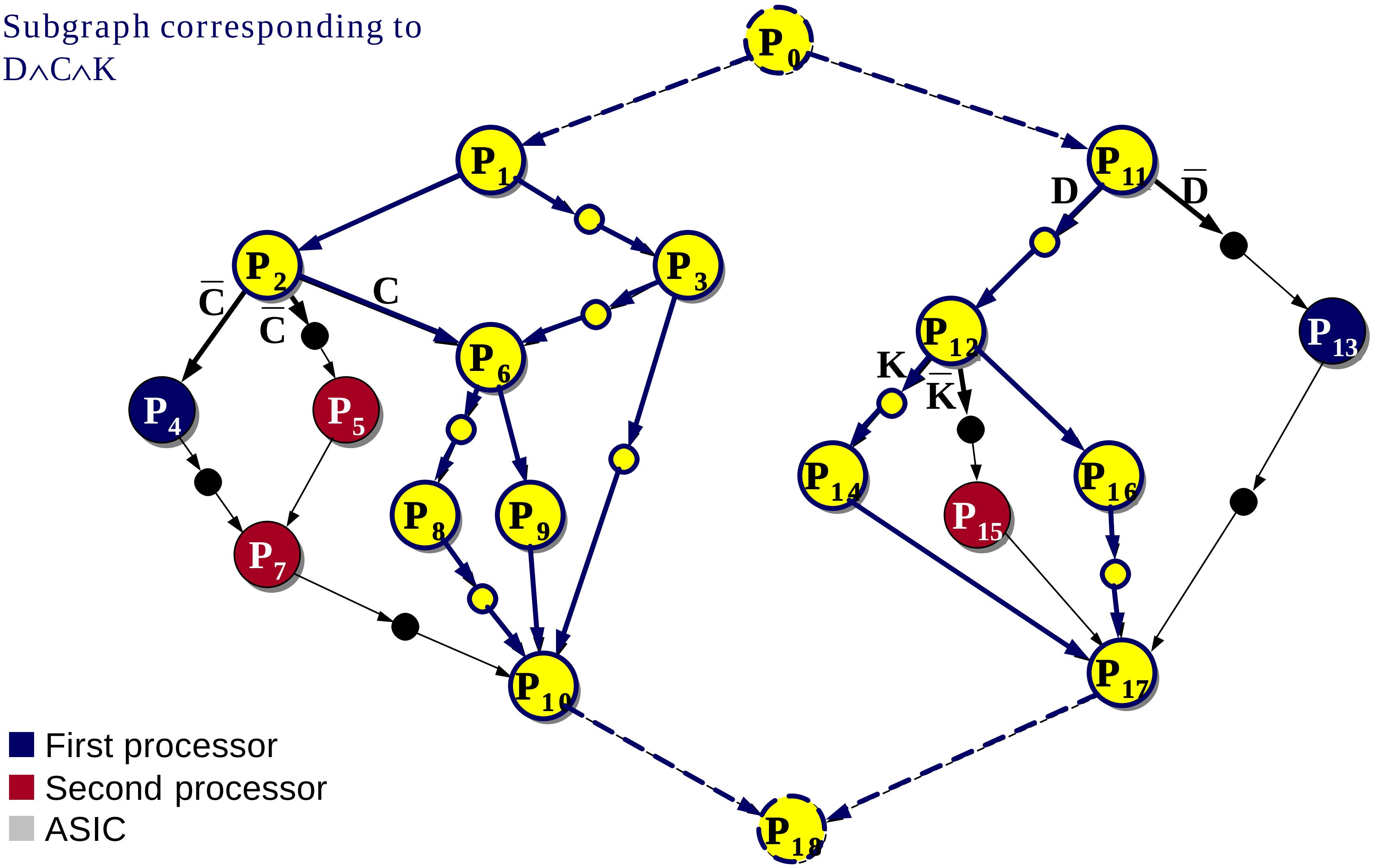
- Heterogeneous system architecture.
- Fixed priority preemptive scheduling.
- Systems with data and control dependencies.
- Tighter worst case delay estimations.

Message:

- The pessimism of the analysis can be drastically reduced by considering the conditions during the analysis.

Conditional Process Graph

Subgraph corresponding to
D∧C∧K



Problem Formulation

Input

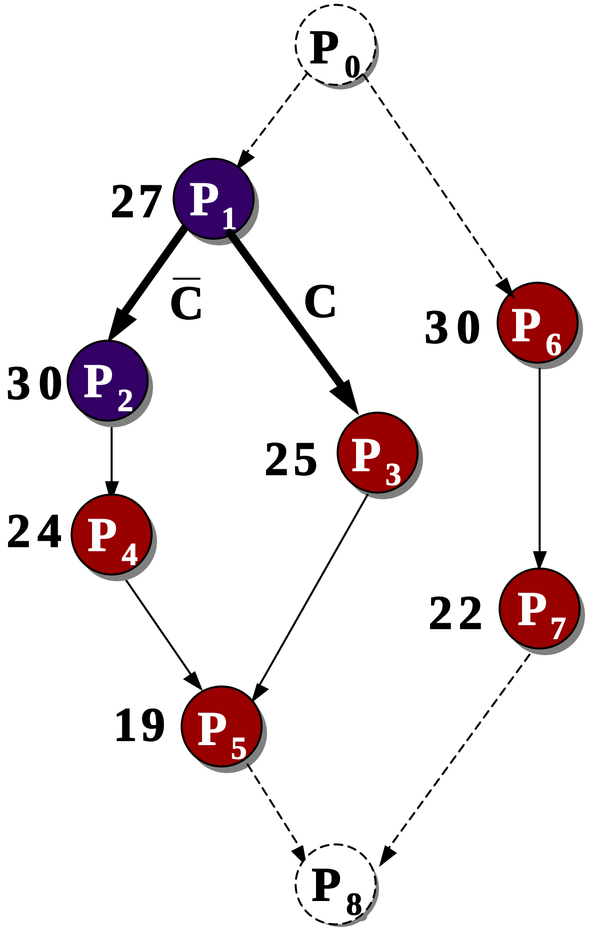
- An application modelled as a set of conditional process graphs (CPG).
- Each CPG in the application has its own independent period.
- Each process has an execution time, a deadline, and a priority.
- The system architecture and mapping of processes are given.

Output

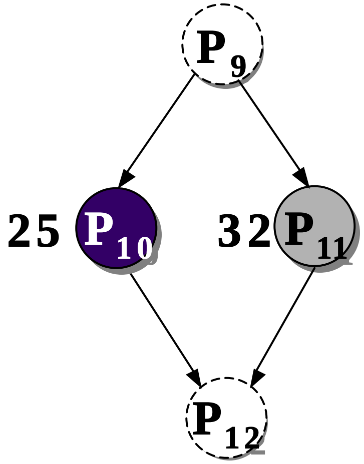
- Schedulability analysis for systems modelled as a set of conditional process graphs (both data and control dependencies).

- Fixed priority preemptive scheduling.
- Communication of messages not considered, but can be easily added.

Example



G_1: 200



G_2: 150

CPG	Worst Case Delays	
	No conditions	Conditions
G_1	120	100
G_2	82	82

Task Graphs with Data Dependencies

- K. Tindell: Adding Time-Offsets to Schedulabilty Analysis, Research Report

  Offset: fixed interval in time between the arrival of sets of tasks.

  Can reduce the pessimism of the schedulability analysis.

  Drawback: how to derive the offsets?

- T. Yen, W. Wolf: Performance Estimation for Real-Time Distributed Embedded Systems, IEEE Transactions On Parallel and Distributed Systems

  Phase (similar concept to offsets).

  Advantage: gives a framework to derive the phases.

Schedulability Analysis for Task Graphs

```
DelayEstimate(task graph G, system S)
      for each pair (P_i, P_j) in G
            maxsep[P_i, P_j]=∞
      end for
      step = 0
      repeat
            LatestTimes(G)
            EarliestTimes(G)
            for each P_i ∈ G
                  MaxSeparations(P_i)
            end for
      until maxsep is not changed or step < limit
      return the worst case delay δ_G of the graph G
end DelayEstimate
```

worst case response times and upper bounds for the offsets (→ LatestTimes(G))

lower bounds for the offsets (→ EarliestTimes(G))

maximum separation: $maxsep[P_i, P_j]=0$ if the execution of the two processes never overlaps (→ MaxSeparations(P_i))

Schedulability Analysis for CPGs, 1

Two extreme solutions:

- Ignoring Conditions (IC)

  Ignore control dependencies and apply the schedulability analysis for the (unconditional) task graphs.

- Brute Force Algorithm (BF)

  Apply the schedulability analysis after each of the CPGs in the application have been decomposed in their constituent unconditional subgraphs.

Schedulability Analysis for CPGs, 2

In between solutions:

- Conditions Separation (CS)

  Similar to *Ignoring Conditions* but uses the knowledge about the conditions in order to update the **maxsep** table:

  maxsep[P_i, P_j] = 0 if P_i and P_j are on different conditional paths.

- Relaxed Tightness Analysis (two variants: RT1, RT2)

  Similar to the *Brute Force Algorithm*, but tries to reduce the execution time by removing the iterative tightening loop (relaxed tightness) in the **DelayEstimation** function.

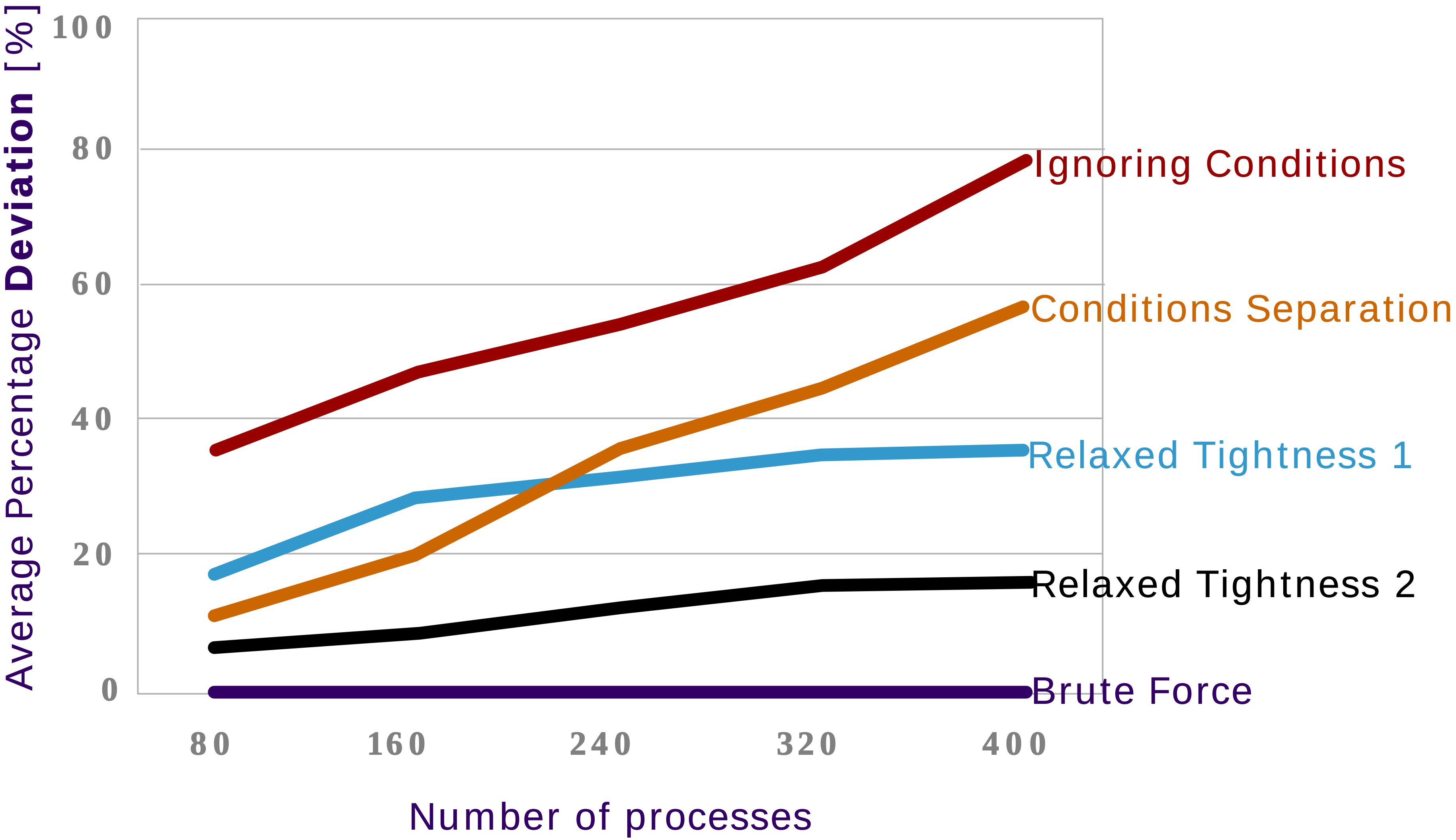
Experiments Setup

- Number of Graphs: 150
  30 for each dimension of 80, 160, 240, 320, 400 nodes;
  2, 4, 6, 8, 10 conditions.
- Graphs Structure:
  Random and regular (trees, groups of chains).
- Architecture:
  2, 4, 6, 8, 10 nodes.
- Mapping:
  40 processes / node; random and using simple heuristics.

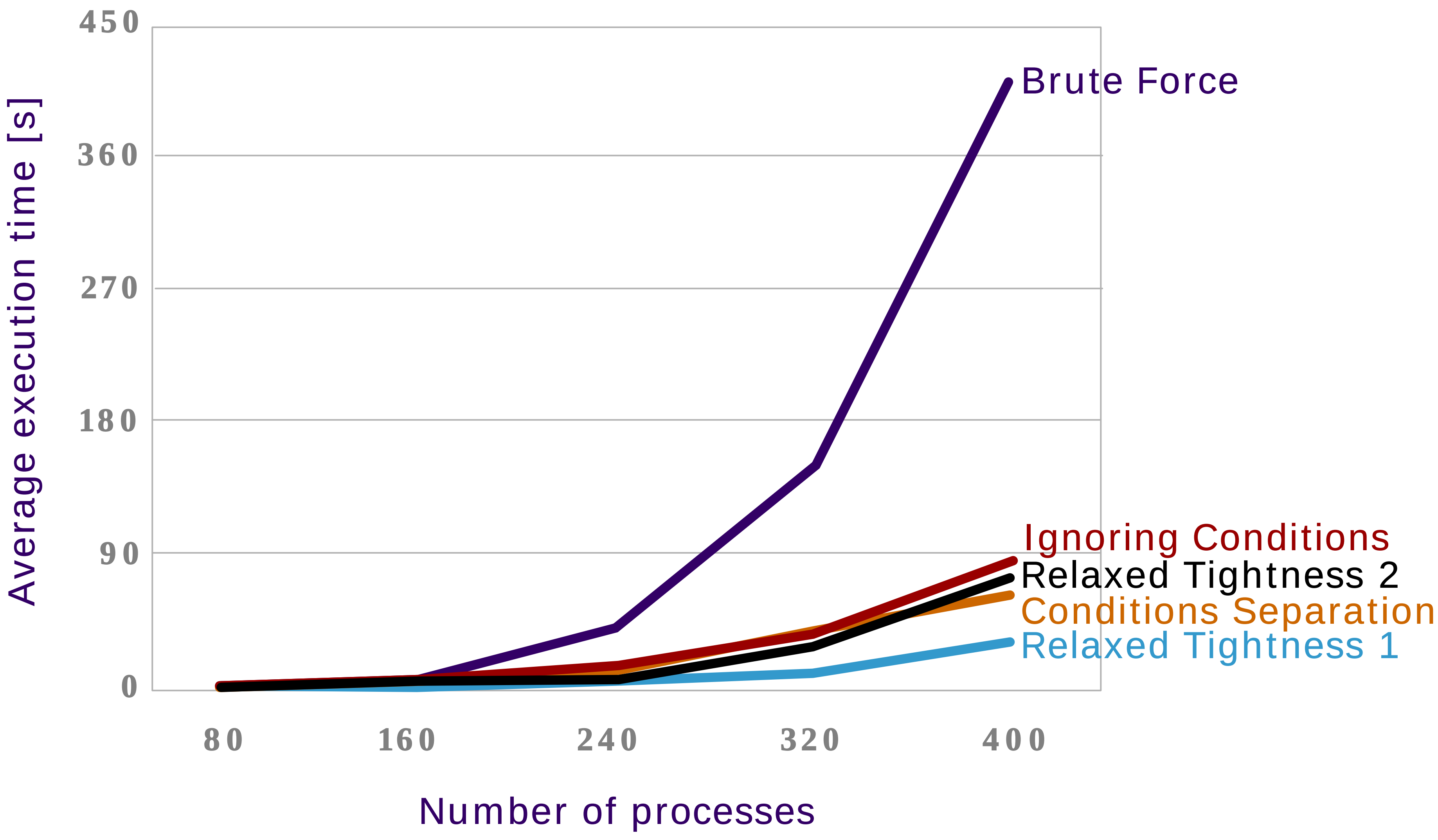
- Cost function: **degree of schedulability**

$$Cost\ function = \sum_{i=1}^{n} \left(D_{\Gamma_i} - d_{\Gamma_i} \right)$$

Experimental Results

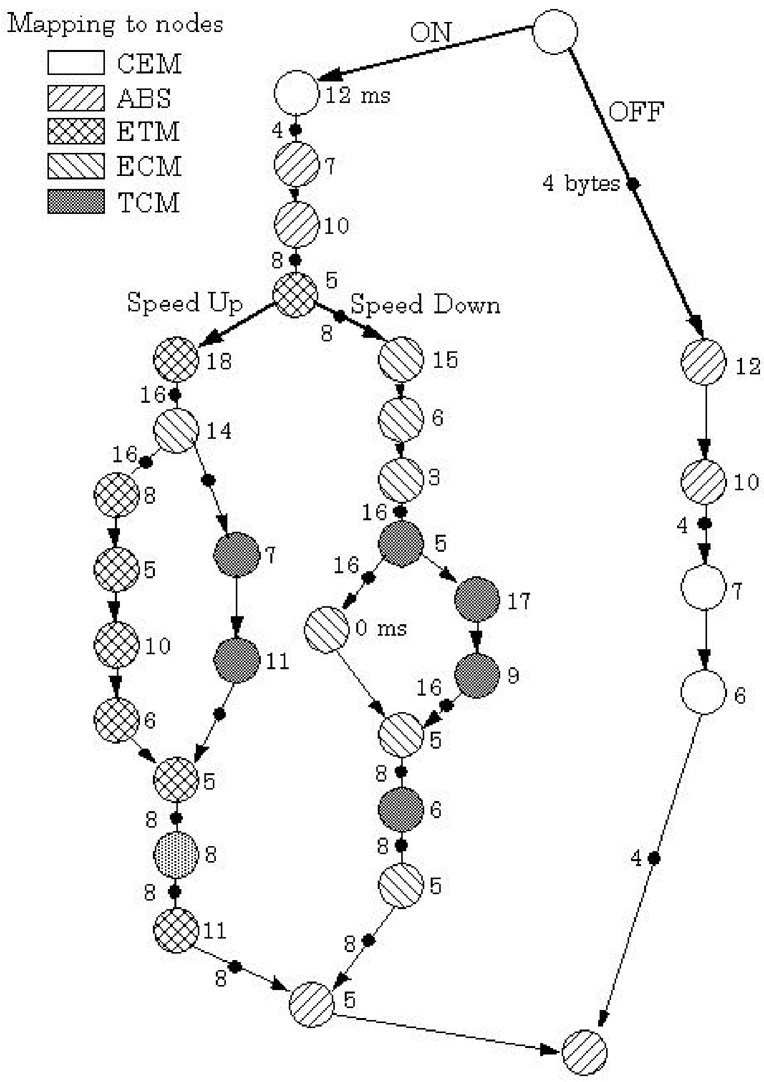


Experimental Results (Cont.)



Real Life Example

- **Vehicle cruise controller.**
- Modelled with a CPG of 32 processes and two conditions.
- Mapped on 5 nodes: CEM, ABS, ETM, ECM, TCM.



- Deadline 130:
  - Ignoring Conditions: 138 ms
  - Conditions Separation: 132 ms
  - Relaxed Tightness 1, 2: **124** ms
  - Brute Force: **124** ms

Conclusions

- Schedulability analysis for hard real-time systems with control and data dependencies.
- The systems are modelled using conditional process graphs that are able to capture both the flow of data and that of control.
- Distributed architectures, fixed priority scheduling policy.
- Five approaches to the schedulability analysis of such systems.
- Extensive experiments and a real-life example show that: **considering the conditions during the analysis the pessimism of the analysis can be significantly reduced.**