



Verification and validation in computational engineering and science: basic concepts

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1. Introduction

Computational engineering and science, the discipline concerned with the use of computational methods and devices to simulate physical events and engineering systems, is being heralded by many as one of the most important developments in recorded history [11]. Computer predictions of physical events, it is argued, can be of enormous importance in making critical decisions that affect every facet of human existence. As the speed and capacity of computer systems continue to grow, the expectations of users of computer models in decision making continues to grow in kind. Today, some look toward computer-based predictions as a means to obtain vital quantitative information on events that influence the security, health, and well being of much of mankind and many nations and that influence the success of major businesses and other enterprises worldwide.

It is understandable that the reliability of computer predictions has been an issue of growing concern for several decades. Major questions that arise with increasing frequency are “can computer predictions be used as a reliable bases for crucial decisions? How can one assess the accuracy or validity of a computer prediction? What confidence can be assigned to a computer prediction of a complex event?” **The collection of processes, philosophical issues, and procedures connected with answering these questions has become known as the subject of verification and validation (V&V),** the verification process addressing the quality of the numerical treatment of the model used in the prediction and the validation process addressing the quality of the model. V&V has been the focus of much study and debate for many years, and a relatively large literature exists on the subject. Among noteworthy works on the subject in the engineering literature are the book of Roache [14], the survey articles of Oberkampf and collaborators, e.g. [9,10], the AIAA standards on the subject as it applies to computational and fluid dynamics [3]. Many other relevant references are cited in these works. Closely akin to works on V&V are those on risk analysis prevalent in applications in, for example, civil engineering [6,7], nuclear engineering [4,13], and in environmental engineering and sciences [2].

The broad interest in V&V in many different scientific and technological areas has led to a diverse and often incompatible list of definitions and concepts as it pertains to different disciplines. Moreover, despite the fact that modern views of the subject have been under development for nearly a decade, much remains to be done toward developing concrete approaches for implementing V&V procedures for particular applications.

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Verification And Validation In Computational Science And Engineering

**William L. Oberkampf, Christopher J.
Roy**



Verification And Validation In Computational Science And Engineering:

Verification and Validation in Computational Science and Engineering Patrick J. Roache, 1998 **Verification and Validation in Scientific Computing** William L. Oberkampf, Christopher J. Roy, 2010-10-14 Advances in scientific computing have made modelling and simulation an important part of the decision making process in engineering science and public policy This book provides a comprehensive and systematic development of the basic concepts principles and procedures for verification and validation of models and simulations The emphasis is placed on models that are described by partial differential and integral equations and the simulations that result from their numerical solution The methods described can be applied to a wide range of technical fields from the physical sciences engineering and technology and industry through to environmental regulations and safety product and plant safety financial investing and governmental regulations This book will be genuinely welcomed by researchers practitioners and decision makers in a broad range of fields who seek to improve the credibility and reliability of simulation results It will also be appropriate either for university courses or for independent study Measures of Agreement Between Computation and Experiment William L. Oberkampf, Matthew Franklin Barone, 2005 **Scale-Up Processes** Jamal Chaouki, Rahmat Sotudeh-Gharebagh, 2021-09-20 Common scale up methods are conventional where the blind piloting is essential This imposes huge investment and leads to failures mostly in solid processing However the limitations of resources current shortcomings short time to market demand are forced companies to minimize piloting With these situations in mind current digitalization outlook and computational facilities we proposed and developed a novel iterative scale up method with case studies which highly expedites the process innovation through the following key sequences Engineering Design Reliability Handbook Efstratios Nikolaidis, Dan M. Ghiocel, Suren Singhal, 2004-12-22 Researchers in the engineering industry and academia are making important advances on reliability based design and modeling of uncertainty when data is limited Non deterministic approaches have enabled industries to save billions by reducing design and warranty costs and by improving quality Considering the lack of comprehensive and definitive presentations on the subject Engineering Design Reliability Handbook is a valuable addition to the reliability literature It presents the perspectives of experts from the industry national labs and academia on non deterministic approaches including probabilistic interval and fuzzy sets based methods generalized information theory Dempster Shaffer evidence theory and robust reliability It also presents recent advances in all important fields of reliability design including modeling of uncertainty reliability assessment of both static and dynamic components and systems design decision making in the face of uncertainty and reliability validation The editors and the authors also discuss documented success stories and quantify the benefits of these approaches With contributions from a team of respected international authors and the guidance of esteemed editors this handbook is a distinctive addition to the acclaimed line of handbooks from CRC Press *Extension of Latin Hypercube Samples with Correlated Variables* William L. Oberkampf, Timothy Guy Trucano, 2007 Verification and

validation V V are the primary means to assess the accuracy and reliability of computational simulations V V methods and procedures have fundamentally improved the credibility of simulations in several high consequence fields such as nuclear reactor safety underground nuclear waste storage and nuclear weapon safety Although the terminology is not uniform across engineering disciplines code verification deals with assessing the reliability of the software coding and solution verification deals with assessing the numerical accuracy of the solution to a computational model Validation addresses the physics modeling accuracy of a computational simulation by comparing the computational results with experimental data Code verification benchmarks and validation benchmarks have been constructed for a number of years in every field of computational simulation However no comprehensive guidelines have been proposed for the construction and use of V V benchmarks For example the field of nuclear reactor safety has not focused on code verification benchmarks but it has placed great emphasis on developing validation benchmarks Many of these validation benchmarks are closely related to the operations of actual reactors at near safety critical conditions as opposed to being more fundamental physics benchmarks This paper presents recommendations for the effective design and use of code verification benchmarks based on manufactured solutions classical analytical solutions and highly accurate numerical solutions In addition this paper presents recommendations for the design and use of validation benchmarks highlighting the careful design of building block experiments the estimation of experimental measurement uncertainty for both inputs and outputs to the code validation metrics and the role of model calibration in validation It is argued that the understanding of predictive capability of a computational model is built on the level of achievement in V V activities how closely related the V V benchmarks are to the actual application of interest and the quantification of uncertainties related to the application of interest

Fundamentals of Finite Element Analysis Ioannis Koutromanos, 2017-11-15 An introductory textbook covering the fundamentals of linear finite element analysis FEA This book constitutes the first volume in a two volume set that introduces readers to the theoretical foundations and the implementation of the finite element method FEM The first volume focuses on the use of the method for linear problems A general procedure is presented for the finite element analysis FEA of a physical problem where the goal is to specify the values of a field function First the strong form of the problem governing differential equations and boundary conditions is formulated Subsequently a weak form of the governing equations is established Finally a finite element approximation is introduced transforming the weak form into a system of equations where the only unknowns are nodal values of the field function The procedure is applied to one dimensional elasticity and heat conduction multi dimensional steady state scalar field problems heat conduction chemical diffusion flow in porous media multi dimensional elasticity and structural mechanics beams shells as well as time dependent dynamic scalar field problems elastodynamics and structural dynamics Important concepts for finite element computations such as isoparametric elements for multi dimensional analysis and Gaussian quadrature for numerical evaluation of integrals are presented and explained Practical aspects of FEA and

advanced topics such as reduced integration procedures mixed finite elements and verification and validation of the FEM are also discussed Provides detailed derivations of finite element equations for a variety of problems Incorporates quantitative examples on one dimensional and multi dimensional FEA Provides an overview of multi dimensional linear elasticity definition of stress and strain tensors coordinate transformation rules stress strain relation and material symmetry before presenting the pertinent FEA procedures Discusses practical and advanced aspects of FEA such as treatment of constraints locking reduced integration hourglass control and multi field mixed formulations Includes chapters on transient step by step solution schemes for time dependent scalar field problems and elastodynamics structural dynamics Contains a chapter dedicated to verification and validation for the FEM and another chapter dedicated to solution of linear systems of equations and to introductory notions of parallel computing Includes appendices with a review of matrix algebra and overview of matrix analysis of discrete systems Accompanied by a website hosting an open source finite element program for linear elasticity and heat conduction together with a user tutorial Fundamentals of Finite Element Analysis Linear Finite Element Analysis is an ideal text for undergraduate and graduate students in civil aerospace and mechanical engineering finite element software vendors as well as practicing engineers and anybody with an interest in linear finite element analysis **Applied System**

Simulation Mohammad S. Obaidat, Georgios I. Papadimitriou, 2012-12-06 Simulation and modeling are efficient techniques that can aid the city and regional planners and engineers in optimizing the operation of urban systems such as traffic light control highway toll automation consensus building public safety and environmental protection When modeling transportation systems such as freeway systems arterial or downtown grid systems the city planner and engineer is concerned with capturing the varied interactions between drivers automobiles and the infrastructure Modeling and simulation are used to effectively optimize the design and operation of all of these urban systems It is possible that in an urban simulation community workshop citizens can work interactively in front of computers and be able using the click of the mouse to walk up to their own front porch looking at the proposed shopping mall alternatives across the street from virtually any angle and proposed bridge or tunnel and see how it can reduce traffic congestion Buildings can be scaled down or taken out their orientation can be changed in order to check the view and orientation in order to have better site with efficient energy conservation The stone or brick material on a building can be replaced by colored concrete or more trees and lampposts can be placed on the site Such flexibility in simulation and animation allows creative ideas in the design and orientation of urban sites to be demonstrated to citizens and decision makers before final realization *Computer*

Simulation Validation Claus Beisbart, Nicole J. Saam, 2019-04-09 This unique volume introduces and discusses the methods of validating computer simulations in scientific research The core concepts strategies and techniques of validation are explained by an international team of pre eminent authorities drawing on expertise from various fields ranging from engineering and the physical sciences to the social sciences and history The work also offers new and original philosophical

perspectives on the validation of simulations Topics and features introduces the fundamental concepts and principles related to the validation of computer simulations and examines philosophical frameworks for thinking about validation provides an overview of the various strategies and techniques available for validating simulations as well as the preparatory steps that have to be taken prior to validation describes commonly used reference points and mathematical frameworks applicable to simulation validation reviews the legal prescriptions and the administrative and procedural activities related to simulation validation presents examples of best practice that demonstrate how methods of validation are applied in various disciplines and with different types of simulation models covers important practical challenges faced by simulation scientists when applying validation methods and techniques offers a selection of general philosophical reflections that explore the significance of validation from a broader perspective This truly interdisciplinary handbook will appeal to a broad audience from professional scientists spanning all natural and social sciences to young scholars new to research with computer simulations Philosophers of science and methodologists seeking to increase their understanding of simulation validation will also find much to benefit from in the text

Mathematical and Computational Modelling Across the Scales Pedro Diez, Matteo Giacomini, 2025-06-25 Many physical and engineering systems deal with micro meso macro and multi scale phenomena The accurate description and the reliable simulation of such phenomena entail major challenges from the point of view of both mathematical modelling and computational engineering This book covers a selection of challenges related to Mathematical and Computational Modelling Across the Scales stemming from the lecture notes of the XX edition of the Jacques Louis Lions Spanish French School in Numerical Simulations in Physics structural health monitoring integrating small scale sensor data in large scale computational models frontier numerical methods for the simulation of geophysical and heliophysical dynamics accounting for multi scale heterogeneous media multi physics multi scale models for the mechanobiology of atheroma plaques formation locomotion models for swimming at the micro scale mathematical foundations of quantum mechanics phenomena at the micro scale The book is addressed to scientists and engineers from both academia and industry interested in the mathematical modelling and numerical simulation of a variety of complex systems in physics and engineering characterised by multiple scales

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