# An Approach to Incremental Design of Distributed Embedded Systems

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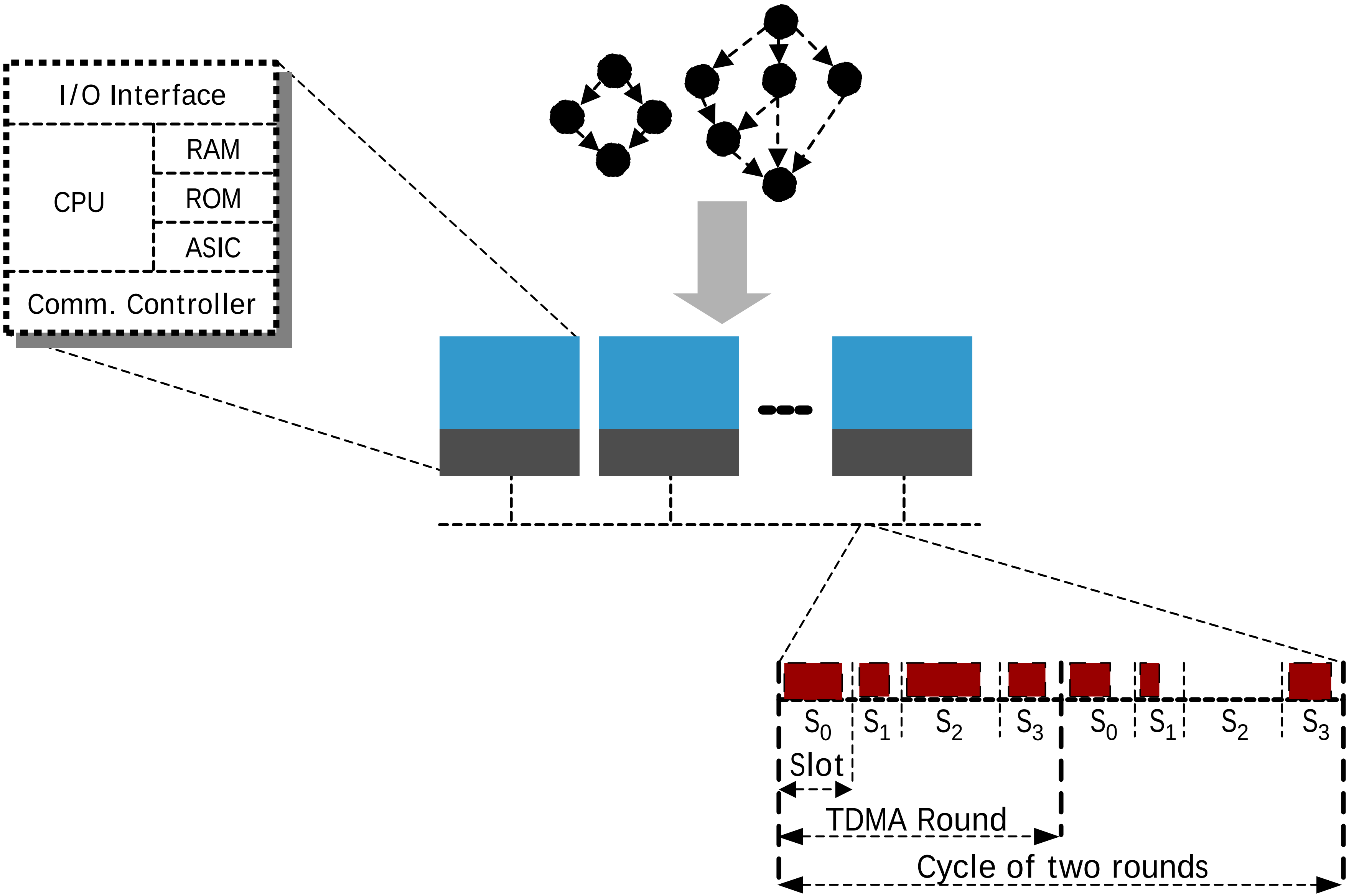
# Outline

- Incremental design process
  - Mapping and scheduling
- Problem formulation
- Mapping strategy
- Experimental results
- Conclusions and future work

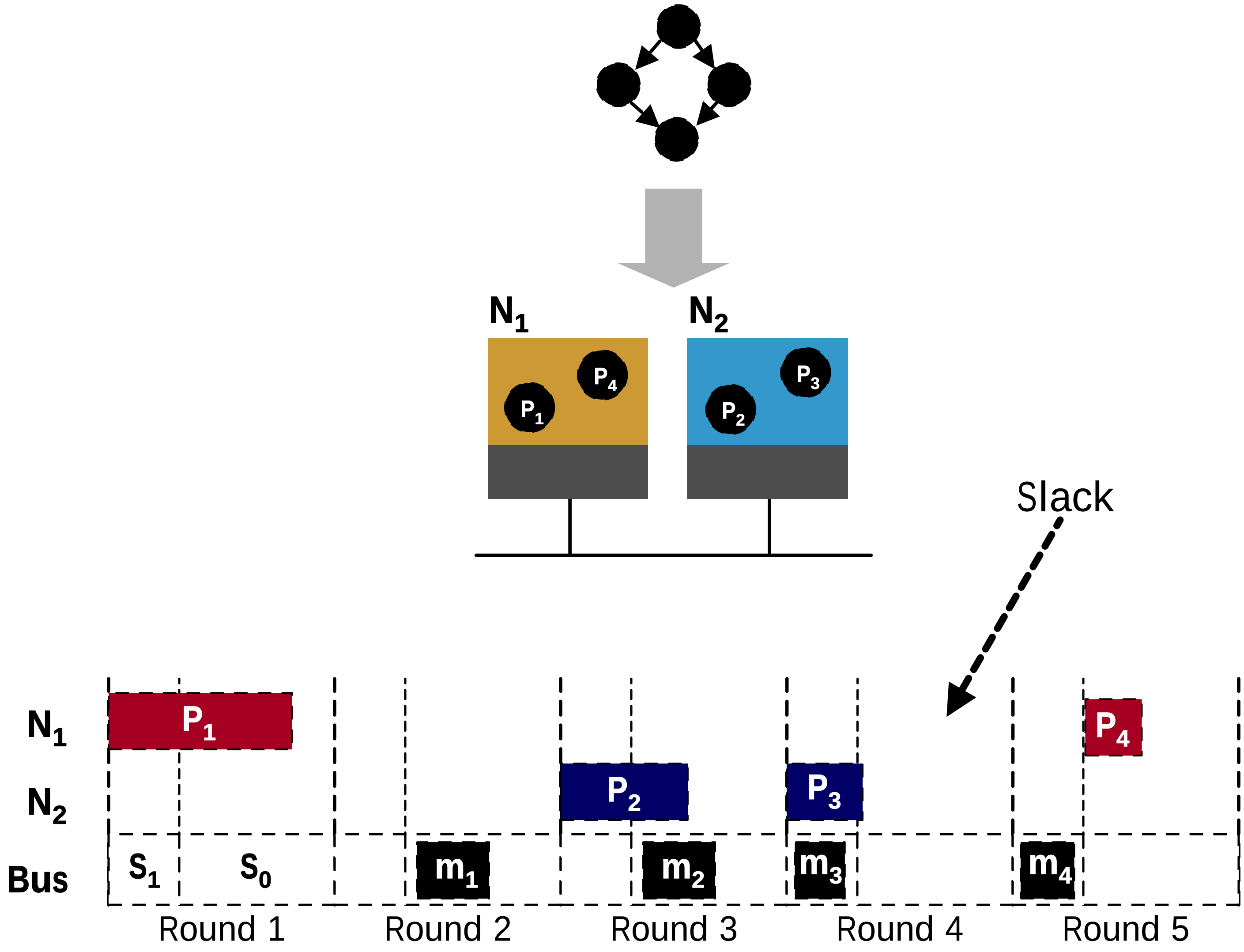
# Introduction

- **Characteristics:**
  - Incremental design process, engineering change;
  - Distributed real-time embedded systems; Heterogeneous architectures;
  - Static cyclic scheduling for processes and messages;
  - Communications using a time-division multiple-access (TDMA) scheme:
    H. Kopetz, G. Grünsteidl. TTP-A Protocol for Fault-Tolerant Real-Time Systems. IEEE Computer '94.
- **Contributions:**
  - Mapping and scheduling considered inside an incremental design process;
  - Two design criteria (and their metrics) that drive our mapping strategies to solutions supporting an incremental design process;
  - Two mapping algorithms.
- **Message:**
  - Engineering change can be successfully addressed at system level.

# “Classic” Mapping and Scheduling



# “Classic” Mapping and Scheduling Example

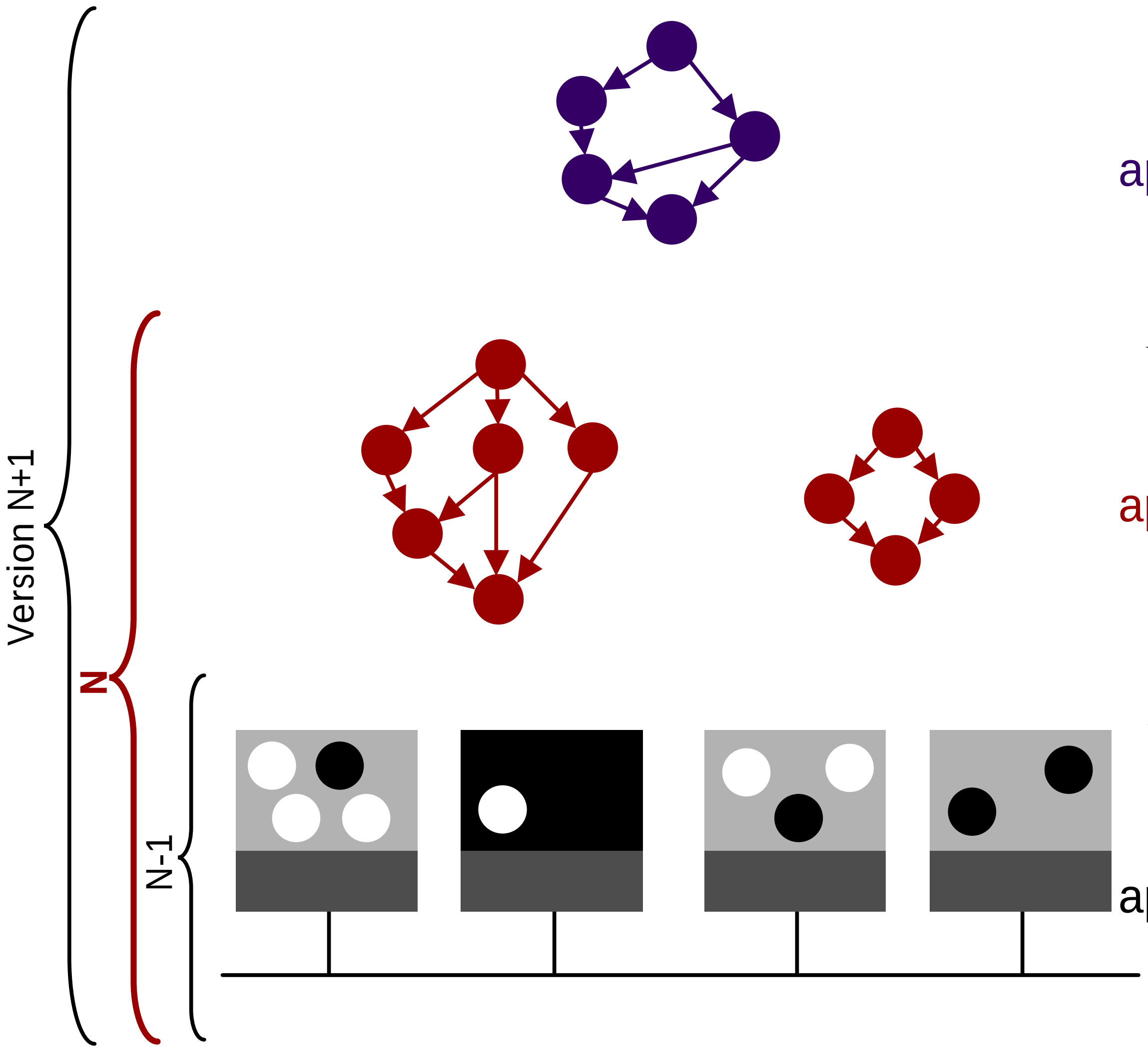


# Incremental Design Process

- Start from an already existing system with applications:
  - In practice, very uncommon to start from scratch.

- Implement new functionality on this system (increment):
  - As few as possible modifications of the existing applications, to reduce design and testing time;
  - Plan for the next **increment**:
    It should be easy to add functionality in the future.

# Mapping and Scheduling




**Future** applications

**Do not exist yet** at Version N!

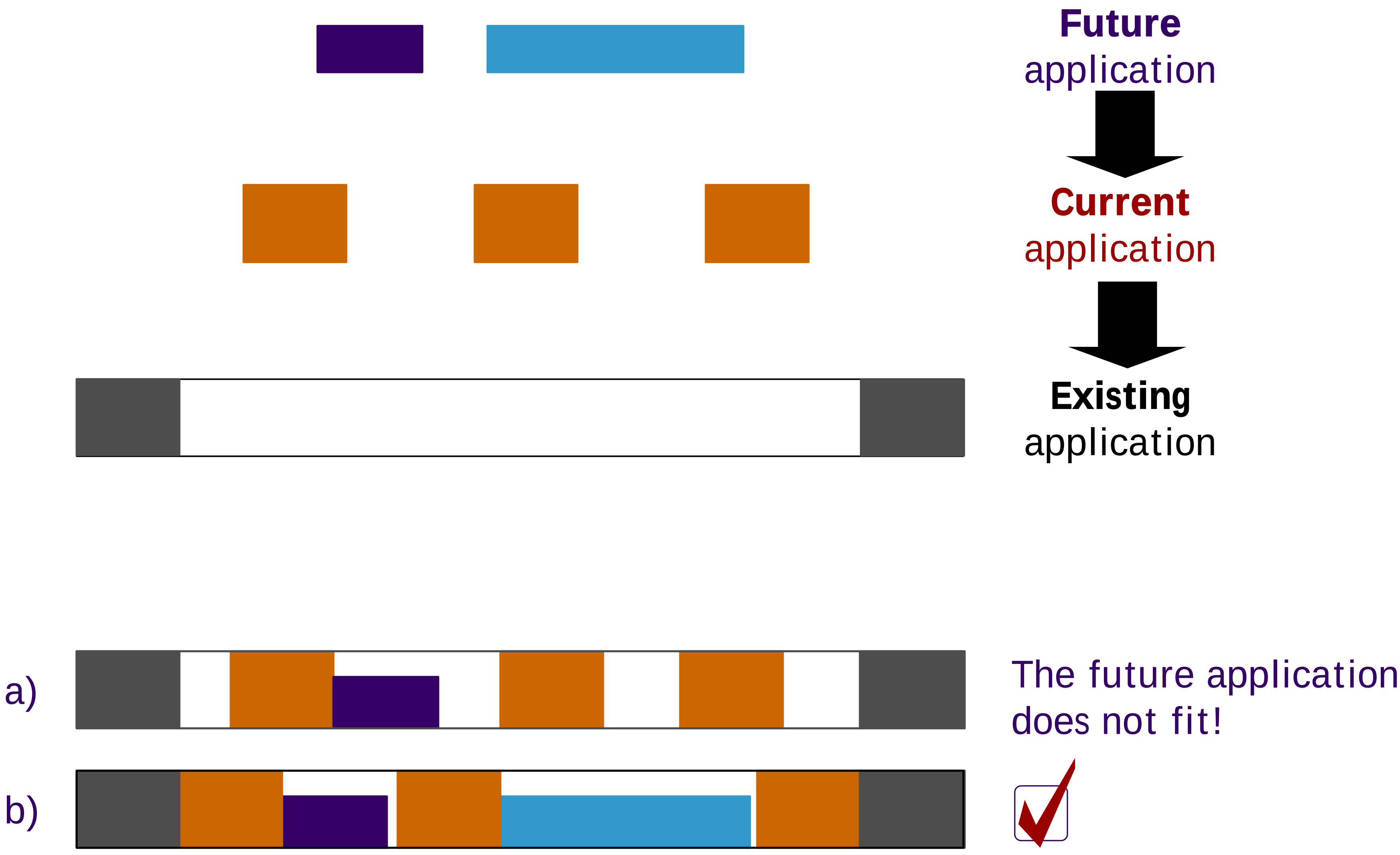
**Current** applications

**Map and schedule** so that the future applications will have a chance to fit.

**Existing** applications

**No modifications** are performed to the existing applications.

# Mapping and Scheduling Example



# Problem Formulation

## Input

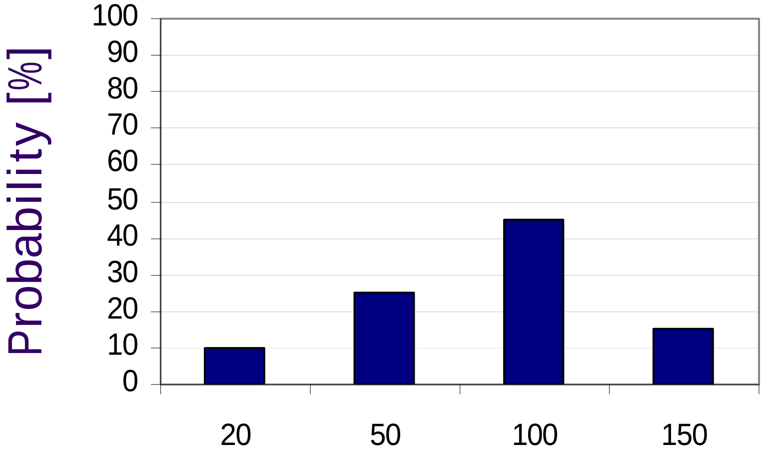
- A set of *existing* applications modelled using process graphs;
- A *current* application to be mapped modelled using process graphs;
- Each process graph in the application has its own *period* and *deadline*;
- Each process has a *potential set of nodes* to be mapped to and a *WCET*;
- Certain information about *future* applications (next slide);
- The system architecture is given.

## Output

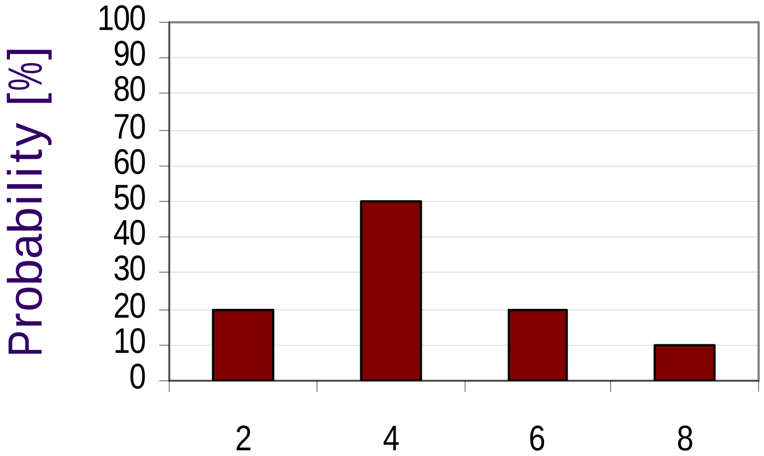
- A **mapping and scheduling of the *current* application**, so that:
  Requirement a: constraints of the *current* application are satisfied
  and no modifications are performed to the *existing* applications;
  Requirement b: new *future* applications can be mapped
  on the resulted system.

# Characterizing Future Applications

For a family of future applications we know:




Typical process WCET [time units]




Typical message size [bytes]

The most demanding future application:

- Smallest expected period $T_{min}$
- Expected necessary processor time $t_{need}$ inside $T_{min}$
- Expected necessary bandwidth $b_{need}$ inside $T_{min}$

# Mapping and Scheduling Strategy

Mapping and scheduling of the *current* application, so that:

- **Requirement a)**

  Constraints of the *current* application are satisfied and

  no modifications are performed to the *existing* applications.

  - Initial Mapping (IM) constructs an initial mapping with a valid schedule;

    starting point: Heterogeneous Critical Path (HCP) algorithm from

    P.B. Jorgensen, J. Madsen. Critical Path Driven Cosynthesis for Heterogeneous Target Architectures. CODES'97

- **Requirement b)**

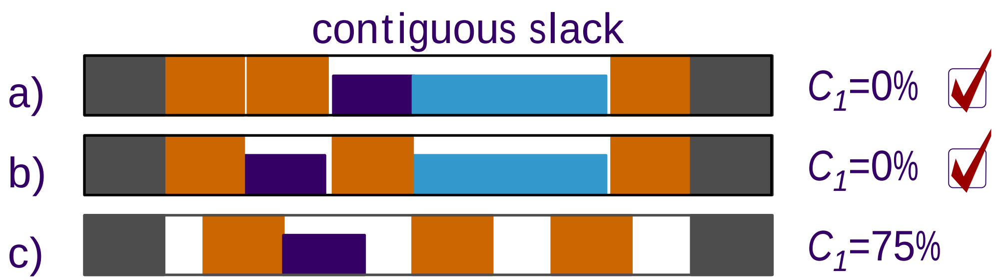
  New *future* applications can be mapped on the resulted system.

  - Design criteria reflect the degree to which a design meets the requirement b);
  - Design metrics quantify the degree to which the criteria are met;
  - Heuristics to improve the design metrics.

# Mapping and Scheduling: First Criterion

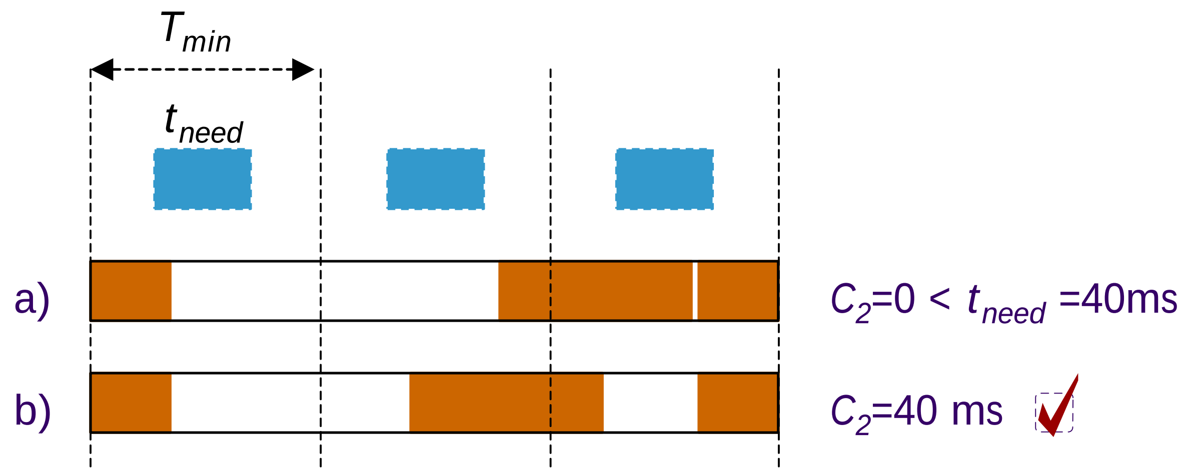
- First design criterion: slack sizes
  - How well the slack sizes of the *current* design alternative accommodate a family of *future* applications that are characterized as outlined before;
  - Tries to cluster the available slack: the best slack would be a contiguous slack.

- Design metrics for the first design criterion
  - $\boldsymbol{C_1^P}$ for processes, $\boldsymbol{C_1^m}$ for messages;
  - How much of the largest *future* application (contiguous slack), *cannot* be mapped on the *current* design alternative;
  - *Bin-packing algorithm* using the *best-fit policy*: processes as objects to be packed, and the slack as containers.



# Mapping and Scheduling: Second Criterion

- Second design criterion: slack distribution
  - How well the slack of the *current* design alternative is distributed in time to accommodate a family of *future* applications;
  - Tries to distribute the slack so that we periodically (***$T_{min}$***) have enough necessary processor time ***$t_{need}$*** and bandwith ***$b_{need}$*** for the most demanding future application.
- Design metrics for the second design criterion
  - ***$C_2^P$*** for processes, ***$C_2^m$*** for messages;
  - ***$C_2^P$*** is the sum of minimum *periodic* slack inside a ***$T_{min}$*** period on each processor.



# Mapping and Scheduling Strategy, Cont.

- Two steps:
  - Initial mapping and scheduling (IM) produces a valid solution
  - Starting from a valid solution, heuristics to minimize the objective function:

$$C = w_1^P(C_1^P) + w_1^m(C_1^m) + w_2^P \max(0, t_{need} - C_2^P) + w_2^m \max(0, b_{need} - C_2^m)$$

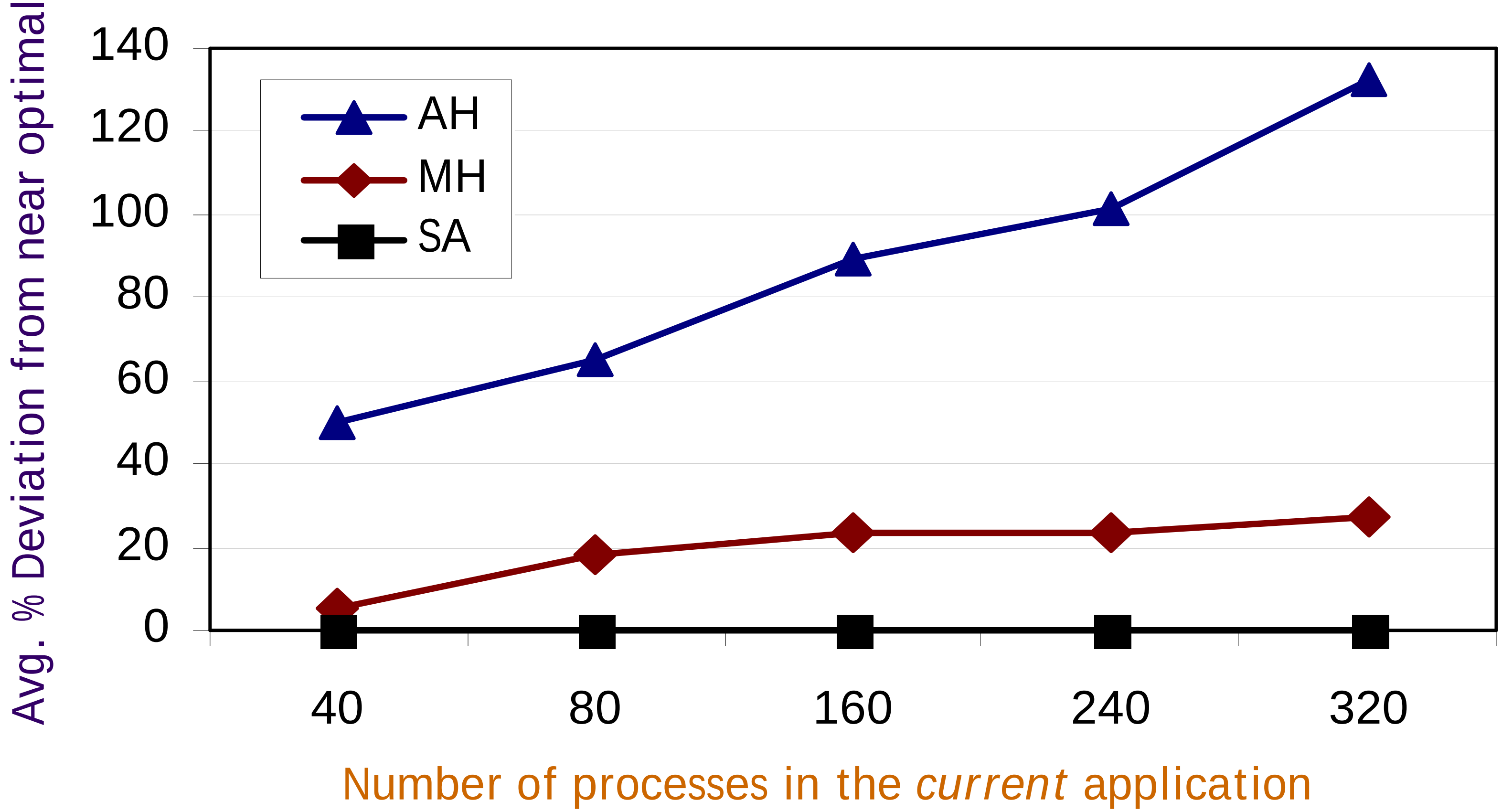
- Three heuristics:
  - Ad-Hoc approach (AH), little support for incremental design.
  - Simulated Annealing (SA), near optimal value for *C.*
  - Mapping Heuristic (MH):
    - Iteratively performs *design transformations* that improve the design;
    - Examines only transformations with the *highest potential* to improve the design;
    - Design transformations:

      moving a process to a different slack on the same or different processor,

      moving a message to a different slack on the bus.

# Experimental Results

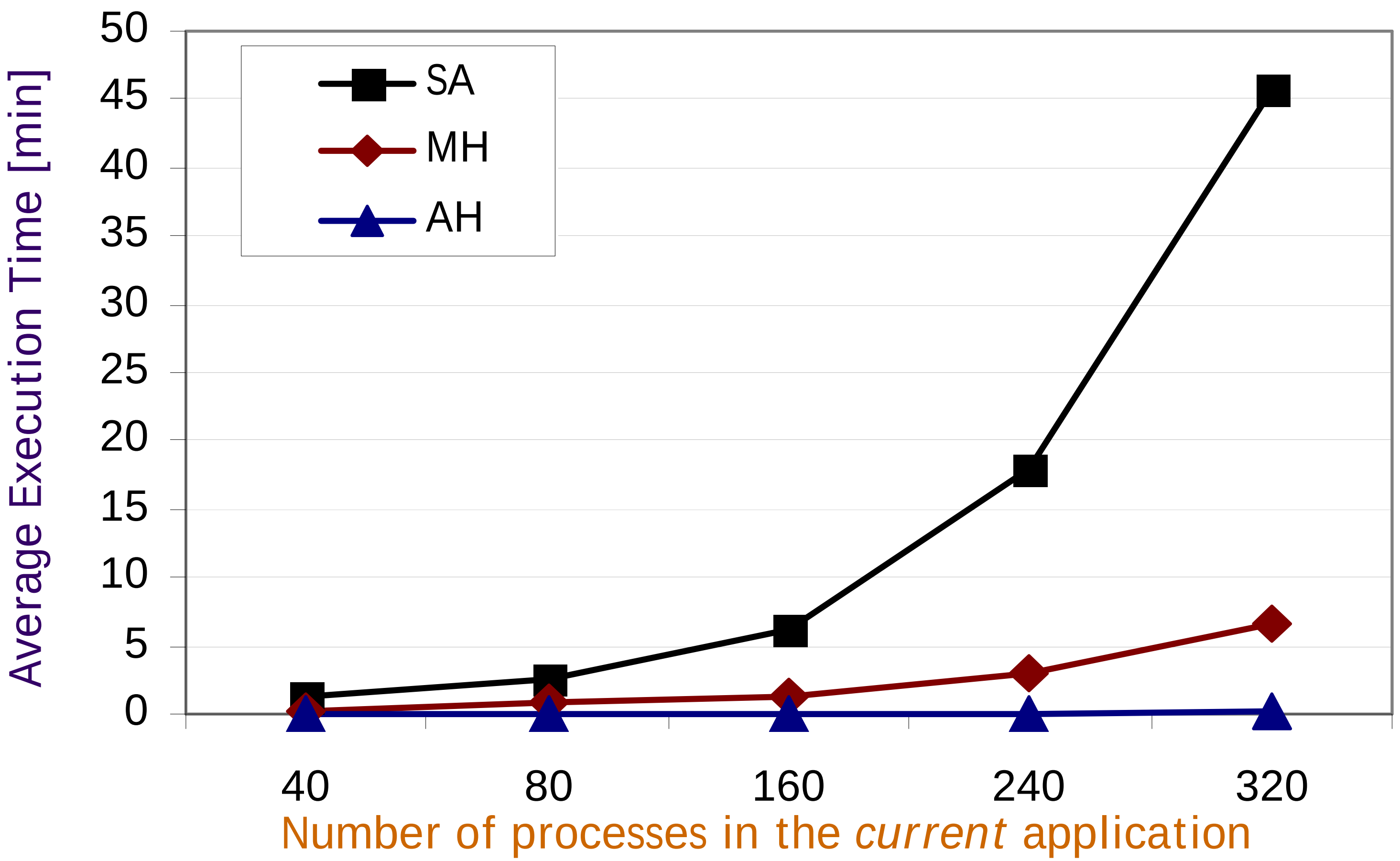
How does the **quality** (cost function) of the mapping heuristic (MH) compare to the ad-hoc approach (AH) and the simulated annealing (SA)?




*existing* applications: 400

# Experimental Results, Cont.

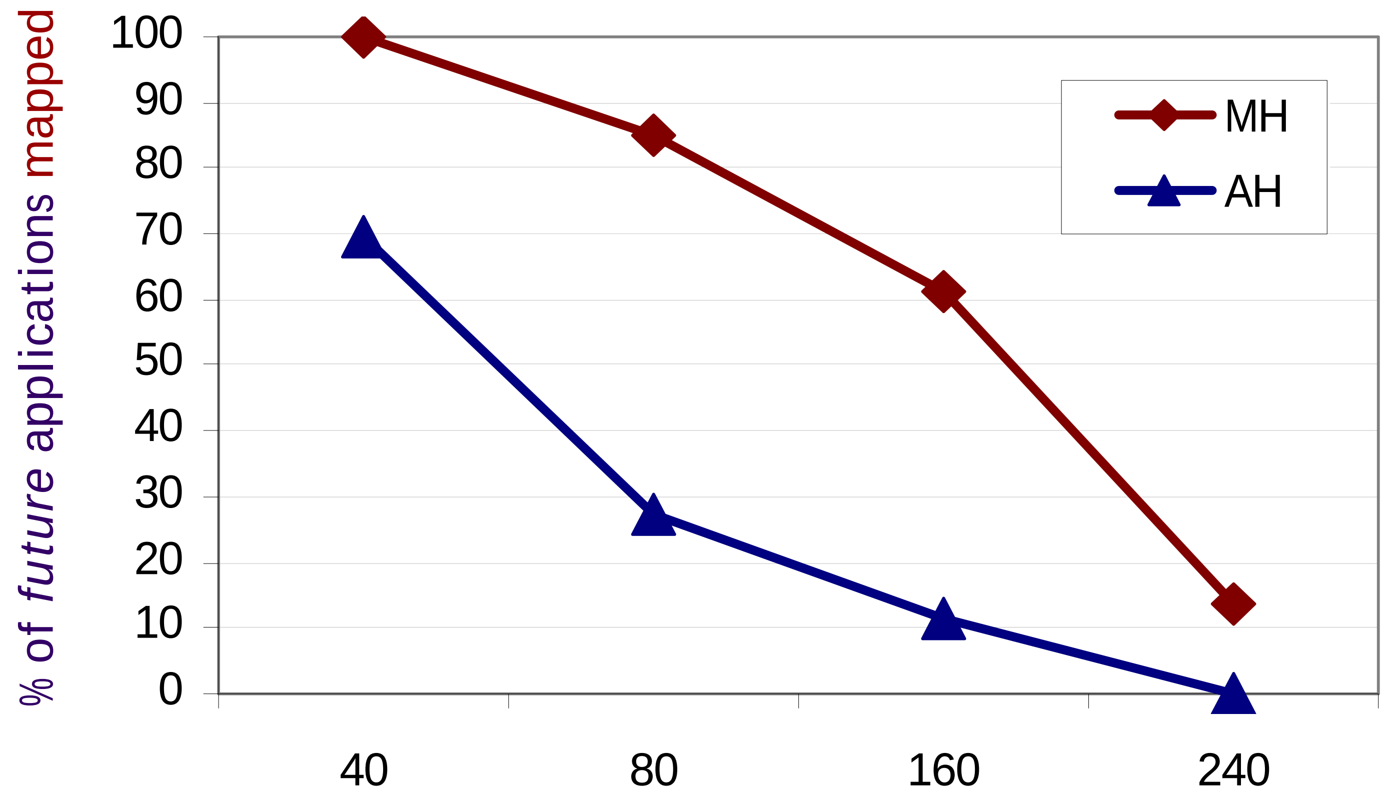
How does the **runtime** of the mapping heuristic (MH) compare to the ad-hoc approach (AH) and the simulated annealing (SA)?




*existing* applications: 400

# Experimental Results, Cont.

Are the mapping strategies proposed facilitating the implementation of future applications?




Number of processes in the *current* application

*existing* applications: 400, future application: 80

# Conclusions and Future Work

- **Conclusions:**
  - Mapping and scheduling considered inside an incremental design process;
  - Two design criteria (and their metrics) that drive our mapping strategies to solutions supporting an incremental design process;
  - Iterative improvement mapping heuristic.

- **CODES 2001:**
  - Allow modifications to the existing applications:
    - How to capture the modification cost (engineering changes);
    - How to decide which applications should be modified;
    - Modification cost should be minimized.