VERIFICATION VALIDATION AND UNCERTAINTY QUANTIFICATION

Introduction to VVUQ | Part 1
Simulation Credibility Assessment

Task Group on VVUQ Concepts in Engineering Education

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

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Outline

- Why do we care?
- Structure of a simulation model
- How is a simulation model assessed?
- How is simulation credibility assessed?
- Context of use of the simulation

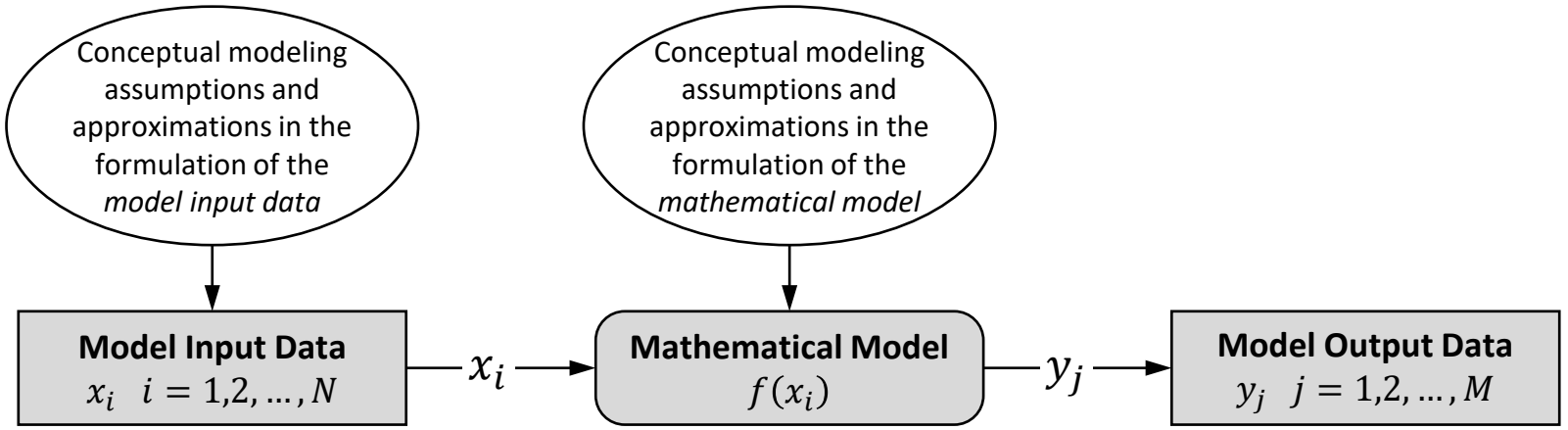
Why do we care?

- “All models are wrong – some are useful.” – Prof. George E. P. Box
- Why is this true?
  - All models rely on assumptions and approximations in the formulation of the model
  - All models require input data to describe the system of interest and its surroundings, which are approximate or possibly not measurable
  - All models require numerical solution, which results in numerical errors
- Infamous system failures due to erroneous modeling:

Space Shuttle Columbia Disaster

Fukushima Nuclear Disaster

Structure of a simulation model



Examples of model input data:
- System mass
- System geometry
- Thermal conductivity
- Young's modulus
- System initial conditions
- External loading
- Magnetic field intensity
- Acoustic environment

Examples of mathematical models:
- Nonlinear algebraic equation
- Ordinary differential equation
- Partial differential equation
- Integral equation

Examples of model output data:
- System thermal response
- System deflection
- Local stress and strain
- Vibrational modes of a structure
- Fluid lift and drag
- Electrical current
- Magnetic field strength
- Acoustic response

How is a simulation model assessed?

- Simulation models are used to produce **information** about the system of interest and its response.

- Examples how this information can be used:
  - Design of new systems or modification of existing systems
  - Optimization of system design to increase performance, reliability, and safety
  - Reduce development time and physical testing of the final system
  - Assess system safety in untestable accident environments

- Simulation models are assessed for:
  - Accuracy and uncertainty in the simulation result
  - Credibility and applicability of the simulation result to the issue at hand
  - Time and cost to develop a simulation model vs physical testing of the system
  - Are the approximations and assumptions in construction of the model consistent with the **context of use** of the model?

How is simulation credibility assessed?

- Numerical accuracy is assessed by simulation verification:
  - **Simulation verification:** assessment of the accuracy of the numerical solution relative to the exact solution of the mathematical model
- Physics-based accuracy is assessed by model validation:
  - **Model validation:** assessment of the accuracy of the simulation result relative to experimental measurements of the system responses
- Uncertainty in the simulation result is assessed by uncertainty quantification:
  - **Uncertainty quantification:** estimation of the total uncertainty in the simulation result due to all sources of error and uncertainty
- These assessments are collectively referred to as **VVUQ**

- Note: These concepts of verification and validation are *distinctly different* from the systems engineering concepts of V&V

Context of use of the simulation

- **Context of use:** the relationship between the applicability and accuracy of the model relative to the requirements for the intended use of the model

- Examples of issues related to the context of use:
  - Are the assumptions and approximations of the formulation of the model consistent with the intended use of the model?
  - Is the accuracy and uncertainty of the simulation result sufficient for the needs of the intended use of the model?
  - Are the VVUQ assessment activities sufficient to insure credibility for the intended use of the model?
  - Are the conditions of model validation sufficiently relevant to the actual conditions of the system of interest?
  - What are the consequences and risks involved if the simulation result is inaccurate?

References

- AIAA (2021), "Recommended Practice: Code Verification in Computational Fluid Dynamics." American Institute of Aeronautics and Astronautics, AIAA R-141-2021, Reston, VA.
- ASME (2019), "Standard for Verification and Validation in Computational Solid Mechanics." American Society of Mechanical Engineers, ASME Standard V&V 10-2019, New York, NY.
- ASME (2021), "The Role of Uncertainty Quantification in Verification and Validation of Computational Solid Mechanics Models," American Society of Mechanical Engineers, ASME VVUQ 10.2-2021.
- ASME (2022), "Verification, Validation, and Uncertainty Quantification Terminology in Computational Modeling and Simulation," American Society of Mechanical Engineers, ASME VVUQ 1-2022.
- McClarren, R. G. (2018), Uncertainty Quantification and Predictive Computational Science, Springer, Cham, Switzerland.
- NaRC (2012), "Assessing the Reliability of Complex Models: Mathematical and Statistical Foundations of Verification, Validation, and Uncertainty Quantification." National Research Council of the National Academies, ISBN-13: 978-0-309-25634-6, Washington, DC.
- NASA (2016), "Standard for Models and Simulations." National Aeronautics and Space Administration, NASA-STD-7009A, Washington, DC.
- Oberkampf, W. L. and C. J. Roy (2010), Verification and Validation in Scientific Computing, Cambridge University Press, UK.
- Roache, P. J. (2009), Fundamentals of Verification and Validation, Hermosa Publishers, Socorro, New Mexico.
- TMS (2019), Verification & Validation of Computational Models Associated with the Mechanics of Materials, The Minerals, Metals & Materials Society, ISBN 978-0-578-45369-9, Pittsburgh, PA.