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Global Mixed-Criticality Scheduling on Multiprocessors

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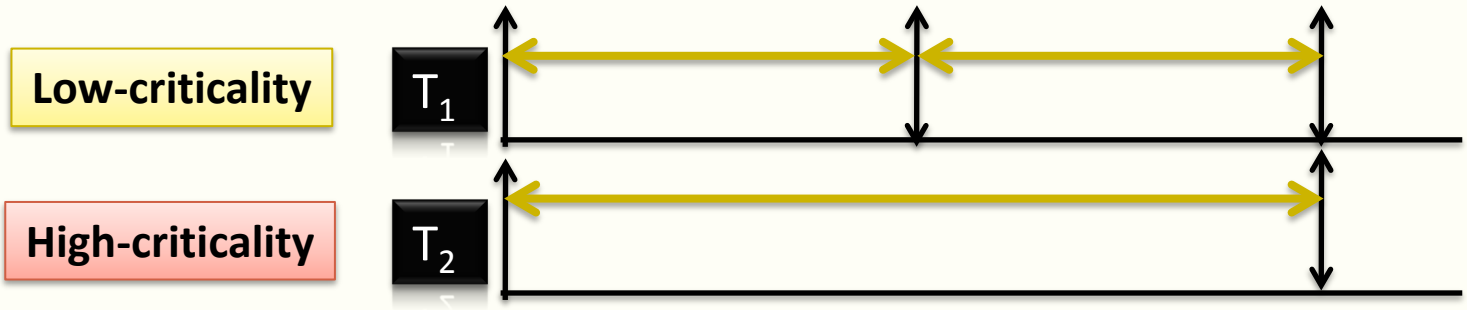
Introduction

- **Scheduling mixed-criticality task systems**
  - Sporadically releasing
  - Identical multiprocessors
  - Global scheduling
  - Two criticality levels
  - Implicit deadlines

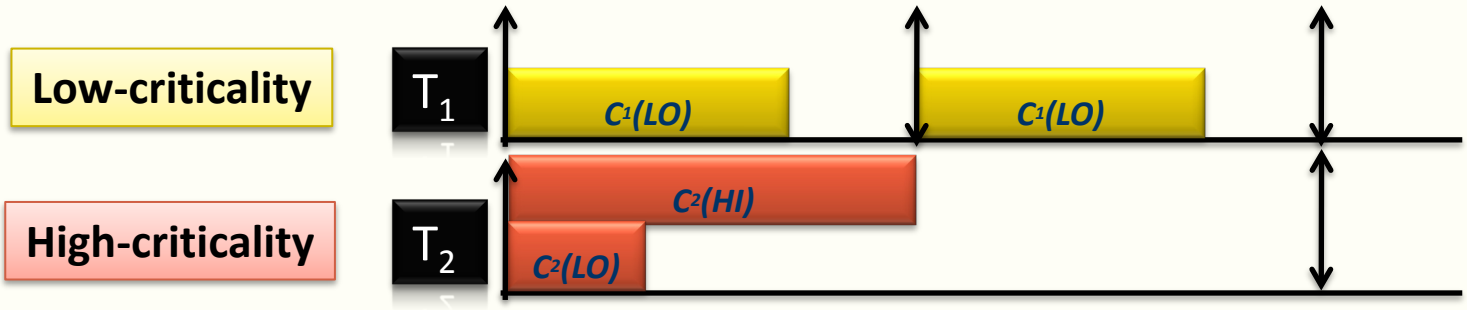
Model

- **Mixed-criticality sporadic task model**
  - **Period: P_i**
    - $P_1=3$, $P_2=6$



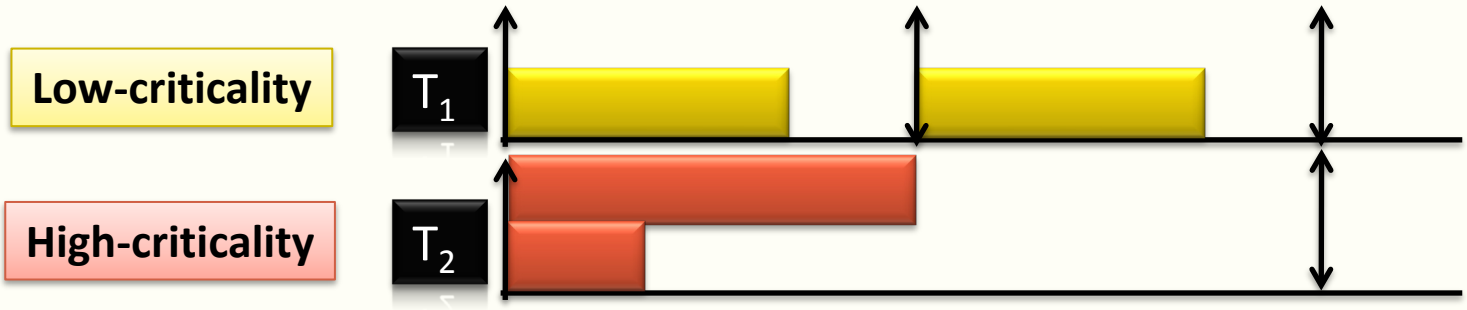
Model

- **Mixed-criticality sporadic task model**
  - **Period: P_i**
    - $P_1=3$, $P_2=6$
  - **WCET: $C_i(LO)$, $C_i(HI)$**
    - For T_1: $C_1(LO)=2$
    - For T_2: $C_2(LO)=1$, $C_2(HI)=3$



Model

- **Mixed-criticality sporadic task model**
  - If every job uses up to **low-criticality WCET**, all **deadlines** must be met



Model

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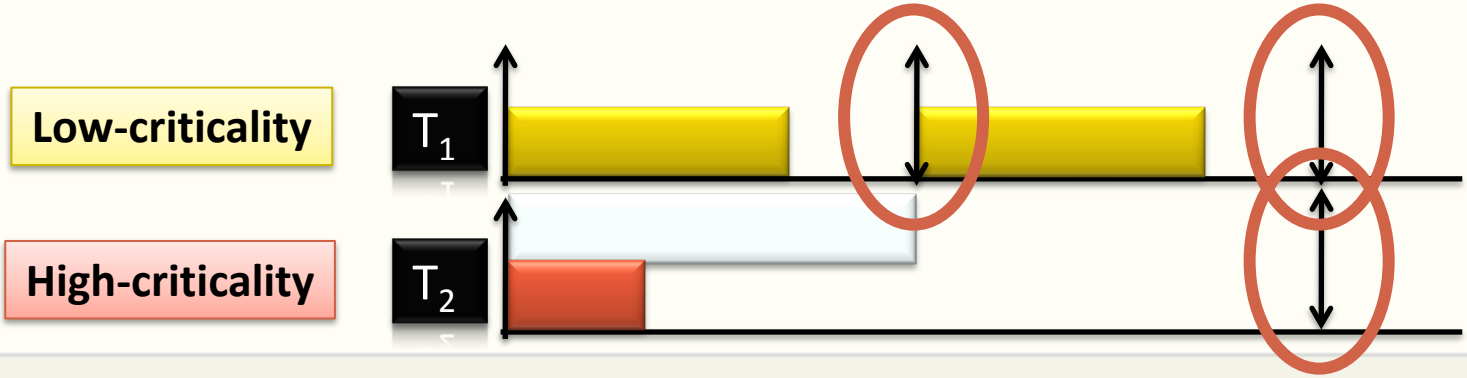
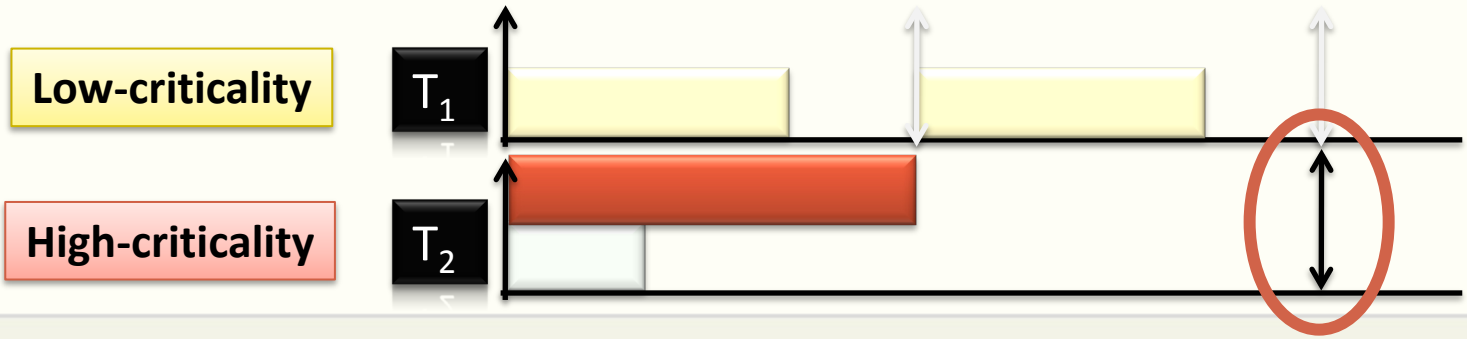


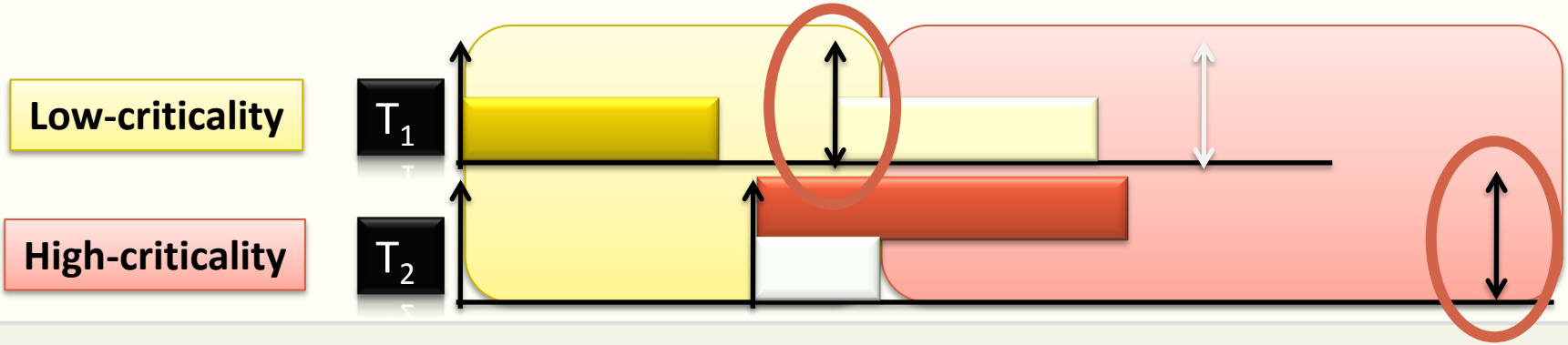
Model

- **Mixed-criticality sporadic task model**
  - If every job uses up to **low-criticality WCET**, all **deadlines** must be met
  - If some job uses **more than low-criticality WCET**, only **high-criticality deadlines** must be met



Model

- **Mixed-criticality sporadic task model**
  - If every job uses up to low-criticality WCET, all deadlines must be met
  - If some job uses more than low-criticality WCET, only high-criticality deadlines must be met
  - Execution times are only known at run-time



Prior Work

- **EDF-VD**
  - ***Mixed-Criticality Scheduling of Sporadic Task Systems*, Baruah et al., ESA 2011**
    - Earliest Deadline First with Virtual Deadlines
    - An EDF-based **mixed-criticality** scheduling algorithm for **implicit-deadline** systems on **uniprocessor**
    - Speed-up factor is at most $(\sqrt{5}+1)/2 \approx 1.618$

Prior Work

- **fpEDF**
  - ***Optimal Utilization Bounds for the Fixed-Priority Scheduling of Periodic Task Systems on Identical Multiprocessors,* Baruah, TC 2004**
    - Fixed Priority Earliest Deadline First
      - Fixed-job-priority scheduling algorithm
    - An EDF-based **global** scheduling algorithm for **implicit-deadline** systems on **multiprocessors**
    - Speed-up factor is at most 2

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Contribution

A global preemptive algorithm for scheduling mixed-criticality implicit-deadline systems on identical multiprocessors

- **Proving that speed-up factor is at most** $\sqrt{5}+1 \approx 3.236$
- **Experiments to show effectiveness**

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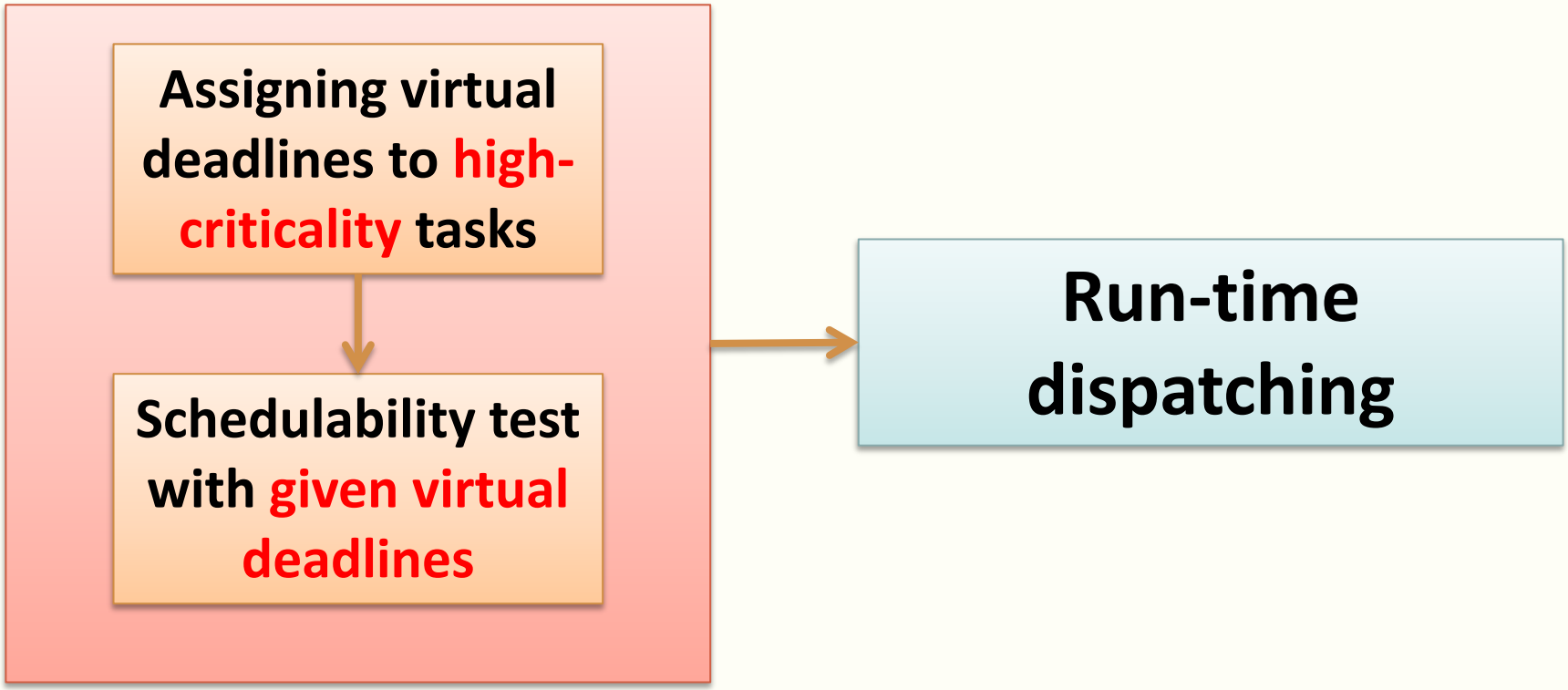
Scheduling Algorithm

Offline pre-processing step → **Run-time dispatching**

Scheduling Algorithm



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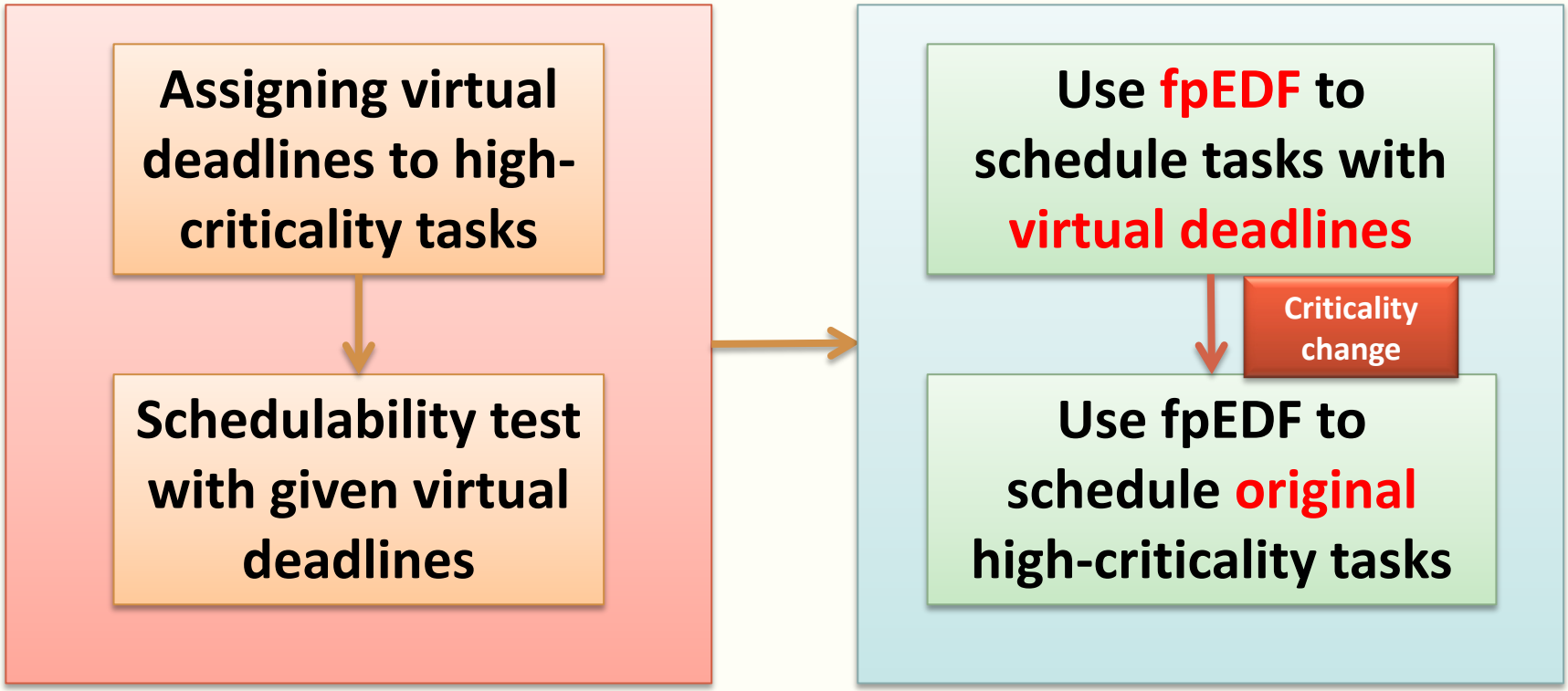

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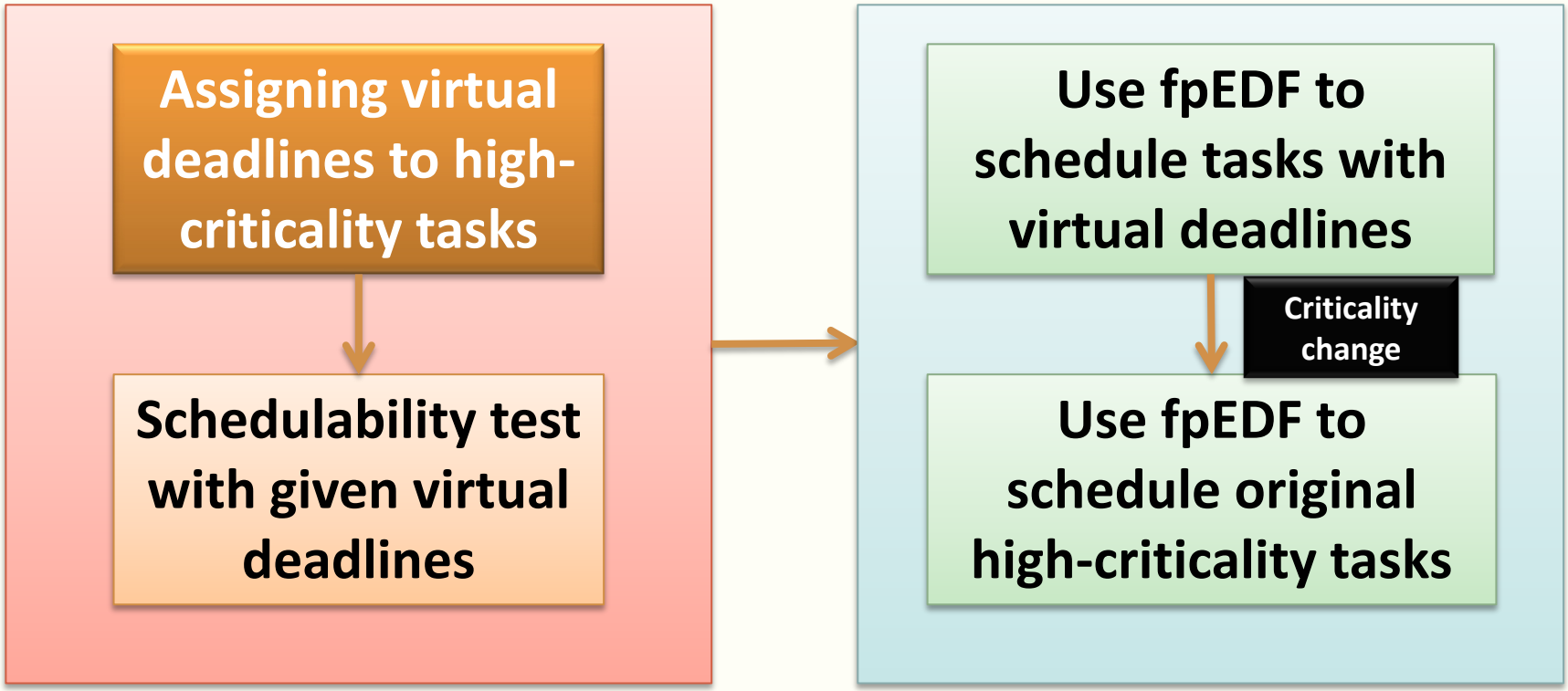
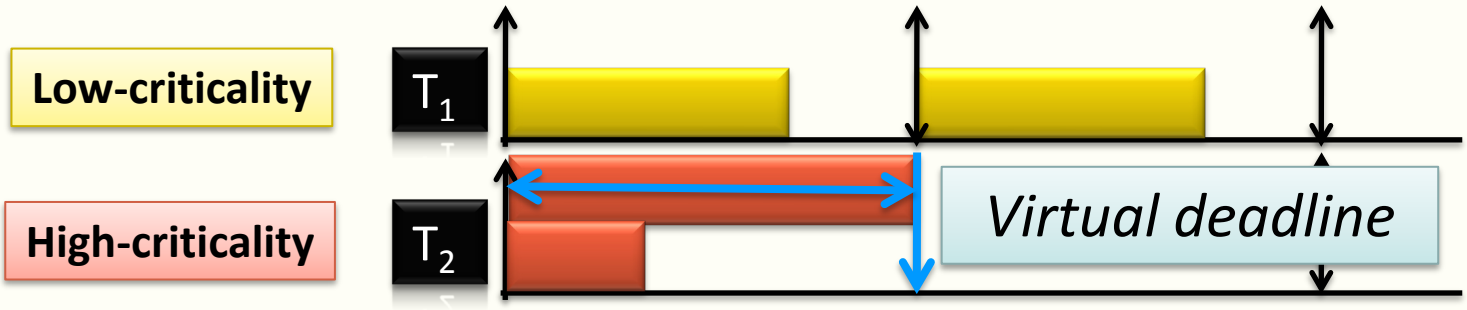


Scheduling Algorithm

- **Assigning virtual deadlines to high-criticality tasks**
  - **Virtual deadlines are assigned proportionally to original deadlines with factor x ($0<x<1$)**
    - **In the example, assume that $x=1/2$, then the virtual deadline is $xP_2=1/2*6=3$**



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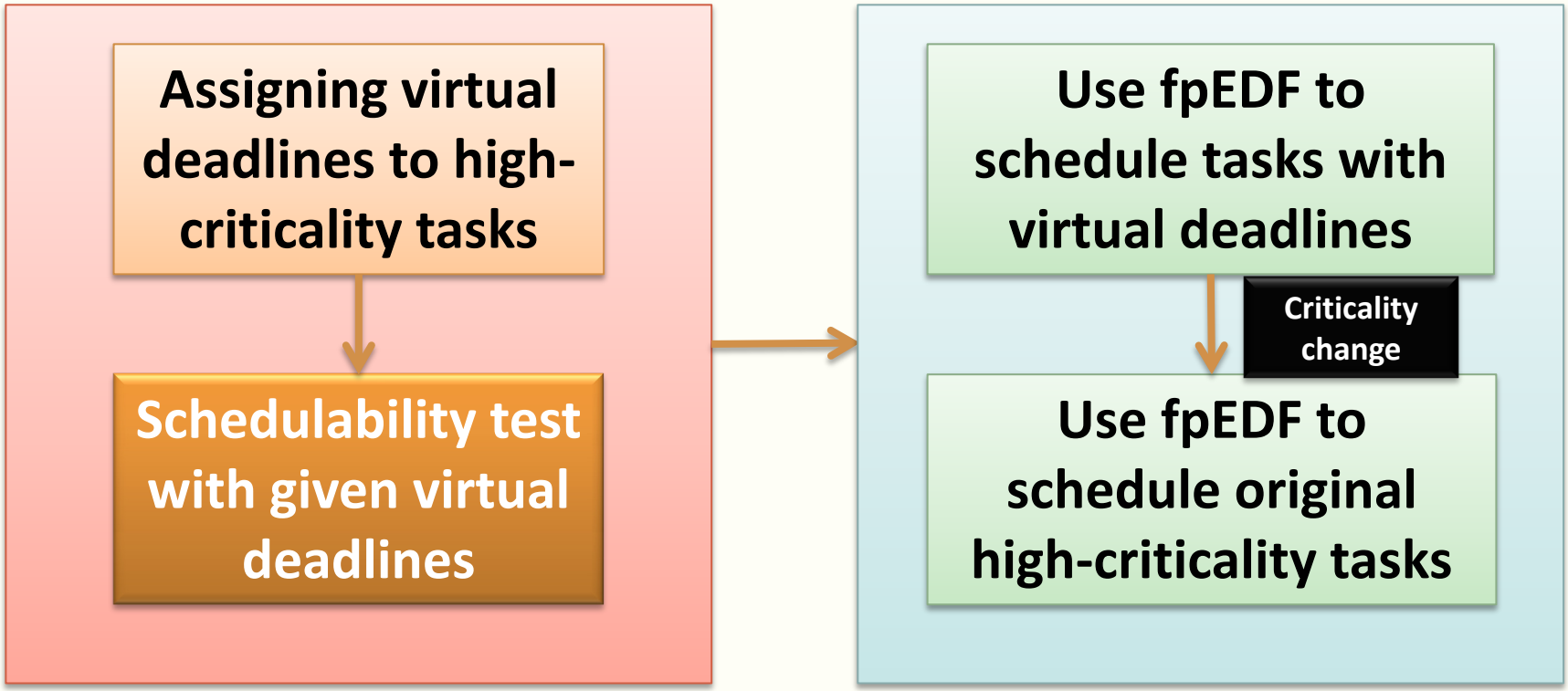
Scheduling Algorithm



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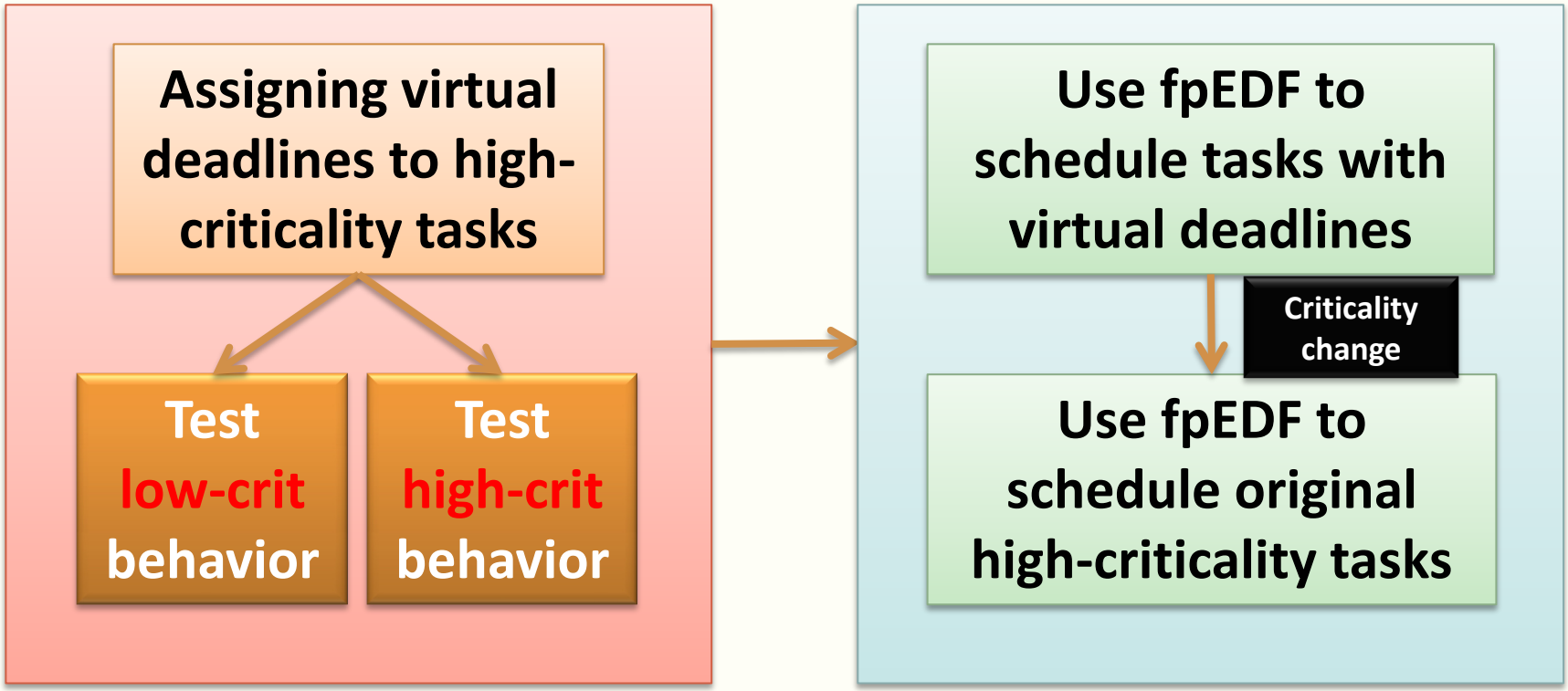
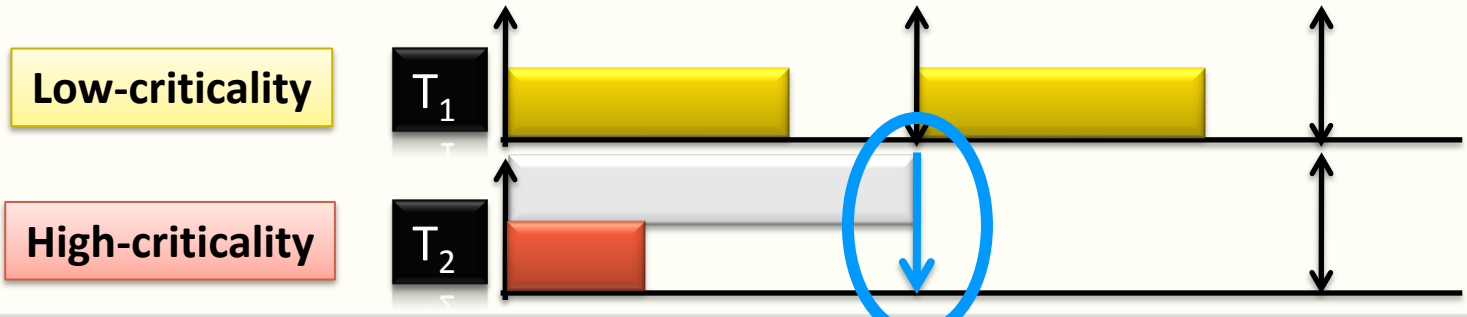
Scheduling Algorithm



Scheduling Algorithm

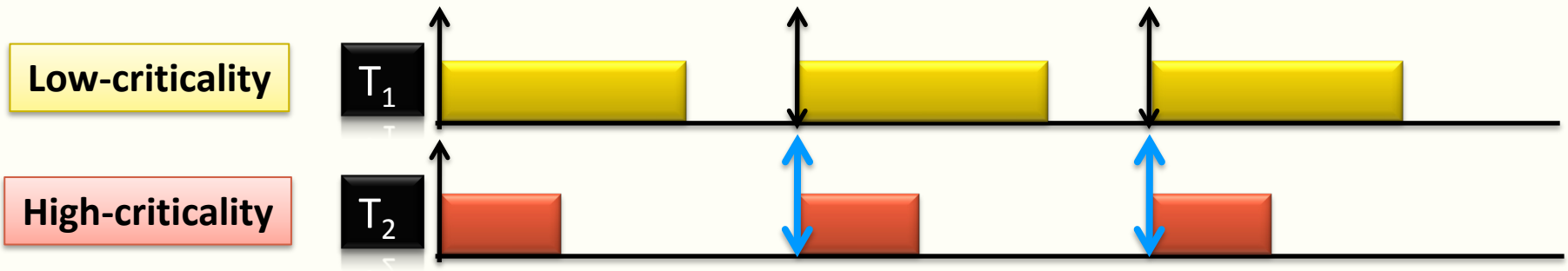
- **Schedulability test with given virtual deadlines**
  - Low-criticality **sufficient schedulability condition**
    - at low-criticality, the virtual system with **virtual periods** is schedulable

Assuming that in low-criticality behavior, all high-criticality tasks must be completed by their virtual deadlines



Scheduling Algorithm

- **Schedulability test with given virtual deadlines**
  - **Low-criticality sufficient schedulability condition**
    - at low-criticality, the virtual system with **virtual periods** is schedulable
    - The virtual periods of high-crit tasks will be xP_i
    - Test the virtual system with **fpEDF's schedulability condition**



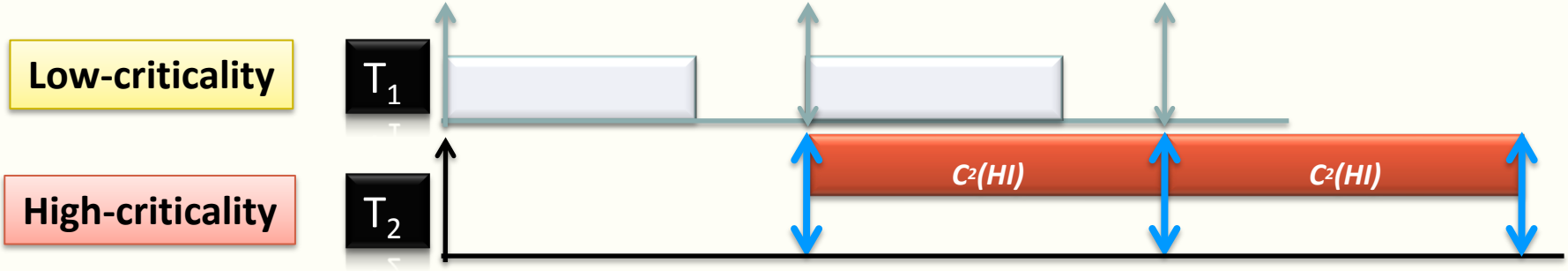
Scheduling Algorithm

- **Schedulability test with given virtual deadlines**
  - **High-criticality sufficient schedulability condition**
    - at high-criticality, the virtual system with **remaining periods** and **high-crit WCETs** is schedulable

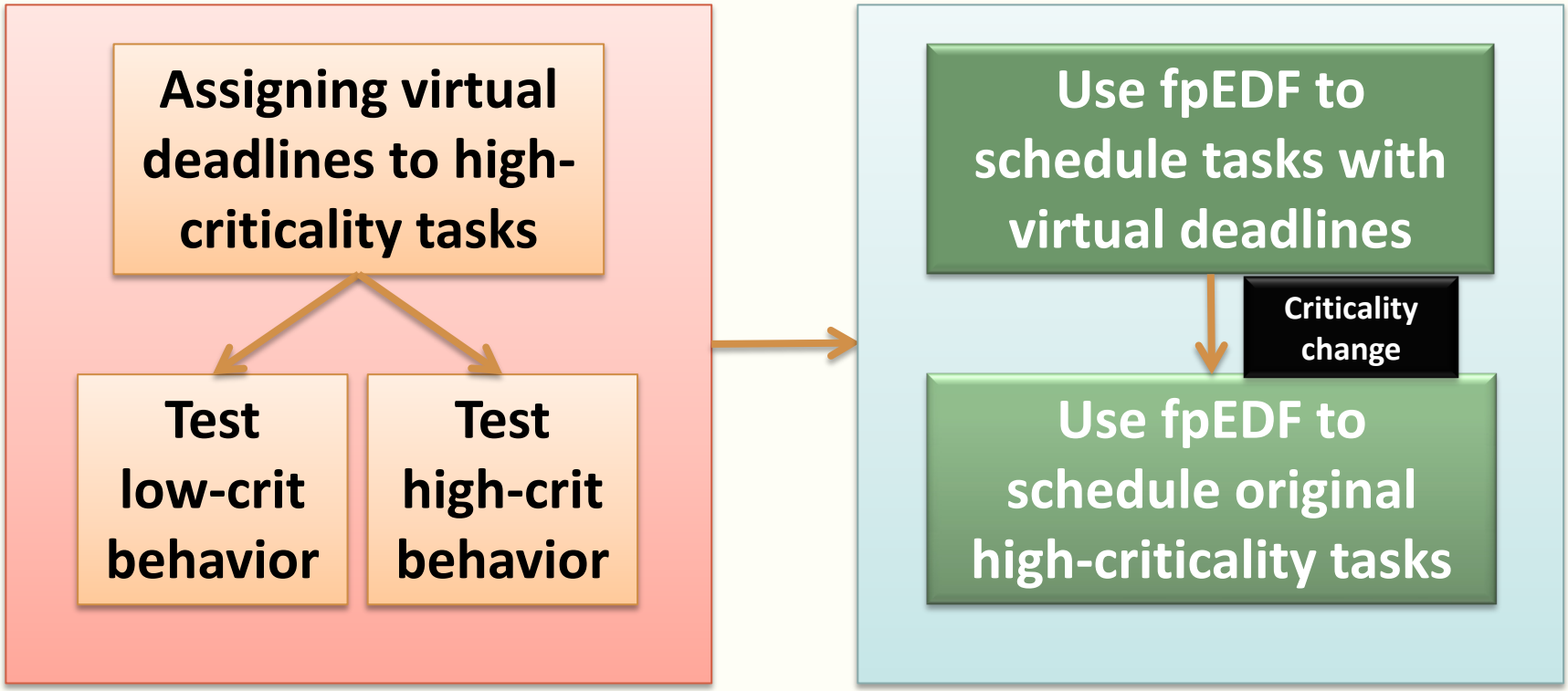
Only high-crit demand is left after criticality change

Scheduling Algorithm

- **Schedulability test with given virtual deadlines**
  - **High-criticality sufficient schedulability condition**
    - at high-criticality, the virtual system with **remaining periods** and **high-crit WCETs** is schedulable
    - The virtual periods and virtual WCET of high-crit tasks will be $(1-x)P_i$ and $C_i(HI)$
    - Test the virtual system with **fpEDF's schedulability condition**

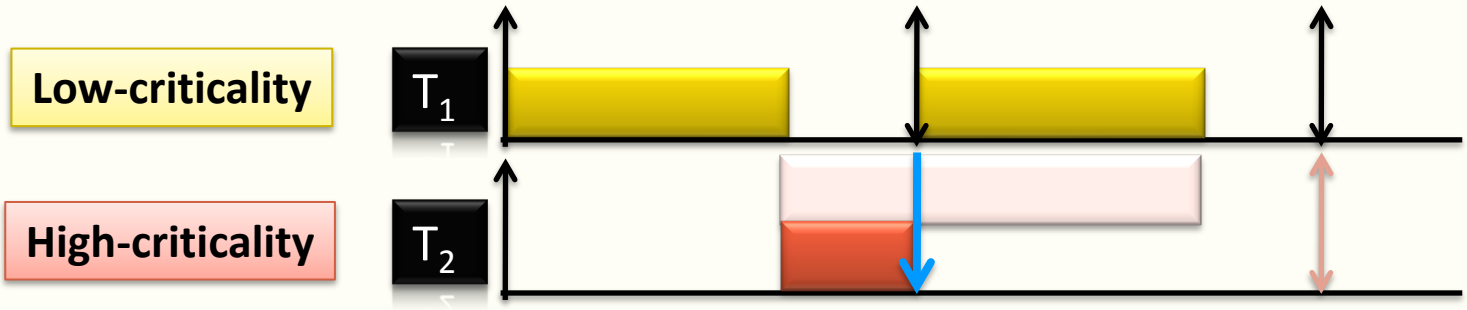


Scheduling Algorithm



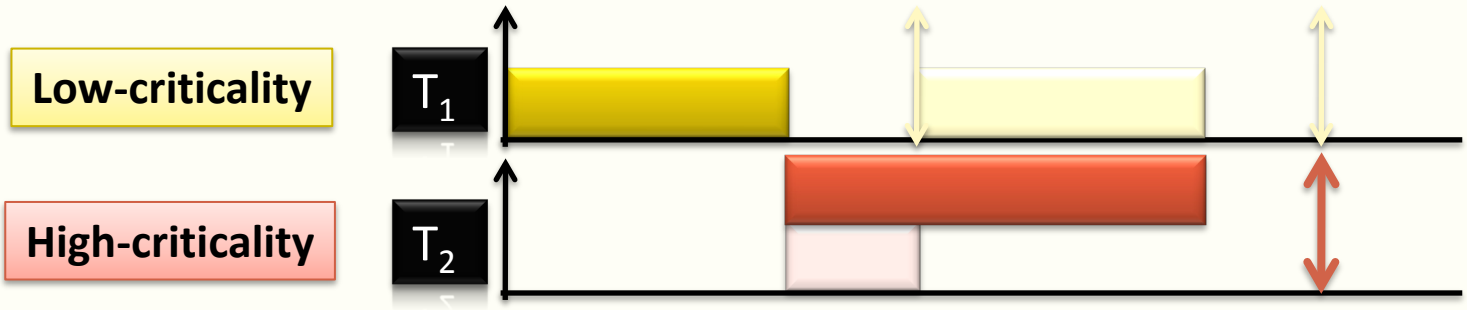
Scheduling Algorithm

- **Run-time dispatching**
  - Use **fpEDF** to schedule tasks with **virtual deadlines**



Scheduling Algorithm

- **Run-time dispatching**
  - Use fpEDF to schedule tasks with virtual deadlines
  - If high-crit behavior detected, drop low-crit tasks and use fpEDF to schedule high-crit tasks with original deadlines



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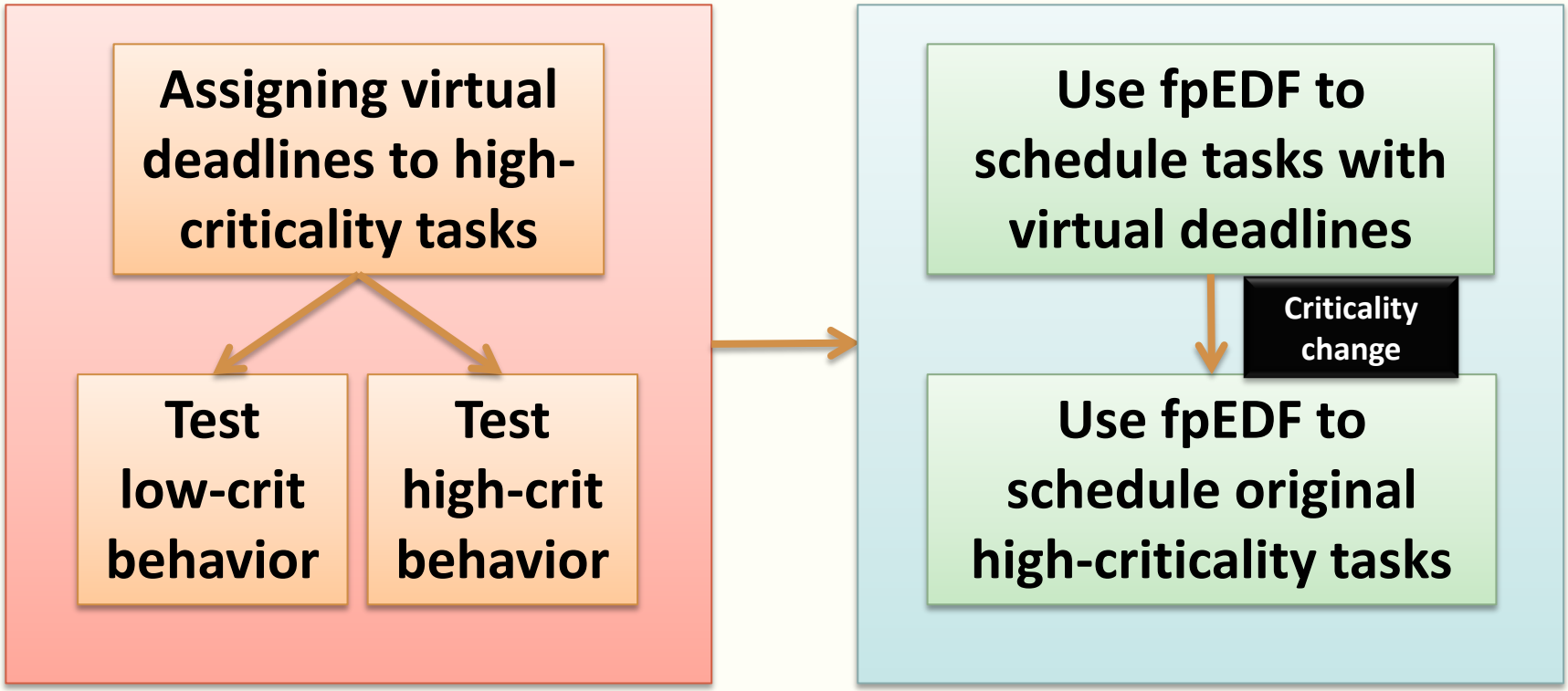
Scheduling Algorithm



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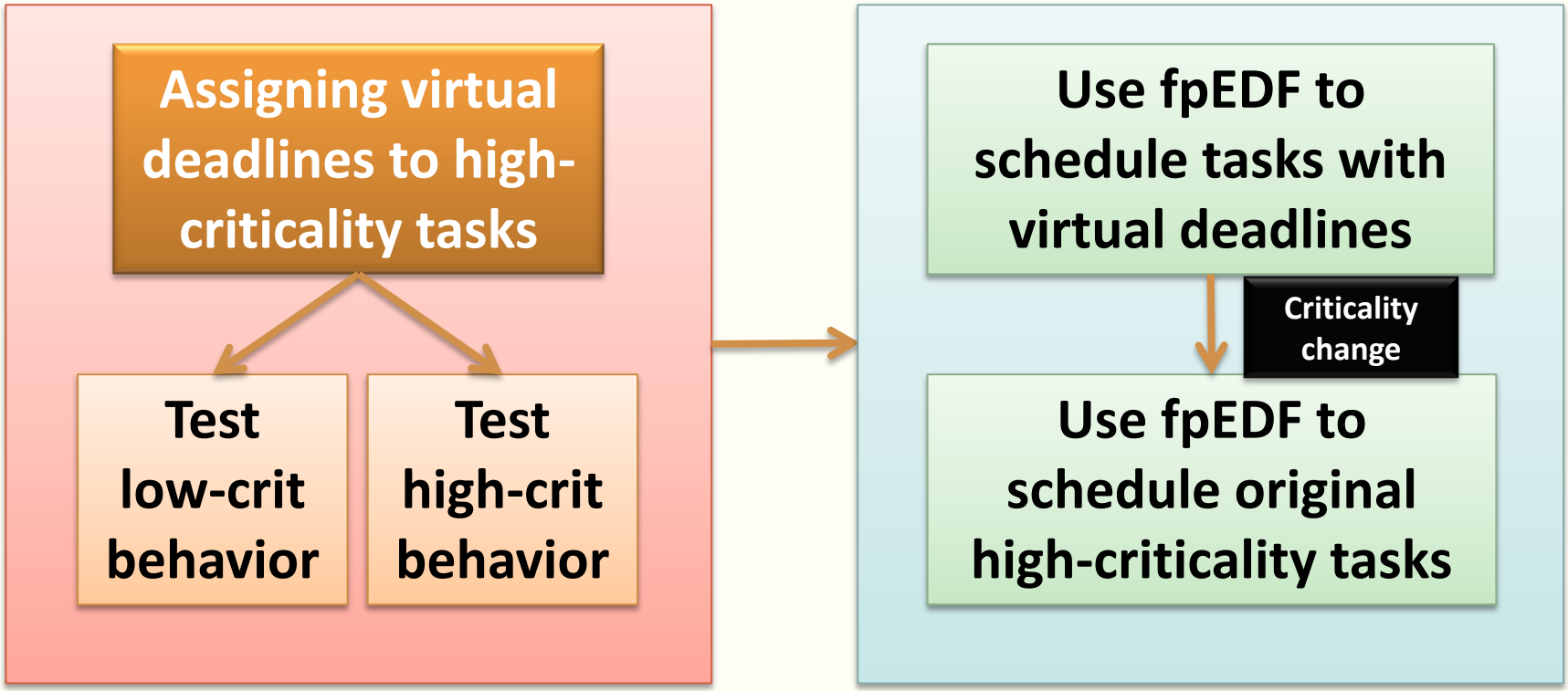

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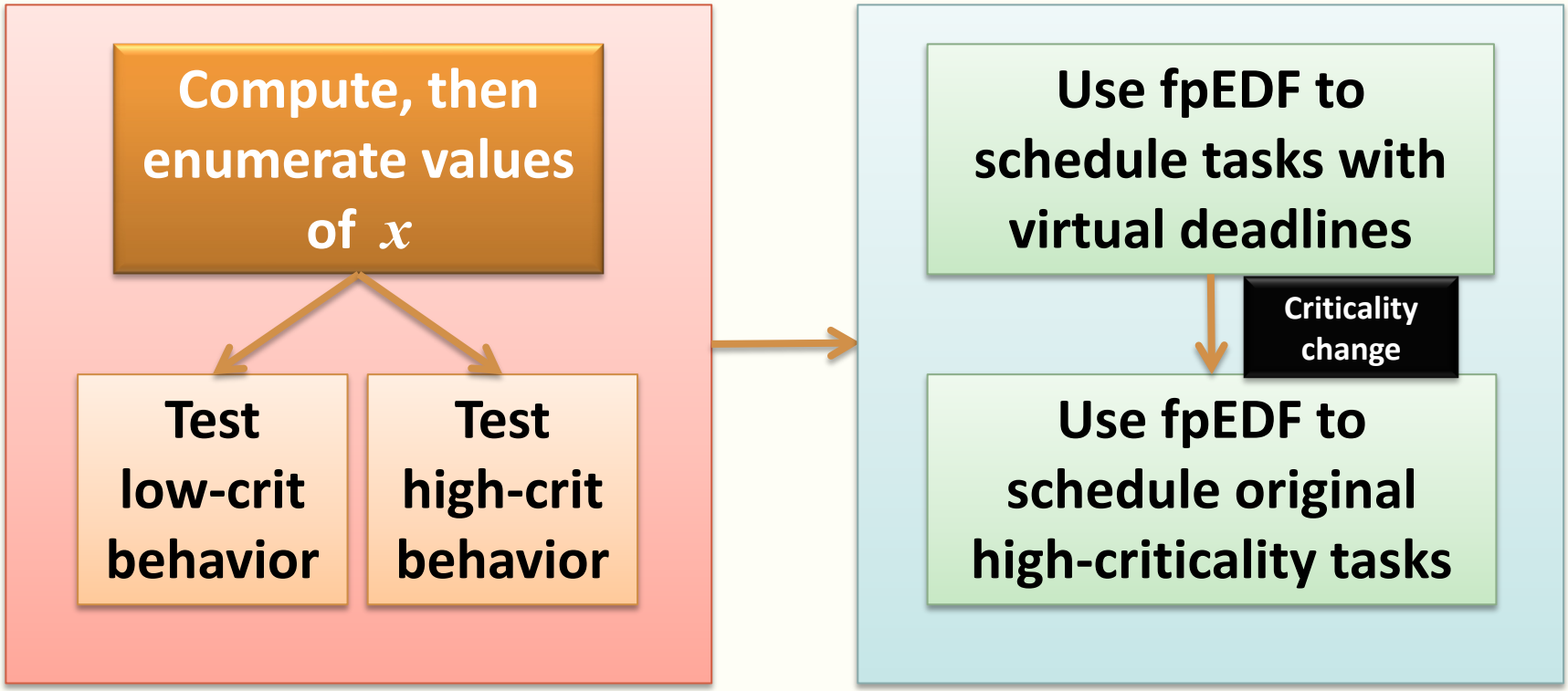
Scheduling Algorithm

- **The selection of x**
  - **Computation from theoretical analysis**
    - *Fig. 2* **and** *Theorem 3* **in the paper**
    - **Does not always generate a proper x**
    - **Guarantees the speed-up factor**
  - **Enumeration as a pragmatic improvement**
    - **The possible values of x are finite**
    - **If none of them passes the test, report unschedulable**

Scheduling Algorithm



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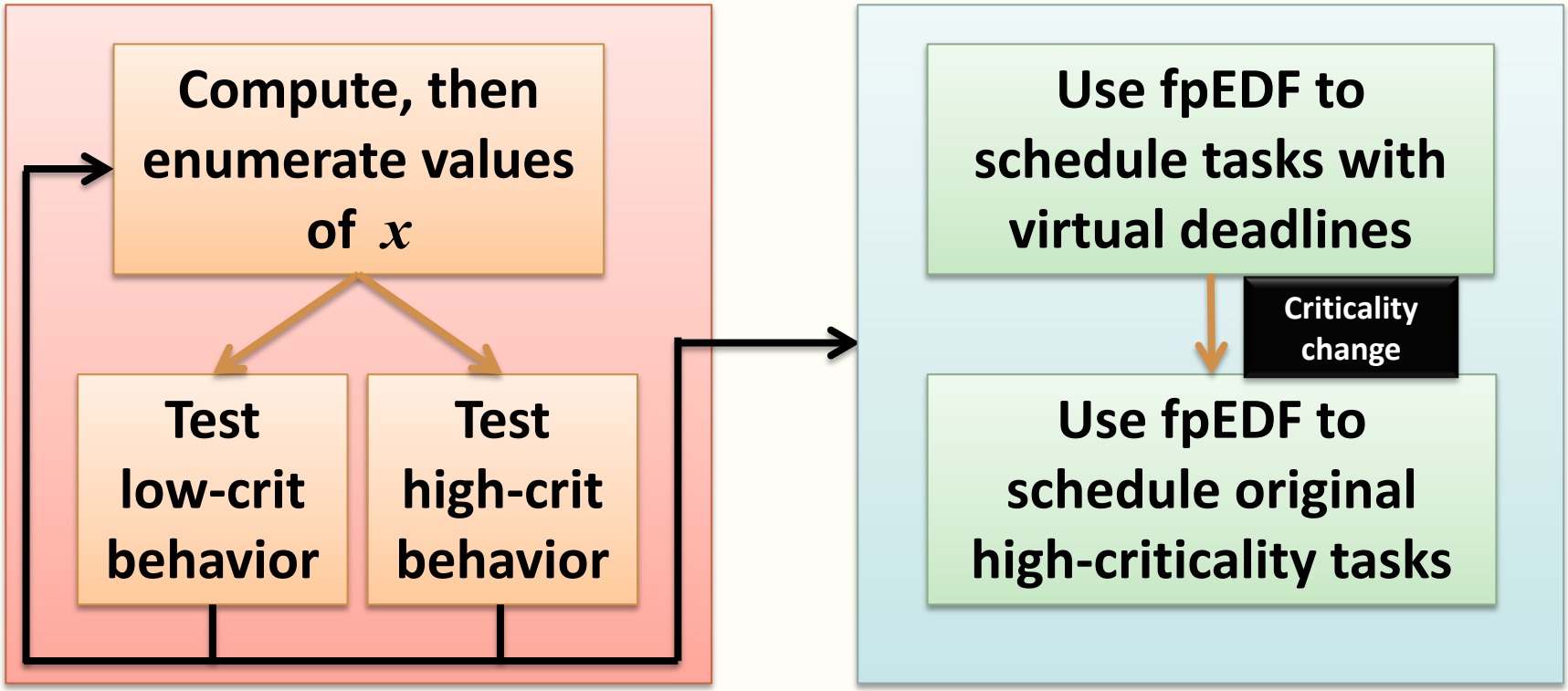
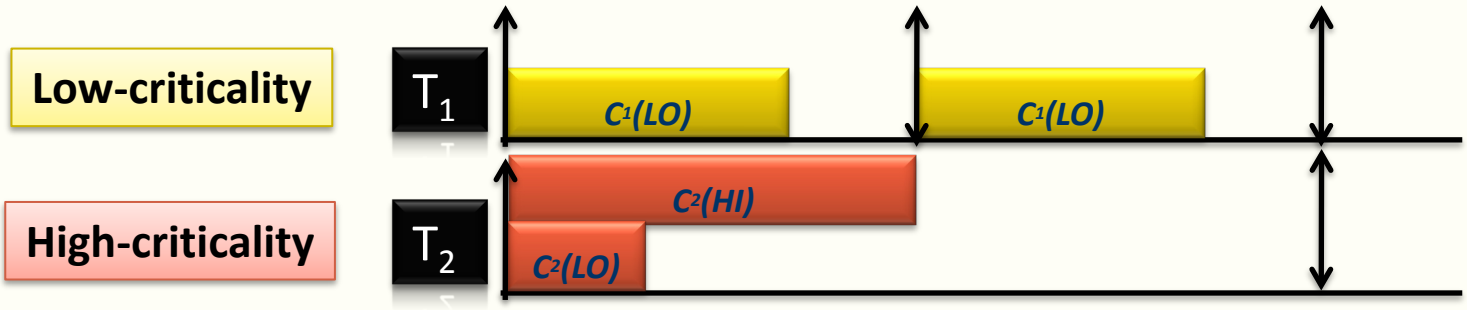


Performance

- **Simulation experiments**
  - Generate random MC implicit-deadline tasks with given utilization in low and high criticality
    - Utilization is defined as the maximum fraction of time demand in each criticality
    - *U(LO)=2/3+1/6=5/6*
    - *U(HI)=3/6*



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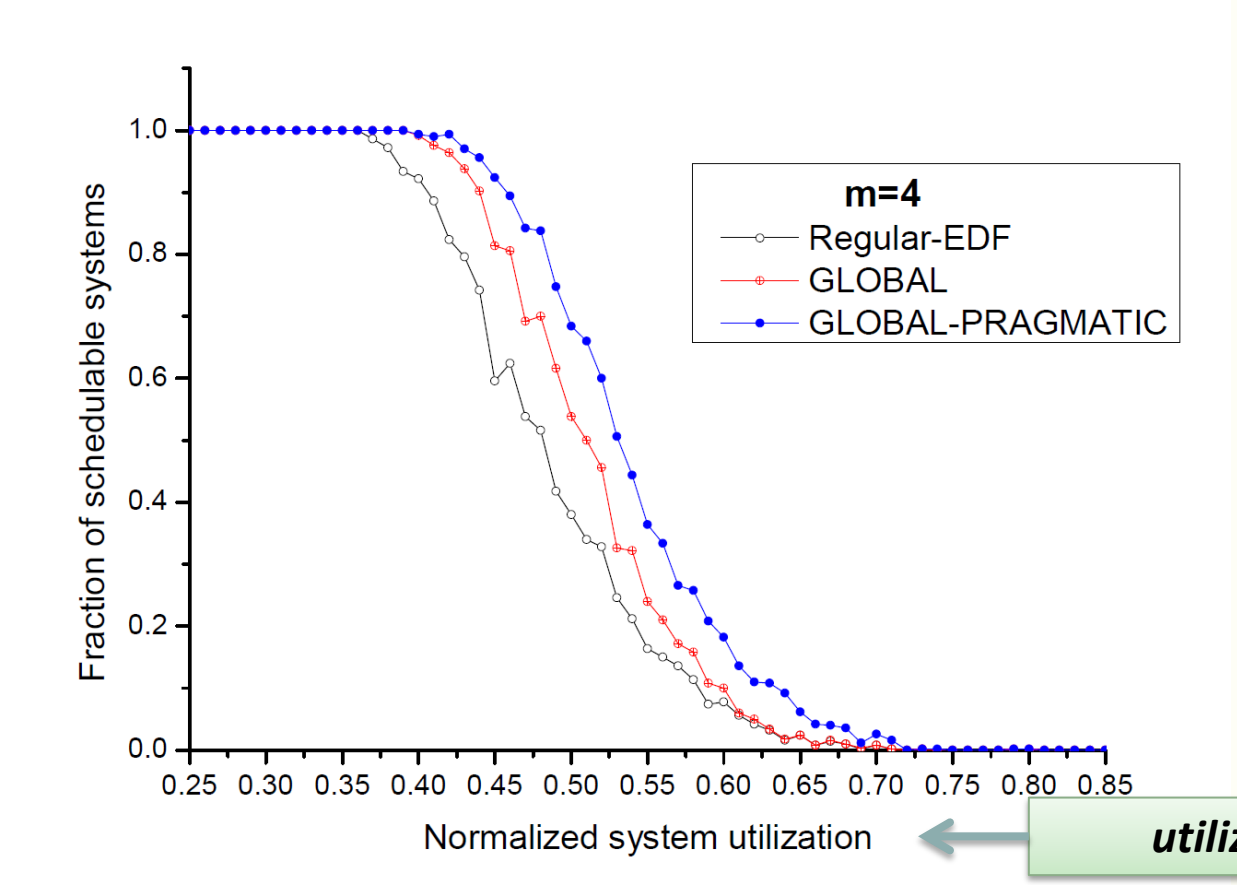
Performance

- **Simulation experiments**
  - **Generate random MC implicit-deadline tasks with given utilization in low and high criticality**
    - **The task generation algorithm is in *Fig. 4***
  - **Compare 3 algorithms**
    - **Regular-EDF: *Worst-case reserving to meet all deadlines***
    - **GLOBAL: *Using computed x only***
    - **GLOBAL-PRAGMATIC: *Using computed and enumerated x***

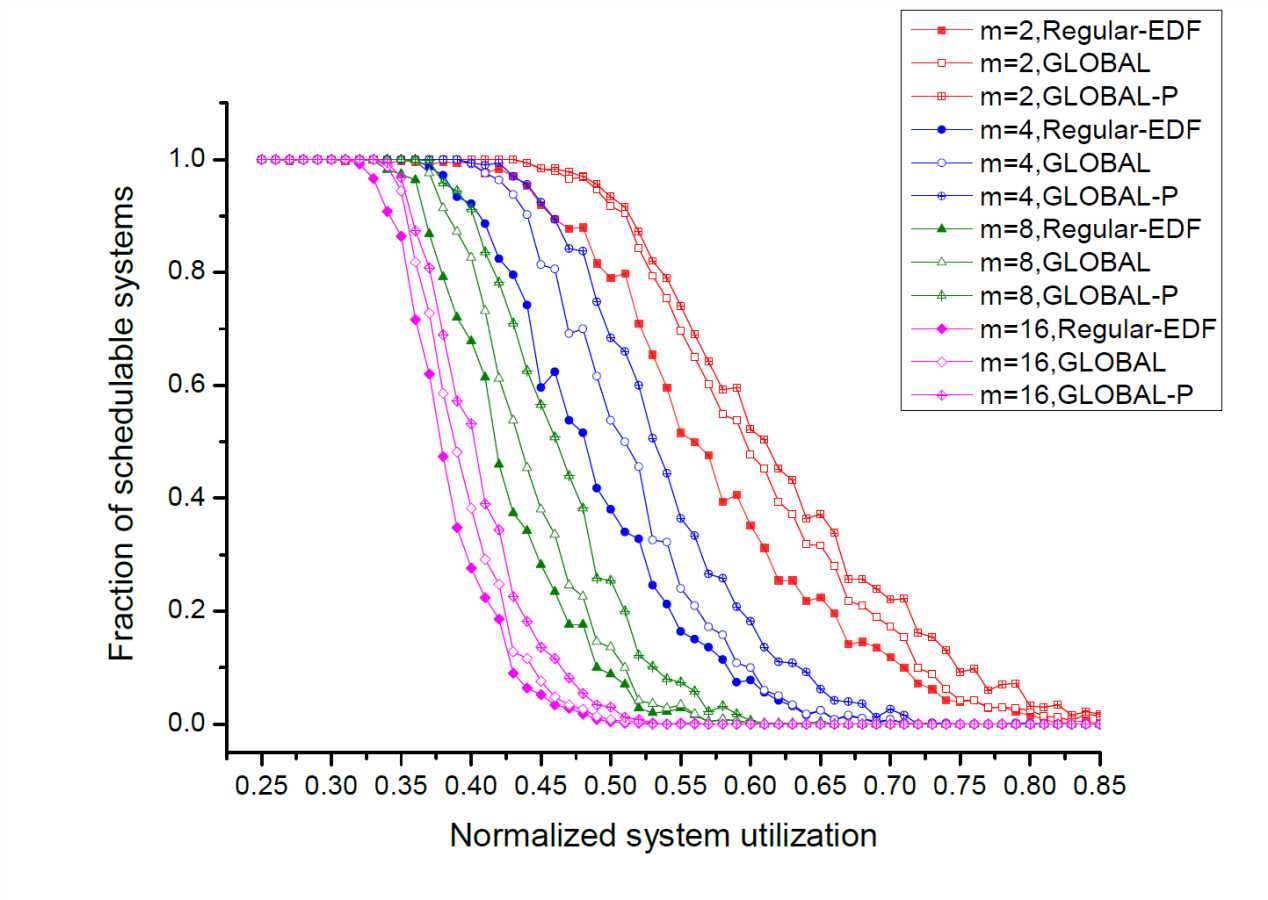
Performance

- **Experimental results**



Performance

- **Experimental results**



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Conclusion

- **Global mixed-criticality scheduling**
  - Global-EDF with virtual deadlines
  - Schedulability test on two virtual systems
  - Selected virtual deadlines
  - Speed-up factor 3.236, and experiments
- **Future work**
  - More criticality levels
  - Better scheduling strategies

Thank you

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