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Safe, Autonomous and Intelligent Vehicles

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Preface

An autonomous and intelligent system generally refers to a system that can automatically sense and adapt to dynamically varying environment. The term broadly covers numerous emerging and critical applications including self-driving vehicles, unmanned aircraft systems, and autonomous ships. A broad application of modern artificial intelligence and machine learning technologies is featured in these systems.

The design, modeling, verification, and validation of today's autonomous and intelligent systems have become increasingly challenging with growing functional complexity in scale and features, the integration of new artificial intelligence and machine learning technologies, the adoption of more distributed and networked architectural platforms, and stringent demands on various design constraints imposed by performance, fault tolerance, reliability, extensibility, and security. The aforementioned trend on growing complexity presents tremendous design and validation challenges to safety assurance and certification and calls for an immediate attention to this emerging area for developing radically new methodologies and practices to address the grand challenges, as well as enormous opportunities that have been rarely explored in the past.

Over the past several years, a large number of academic articles, technical reports, and industrial whitepapers have been published in this area. However, due to the highly interdisciplinary nature of the area, they are often independently reported across diverse technical communities like verification and validation, artificial intelligence, signal processing, system control, computer vision, and circuit design. Recent research and development in these areas has advanced to the point where an organized, integrated account seamlessly integrating the state of the art is immediately needed. This will help in comparing a large body of techniques in the literature and clarifying their trade-offs in terms of performance, cost, utility, etc. For this reason, there is increasing demand to report the state-of-the-art advances recently made by both academic and industrial researchers closely collaborating together in this area.

This book aims to answer this demand and to cover the important aspects of autonomous and intelligent systems, including perception, decision making, and control. It also covers the important application domains of these systems such as automobile and aerospace and, most importantly, how to define and validate the safety requirements as well as the designed systems, in particular machine learning enabled systems. To achieve these goals, rigorous verification and validation methods are developed to address different challenges, based on formal methods, compositional synthesis, machine learning, adaptive stress testing, statistical validation, model-based design, and cyber resilience.

The main objective of this book is to present the major challenges related to safety of next-generation machine learning enabled autonomous and intelligent systems with growing complexity and new applications, discuss new design and validation methodologies to address these safety issues, and offer sufficient technical background to facilitate more academic and industrial researchers to collaboratively contribute to this emerging and promising area.

We anticipate that this book will provide the knowledge and background for the recent research and development and, more importantly, bring together multiple communities for interdisciplinary cross-culture interaction and set the stage for future growth in the field.

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Durham, NC, USA — Xin Li
Pasadena, CA, USA — Richard M. Murray
Warren, MI, USA — S. Ramesh
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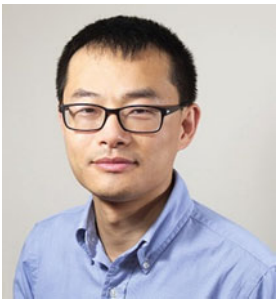

Huafeng Yu is a senior researcher with Boeing Research & Technology. He is currently working on Safety, Assurance and Certification for Unmanned Aircraft Systems and Self-Driving Vehicles and is the technical lead for AI safety and assurance in The Boeing Company. Huafeng's main research interests include formal methods, safety assurance, artificial intelligence, machine learning, model-based engineering, and cyber security. Prior to joining Boeing, he has been working in TOYOTA, ALTRAN, INRIA, Gemplus, and Panasonic. He has more than 15 years of experience in safety research and development in the domains of automobile and aerospace. Huafeng is currently a member of IEEE Technical Committee on Cybernetics for Cyber-Physical Systems (CCPS) and chair of its industry outreach subcommittee. He has been a member of SAE standard committee for AADL. Huafeng serves as associate editor of *IET Journal on Cyber-Physical Systems* and guest editor of *IEEE Transaction on Sustainable Computing* and *ACM Transactions on Cyber-Physical Systems*. He has served on Program Committees of DAC, DATE, ICCAD, SAC, ICPS, DASC, SmartWorld, ARCH, SLIP, WICSA and CompArch, and AVICPS. Huafeng received his PhD from INRIA and the University of Lille 1 (France, 2008) and master's from University Joseph Fourier (France, 2005), both in computer science.

Xin Li received his Ph.D. degree in electrical and computer engineering from Carnegie Mellon University, Pittsburgh, PA, in 2005, and his M.S. and B.S. degrees in electronics engineering from Fudan University, Shanghai, China, in 2001 and 1998, respectively. He is currently a professor in the Department of Electrical and Computer Engineering at Duke University, Durham, NC, and is leading the Institute of Applied Physical Sciences and Engineering (iAPSE) at Duke Kunshan University, Kunshan, Jiangsu, China. In 2005, he co-founded Xigmix Inc. to commercialize his PhD research and served as the Chief Technical Officer until the company was acquired by Extreme DA in 2007. From 2009 to 2012, he was the Assistant Director for FCRP Focus Research Center for Circuit & System Solutions (C2S2), a national consortium working on next-generation integrated circuit design challenges. He is now on the Board of Directors for R&D Smart Devices (Hong Kong) and X&L Holding (Hong Kong). His research interests include integrated circuit, signal processing, and data analytics. Dr. Xin Li is the Deputy Editor-in-Chief of *IEEE TCAD*. He was an Associate Editor of *IEEE TCAD*, *IEEE TBME*, *ACM TODAES*, *IEEE D&T*, and *IET CPS*. He served on the Executive Committee of DAC, ACM SIGDA, IEEE TCCPS, and IEEE TCVLSI. He was the General Chair of ISVLSI, iNIS, and FAC and the Technical Program Chair of CAD/Graphics. He received the NSF CAREER Award in 2012, two IEEE Donald O. Pederson Best Paper Awards in 2013 and 2016, the DAC Best Paper Award in 2010, two ICCAD Best Paper Awards in 2004 and 2011, and the ISIC Best Paper Award in 2014. He also received six Best Paper Nominations from DAC, ICCAD, and CICC. He is a Fellow of IEEE.

Richard M. Murray is the Thomas E. and Doris Everhart Professor of Control and Dynamical Systems and Bioengineering at the California Institute of Technology (Caltech). He received his B.S. degree in electrical engineering from Caltech in 1985 and his M.S. and Ph.D. degrees in electrical engineering and computer sciences from the University of California, Berkeley, in 1988 and 1991, respectively. He joined the Caltech faculty in Mechanical Engineering in 1991 and helped found the Control and Dynamical Systems program in 1993. In 1998–1999, he took a sabbatical leave and served as the director of Mechatronic Systems at the United Technologies Research Center, Hartford, Connecticut. Upon returning to Caltech, he served as the division chair (dean) of Engineering and Applied Science from 2000 to 2005, the director for Information Science and Technology from 2006 to 2009, and interim division chair from 2008 to 2009. He received the Donald P. Eckman Award in 1997, the IFAC Harold Chestnut Textbook Prize (with Karl Åström) in 2011, and the IEEE Bode Lecture Prize in 2016 and is an elected member of the National Academy of Engineering (2013). His research is in the application of feedback and control to networked systems, with applications in biology and autonomy. Current projects include the analysis and design of biomolecular feedback circuits, the synthesis of discrete decision-making protocols for reactive systems, and the design of highly resilient architectures for autonomous systems. He is a cofounder of Synvitrobio, Inc., a cell-free synthetic biology company in San Francisco, and a member of the Defense Innovation Board, which advises the U.S. Secretary of Defense.

S. Ramesh has been with General Motors Global R&D in Warren, MI, where he currently holds the position of Senior Technical Fellow and thrust area lead for model-based embedded software. At General Motors, he is responsible for providing technical leadership for research and development in several areas related to Electronics, Control, and Software processes, methods, and tools. Earlier he was in India Science Lab serving as the lab group manager for two research groups on Software and System Verification and Validation. During this time, he led several projects on next-generation rigorous verification and testing methods for control software, which resulted in proof of concept methods and tools that were piloted on several SW subsystems across different domains like BCM, HVAC, and Active Safety. His broad areas of interests are rigorous software engineering, embedded systems, and real-time systems. He is the author of several patents and has published more than 100 papers in peer-reviewed international journals and conferences. He is on the editorial boards of the *International Journal on Real-Time Systems* and *EURASIP Journal on Embedded Systems* and earlier on *IEEE Journal on Embedded System Letters*. Prior to joining GM R&D, he was on the faculty of the Department of Computer Science and Engineering at IIT Bombay for more than fifteen years. At IIT Bombay, he played a major role in setting up a National Centre for Formal Design and Verification of Software. As the founding head of this Centre, he carried out many projects on verification of embedded software, for several government organizations. He is a fellow of the Indian National Academy of Engineering and was visiting/adjunct faculty of many institutions. Ramesh earned his B.E. degree in electronics and communication engineering from Indian Institute of Science, Bangalore, and his PhD degree in computer science and engineering from Indian Institute of Technology Bombay, India.

Claire J. Tomlin is a professor of electrical engineering and computer sciences at the University of California at Berkeley, where she holds the Charles A. Desoer Chair in Engineering. She was assistant, associate, and full professor at Stanford (1998–2007) and joined Berkeley in 2005. She has been an affiliate at Lawrence Berkeley National Laboratory in the Life Sciences Division since January 2012. She works in hybrid systems and control, with applications to air traffic and unmanned air vehicle systems, robotics, energy, and biology. Dr. Tomlin pioneered methods for computing the reachable set to encompass all behaviors of a hybrid system, which makes it possible to verify that the system stays within a desired safe range of operation and to design controllers to satisfy constraints. She has applied these methods to collision avoidance control for multiple aircraft and to the analysis of switched control protocols in avionics and embedded controllers in aircraft. Her work has been tested in simulation and UAV test flights, and applied to and flown on two large commercial platforms: (1) Boeing aircraft: Her method was used to compute collision zones for two aircraft paired approaches, and was flown on a Boeing T-33 test aircraft, flying close to a piloted F-15. The F-15 pilot flew "blunders" into the path of the T-33, which used Tomlin's algorithm to avoid collision. (2) Driven on Scania trucks: Dr. Tomlin's method was used to derive a minimum safe distance between transport trucks driving in high-speed platoons for fuel savings, and revealed that the relative distance used today can be reduced significantly with this automation. Her work is also being considered for application in the Next Generation Air Transportation System (NextGen) and in Unmanned Aerial Vehicle Traffic Management (UTM). Dr. Tomlin is a MacArthur Foundation, IEEE, and AIMBE fellow. She has received the Donald P. Eckman Award of the American Automatic Control Council in 2003, the Tage Erlander Guest Professorship of the Swedish Research Council in 2009, an honorary doctorate from KTH in 2016, and in 2017 the IEEE Transportation Technologies Award.