VERIFICATION VALIDATION AND UNCERTAINTY QUANTIFICATION

Introduction to VVUQ | Part 4
Uncertainty Quantification

Task Group on VVUQ Concepts in Engineering Education

ASME Codes & Standards | Committee on Verification, Validation, and Uncertainty Quantification

Contacts: Lydia Stanford (stanfordl@asme.org) | Daniel Papert (papertd@asme.org)

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Outline

- What is uncertainty quantification and why do we care?
- Steps of uncertainty quantification and how it is performed
  - Characterization of uncertainties
  - Propagation of uncertainties
  - Interpretation of uncertainties
- Sensitivity Analysis

What is uncertainty quantification and why do we care?

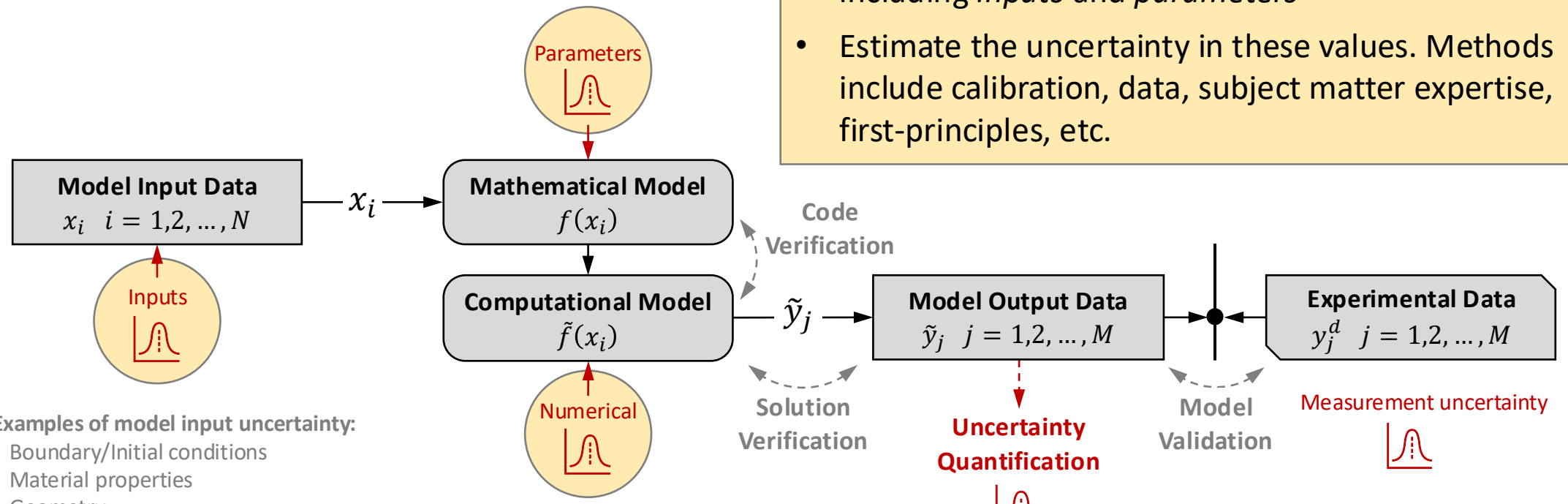
- **Uncertainty Quantification** (UQ) is the process of using statistical models to provide an estimate of uncertainty in the experimental and simulation results.

- Uncertainty Quantification has three basic steps:
  - **Characterize Uncertainties:** Identify all relevant uncertainties and characterize the uncertainties as much as is possible
  - **Propagate Uncertainties:** Perform model evaluations to estimate the impact of model input uncertainties on the system response quantities of interest (QoIs)
  - **Interpret Results:** Compute and explain the sources and impact of the uncertainties to the simulation customer

- Uncertainty quantification is important because it informs the customer of the simulation results how the uncertainties impact the simulation results.

Characterize uncertainties

- Identify most import sources of uncertainties including *inputs* and *parameters*
- Estimate the uncertainty in these values. Methods include calibration, data, subject matter expertise, first-principles, etc.



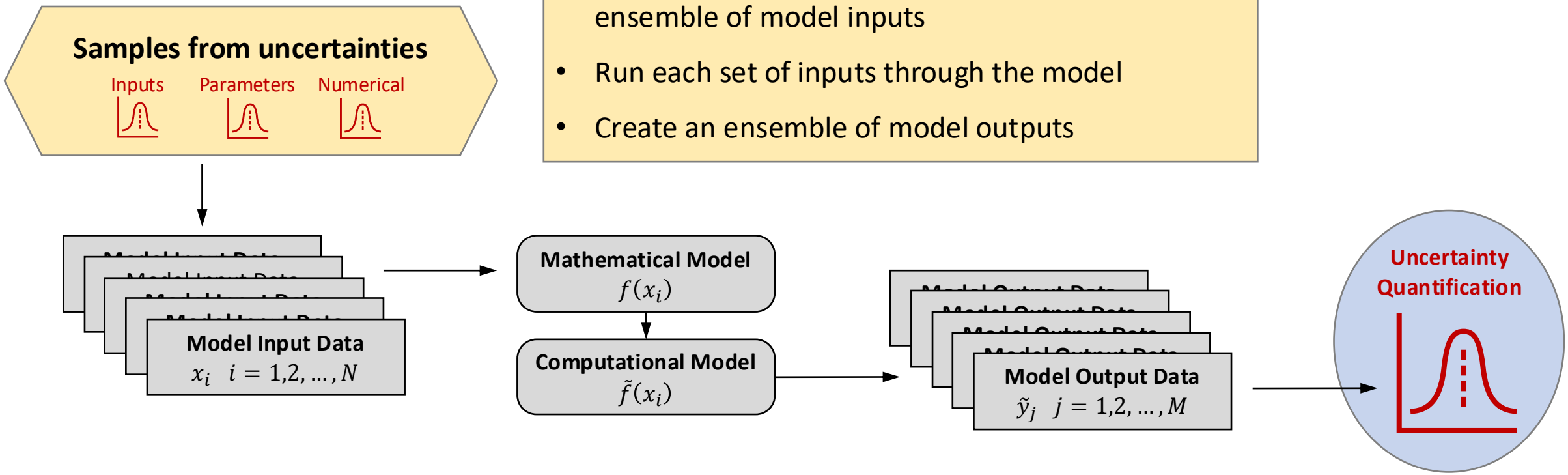
Examples of model input uncertainty:
- Boundary/Initial conditions
- Material properties
- Geometry
- Measurement uncertainty (inputs)

Examples of model uncertainty:
- Model form (physical assumptions/simplifications)
- Parameters (calibration/tuning)
- Numerical errors (solution errors, surrogate model errors, statistical sampling errors)

Examples of measurement uncertainty:
- Limited number of measurements
- Statistical sampling errors
- Measurement bias
- Data reduction

Propagate uncertainties and interpret results

- Take samples of uncertainty sources to create an ensemble of model inputs
- Run each set of inputs through the model
- Create an ensemble of model outputs



Results can be interpreted in many ways including:

- Mean and standard deviation
- Median and other percentiles
- Histogram or probability distribution

Rank the impact of uncertain inputs using sensitivity analysis

Closely related to UQ is **Sensitivity Analysis** where the importance of the model parameters are identified and potentially ranked.

Various approaches:

- **Local Sensitivity Analysis:** Estimate sensitivity with small perturbations to the nominal model parameters
- **Global Sensitivity Analysis:** Evaluate the sensitivity over the full range of the parameters

Sensitivity Analysis can be used to:

- Select optimal design parameters to achieve system performance requirements
- Identify the largest contributors to uncertainty in system responses

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