SimCenter Community Roundtable
"UQ Approaches for Computational Efficient Hazard / Vulnerability Assessment at the Regional Scale"

September 23, 2024

This SimCenter Community Roundtable meeting was organized by the **Working Group on Uncertainty Quantification (UQ) in Natural Hazards Engineering**. The meeting showcased research efforts in UQ that enable regional-scale modeling and risk assessment, with the intention to create a dialog and foster collaborative efforts between researchers. The meeting combined a small number of invited presentations and open dialog on this broader topic.

Advancements in computational modeling and probabilistic analysis techniques are enabling the assessment of natural hazards and their impact on the built environment (buildings and lifelines) and communities with unprecedented scale and resolution. The outcome of such analysis techniques becomes an invaluable ingredient in guiding emergency responses, assessing societal consequences, simulating the recovery phase, and optimizing disaster policy and design decisions. At the same time, such an attempt at large-scale regional risk assessment presents opportunities for researchers to tackle previously unexplored challenges. Such challenges can be associated, for example, with high-dimensional, spatiotemporally correlated hazard and system response descriptions, scarcity of data needed for the development of models for extreme hazard and corresponding system response, trade-offs between the analysis resolution and computational burden under limited resources, complex interdependency between component and system behaviors, and conflicting influences of hazards on the subcomponents of the system and resulting conflicting policy decision objectives. This setting creates new opportunities (for addressing the aforementioned challenges) for the use of advanced UQ techniques (e.g., surrogate modeling, sensitivity analysis, adaptive sampling, multi-fidelity approaches, low-dimensional latent space projections, multi-objective optimization) and for promoting interdisciplinary efforts to expand the frontiers of the domain.

Presentations and Key Ideas

1. **"On adaptive Monte Carlo simulation strategies for regional-scale uncertainty propagation: challenges in achieving computational efficiency across competing quantities of interest"**
   Presenter: Alexandros Taflanidis, University of Notre Dame.
   Prof. Taflanidis presented adaptive Monte Carlo methods for real-time surge forecasting, emphasizing computational efficiency and the challenges when adaptivity needs to be established for large dimensional outputs with competing objectives. He highlighted the use of adaptive importance sampling and adaptive multi-fidelity Monte Carlo, while he also discussed low-dimensional latent spaces for improving scalability.

2. **"Uncertainty quantification as a mechanism to drive multi-hazard scenario selection"**
   Presenter: Paolo Bocchini, Lehigh University.
   Prof. Bocchini focused on multi-hazard scenario selection using uncertainty quantification. He demonstrated how regional hazard maps and scenario tessellation could efficiently represent correlated hazards across sites.

3. **"Toward high-fidelity yet efficient structural portfolio representation: The role of surrogate modeling for fragility analysis and influence of model choices on risk and resilience estimates"**
   Presenter: Jamie Padgett, Rice University.
   Prof. Padgett explored surrogate modeling to analyze structural portfolios under multi-hazard risks. She emphasized the need for multi-output surrogate models and discussed the impact of uncertainty on portfolio-level loss estimates.

4. **"Enhancing System Reliability and Resilience under Natural Hazards: Active Learning and Stochastic Robust Optimization for Critical Infrastructures"**
   Presenter: Abdollah Shafieezadeh, Ohio State University.
   Prof. Shafieezadeh presented active learning approaches and PINNs for analyzing critical infrastructure reliability under hazards, showing how these methods could accelerate uncertainty quantification and sensitivity analysis.

Discussion Highlights

- **Challenges in Regional UQ:**
  - The high dimensionality of regional-scale problems, often exceeding millions of variables, necessitates scalable methods.
  - Identifying which uncertainties are most critical to propagate at the regional scale is a persistent challenge. Discussions emphasized the need to prioritize uncertainties based on their impact on decision-making.
- **Computational Efficiency:**
  - All speakers highlighted computational efficiency as a significant hurdle, especially for real-time applications and large-scale networks.
  - Techniques such as adaptive Monte Carlo, surrogate modeling, and active learning were recognized as promising solutions to balance accuracy and efficiency.
- **Collaboration Opportunities:**
  - There is a need for community-wide collaboration to create plug-and-play models for regional simulations, enabling researchers to integrate diverse algorithms into unified frameworks.
  - Cross-disciplinary approaches, such as combining graph neural networks with optimization models, offer innovative pathways for future research.
- **Big-Picture Questions:**
  - How can we effectively define and address the regional uncertainty problem across scales and domains?
  - What methodologies can best handle deep uncertainties that are difficult to characterize or propagate?
  - The group acknowledged the need for better benchmarks and standardized practices for comparing UQ algorithms across applications.
- Despite the limited new insights from the discussion, the event underscored the importance of computational efficiency and collaboration in addressing the scalability and complexity of regional uncertainty quantification.

More Information

Additional SimCenter Community Roundtable meetings can be found at https://simcenter.designsafe-ci.org/collaborate/scr/.

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