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PASTA: an efficient Proactive Adaptation approach based on STAtistical model checking for self-adaptive systems

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   B. To Be: PASTA Process
   C. PASTA Implementation
3. **Evaluation**
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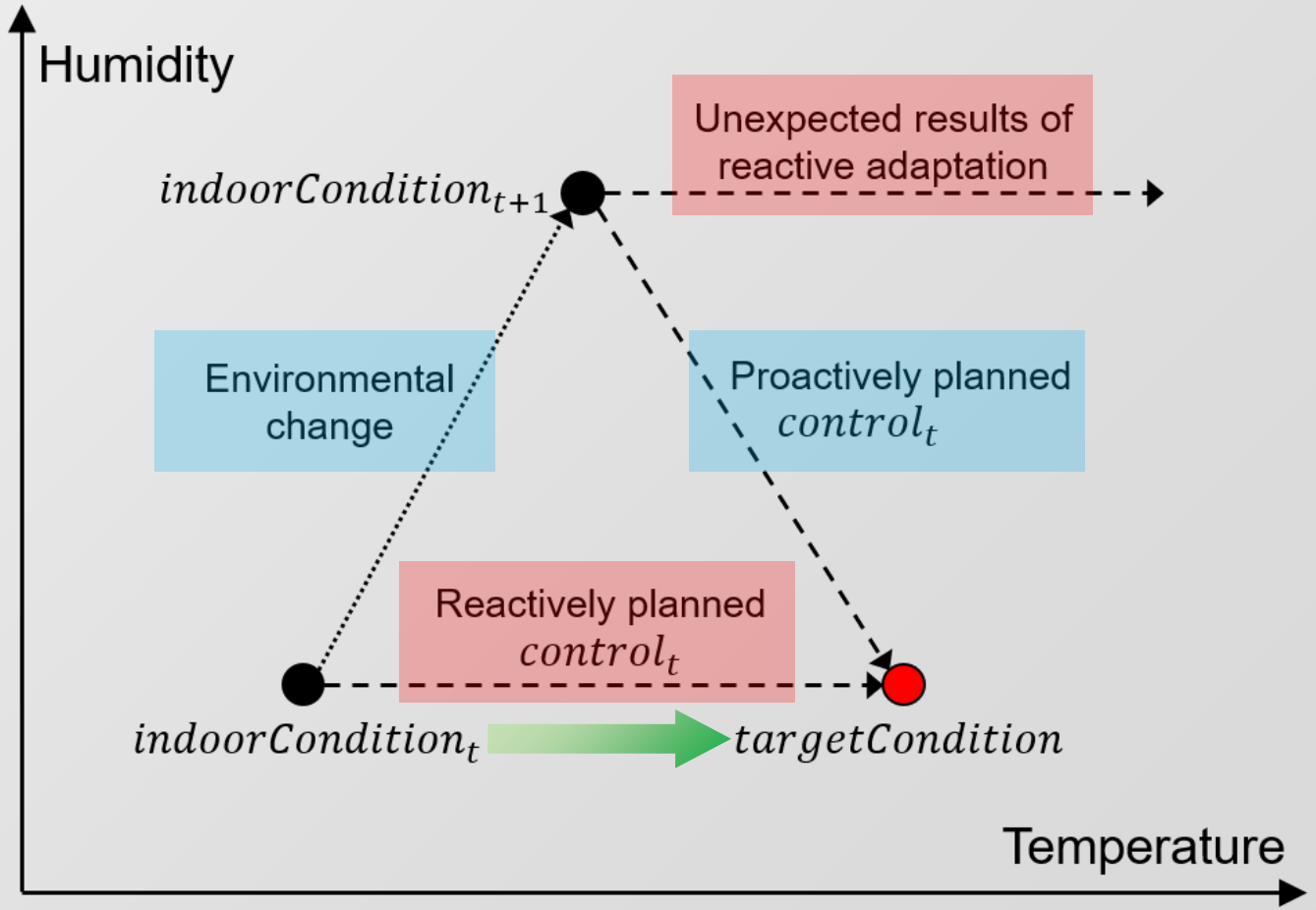
PASTA: Proactive Adaptation based on STAtistical model checking

Introduction

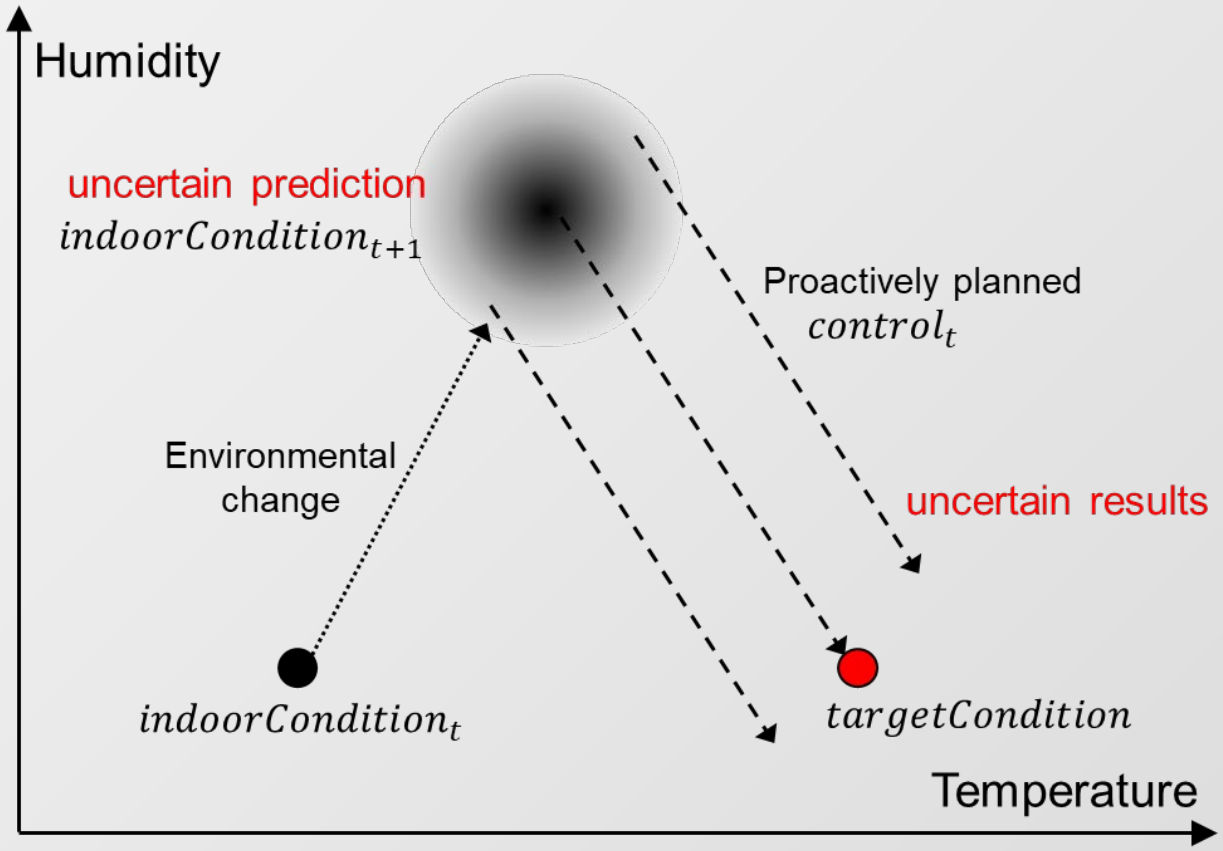
Reactive vs. Proactive Adaptation

- **Reactive adaptation**
  - An adaptation decision is made immediately responding to **current situation** of system and environmental.
- **Proactive adaptation**
  - An adaptation decision is made based on **prediction of future situation** of system and environment.



Resolving Uncertainty in Proactive Adaptation

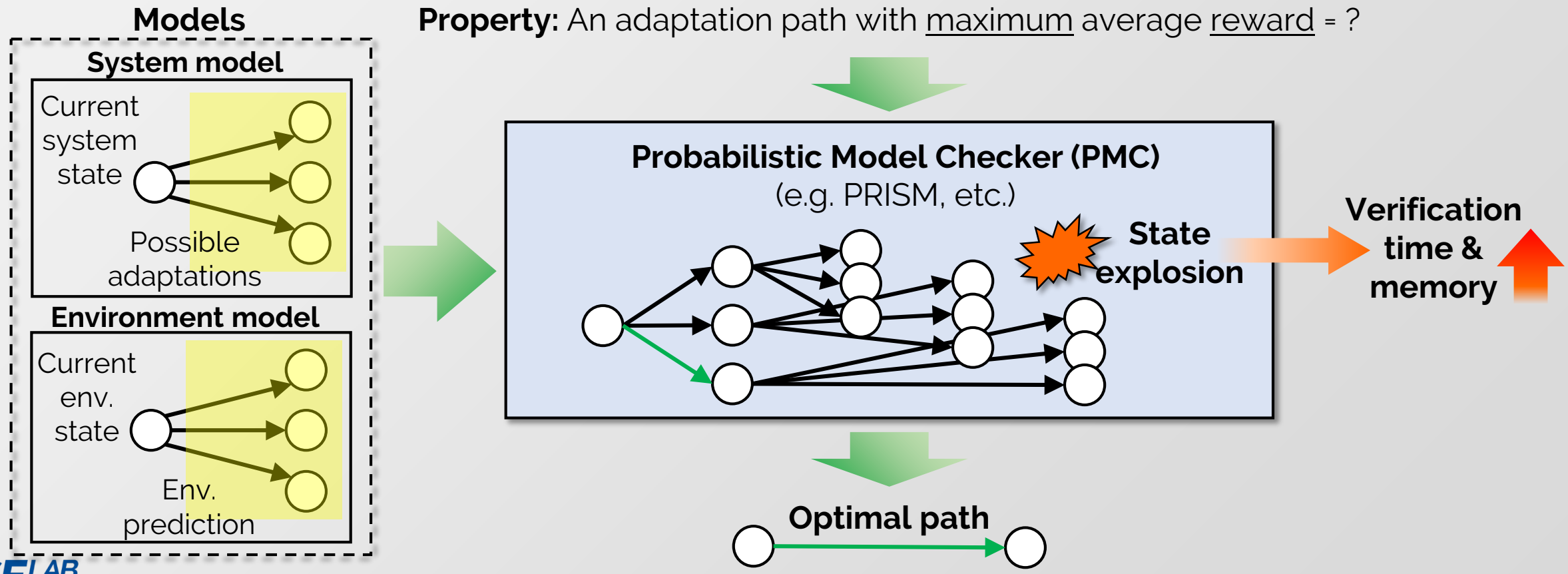
- **Uncertainty of proactive adaptation could be resolved verifying adaptation tactics using Probabilistic Model Checking (PMC)**



Adaptation tactics $control_t$	Probabilistically verified expected results
------→	**10%** satisfaction
⟋	**30%** satisfaction
✓ chosen ⟋	**70%** satisfaction
...	

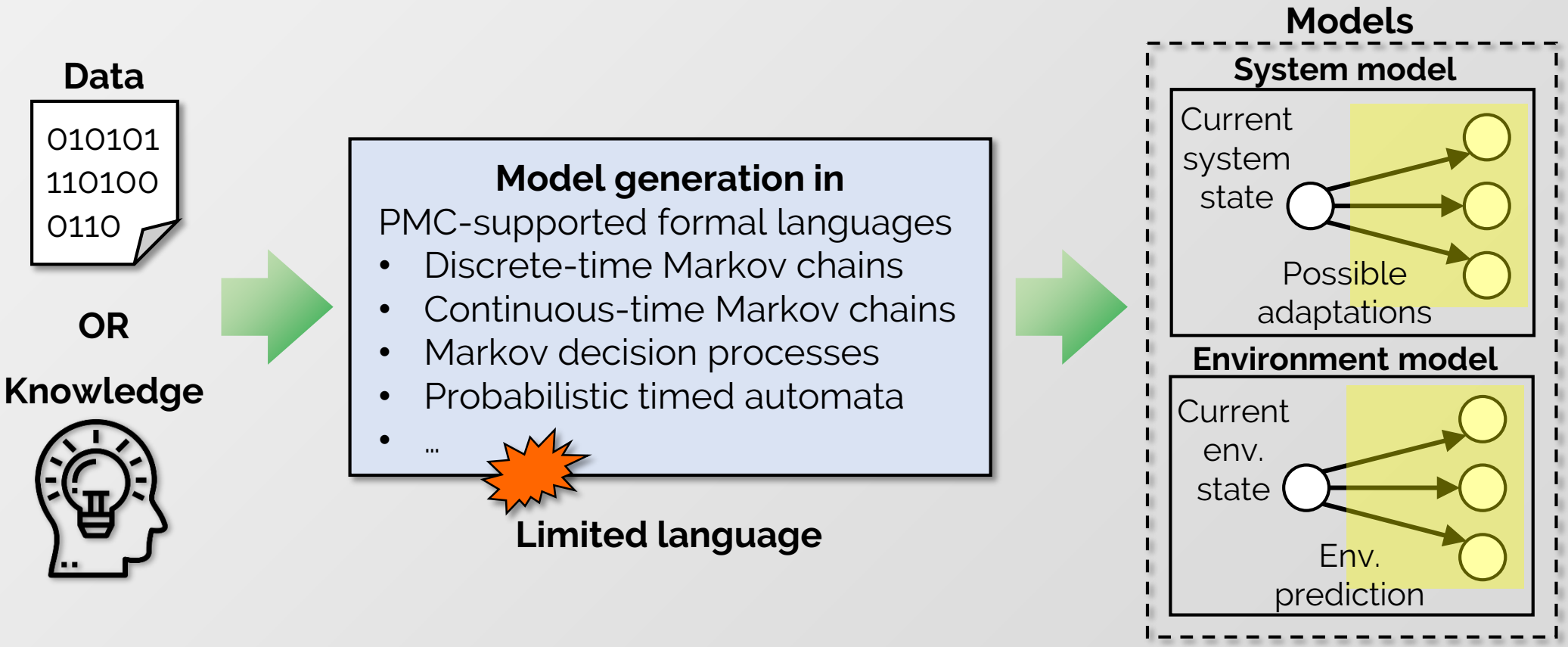
Limitations of PMC-based Proactive Adaptation (1/2)

- **Due to the state explosion problem, it is difficult to apply the PMC-based approach to complex self-adaptive systems.**



Limitations of PMC-based Proactive Adaptation (2/2)

- **Modeling languages supported by probabilistic model checkers must be used for the modeling of the SAS and the environment.**



Motivation & Goal

- **Motivation**
  - PMC-based approach is the main stream of proactive adaptation research, but efficient alternative of that is needed to tackle the limitations of PMC.
    - State-explosion problem of PMC for complex SAS
    - Limited modeling languages supported by specific model checkers
- **Goal**
  - Proposing a general process of Statistical Model Checking (SMC)-based proactive adaptation approach that
    - is more efficient in verification (adaptation decision-making) cost
    - does not limit system and environment specification language.

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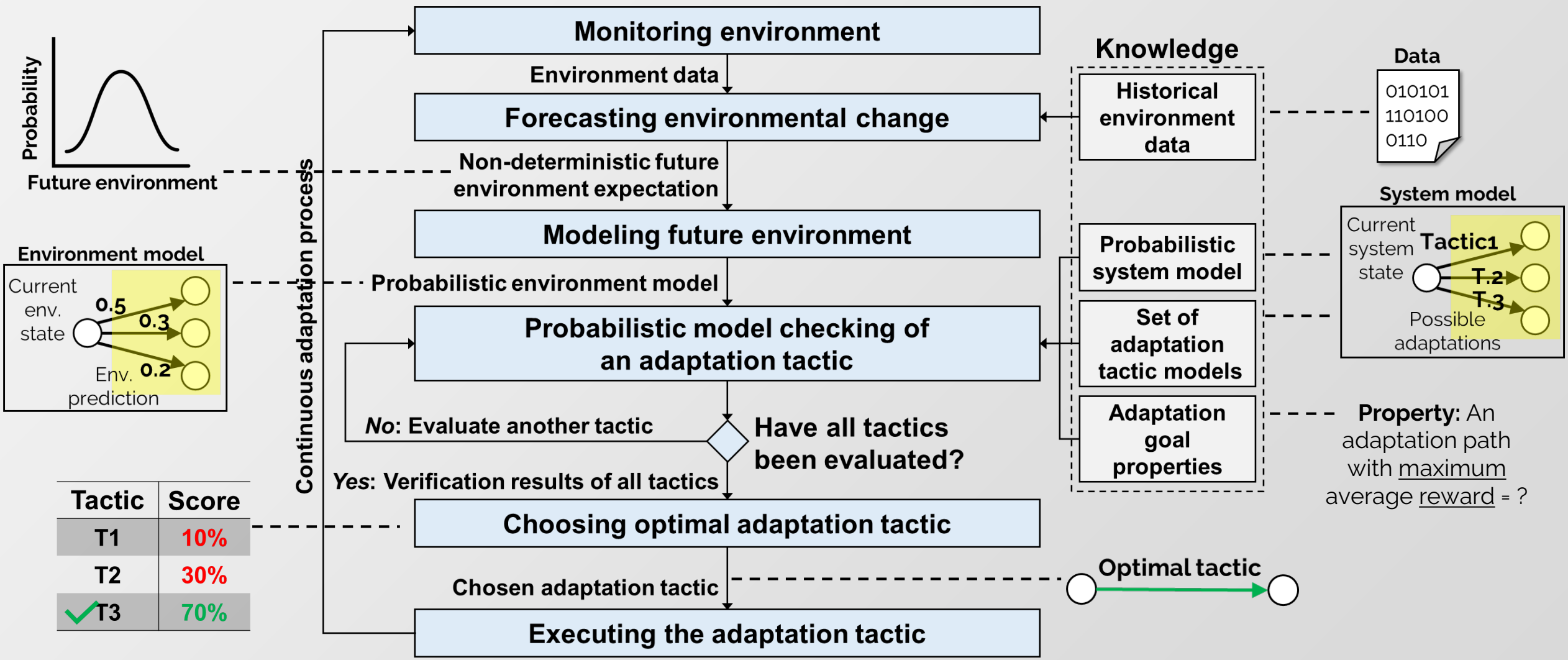
Proactive Adaptation Based on SMC

As Is: PMC-based Proactive Adaptation



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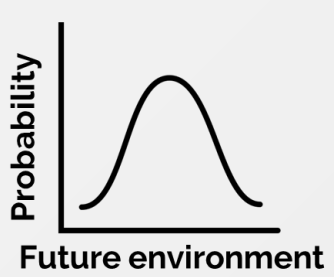
To Be: PASTA Process



$ENV_{t+1}=(e_1,\ldots)$

Run( )

Tactic	Score
T1	10%
T2	30%
✓T3	70%

Continuous adaptation process

1) Monitoring environment

Environment data

2) Forecasting environmental change

Non-deterministic future environment expectation

3) Sampling future environment

A sample of future environment

4) Simulation (execution) of an adaptation tactic

No: Execute new sample

Are there enough samples?

Yes: Set of simulation results

5) Verification (evaluation) of the adaptation tactic

No: Evaluate another tactic

Have all tactics been evaluated?

Yes: Evaluation results of all tactics

6) Choosing optimal adaptation tactic

Chosen adaptation tactic

7) Executing the adaptation tactic

Knowledge

- Historical environment data
- Simulation-executable system model
- Set of adaptation tactics specification
- Adaptation goals specification

Data

010101
110100
0110

score= ***evaluation****(simulResults)*

Difference from PMC-based approach

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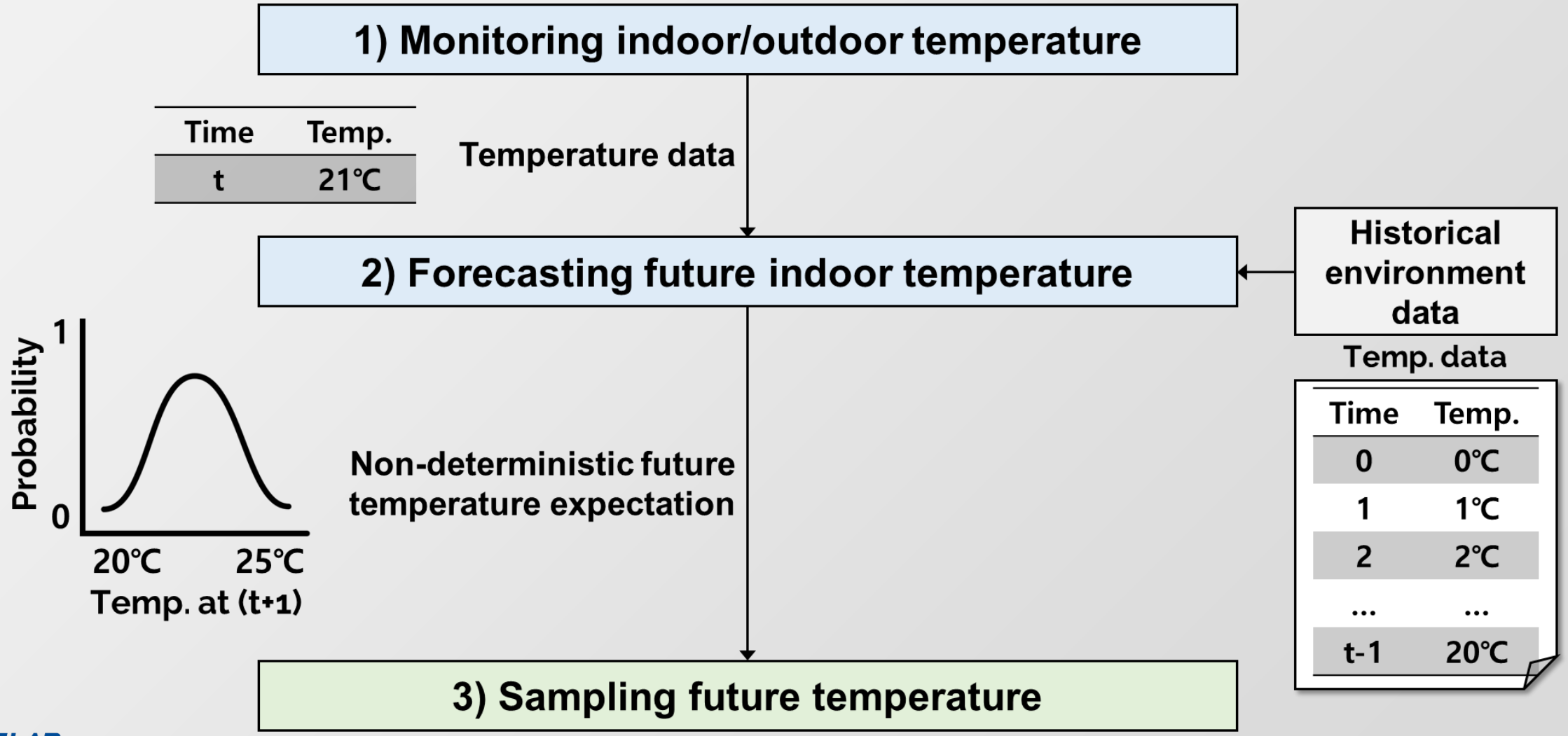
Smart Air Condition Controller with PASTA (1/3)



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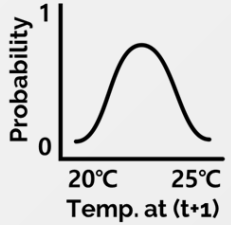
Smart Air Condition Controller with PASTA (2/3)

* Algorithm 1 in the paper



Non-deterministic future temperature expectation

3) Sampling future temperature

$temp_{t+1}$=23℃ Future temp. sample

Log=Run($temp_{t+1}$=23℃ A.C. Sim. Model +1℃)

4) Simulation (execution) of an adaptation tactic

Simulation-executable system model

A.C. Sim. Model

Set of adaptation tactics specification

+1℃ +2℃ +3℃ +x℃

No: Execute new sample

Are there enough samples?

Yes: Set of simulation results

+1℃ 's score=90

5) Verification (evaluation) of the adaptation tactic

Adaptation goals specification

```
evaluation(Logs){
  goalTemp=24 ℃
  return goalTemp-
    expectedTemp
}
```

No: Evaluate another tactic

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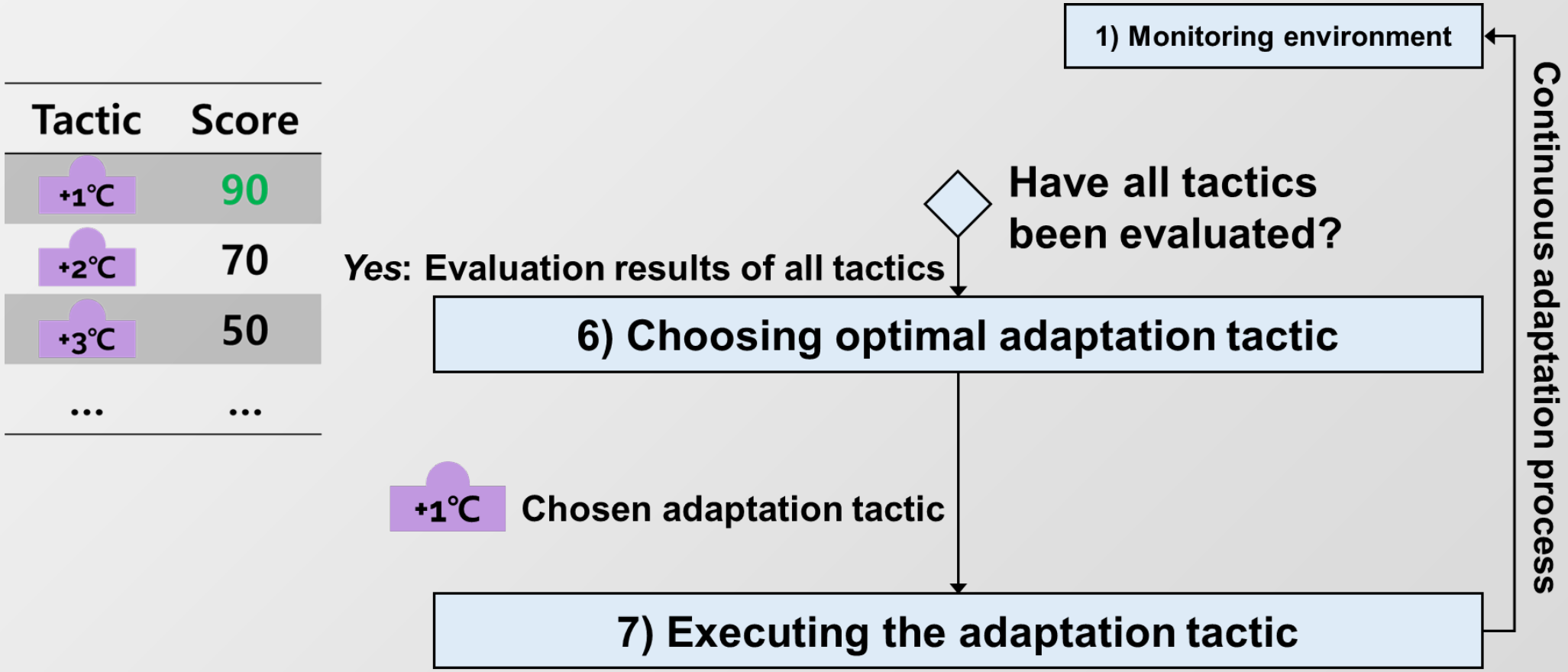
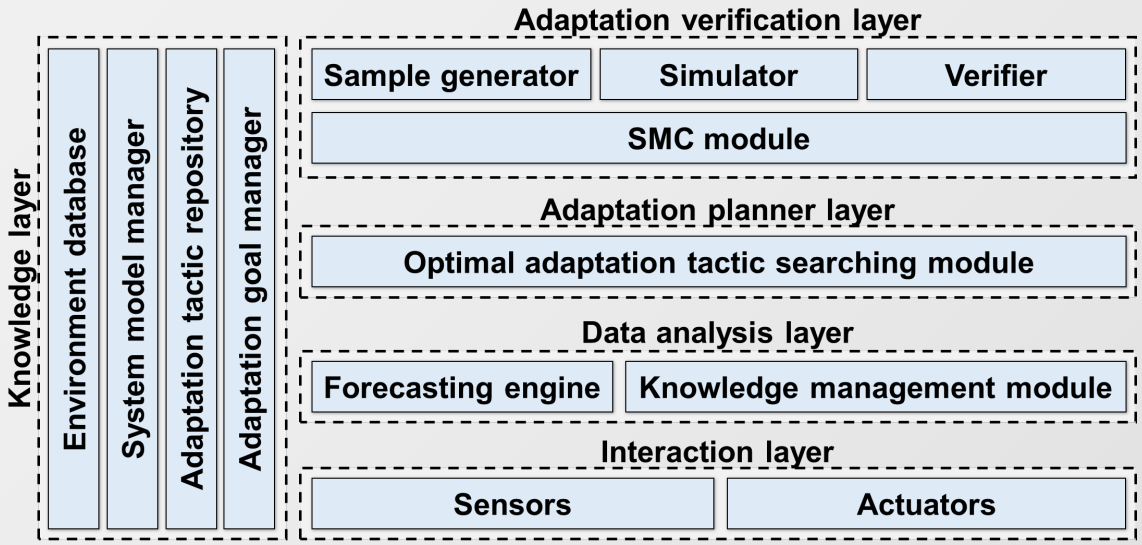
Smart Air Condition Controller with PASTA (3/3)



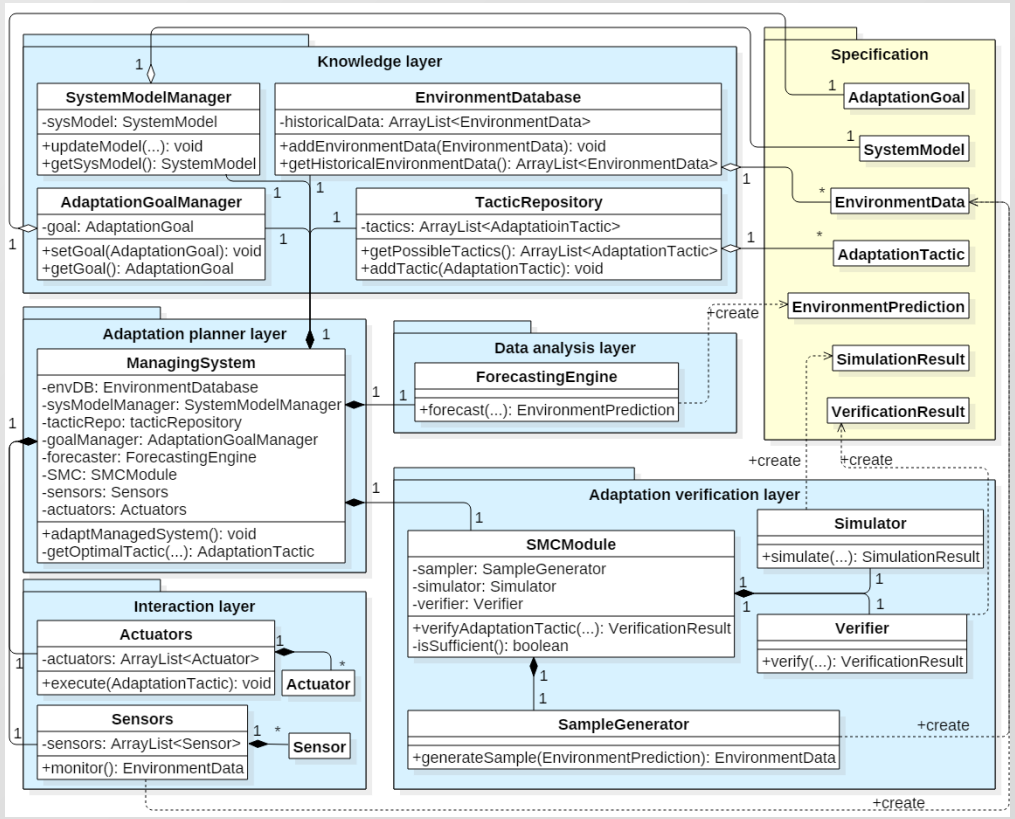
PASTA Implementation

Reference architecture



Open Code skeleton[1]

- Java & Python



[1] https://github.com/yongjunshin/PASTA

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Evaluation

Research Questions

- **RQ1: (Cost efficiency of PASTA)** How fast is PASTA's adaptation planning?
  - **Evaluation**: Verification time to choose an optimal tactic by SMC and PMC

- **RQ2: (Adaptation planning accuracy of PASTA)** How accurately does PASTA search for the optimal adaptation tactic?
  - **Evaluation**: Difference between tactics chosen by SMC (PASTA) and PMC (regarded as optimal)

- **RQ3: (Adaptation performance of PASTA)** How effective is the adaptation goal achievement performance of PASTA?
  - **Evaluation**: adaptation goal achievement

Evaluation Setup

Evaluation target

- PASTA
  - Discrete time simulation in Java
  - Simple Monte Carlo Simulation SMC algorithm
- PMC-based approach[1]
  - Modeling in MDP
  - Verification using PRISM

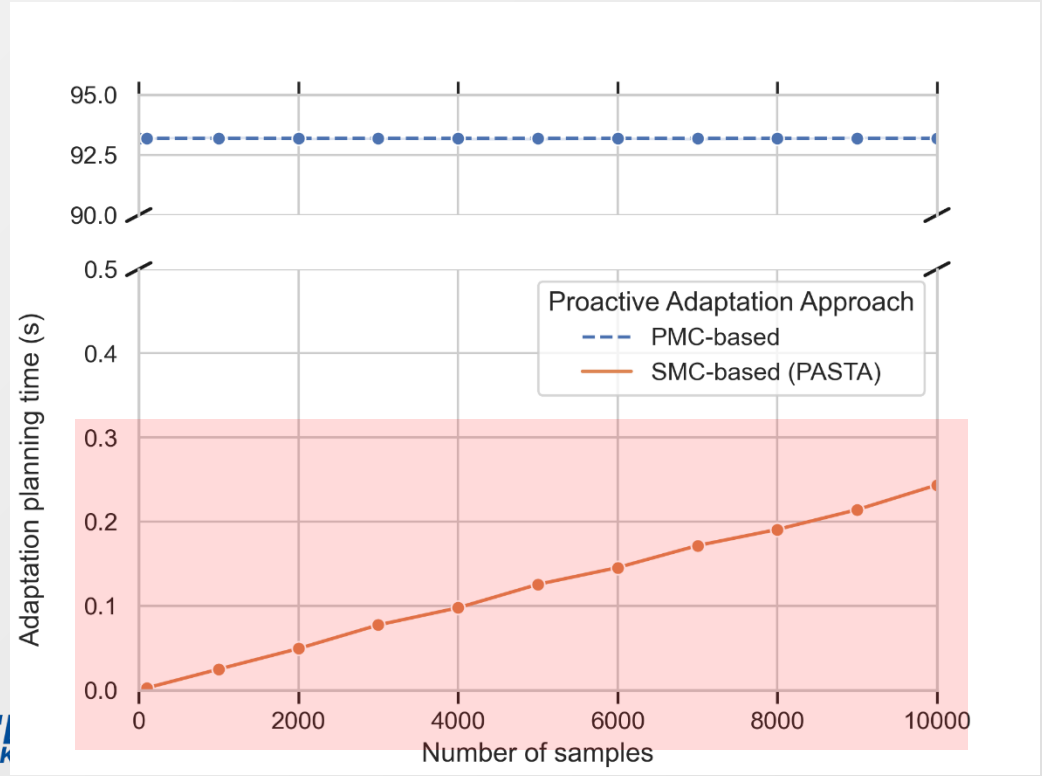
Evaluation cases

- Air condition controller
  - Adapting air conditioner operation to achieve desired indoor temperature/humidity
- Traffic signal controller
  - Adapting traffic signal pattern to minimize waiting times in the intersection

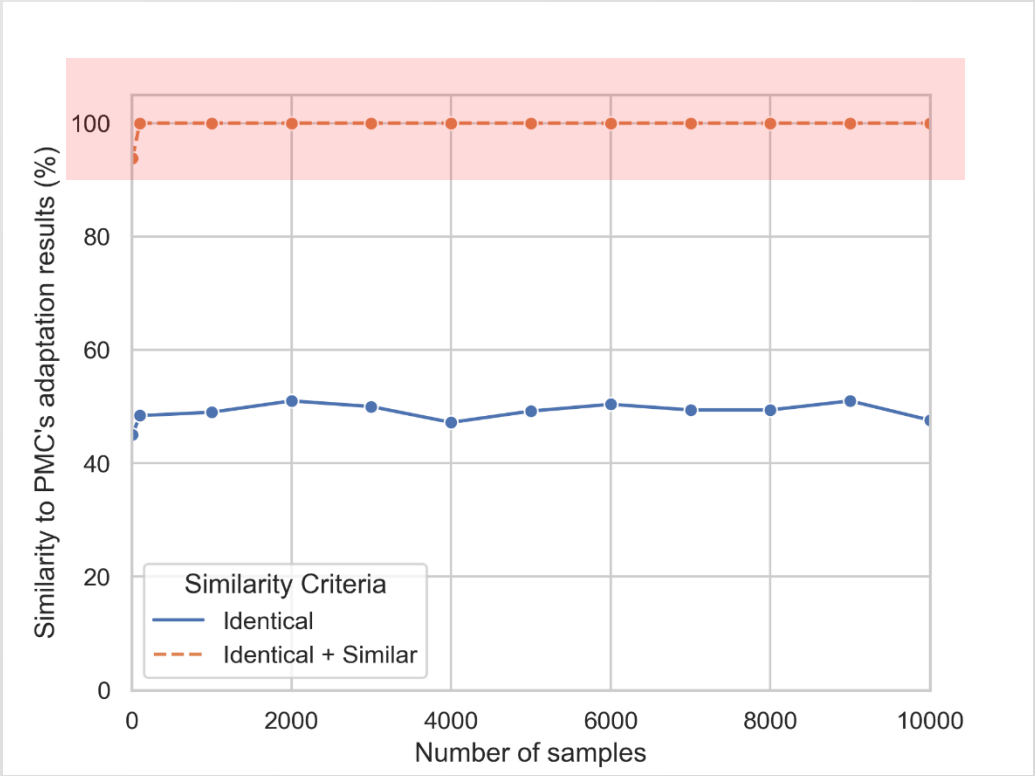
[1] Moreno, Gabriel A., et al. "Proactive self-adaptation under uncertainty: a probabilistic model checking approach." *Proceedings of the 2015 10th joint meeting on foundations of software engineering*. 2015.

RQ1 & 2: Cost efficiency & Adaptation Accuracy

- **Adaptation planning time comparison**
  - $time\ for\ step\ 3{\sim}6\ (sampling{\sim}choosing\ optimal)$



- **Adaptation tactic choice comparison**
  - Identical: $PMC's\ result\ =\ SMC's\ result$
  - Similar: $PMC's\ result = SMC's\ result + e$
    - $e = [-0.1℃, +0.1℃]$ (in temp. control)



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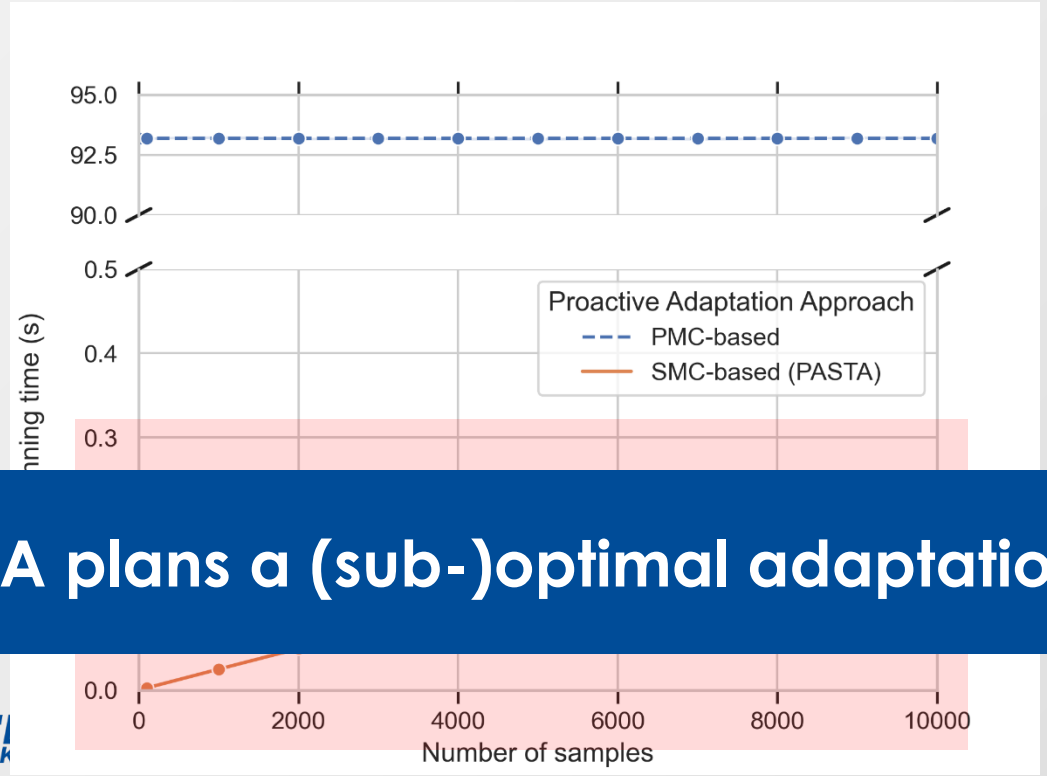

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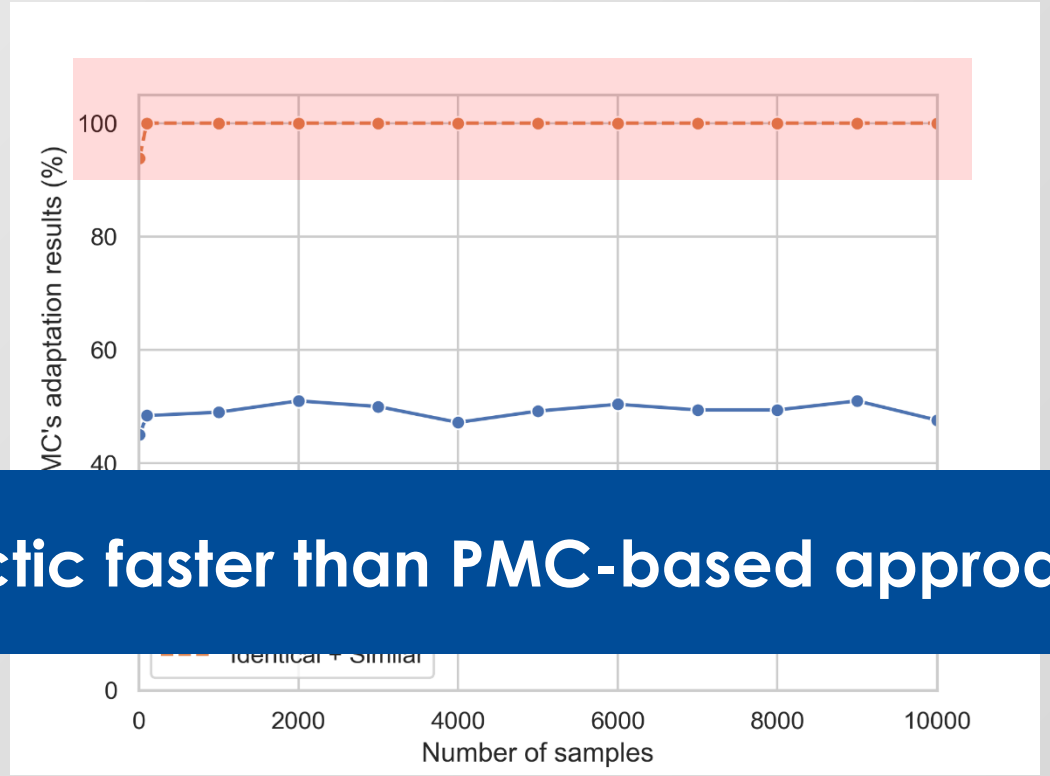
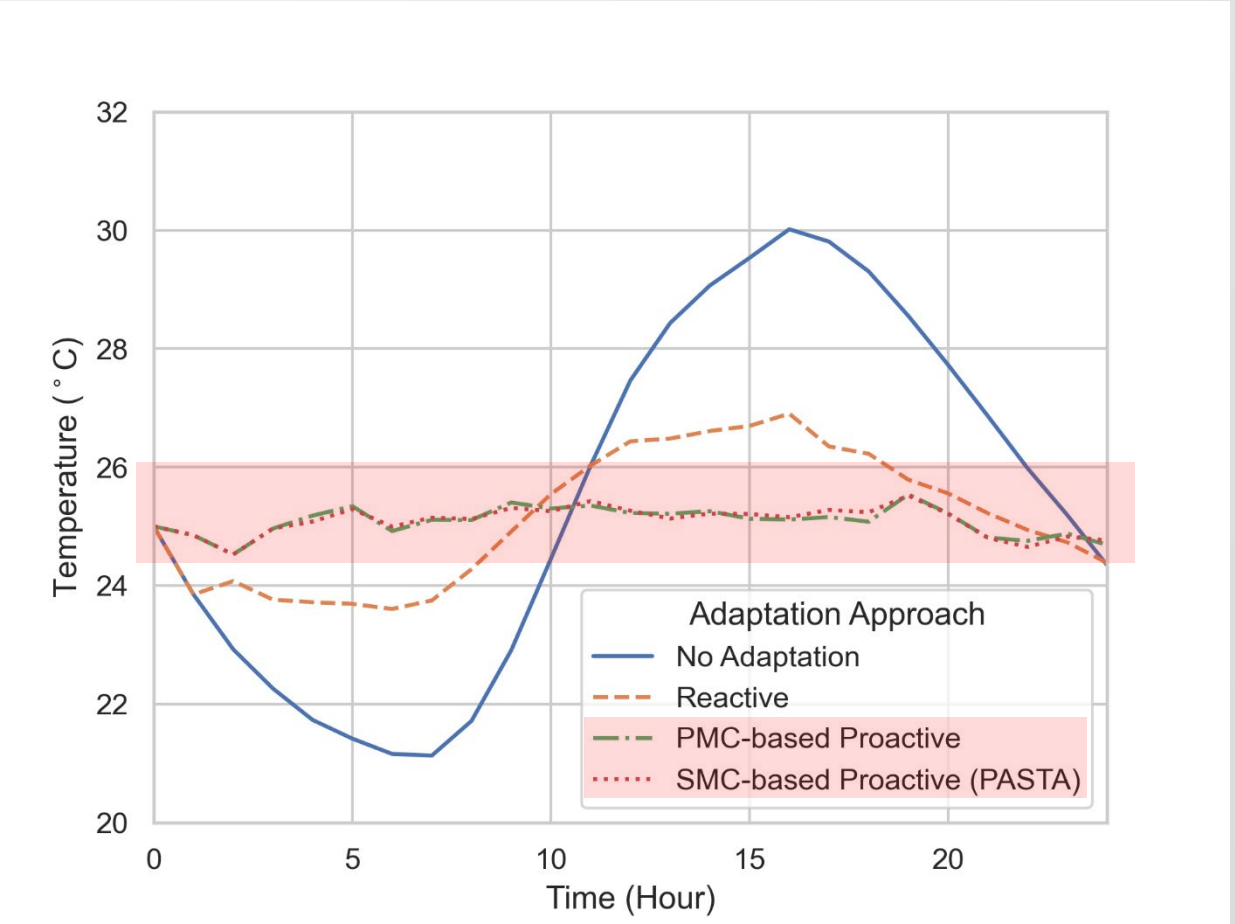


PASTA plans a (sub-)optimal adaptation tactic faster than PMC-based approach.

RQ3: Adaptation Performance of PASTA

- **Goal achievement (domain-specific) comparison**
  - User's desired temperature is 25℃ in the below graph.



RQ3: Adaptation Performance of PASTA

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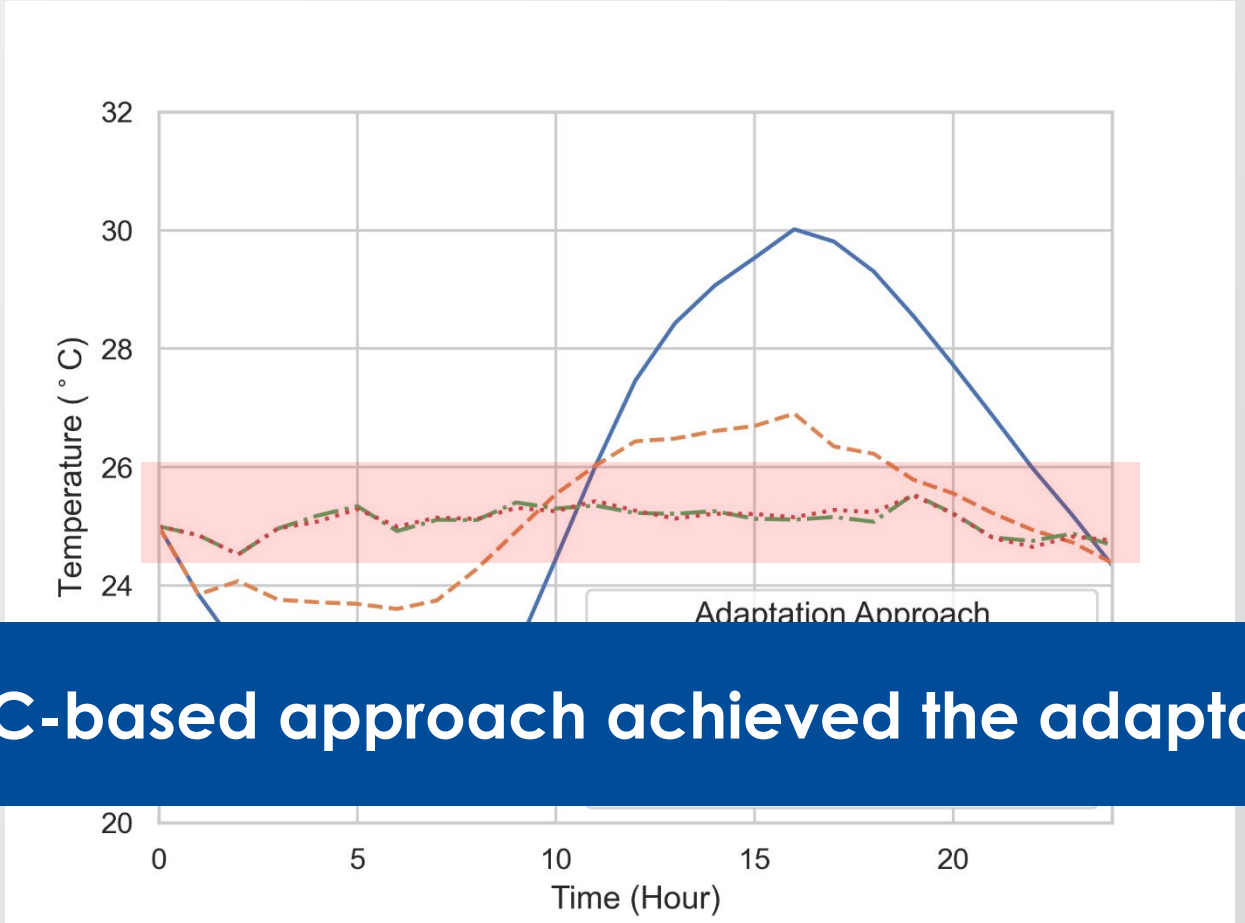

Both PMC- and SMC-based approach achieved the adaptation goal similarly.

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Conclusion

Summary

- **PASTA was proposed as an cost-efficient alternative to PMC-based proactive adaptation approaches.**

	PMC-based approach	SMC-based approach (PASTA)
Adaptation cost	Forecasting time	Forecasting time
	Modeling time (***relatively high***)	Sampling time (***relatively low***)
	Probabilistic verification time (***relatively high***)	Statistical verification (simulation + evaluation) time (***relatively low***)
Adaptation accuracy	Theoretically correct adaptation based on the given models (***high***)	Statistically good adaptation based in the limited confidence (***relatively low***)
System specification	Modeling languages supported by model checkers must be used.	If the model can be simulated, it is not limited to a particular language.
Proper application	Safety-critical system	Real-time system

Thank You.

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