VERIFICATION
VALIDATION
AND
UNCERTAINTY
QUANTIFICATION

Introduction to VVUQ | Part 2

Verification

Task Group on VVUQ Concepts in Engineering Education

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

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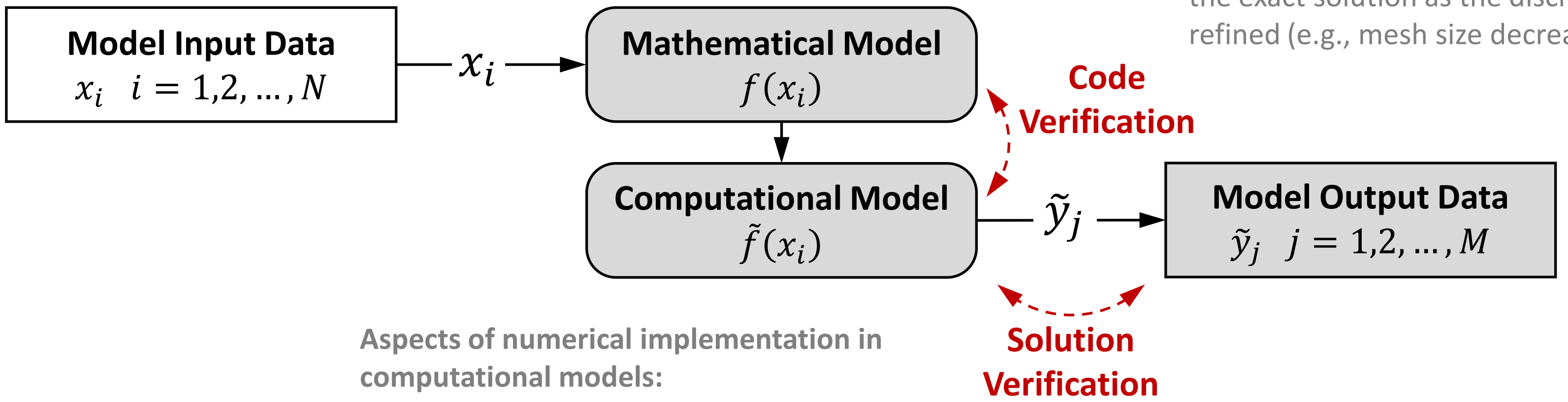
Module Outline

- What is verification, and why do we care?
- Verification activities: code and solution verification
- How is code verification performed?
- How is solution verification performed?

What is verification and why do we care?

- Verification is the process that establishes the *mathematical correctness* and *numerical accuracy* of the computational model result.
- Verification includes two different activities:
  1. **Code verification** is the process of determining that the mathematical model is correctly implemented in the computer code. Code verification *evaluates* the numerical error using a reference solution.
  2. **Solution verification** is the process of determining the numerical accuracy of an output quantity of the computational model for the application of interest. Solution verification *estimates* the numerical error of the output quantity of interest.

Verification activities



Examples of code verification activities:

- Check for coding errors
- Check numerical solution convergence to the exact solution as the discretization is refined (e.g., mesh size decreases)

Aspects of numerical implementation in computational models:

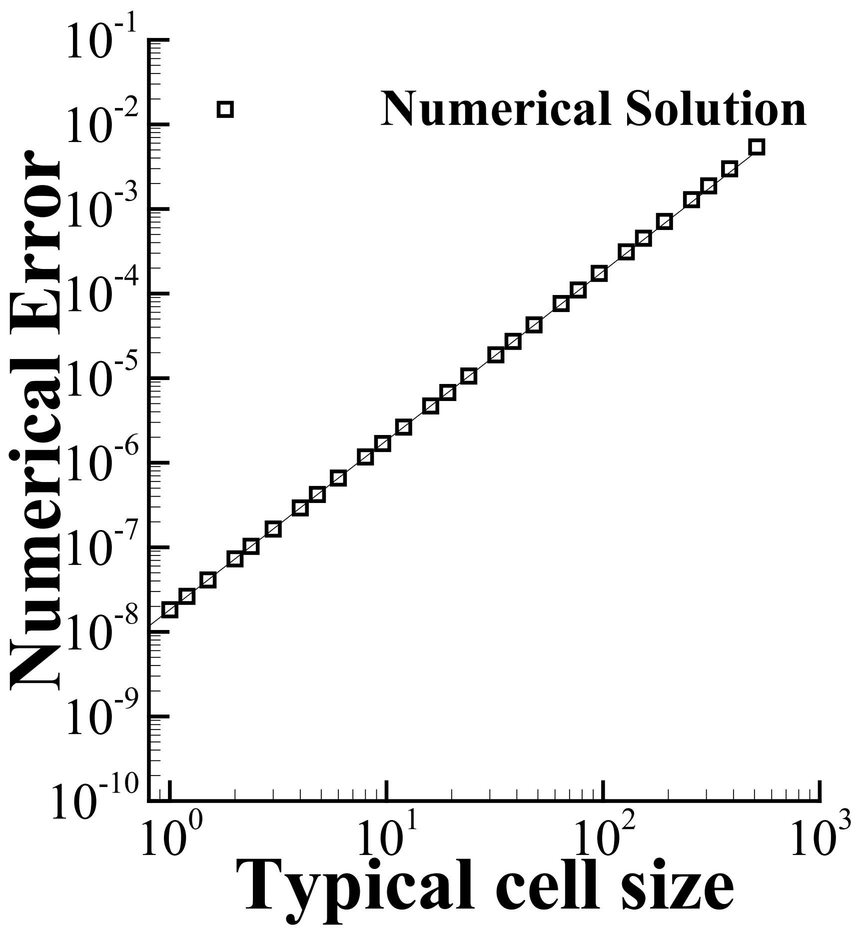
- Discretization of equations in space and time
- Algorithms (linearization, iterative methods, coupling,…)
- Computer programming (coding)
- Discretization of domain (meshing, time stepping)

Examples of numerical errors assessed in solution verification:

- Round-off errors
- Iterative errors
- Discretization errors
- Statistical sampling errors

How is it code verification performed?

- Code verification requires a *known solution* to a problem that is solved with the mathematical model used in the application of interest. For example, a problem that uses the same terms for the transport of mass, momentum and energy as the application of interest.
- Known reference solutions can come from:
  - Classical analytical solutions
  - Manufactured solutions
  - Highly accurate numerical solutions
- Numerical solutions are computed and the error is *evaluated* on a series of refined grids and time steps to determine the numerical order of accuracy.
- Code verification is a *software testing procedure*.



How is it solution verification performed?

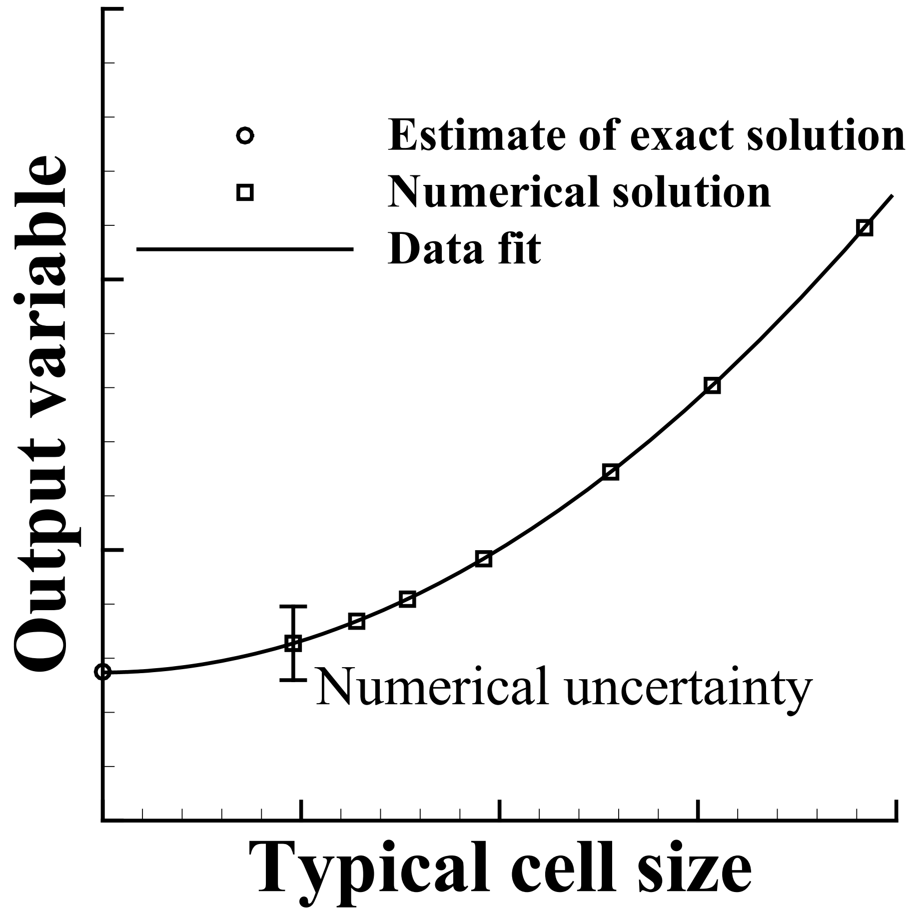
- Solution verification is the process of estimating the numerical solution error in the model outputs ϕ for the application of interest. Since the exact solution ϕ_{exact} is unknown, there will be uncertainty $U(\phi)$ in the model outputs of interest ϕ

- Computing solutions on multiply refined grids or using multiple time step sizes is a common technique for estimating the numerical uncertainty $U(\phi)$.

- Since the sign of the numerical uncertainty is not known, the estimated bound on the numerical uncertainty is written as

$$\phi_{\text{exact}} - \phi = \pm U(\phi)$$

with a certain degree of confidence



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