What is Verification and Validation?

SETTING THE STANDARD

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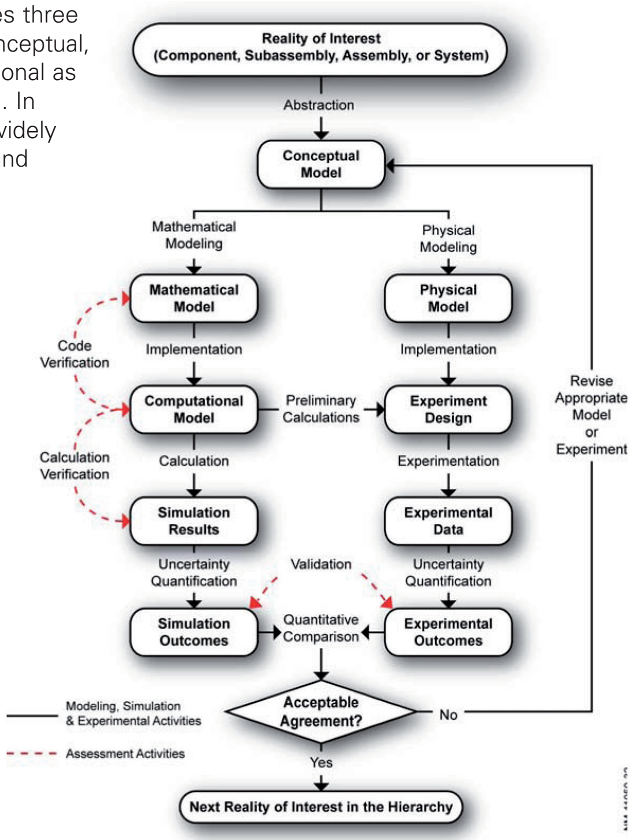
Engineering Simulation involves three types of models, namely Conceptual, Mathematical and Computational as indicated in the flow diagram. In relation to these model types, the widely accepted definitions of Verification and Validation (V&V) are:

- **Verification:**
  The process of determining that a computational model accurately represents the underlying mathematical model and its solution.

- **Validation:**
  The process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model.

Put most simply, Verification is the domain of mathematics and Validation is the domain of physics.



Verification

It follows by definition that it is necessary to establish confidence in the Computational model by carrying out two fundamental processes to collect evidence that for:

1 Code Verification – the mathematical model and solution algorithms are working correctly.

2 Calculation Verification - the discrete solution of the mathematical model is accurate.

Code Verification

In general, Code Verification is the domain of software developers who hopefully use modern Software Quality Assurance techniques along with testing of each released version of the software. Users of software also share in the responsibility for code verification, even though they typically do not have access to the software source.

Among the Code Verification techniques, the most popular method is to compare code outputs with analytical solutions; this type of comparison is the mainstay of regression testing. Unfortunately, the complexity of most available analytical solutions pales compared to even rather routine applications of most commercial software. One Code Verification method with the potential to greatly expand the number and complexity of analytical solutions is what is termed in the V&V literature as manufactured solutions.

Calculation Verification

The other half is what is termed Calculation Verification, or estimating the errors in the numerical solution due to discretization. However, any comparison of the numerical and analytical results will contain some error, as the discrete solution, by definition, is only an approximation of the analytical solution. So the goal of calculation verification is to estimate the amount of error in the comparison that can be attributed to the discretization.

Discretization error is most often estimated by comparing numerical solutions at two more discretizations (meshes) with increasing mesh resolution, i.e. decreasing element size. The objective of these mesh-to-mesh comparisons is to determine the rate of convergence of the solution.
The main responsibility for Calculation Verification rests with the analyst, or user of the software. While it is clearly the responsibility of the software developers to assure that their algorithms are implemented correctly, they cannot provide any assurance that a user-developed mesh is adequate to obtain the available algorithmic accuracy, i.e. large solution errors due to use of an coarse (unresolved) mesh are attributable to the software user. The lack of mesh-refinement studies in solid mechanics is often the largest omission in the verification process. This is particularly distressing, since it is relatively easy to remedy using available adaptive meshing techniques.

Validation

Neither part of Verification addresses the question of the adequacy of the selected models for representing the reality of interest. Answering the adequacy question is the domain of Validation, i.e. are the mechanics (physics) included in the models sufficient to provide reliable answers to the questions posed in the problem statement.

The manner in which the mathematics and physics interact in the V&V process is illustrated in the flow chart. After the selection of the Conceptual model, the V&V process has two branches: the left branch contains the modeling elements and the right branch the physical testing (experimental) elements.

This figure is intentionally designed to illustrate the paramount importance of physical testing in the V&V process, as ultimately, it is only through physical observations (experimentation) that assessments about the adequacy of the selected Conceptual and

Mathematical models for representing the reality of interest can be made. Close cooperation among modelers and experimentalist is required during all stages of the V&V process, until the experimental outcomes are obtained. Close cooperation is required because often the mathematical and physical model will be different. As an example consider a fixed-end condition, the two groups will have quite different views of the Conceptual model, (clamped) boundary for a cantilever beam as an example. Mathematically this boundary condition is quite easy to specify, but in the laboratory there is no such thing as a 'clamped' boundary. In general, some parts of the Conceptual model will be relatively easy to include in either the mathematical or physical model, and others more difficult. A dialogue between the modelers and experimentalist is critical to resolve these differences. To aid in this dialogue, the 'cross-talk' activity labeled as "Preliminary Calculations" in the chart is intended to emphasize the goal that both numerical modelers and experimentalist attempt to model the same Conceptual model.

Of equal importance is the idea that the experimental outcomes should not be revealed to the modelers until they have completed the simulation outcomes. The chief reason for segregation of the outcomes is to enhance the confidence in the model's predictive capability. When experimental outcomes are made available to modelers prior to establishing their simulation outcomes, the human tendency is to 'tune' the model to the experimental outcomes to produce a favorable comparison. This tendency decreases the level of confidence in the model's ability to predict, and moves the focus to the model's ability to mimic the provided experimental outcomes.

Lastly, the role of uncertainty quantification (UQ), again for both modelers and experimentalists, is emphasized. It is excepted that when more than one experiment is performed they produce somewhat different results. It is the role of UQ to quantify "somewhat" in a meaningful way. Similarly, every computation involves both numerical and physical parameters that have ranges, and likely distributions, of values. Uncertainty quantification techniques attempt to quantify the affect of these parameter variations on the simulation outcomes.

Further Reading

Guide for Verification and Validation in Computational Solid Mechanics available through ASME publications as V&V 10-2006