Technische Universität Braunschweig

INSTITUTE OF COMPUTER AND NETWORK ENGINEERING

Deriving Monitoring Bounds for Distributed Real-Time Systems

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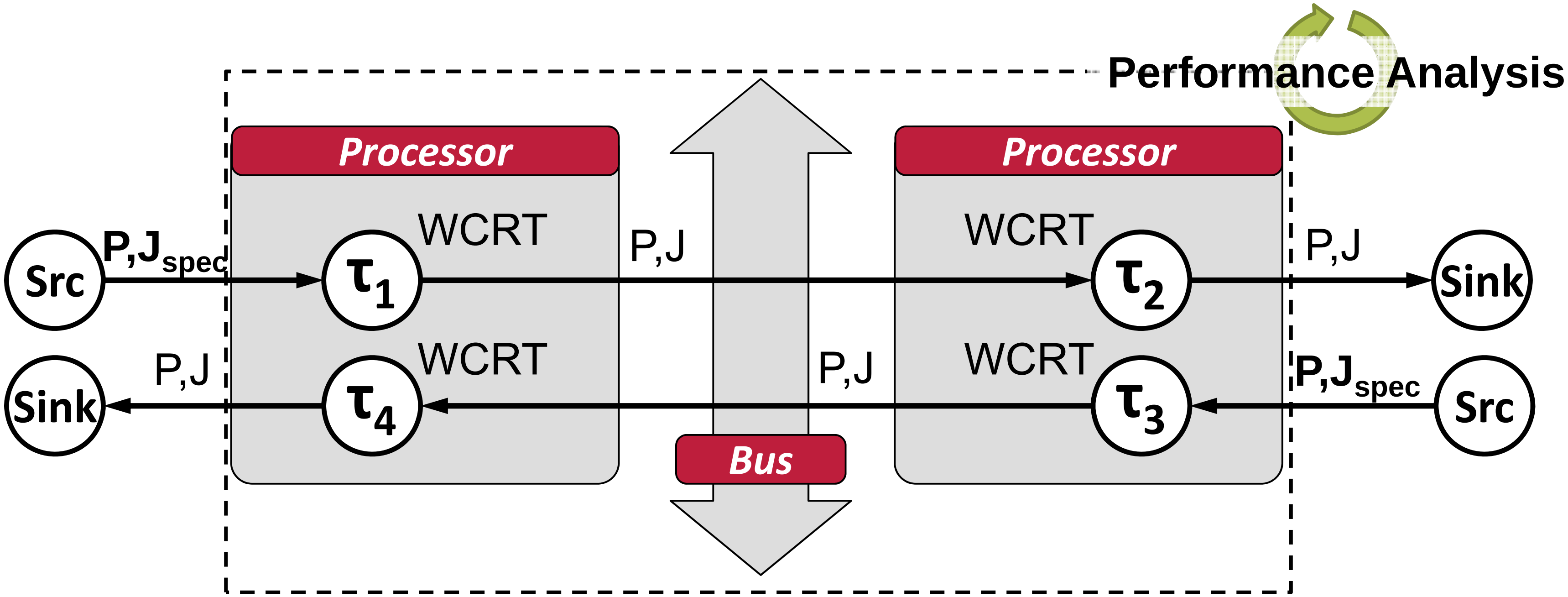
Ensuring Timing Constraints

To **ensure real-time constraints** systems are

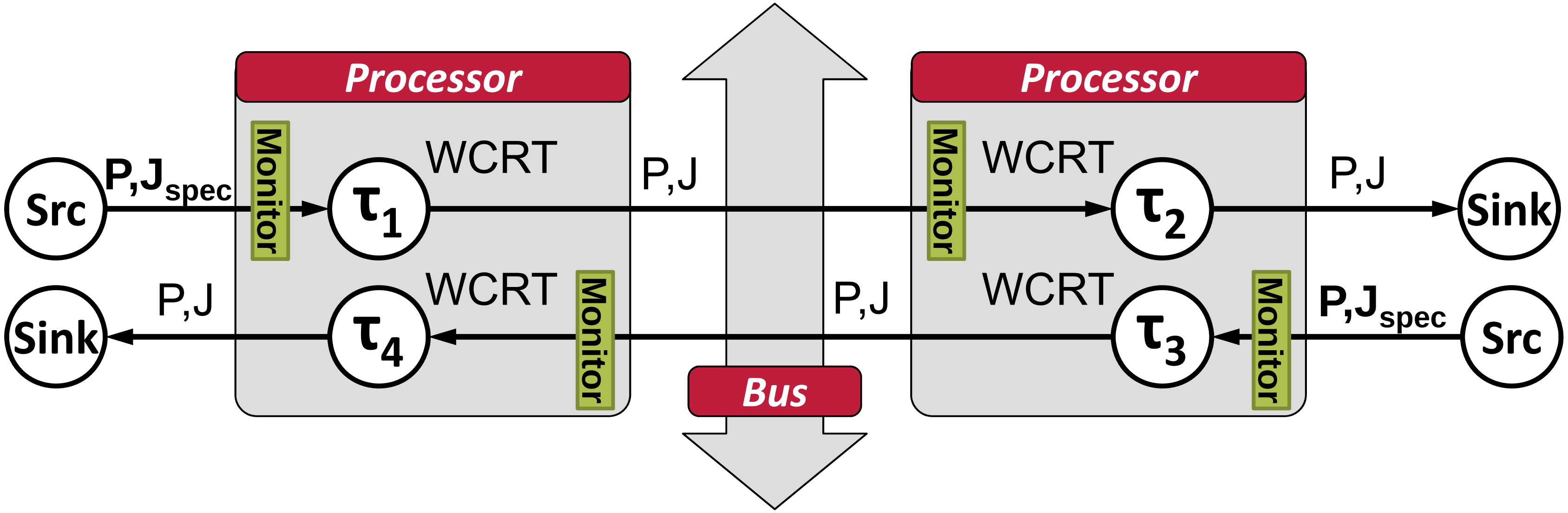
- **verified** at design-time (e.g. RTC, SymTA/S)



Ensuring Timing Constraints

To **ensure real-time constraints** systems are

- **verified** at design-time (e.g. RTC, SymTA/S)
- **monitored** at run-time (key to efficient **mixed-criticality** [Baruah11])
- both **based on model** and formal **specification**



[Baruah11] Baruah, S.; Burns, A. & Davis, R., “Response-Time Analysis for Mixed Criticality Systems,” RTSS 2011

Monitoring According to Verification Model

Monitoring according to **verification model**

- Bounds are **safe**
- Bounds are fairly **efficient to derive** through performance analysis
  e.g. Real-Time Calculus, Compositional Performance Analysis

- overly **pessimistic**
- does **not** allow **worst <u>acceptable</u>** timing behavior

Sensitivity Analysis derives **maximum parameter** variation under which **constraints** still **hold**

MONITORING SHOULD BE PERFORMED ACCORDING TO **SENSITIVITY BOUNDS**

Outline

- Monitoring based on Sensitivity Analysis
- Compositional Sensitivity Analysis
- Evaluation

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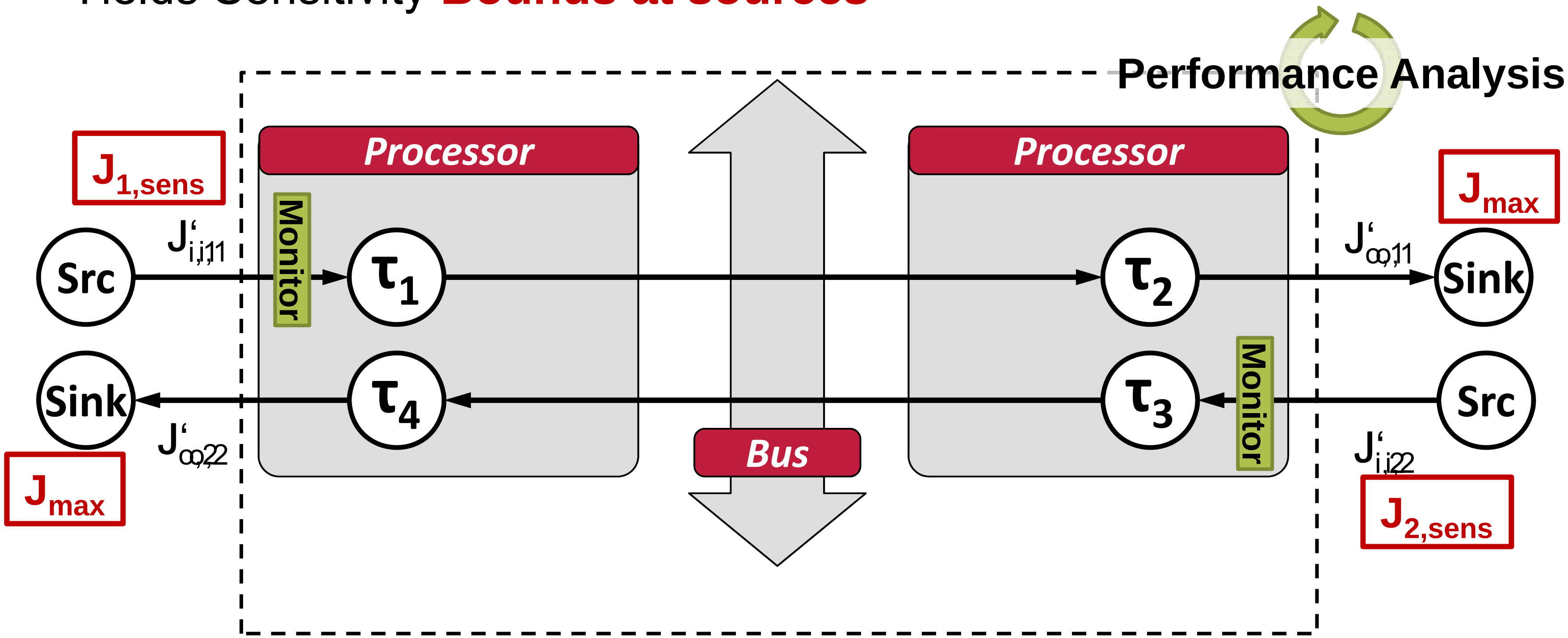
Search-based Sensitivity Analysis

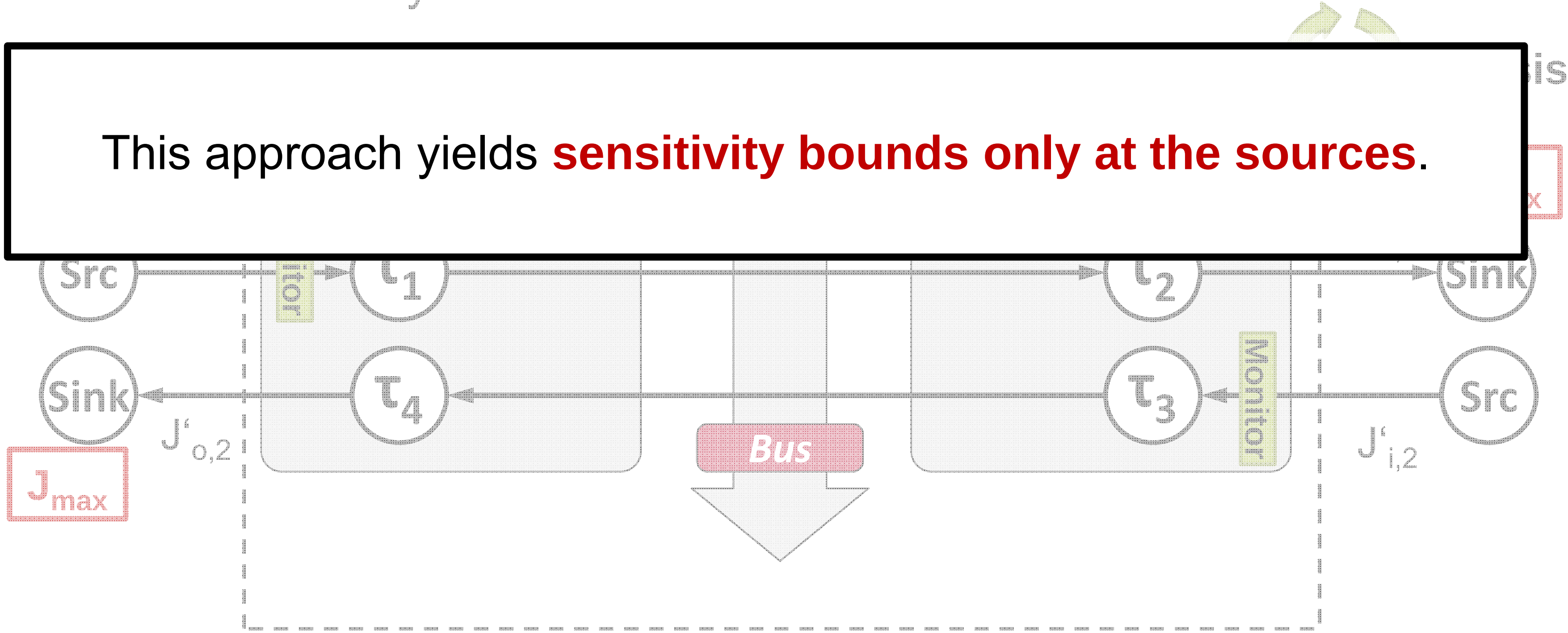
- **Modify parameters** until constraints are violated
- **System-level** Performance **Analysis** (e.g. SymTA/S, MPA) as **feasibility test**
- Yields Sensitivity **Bounds at sources**



Search-based Sensitivity Analysis

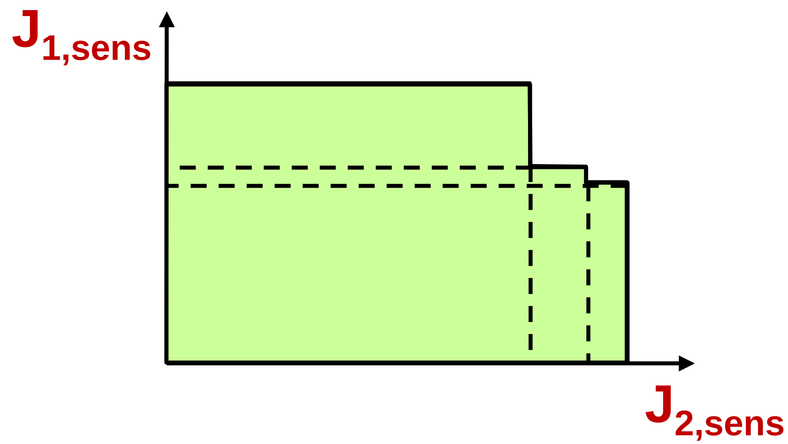
- **Modify parameters** until constraints are violated
- **System-level** Performance **Analysis** (e.g. SymTA/S, MPA) as **feasibility test**
- Yields Sensitivity **Bounds at sources**

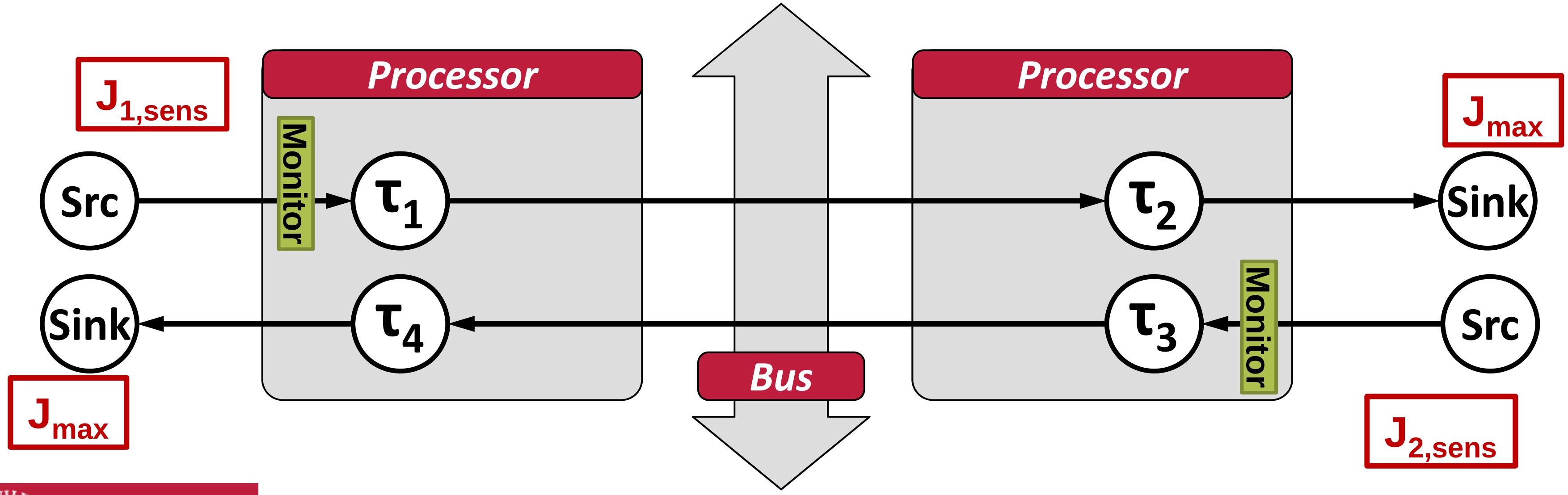
This approach yields **sensitivity bounds only at the sources**.



Interdependence of Sensitivity Bounds

- **Sensitivity Bounds** are **NOT independent** of each other
- Existing Analysis yield **entire pareto-front**



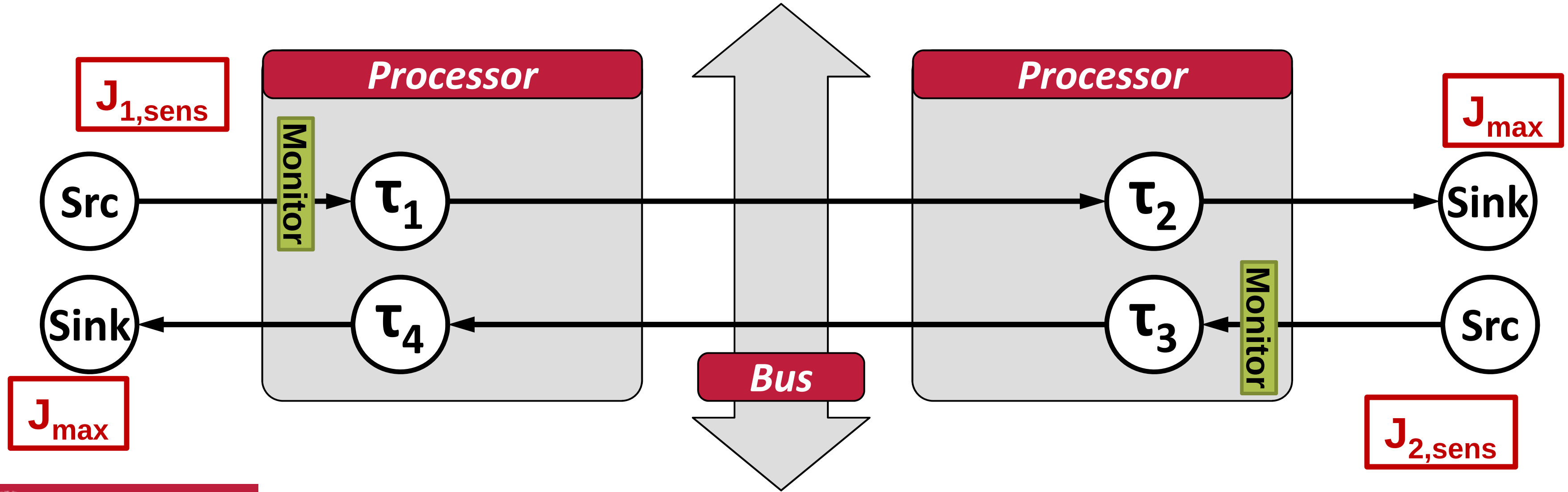


Interdependence of Sensitivity Bounds

- Sensitivity Bounds are

entire pareto-front

For **monitoring** only **one point** of the **pareto front** can be applied.



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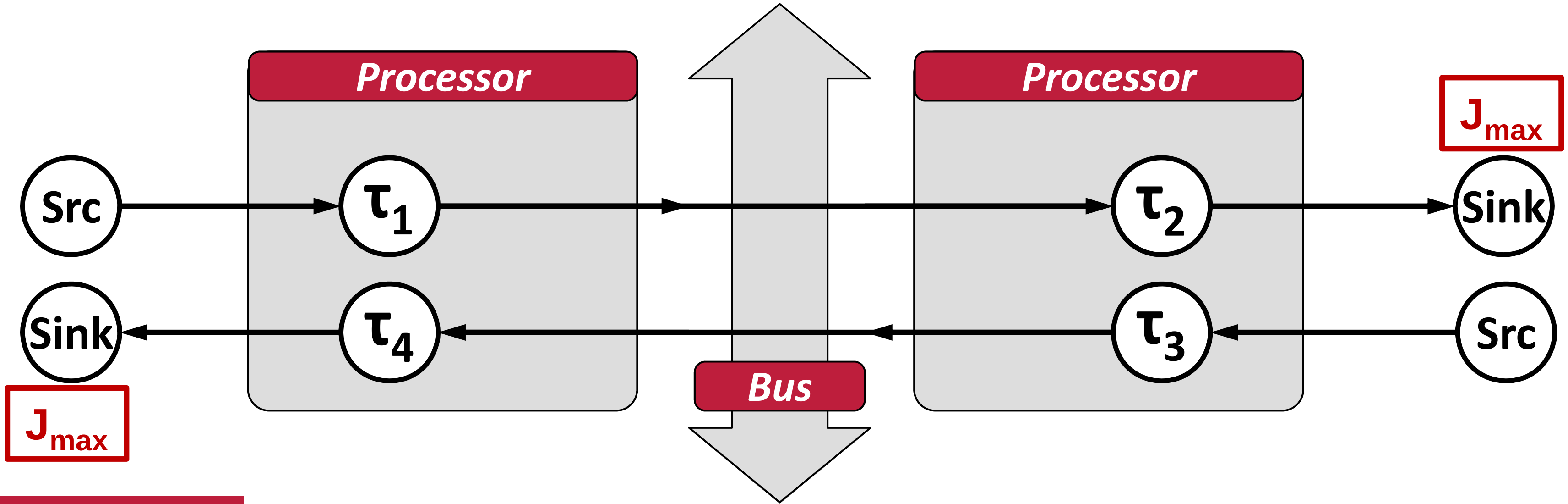
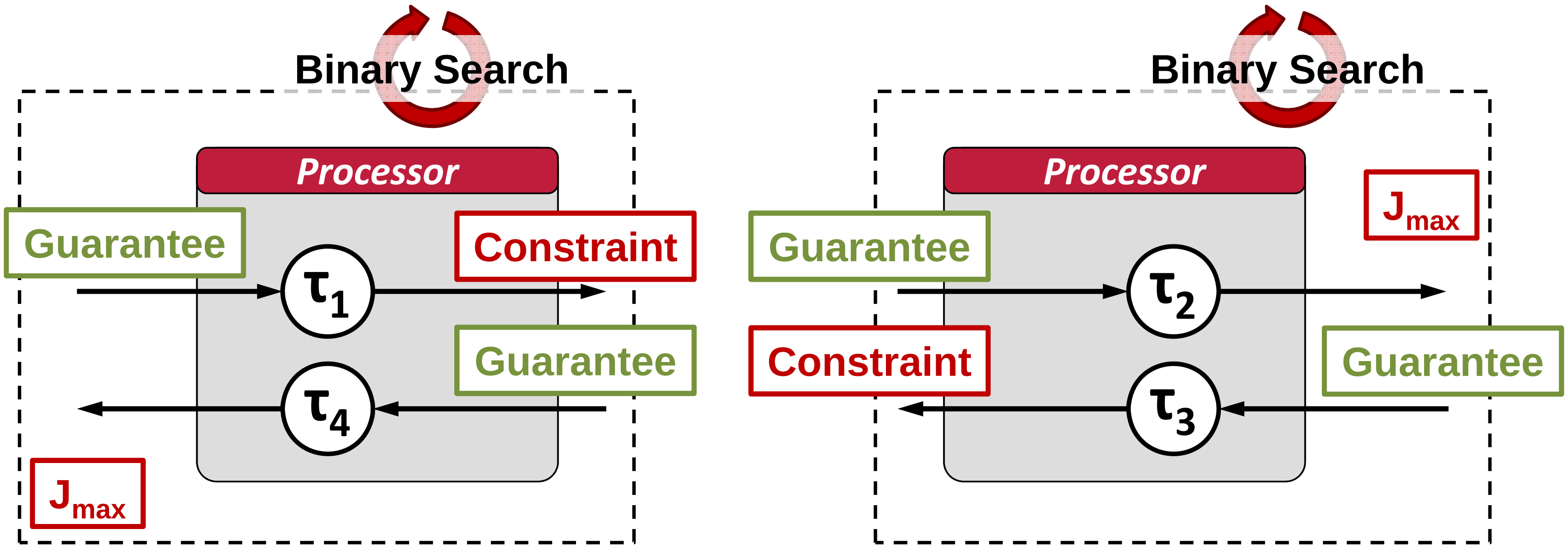
Compositional Sensitivity Analysis

- Perform **sensitivity analysis of resources** in isolation



Compositional Sensitivity Analysis

- Perform **sensitivity analysis of resources** in isolation (WCRT analysis)
- Resource gives **guarantee** on allowed **input jitter**
- **Guarantee serves as constraint** at other resource
- Execution as **distributed fixed point algorithm**



Compositional Sensitivity Analysis

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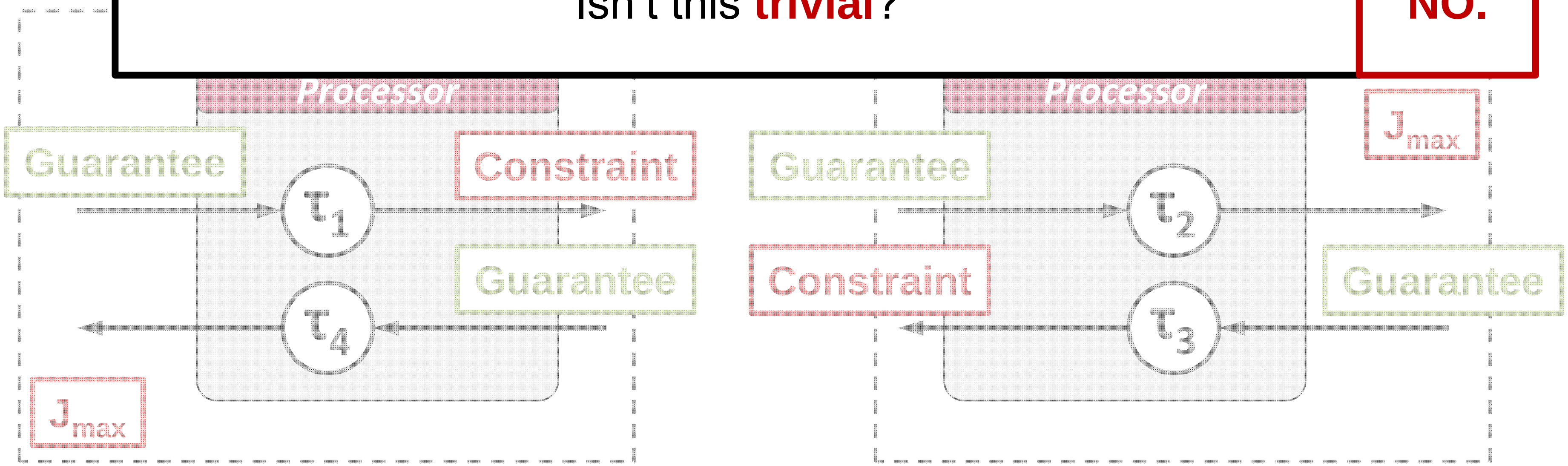


This is **Compositional Performance Analysis reversed!**
Isn't this **trivial**?

YES.
NO.

Problems in Compositional Sensitivity Analysis

Starting Value (see paper):

- Some tasks may **not** have **valid guarantees when analyzed**
- Cannot be resolved when **cyclic dependencies** exist
- **Conservative starting point** has to be defined

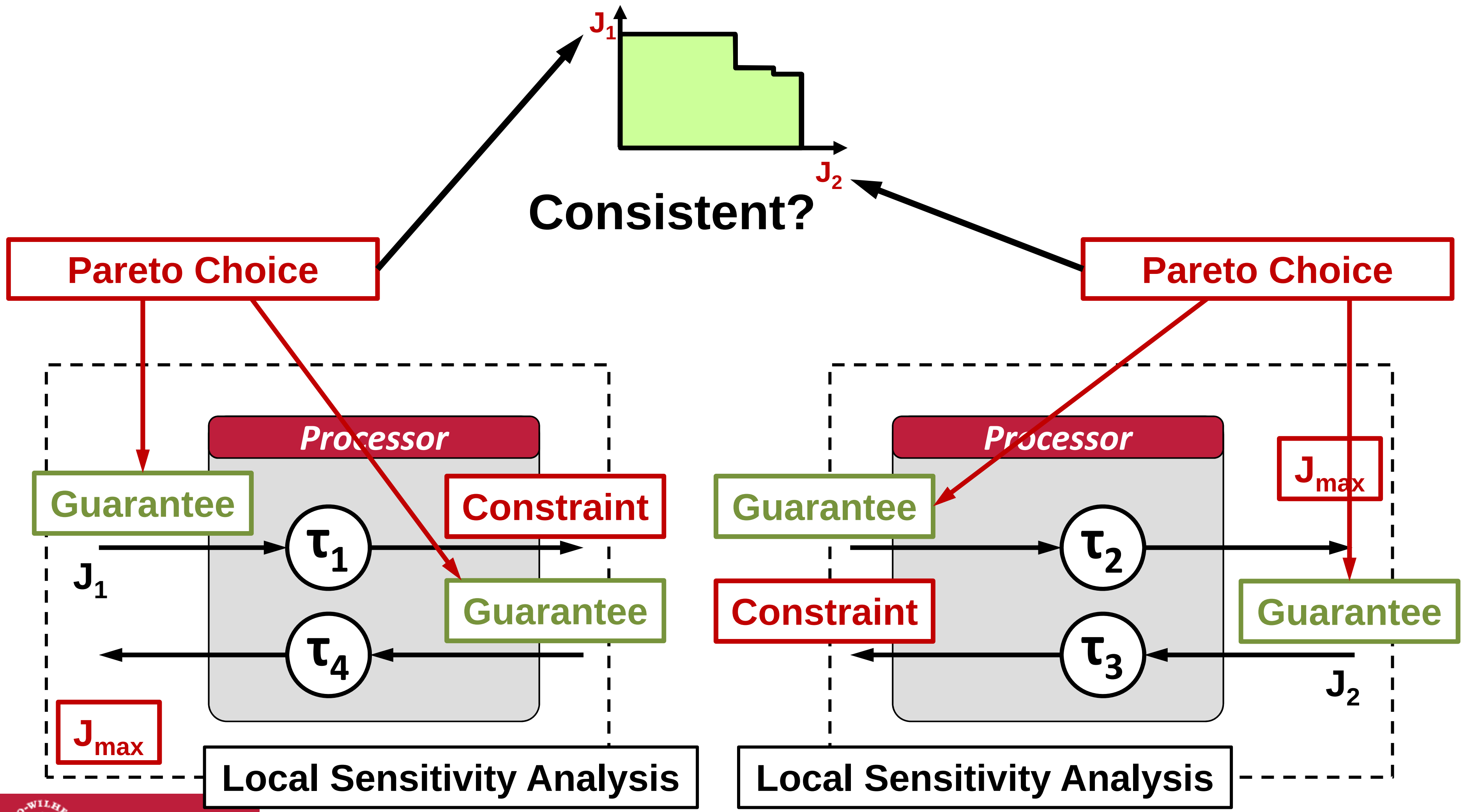
Convergence (see paper):

- Distributed fixed point algorithm
- Convergence has to be ensured

Pareto-Choice and Consistency:

- Each **local analysis** performs **pareto choice**
- **Local** pareto **choices** have to be **globally consistent**

Pareto Choice And Consistency

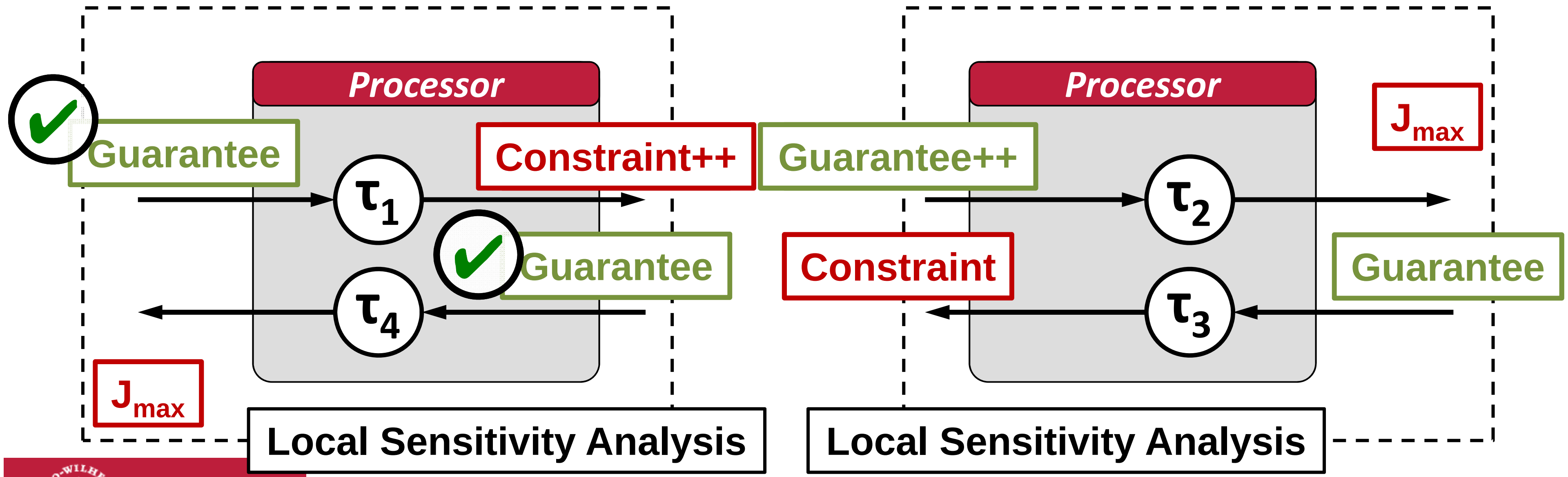


Consistency

- Assume **initial guarantee/constraint** assignment **correct**
- **Local sensitivity analysis** are **increasing**
  i.e. larger constraint at output → larger or equal guarantee at input

→ **Tuple G of all guarantees**/constraints can only increase

→ **Increasing** a **single guarantee**/constraint **cannot violate constraint**



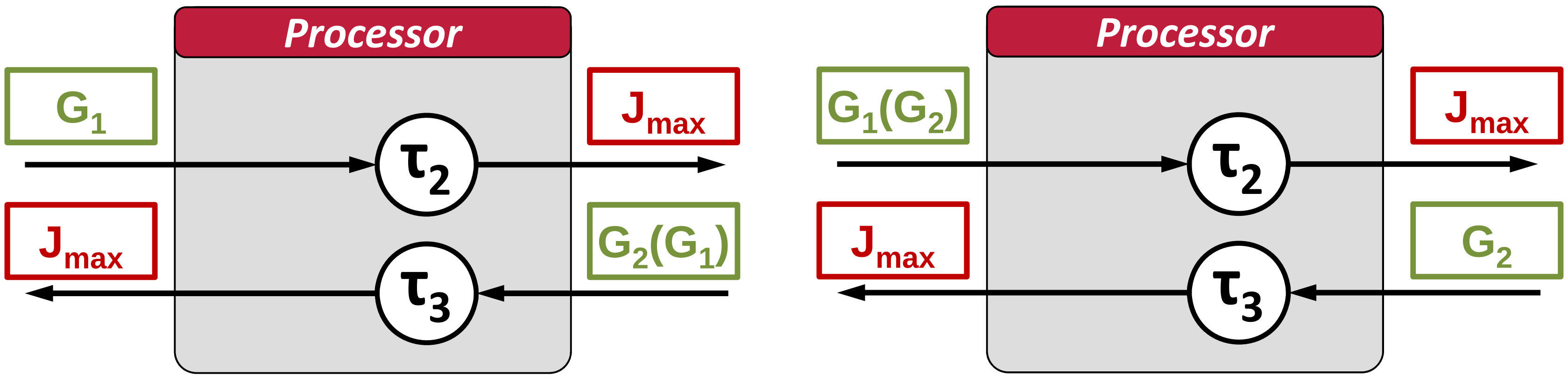
Pareto Choice

- **Execution order** of greedy local analyses **determines pareto choice**
- Guarantee, that is **analyzed first**, is **maximized**

Possible exploitation:

- *Analyze low criticality tasks first*

→ *Low criticality tasks can accomodate largest design uncertainty*



$G_1(G_2) \leq G_1 \qquad G_2(G_1) \leq G_2$

Pareto Choice and Consistency (Summary)

- **Consistency/Correctness** of guarantees formally **proven**
  Theorems 2 & 5 in the paper
- All guarantee assignments (**sensitivity bounds**) **conservative**
  - All **intermediate** guarantee **assignments** are **conservative**

  → Algorithm can be **stopped at any time** and **results** are **valid**

- **Correctness** holds for **any execution order** of local sensitivity analyses
- **Local sensitivity analyses** can be (partly) performed **in parallel**

- **Execution Order** of Local Analyses **determines pareto choice**
  *e.g. analyze **low criticality** applications **first** to allow for **largest uncertainty***

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Evaluation

- **Our algorithm** yields **one approximated n-dimensional** pareto point
- **Existing** system-level sensitivity **analyses** [8,18] yield **pareto front** of **up to 4 dimensions** (in reasonable runtimes)
- **[8,18]** build on the **same performance analysis** algorithms

- Comparison of **solution quality** for systems up to 4 dimensions
  i.e. where comparison to exact solution is possible
- Evaluation of **runtime**
  in terms of required WCRT analyses

[8] A. Hamann, R. Racu, and R. Ernst, “A formal approach to robustness maximization of complex heterogeneous embedded systems,” CODES 2006

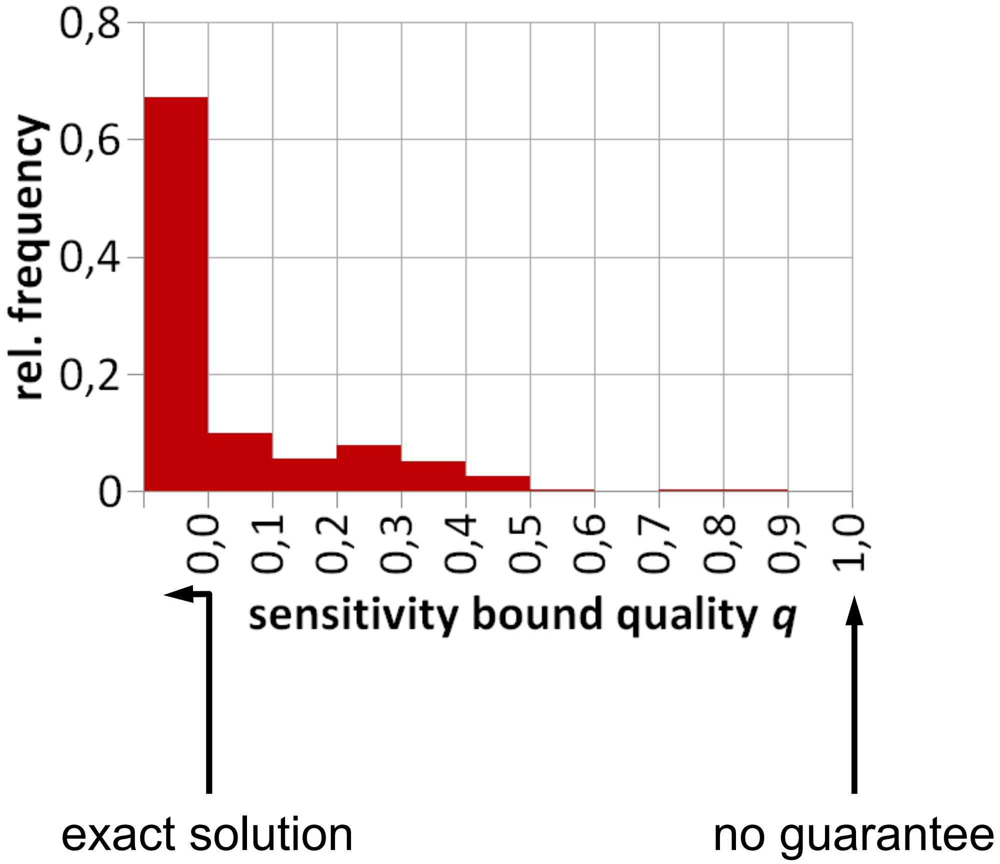
[18] R. Racu, A. Hamann, and R. Ernst, “Sensitivity analysis of complex embedded real-time systems,” Real-Time Systems, 39:31–72, 2008.

Test Setup

- **Synthetic testcases** generated with System Models for Free (SMFF)
  see paper for complete parameter set

- Key characteristics of testcases:
  5 processors + 2 busses
  Utilization 35%-45% (UUnifast)
  Small systems: 4x chain of 3 tasks = **12 tasks,**
  2-8 comm. tasks
  4 dimensions
  Large systems: 50x chain of 3 tasks = **150 tasks**
  52-79 comm. tasks
  50 dimensions

Solution Quality

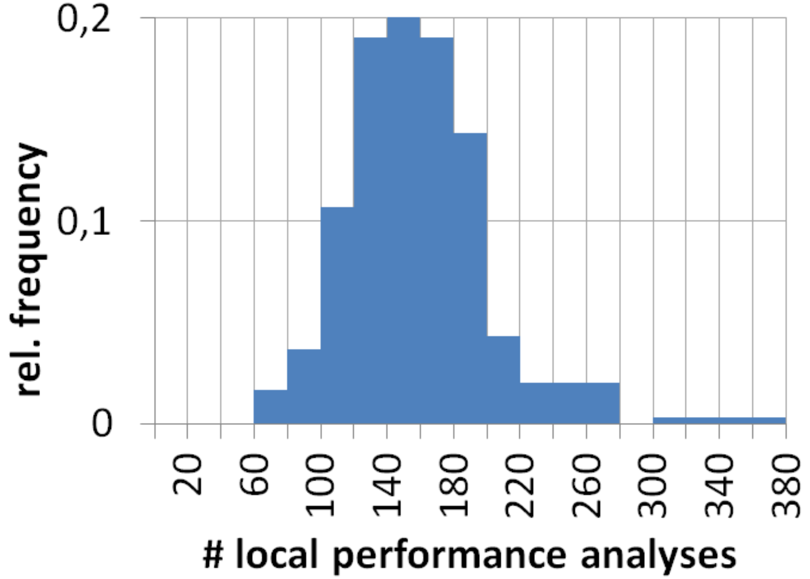


- Solution quality: Normalized Manhattan distance to closest comparable pareto point

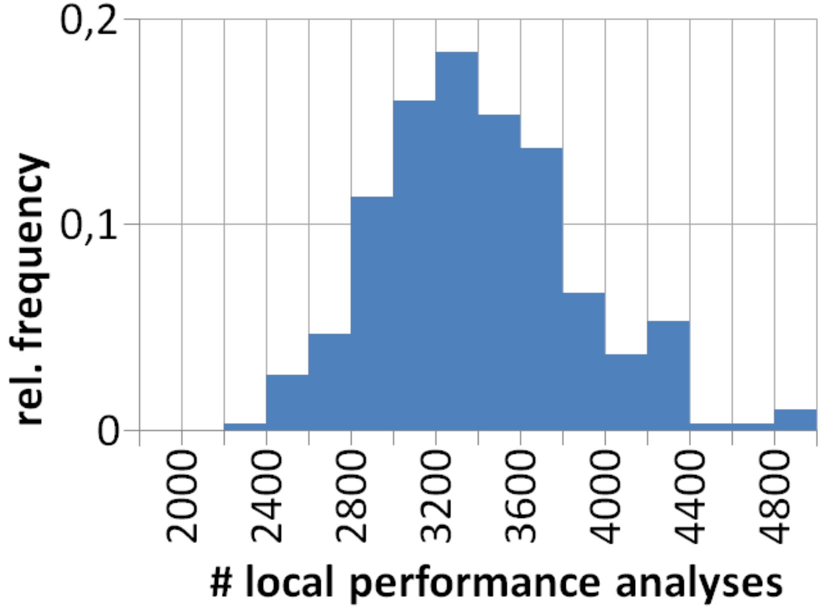
Runtime

- **Existing analyses** require **~10^4** [8] and **~10^8** [18] **WCRT analyses** to derive entire pareto front (**4 sources/dimensions**)

Our Approach



4 sources



50 sources

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[18] R. Racu, A. Hamann, and R. Ernst, “Sensitivity analysis of complex embedded real-time systems,” Real-Time Systems, 39:31–72, 2008.

Conclusion

- **Monitoring** should be performed **according to sensitivity bounds**

- **Existing** system-level sensitivity **analyses** yield
  - **entire pareto front** of **bounds at sources**

- We have introduced **Compositional Sensitivity Analysis**
  - yields sensitivity **bounds at every resource**
  - yields **one multi-dimensional** sensitivity bound

- Analysis **significantly faster** than previous approaches
- **Accuracy comparable**

Thank you for your attention.