

## MODEL VERIFICATION AND VALIDATION

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### ABSTRACT

In this paper we outline practical techniques and guidelines for verifying and validating simulation models. The goal of verification and validation is a model that is accurate when used to predict the performance of the real-world system that it represents, or to predict the difference in performance between two scenarios or two model configurations. The process of verifying and validating a model should also lead to improving a model's credibility with decision makers. We provide examples of a number of typical situations where model developers may make inappropriate or inaccurate assumptions, and offer guidelines and techniques for carrying out verification and validation.

### 1 WHAT IS VERIFICATION AND VALIDATION?

Models are used to predict or compare the future performance of a new system, a modified system, or an existing system under new conditions. When models are used for comparison purposes, the comparison is usually made to a baseline model representing an existing system, to someone's conception of how a new or modified system will work (i.e., to a baseline design), or to current real-world system performance. In any of these cases we want to know that the model has sufficient accuracy. Sufficient accuracy means that the model can be used as a substitute for the real system for the purposes of experimentation and analysis (assuming that it were possible to experiment with the actual system).

After the first phases of a modeling project – the kickoff meeting, the functional specifications document, and initial model development – the model developer enters into a series of activities called debugging, verification, model review and validation. In fact, writing and seeking approval of the functional specifications document lays the foundation for verification and validation; this is where all modeling assumptions and data requirements are laid out for the project team to review, modify if necessary and approve.

In practice, a model developer intermixes debugging, verification and validation tasks and exercises with model development in a complex and iterative process. We separate them conceptually for explanatory purposes and in the hope that in practice verification and especially validation do not receive less time and effort than their due.

#### 1.1 Definitions

*Debugging* occurs when a model developer has a known "bug" in the model and uses various techniques to determine the cause and fix it.

*Verification* occurs when the model developer exercises an apparently correct model for the specific purpose of finding and fixing modeling errors. It refers to the processes and techniques that the model developer uses to assure that his or her model is correct and matches any agreed-upon specifications and assumptions.

*Validation* occurs when the model developer and people knowledgeable of the real system or new/modified design jointly work to review and evaluate how a model works. It refers to the processes and techniques that the model developer, model customer and decision makers jointly use to assure that the model represents the real system (or proposed real system) to a sufficient level of accuracy.

The verification and validation phases often detect bugs that require further debugging, or incorrect assumptions that require significant model modifications and then further model re-verification and re-validation.

It should also be noted that no model is ever 100% verified or validated. Validation is not an absolute. Any model is a representation of a system, and the model's behavior is at best an approximation to the system's behavior. When we (loosely) say that a model has been verified or validated, we mean that we have explicitly carried out a series of tasks to verify and validate our model to the degree necessary for our purposes. Such V&V is always a matter of judgment to a large extent.

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design risk aware and evidence based smart decision making systems He presents the Shadow CRT Machine which shadows the operations of an actual system to think with decision makers challenge threats and design remedies This is the first book to generalize red teaming RT outside the military and security domains and it offers coverage of RT principles practical and ethical guidelines The author utilizes Gilbert s principles for introducing a science Simplicity where the book follows a special style to make it accessible to a wide range of readers Coherence where only necessary elements from experimentation optimization simulation data mining big data cognitive information processing and system thinking are blended together systematically to present CRT as the science of Risk Analytics and Challenge Analytics Utility where the author draws on a wide range of examples ranging from job interviews to Cyber operations before presenting three case studies from air traffic control technologies human behavior and complex socio technical systems involving real time mining and integration of human brain data in the decision making environment

**Index of Conference Proceedings** British Library. Document Supply Centre,2003

**RoadVehicles Surroundings Supervision On-Board Sensors and Communications** Felipe Jimenez,2019-01-29 This book is a printed edition of the Special Issue Road Vehicles Surroundings Supervision On Board Sensors and Communications that was published in Applied Sciences

*Spatial Agent-Based Simulation Modeling in Public Health* S. M. Niaz Arifin,Gregory R. Madey,Frank H. Collins,2016-04-11 Presents an overview of the complex biological systems used within a global public health setting and features a focus on malaria analysis Bridging the gap between agent based modeling and simulation ABMS and geographic information systems GIS Spatial Agent Based Simulation Modeling in Public Health Design Implementation and Applications for Malaria Epidemiology provides a useful introduction to the development of agent based models ABMs by following a conceptual and biological core model of *Anopheles gambiae* for malaria epidemiology Using spatial ABMs the book includes mosquito vector control interventions and GIS as two example applications of ABMs as well as a brief description of epidemiology modeling In addition the authors discuss how to most effectively integrate spatial ABMs with a GIS The book concludes with a combination of knowledge from entomological epidemiological simulation based and geo spatial domains in order to identify and analyze relationships between various transmission variables of the disease Spatial Agent Based Simulation Modeling in Public Health Design Implementation and Applications for Malaria Epidemiology also features Location specific mosquito abundance maps that play an important role in malaria control activities by guiding future resource allocation for malaria control and identifying hotspots for further investigation Discussions on the best modeling practices in an effort to achieve improved efficacy cost effectiveness ecological soundness and sustainability of vector control for malaria An overview of the various ABMs GIS and spatial statistical methods used in entomological and epidemiological studies as well as the model malaria study A companion website with computer source code and flowcharts of the spatial ABM and a landscape generator tool that can simulate landscapes with varying spatial heterogeneity of different types of resources including aquatic habitats and houses Spatial

Agent Based Simulation Modeling in Public Health Design Implementation and Applications for Malaria Epidemiology is an excellent reference for professionals such as modeling and simulation experts GIS experts spatial analysts mathematicians statisticians epidemiologists health policy makers as well as researchers and scientists who use manage or analyze infectious disease data and or infectious disease related projects The book is also ideal for graduate level courses in modeling and simulation bioinformatics biostatistics public health and policy and epidemiology

**International Asia Conference on Industrial Engineering and Management Innovation (IEMI2012) Proceedings** Ershi Qi,Jiang Shen,Runliang Dou,2013-05-29 The International Conference on Industrial Engineering and Engineering Management is sponsored by the Chinese Industrial Engineering Institution CMES which is the only national level academic society for Industrial Engineering The conference is held annually as the major event in this arena Being the largest and the most authoritative international academic conference held in China it provides an academic platform for experts and entrepreneurs in the areas of international industrial engineering and management to exchange their research findings Many experts in various fields from China and around the world gather together at the conference to review exchange summarize and promote their achievements in the fields of industrial engineering and engineering management For example some experts pay special attention to the current state of the application of related techniques in China as well as their future prospects such as green product design quality control and management supply chain and logistics management to address the need for amongst other things low carbon energy saving and emission reduction They also offer opinions on the outlook for the development of related techniques The proceedings offers impressive methods and concrete applications for experts from colleges and universities research institutions and enterprises who are engaged in theoretical research into industrial engineering and engineering management and its applications As all the papers are of great value from both an academic and a practical point of view they also provide research data for international scholars who are investigating Chinese style enterprises and engineering management

*Multi-Agent Systems* Adelinde M. Uhrmacher,Danny Weyns,2018-10-08 Methodological Guidelines for Modeling and Developing MAS Based Simulations The intersection of agents modeling simulation and application domains has been the subject of active research for over two decades Although agents and simulation have been used effectively in a variety of application domains much of the supporting research remains scattered in the literature too often leaving scientists to develop multi agent system MAS models and simulations from scratch Multi Agent Systems Simulation and Applications provides an overdue review of the wide ranging facets of MAS simulation including methodological and application oriented guidelines This comprehensive resource reviews two decades of research in the intersection of MAS simulation and different application domains It provides scientists and developers with disciplined engineering approaches to modeling and developing MAS based simulations After providing an overview of the field s history and its basic principles as well as cataloging the various simulation engines for MAS the book devotes three sections to

current and emerging approaches and applications Simulation for MAS explains simulation support for agent decision making the use of simulation for the design of self organizing systems the role of software architecture in simulating MAS and the use of simulation for studying learning and stigmergic interaction MAS for Simulation discusses an agent based framework for symbiotic simulation the use of country databases and expert systems for agent based modeling of social systems crowd behavior modeling agent based modeling and simulation of adult stem cells and agents for traffic simulation Tools presents a number of representative platforms and tools for MAS and simulation including Jason James II SeSAM and RoboCup Rescue Complete with over 200 figures and formulas this reference book provides the necessary overview of experiences with MAS simulation and the tools needed to exploit simulation in MAS for future research in a vast array of applications including home security computational systems biology and traffic management

**Innovative Algorithms and Techniques in Automation, Industrial Electronics and Telecommunications** Tarek Sobh, Khaled Elleithy, Ausif Mahmood, Mohamed Karim, 2007-09-04 Innovative Algorithms and Techniques in Automation Industrial Electronics and Telecommunications includes a set of rigorously reviewed world class manuscripts addressing and detailing state of the art research projects in the areas of Industrial Electronics Technology not only the reviewing submissions and registration processes but also the actual conference Conference participants authors presenters and attendees only needed an internet connection and sound available on their computers in order to be able to contribute and participate in this international ground breaking conference The on line structure of this high quality event allowed academic professionals and industry participants to contribute work and attend world class technical presentations based on rigorously refereed submissions live without the need for investing significant travel funds or time out of the office Suffice to say that CISSE received submissions from more than 70 countries for whose researchers this opportunity presented a much more affordable dynamic and well planned event to attend and submit their work to versus a classic on the ground conference The CISSE conference audio room provided superb audio even over low speed internet connections the ability to display PowerPoint presentations and cross platform compatibility the conferencing software runs on Windows Mac and any other operating system that supports Java In addition the conferencing system allowed for an unlimited number of participants which in turn granted CISSE the opportunity to allow all participants to attend all presentations as opposed to limiting the number of available seats for each session

*Knowledge Processing and Decision Making in Agent-Based Systems* Lakhmi C Jain, Ngoc Thanh Nguyen, 2009-01-17 Knowledge processing and decision making in agent based systems constitute the key components of intelligent machines The contributions included in the book are Innovations in Knowledge Processing and Decision Making in Agent Based Systems Towards Real World HTN Planning Agents Mobile Agent Based System for Distributed Software Maintenance Software Agents in New Generation Networks Towards the Automation of Telecom Processes Multi agent Systems and Paraconsistent Knowledge An Agent based Negotiation Platform for Collaborative Decision Making in

Construction Supply Chain An Event Driven Algorithm for Agents at the Web A Generic Mobile Agent Framework Toward Ambient Intelligence Developing Actionable Trading Strategies Agent Uncertainty Model and Quantum Mechanics Representation Agent Transportation Layer Adaptation System Software Agents to Enable Service Composition through Negotiation Advanced Technology Towards Developing Decentralized Autonomous Flexible Manufacturing Systems

Human-Computer Interaction. Interaction Platforms and Techniques Masaaki Kurosu, 2016-07-04 The 3 volume set LNCS 9731 9732 and 9733 constitutes the refereed proceedings of the 18th International Conference on Human Computer Interaction HCII 2016 held in Toronto ON Canada in July 2016 The total of 1287 papers and 186 posters presented at the HCII 2016 conferences and were carefully reviewed and selected from 4354 submissions The papers thoroughly cover the entire field of Human Computer Interaction addressing major advances in knowledge and effective use of computers in a variety of application areas The volumes constituting the full 27 volume set of the conference proceedings *Highlights on Practical Applications of Agents and Multi-Agent Systems* Javier Bajo Pérez, Juan M. Corchado Rodríguez, Emmanuel Adam, Alfonso Ortega, María N. Moreno, Elena Navarro, Benjamin Hirsch, Henrique Lopes-Cardoso, Vicente Julián, Miguel A. Sánchez, Philippe Mathieu, 2012-03-08 Research on Agents and Multi Agent Systems has matured during the last decade and many effective applications of this technology are now deployed PAAMS provides an international forum to present and discuss the latest scientific developments and their effective applications to assess the impact of the approach and to facilitate technology transfer PAAMS started as a local initiative but has since grown to become THE international yearly platform to present to discuss and to disseminate the latest developments and the most important outcomes related to real world applications It provides a unique opportunity to bring multi disciplinary experts academics and practitioners together to exchange their experience in the development and deployment of Agents and Multi Agent Systems PAAMS intends to bring together researchers and developers from industry and the academic world to report on the latest scientific and technical advances on the application of multi agent systems to discuss and debate the major issues and to showcase the latest systems using agent based technology It will promote a forum for discussion on how agent based techniques methods and tools help system designers to accomplish the mapping between available agent technology and application needs Other stakeholders should be rewarded with a better understanding of the potential and challenges of the agent oriented approach This edition of PAAMS special sessions This symposium is organized by the Bioinformatics Intelligent System and Educational Technology Research Group <http://bisite.usal.es> of the University of Salamanca The present edition will be held in Salamanca Spain from 28th to 30th March 2012 This edition of PAAMS special sessions This symposium is organized by the Bioinformatics Intelligent System and Educational Technology Research Group <http://bisite.usal.es> of the University of Salamanca The present edition will be held in Salamanca Spain from 28th to 30th March 2012 *Operations Management* Massimiliano Schiraldi, 2013-03-13 Operations Management is an area of business concerned with managing

the process that converts inputs into outputs in the form of goods and or services Increasingly complex environments together with the recent economic swings and substantially squeezed industrial margins put extra pressure on companies and decision makers are pushed to increase operations efficiency and effectiveness This book presents the contributions of a selected group of researchers reporting new ideas original results and practical experiences as well as systematizing some fundamental topics in Operations Management Although it represents only a small sample of the research activity on Operations Management people from diverse backgrounds academia industry and research as well as engineering students can take advantage of this volume

**Data Analytics for Cybersecurity** Vandana P. Janeja,2022-07-21 As the world becomes increasingly connected it is also more exposed to a myriad of cyber threats We need to use multiple types of tools and techniques to learn and understand the evolving threat landscape Data is a common thread linking various types of devices and end users Analyzing data across different segments of cybersecurity domains particularly data generated during cyber attacks can help us understand threats better prevent future cyber attacks and provide insights into the evolving cyber threat landscape This book takes a data oriented approach to studying cyber threats showing in depth how traditional methods such as anomaly detection can be extended using data analytics and also applies data analytics to non traditional views of cybersecurity such as multi domain analysis time series and spatial data analysis and human centered cybersecurity

**Proceedings of the 36th Annual Symposium on Simulation** ,2003 The growing awareness of the effects that simulation is having on the way we design our computing communication and control systems is leading to an increased demand for a better understanding of all aspects of simulation ANSS 03 covers broad topics in the areas of distributed systems network modeling and advances in simulation methodology and practices

Pathways to Supply Chain Excellence Ales Groznik,Yu Xiong,2012-03-16 Over the last decade supply chain management has advanced from the warehouse and logistics to strategic management Integrating theory and practices of supply chain management this book incorporates hands on literature on selected topics of Value Creation Supply Chain Management Optimization and Mass Customization These topics represent key building blocks in management decisions and highlight the increasing importance of the supply chains supporting the global economy The coverage focuses on how to build a competitive supply chain using viable management strategies operational models and information technology It includes a core presentation on supply chain management collaborative planning advanced planning and budgeting system risk management and new initiatives such as incorporating anthropometry into design of products

**Introduction to Grid Computing** Frederic Magoules,Jie Pan,Kiat-An Tan,Abhinit Kumar,2009-03-27 A Thorough Overview of the Next Generation in ComputingPoised to follow in the footsteps of the Internet grid computing is on the verge of becoming more robust and accessible to the public in the near future Focusing on this novel yet already powerful technology Introduction to Grid Computing explores state of the art grid projects core grid

Surveys in Operations Research (invited Surveys from 40R) ,2007 **Handbook of Simulation Optimization** Michael



C Fu,2014-11-13 The Handbook of Simulation Optimization presents an overview of the state of the art of simulation optimization providing a survey of the most well established approaches for optimizing stochastic simulation models and a sampling of recent research advances in theory and methodology Leading contributors cover such topics as discrete optimization via simulation ranking and selection efficient simulation budget allocation random search methods response surface methodology stochastic gradient estimation stochastic approximation sample average approximation stochastic constraints variance reduction techniques model based stochastic search methods and Markov decision processes This single volume should serve as a reference for those already in the field and as a means for those new to the field for understanding and applying the main approaches The intended audience includes researchers practitioners and graduate students in the business engineering fields of operations research management science operations management and stochastic control as well as in economics finance and computer science

**Quality Management for Organizations Using Lean Six Sigma Techniques** Erick Jones,2014-02-25 The next step in the evolution of the organizational quality field Lean Six Sigma LSS has come of age However many challenges to using LSS in lieu of in conjunction with or integrated with other quality initiatives remain An update on the current focus of quality management Quality Management for Organizations Using Lean Six Sigma Techniques covers the concepts and principles of Lean Six Sigma and its origins in quality total quality management TQM and statistical process control SPC and then explores how it can be integrated into manufacturing logistics and healthcare operations The book presents the background on quality and Lean Six Sigma LSS techniques and tools previous history of LSS in manufacturing and current applications of LSS in operations such as logistics and healthcare It provides a decision model for choosing whether to use LSS or other quality initiatives which projects should be selected and prioritized and what to do with non LSS projects The author also details an integration model for integrating and developing integrated LSS and other quality initiatives and common mathematical techniques that you can use for performing LSS statistical calculations He describes methods to attain the different Six Sigma certifications and closes with discussion of future directions of Lean Six Sigma and quality Case studies illustrate the integration of LSS principles into other quality initiatives highlighting best practices as well as successful and failed integrations This guide gives you a balanced description of the good bad and ugly in integrating LSS into modern operations giving you the understanding necessary to immediately apply the concepts to your quality processes

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