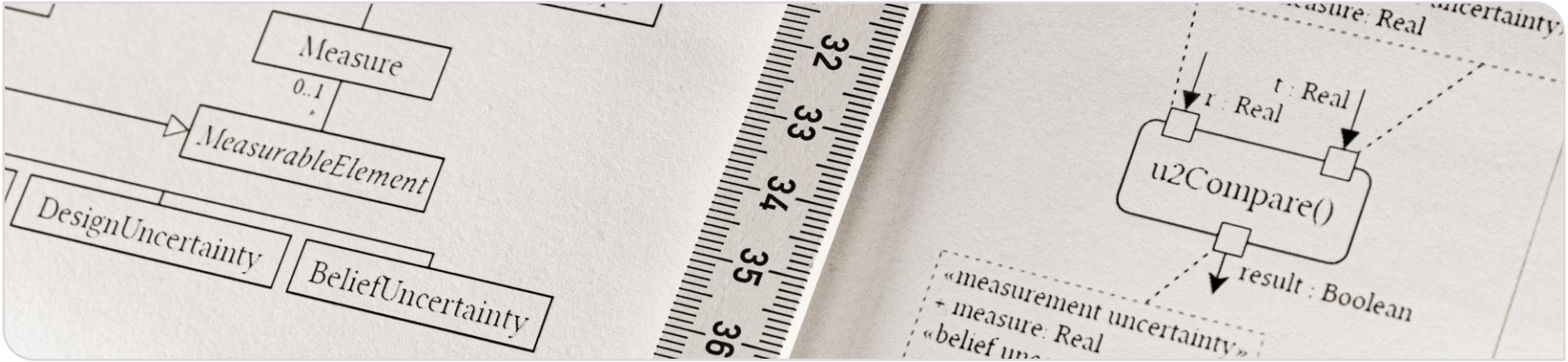
Karlsruhe Institute of Technology

Uncertainty Flow Diagrams: Towards a Systematic Representation of Uncertainty Propagation and Interaction in Adaptive Systems

19th International Conference on Software Engineering for Adaptive and Self-Managing Systems, SEAMS'24

Javier Cámara, Sebastian Hahner, Diego Perez-Palacin, Antonio Vallecillo, Maribel Acosta, Nelly Bencomo, Radu Calinescu, Simos Gerasimou

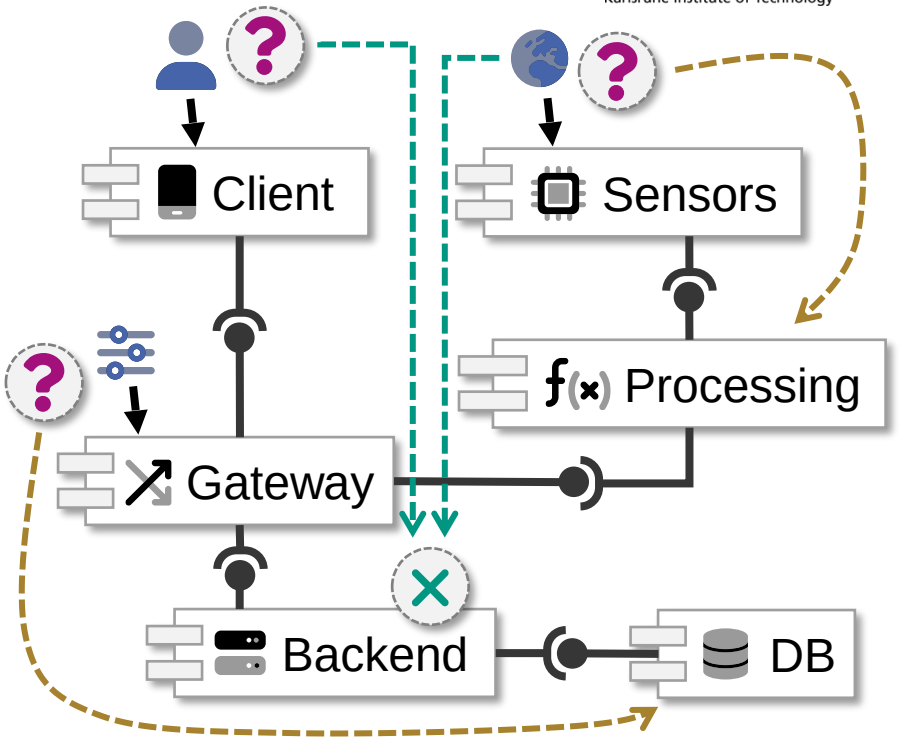


Motivation

- **Uncertainty sources** exist in software systems and their environment [1]
- Many modeling and analysis approaches exist for mitigating different types of uncertainty sources [2]

Challenges

- **Propagation**: Uncertainty source and impact locations may differ
- **Interaction**: Sources are rarely independent and may have an unpredictable impact
- **Heterogeneity**: Joint modeling, analysis and mitigation of different uncertainty types



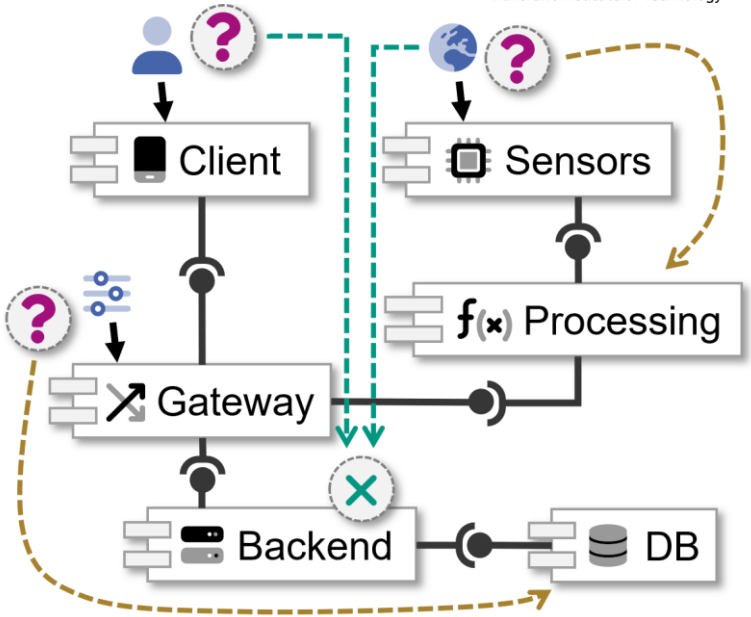
[1] M. Acosta et al., “Uncertainty in coupled models of cyber-physical systems“, In: MODELS-C, ACM, 2022.
[2] S. M. Hezavehi, et al., “Uncertainty in Self-adaptive Systems: A Research Community Perspective,” TAAS, ACM, vol. 15, no. 4, 2021.

Bertinoro Research Seminar on Uncertainty

International Seminar on Uncertainty in Self-Adaptive Systems (USAS), Bertinoro, Italy, 12 – 15 June 2023

State of the Art

- Numerous modeling approaches for many **different uncertainty** types **[3, 4]**
- Initial work towards understanding the **uncertainty interaction** problem **[5]**
- **Propagation** of homogenous uncertainty
  - Measurement uncertainty **[6]**
  - Belief uncertainty, e.g., subjective logic **[7]**
  - Design uncertainty, e.g., using design space exploration **[8]**



[3] J. Troya, N. Moreno, M. F. Bertoa, and A. Vallecillo, “Uncertainty representation in software models: a survey”, Software and Systems Modeling, vol. 20, no. 4, 2021.
[4] Object Management Group (OMG), “Precise Semantics for Uncertainty Modeling (PSUM)”, Version 1.0 Beta 1, 2023.
[5] J. Cámara et al., “Addressing the uncertainty interaction problem in software-intensive systems: challenges and desiderata”, MODELS, ACM, 2022.
[6] JCGM 100:2008, “Evaluation of measurement data—Guide to the expression of uncertainty in measurement (GUM)”, ISO Joint Com. for Guides in Metrology, 2008.
[7] A. Jøsang, „Subjective Logic: A Formalism for Reasoning Under Uncertainty”, AIFTA, Springer, 2016.
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Data Flow Diagrams

- Focus on *data* in software systems
- Enables hierarchical modeling
- Used for uncertainty propagation **[9]**

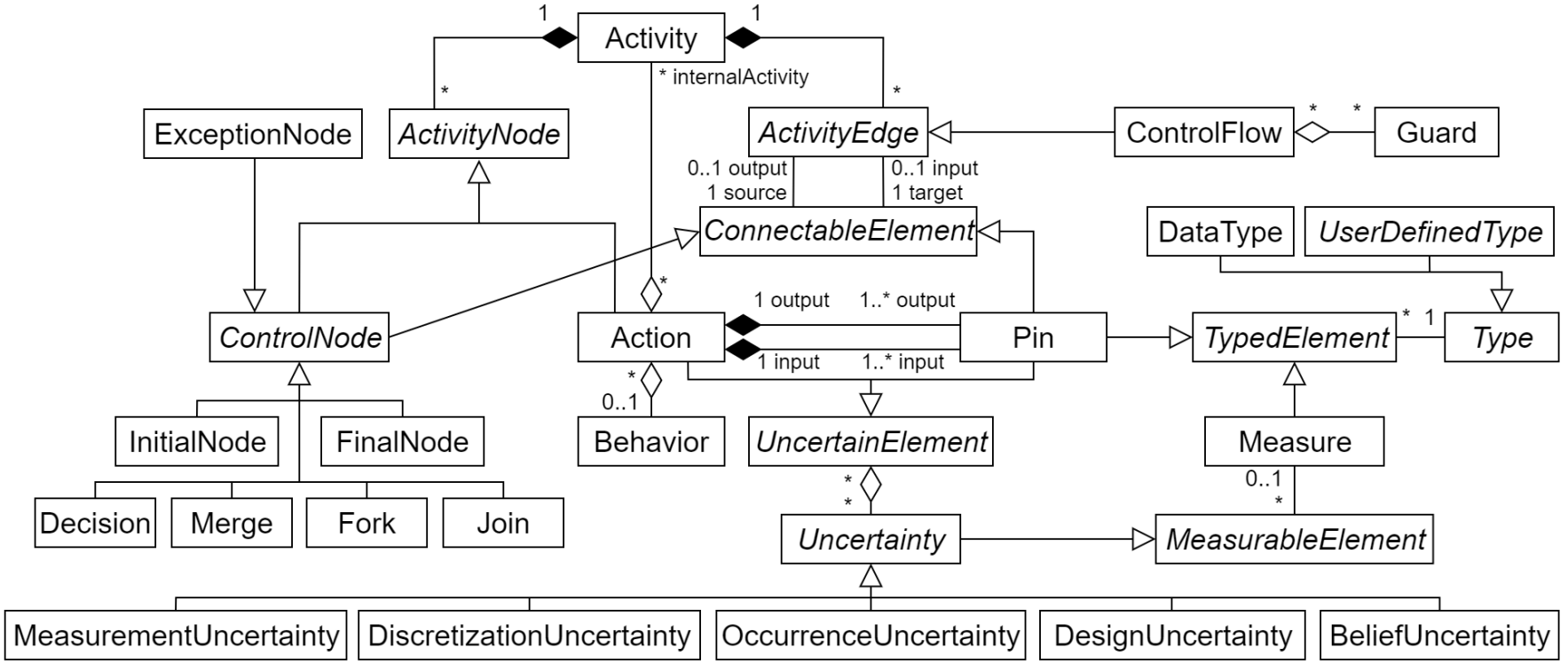
UML Activity Diagrams

- Focus on *control* flow in systems
- Models decisions and concurrency
- Used for uncertainty propagation **[10]**

⇨ Horizontal + vertical propagation to analyze interaction of heterogeneous uncertainty?

[9] S. Hahner, R. Heinrich, and R. Reussner, “Architecture-Based Uncertainty Impact Analysis to Ensure Confidentiality”, SEAMS, IEEE/ACM, 2023.
[10] C. Ghezzi, et al., “Managing non-functional uncertainty via model-driven adaptivity“, ICSE, IEEE, 2013.

Uncertainty Flow Diagram Meta Model



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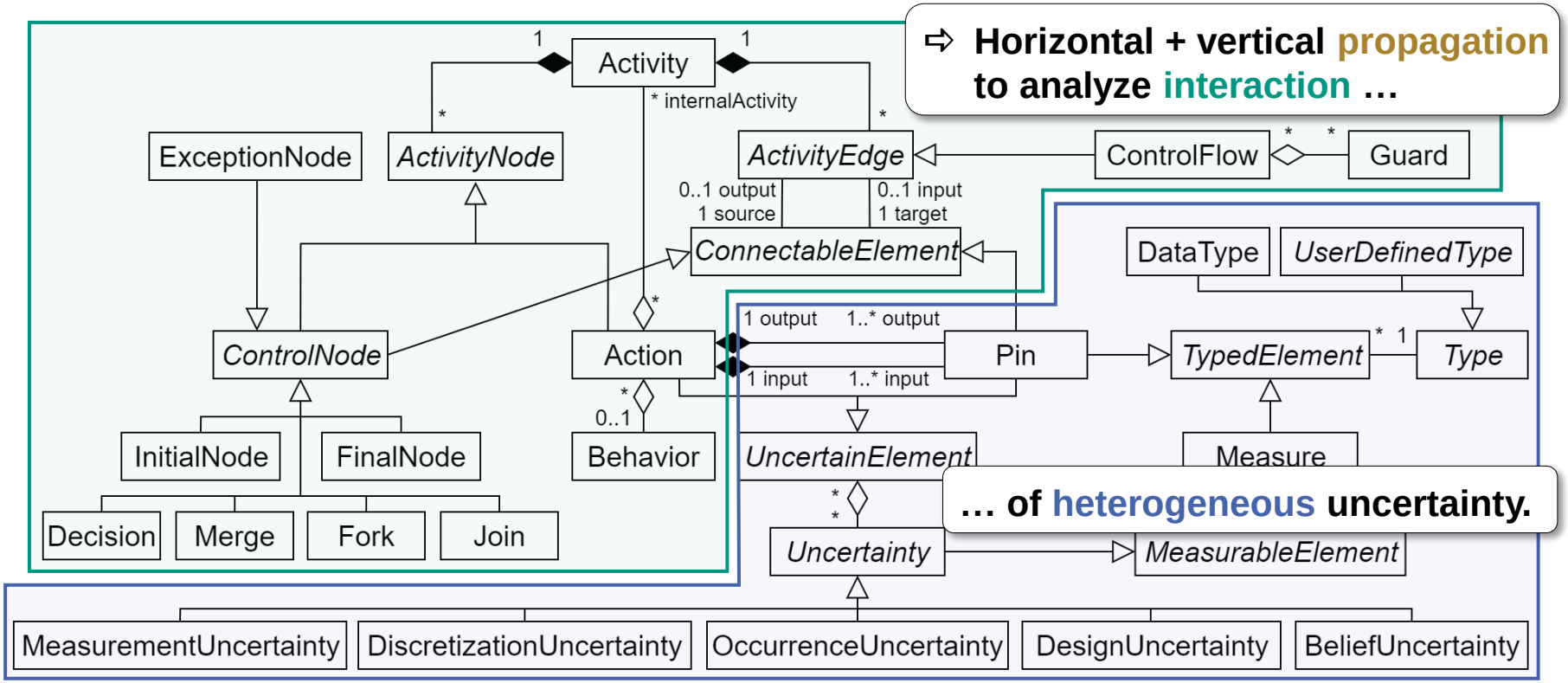

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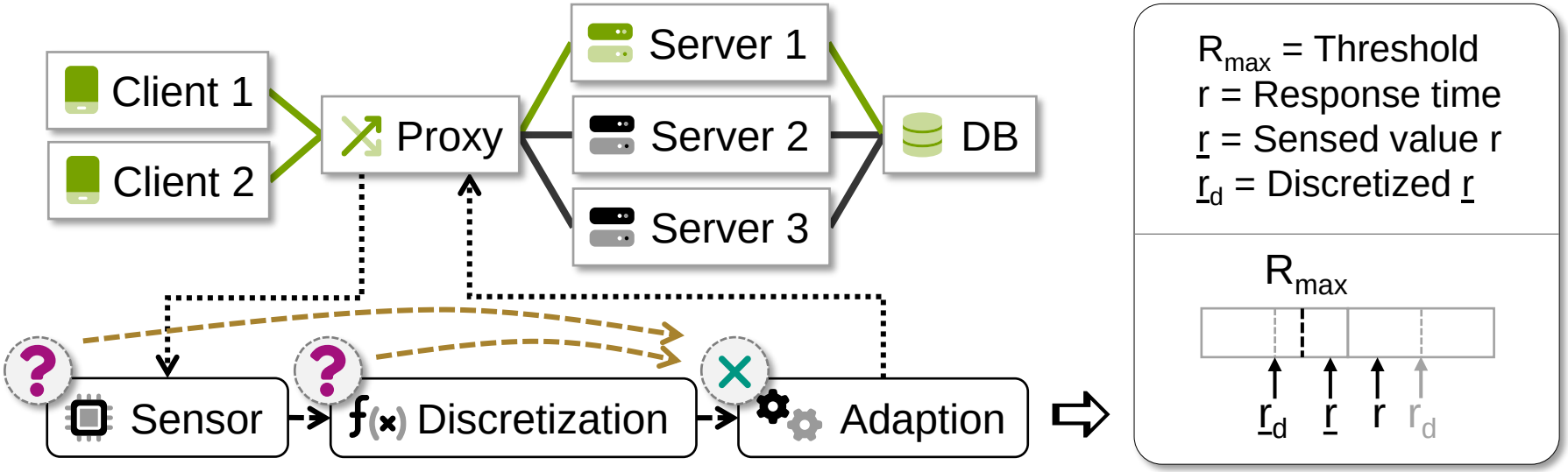
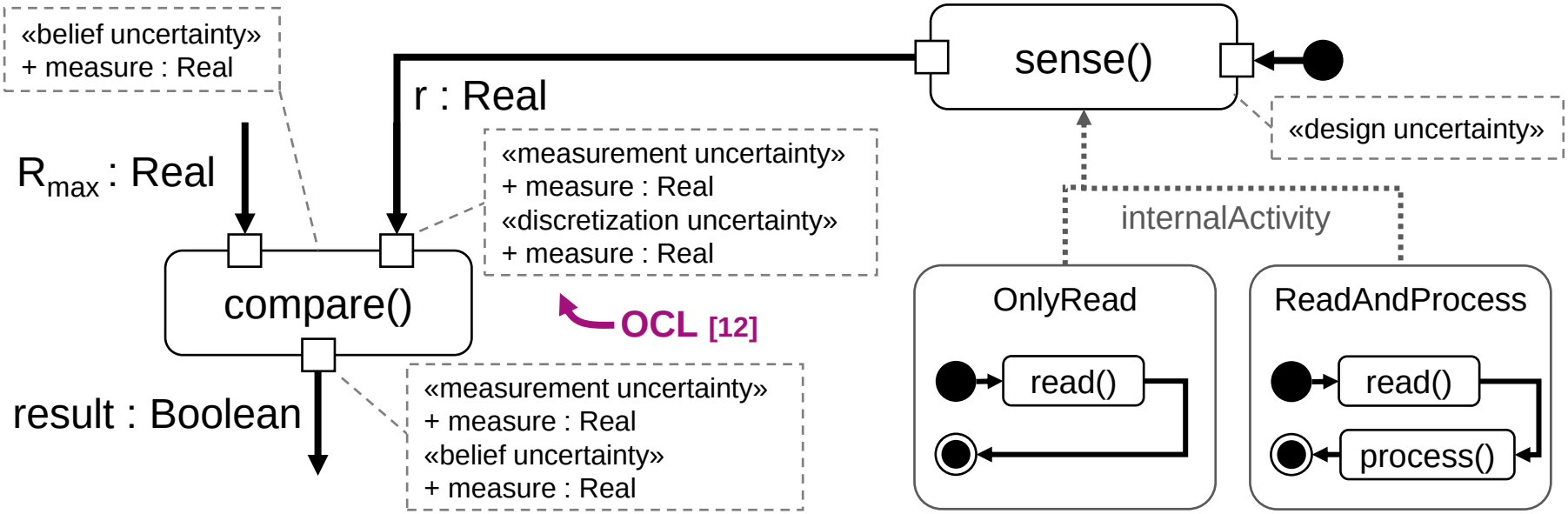
Demonstration with Znn.com [5, 11]



⇨ **Result**: No adaptation because of a *missed* **uncertainty interaction**

[5] J. Cámara et al., "Addressing the uncertainty interaction problem in software-intensive systems: challenges and desiderata", MODELS, ACM, 2022.
[11] S.-W. Cheng, D. Garlan, and B. Schmerl, "Evaluating the effectiveness of the Rainbow self-adaptive system", SEAMS, IEEE, 2009.

Representation of the Uncertainty Interaction



⇨ **Horizontal + vertical propagation to analyze interaction of heterogeneous uncertainty.**

[12] M. F. Bertoa, et al., "Incorporating measurement uncertainty into OCL/UML primitive datatypes," Software and Systems Modeling, vol. 19, no. 5, 2020.

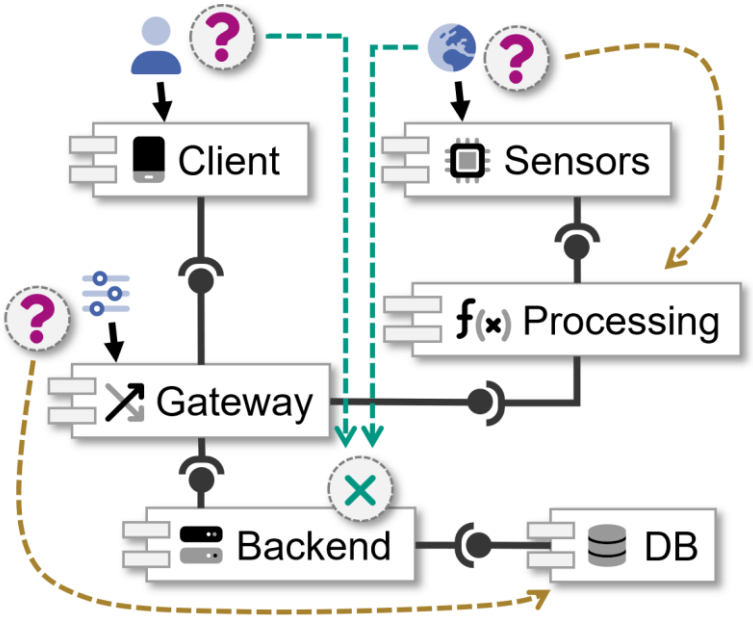
Conclusion and Future Work

Uncertainty Flow Diagrams (UFDs)

- Inspired by activity diagrams and data flow diagrams
- Enable propagation to analyze uncertainty interaction between heterogeneous uncertainty

Future Work

- Tool-supported model transformation between UFDs and other formalisms
- Apply different analysis formalisms for a more comprehensive evaluation



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KASTEL – Institute of Information Security and Dependability
DSiS – Dependability of Software-intensive Systems group

References

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