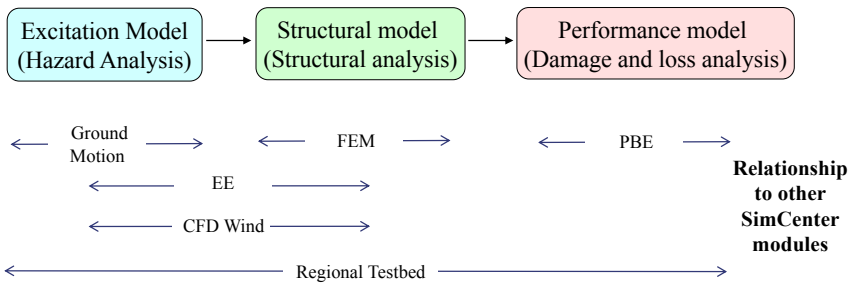

## UQ characterization in natural hazards

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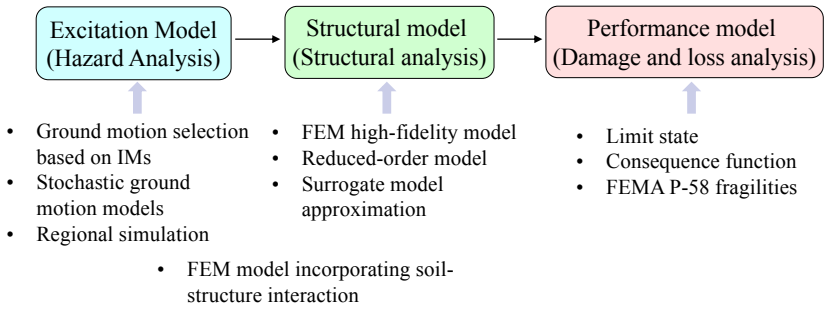
# UQ characterization (Earthquake)

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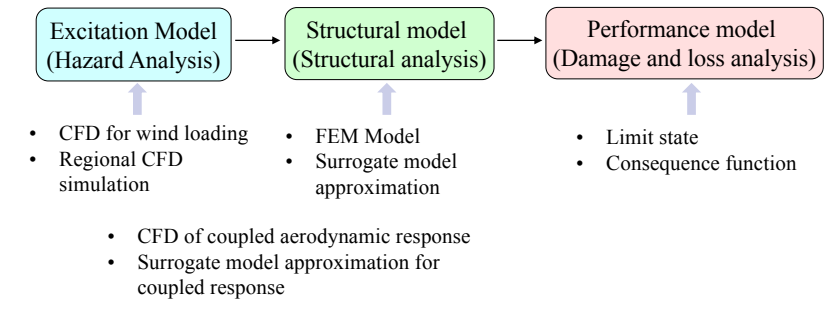
# UQ characterization (Wind)

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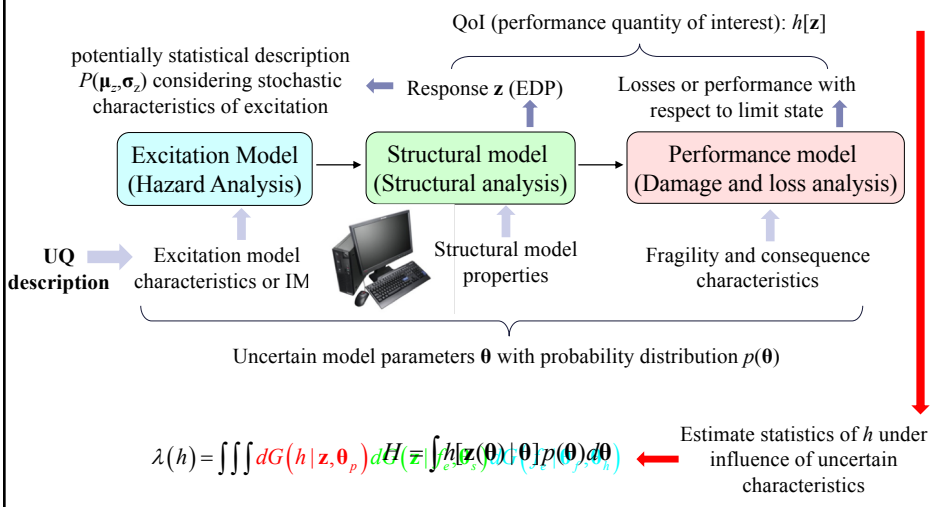
# UQ characterization in natural hazards

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# UQ in SimCenter

- Performance quantification is decomposed to three different modules:
  - **Hazard** (Exposure)
  - **Structural analysis** (Vulnerability)
  - **Loss/performance assessment** (Consequences)
- Hypothesis for ***computational modeling***: response **z** (EDPs) might be computationally intensive to obtain with models that have black box characteristics. Consequences given response $h[\mathbf{z}]$ are analytically tractable and not computationally demanding
- ***UQ objectives related to natural hazards***
  - Address uncertainties in Hazard/Structural/Loss Assessment **model characteristics θ**
    $H=\int h[\mathbf{z}(\boldsymbol{\theta})\,|\,\boldsymbol{\theta}]\,p(\boldsymbol{\theta})\,d\boldsymbol{\theta}$
  - Estimate **statistics of response** considering stochastic (aleatoric) hazard variability
    $G(\mathbf{z}\,|\,f_e,\boldsymbol{\theta}_s)$
  - Provide guidance in defining uncertainties for **θ** and quantifying their importance
- Need to address features associated with natural hazard applications
  - Extreme value statistics approximation
  - Rare event simulation
  - Potentially high modelling complexity

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# Uncertainty propagation tools

**DAKOTA**
implementation

**Integration**
of user supplied algorithms

$G(\mathbf{z} \mid f_e, \boldsymbol{\theta}_s)$ $\quad H = \int h[\mathbf{z}(\boldsymbol{\theta}) \mid \boldsymbol{\theta}] p(\boldsymbol{\theta}) d\boldsymbol{\theta}$

Response **z** $\quad$ QoI $h[.]$

Excitation Model (Hazard Analysis) → Structural model (Structural analysis) → Performance model (Damage and loss analysis)

***Estimation of probabilistic performance***

- Point estimation methods
  - FORM, SORM
  - Taylor series expansion
- Stochastic simulation techniques
  - Monte Carlo simulation (for response statistics)
  - Advanced Monte Carlo approaches (Importance Sampling, Cross Entropy) for infrequent limit state performance approximation
  - Markov Chain Monte Carlo (Subset Simulation) for rare event simulation

***Approximation of response statistics***

$\boldsymbol{\theta}^* = \arg\max\left(h[\mathbf{z}(\boldsymbol{\theta}) \mid \boldsymbol{\theta}] p(\boldsymbol{\theta})\right)$ Approximation of random variables with extreme event characteristics

$H = F(\boldsymbol{\theta}^*)$

***Global sensitivity analysis***

$H \approx \frac{1}{M} \sum_{j=1}^{M} h[\mathbf{z}(\boldsymbol{\theta}^j) \mid \boldsymbol{\theta}^j] \frac{p(\boldsymbol{\theta}^j)}{q(\boldsymbol{\theta}^j)}$ (Identification of importance of different model characteristics)

$\boldsymbol{\theta}^j \sim q(\boldsymbol{\theta})$ Sobol indices (first order, total) calculated through MC analysis or surrogate model decomposition

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# FEM model calibration

**DAKOTA**
implementation

**Integration**
of user supplied algorithms

$H = \int h[\mathbf{z}(\boldsymbol{\theta}) \mid \boldsymbol{\theta}] p(\boldsymbol{\theta}) d\boldsymbol{\theta}$

Response **z** $\quad$ QoI $h[.]$

Excitation Model (Hazard Analysis) → Structural model (Structural analysis) → Performance model (Damage and loss analysis)

**Data** $D$ → $p(\boldsymbol{\theta} \mid D) = \frac{p(D \mid \boldsymbol{\theta}) p(\boldsymbol{\theta})}{P(D)}$

***Bayesian updating***

- Maximum likelihood estimation (optimization-based) $\quad \boldsymbol{\theta}^* = \arg\max p(D \mid \boldsymbol{\theta}) p(\boldsymbol{\theta})$ $\quad \boldsymbol{\theta}^* = \arg\max p(D \mid \boldsymbol{\theta})$
- Advanced Markov Chain Monte Carlo (stochastic-simulation based) $\{\boldsymbol{\theta}^j\} \sim p(D \mid \boldsymbol{\theta}) p(\boldsymbol{\theta})$

***Model class selection***

- Laplace's asymptotic expansion (optimization-based)
- Advanced Markov Chain Monte Carlo (stochastic-simulation based)

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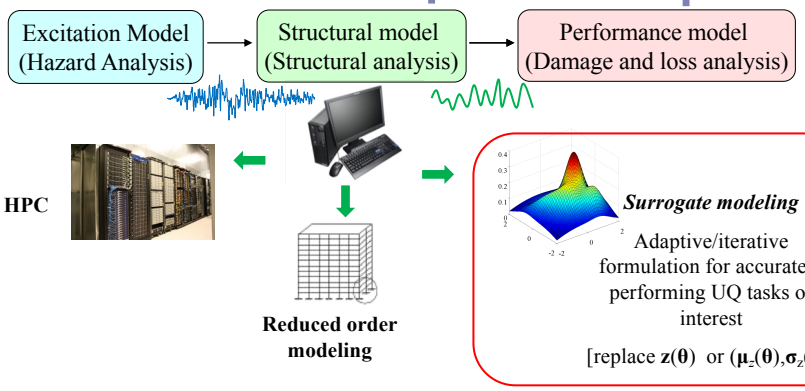
# Addressing model complexity

**DAKOTA**
implementation

**Integration**
of user supplied algorithms

$G(\mathbf{z} \mid f_e, \boldsymbol{\theta}_s)$ $H = \int h[\mathbf{z}(\boldsymbol{\theta}) \mid \boldsymbol{\theta}] p(\boldsymbol{\theta}) d\boldsymbol{\theta}$

Response **z** QoI $h[.]$






# (Performance Based) Design under uncertainty

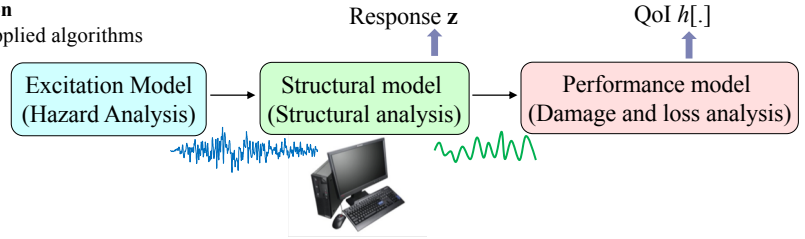
**DAKOTA**
implementation

Controllable properties
(design variables **x**)

$H(\mathbf{x}) = \int h[\mathbf{z}(\boldsymbol{\theta}, \mathbf{x}) \mid \boldsymbol{\theta}, \mathbf{x}] p(\boldsymbol{\theta}) d\boldsymbol{\theta}$

**Integration**
of user supplied algorithms

Response **z** QoI $h[.]$




**Single and multi-objective optimization under uncertainty problems**

$\mathbf{x}^* = \arg\min H(\mathbf{x})$

$\mathbf{x}^* = \arg\min \{H_i(\mathbf{x})\}$

- Problem formulation (role of risk aversion in decision making)
- Incorporation of PBE advances in quantifying performance

- Algorithmic efficiency for performing optimization
  - Surrogate model –aided optimization

# Feedback for UQ development

- Interest in UQ
  - User of tools of SimCenter?
  - Contributor of tools? What type?
  - In what specific UQ sub-problem?
- Characteristics for applications/algorithms of interest
  - Type of QoI examined?
  - Dimension of uncertain model characteristics $\boldsymbol{\theta}$?
  - Complexity of numerical models used?
  - Features of problem that create challenges (rare event properties for example)?



# UQ development milestones

- Implementation of advanced Monte Carlo tools [Aug 2018]. Refinement [Dec 2018].
- Implementation of sensitivity analysis tools for first order and total Sobol' indices [Aug 2018]. Refinement [Dec 2018].
- Fundamental tools for Bayesian updating [Aug 2018].
- Preliminary iterative/adaptive surrogate model implementation for rare event simulation [Aug 2018]. Advanced implementation [Mar 2018].
- Iterative/adaptive surrogate model implementation for Bayesian posterior analysis [Mar 2018]
- Tools for single-objective design under uncertainty problems [Mar 2018]