BAOLUO MENG

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RESEARCH INTERESTS

Formal methods, automated reasoning, and their applications in the following areas: testing and verification of AI-enabled systems, software systems and blockchain applications, ensuring safety and security of cyber-physical systems, and developing assurance cases towards system certification.

EDUCATION

The University of Iowa, Iowa City, IA, USA *December 2018*
PhD in Computer Science (GPA: 4.03/4.00)

The University of Iowa, Iowa City, IA, USA *May 2014*
Master in Computer Science

Beijing Jiaotong University, Beijing, China *May 2009*
Bachelor of Engineering in Software Engineering

PROFESSIONAL EXPERIENCE

GE Research, Niskayuna, NY
Lead Engineer *April 2020 - present*
Formal Verification Research Engineer *February 2019 - April 2020*

- Contribute to proposals and lead projects funded by DARPA, AFRL and NASA
- Conduct research on applying formal methods and SMT technologies in testing and verification of software systems, blockchain applications and Deep Neural Networks-based systems, ensuring safety and security of cyber-physical systems, and developing assurance cases towards system certification.
- Conduct research, design and development of tools that are used to verify that models and (deep neural networks) systems behave correctly as defined.

GE Research, Niskayuna, NY
Research and Development Intern *Summer 2015, Summer 2016, Summer 2017*

- Develop an in-house tool ASSERT to automatically generate test procedures for system requirements by leverage SMT solvers.
- Research on test cases and procedure generation for requirements involving nonlinear functions.

Pearson, Iowa City, IA
Software Development and Engineering Intern *Summer 2013*

- Design and develop software to test online exam systems for mobile platforms.

The University of Iowa, Iowa City, IA
Research Assistant & Teaching Assistant *August 2012 - December 2018*

- Conduct research and development of tools on satisfiability modulo theories, and formal verification on software.
- Teach classes and hold office hours: Algorithm; Formal Methods in Software Engineering.

PUBLICATIONS

Journal

1. **Meng, Baoluo**, Arjun Viswanathan, Saswata Saswata, William William, Abha Moitra, Kit Siu, and Michael Durling. "Attack-Defense Tree-based Security Analysis and Optimal Defense Synthesis for System Design." *Innovations in Systems and Software Engineering* (2023) (**Under Review**).

2. Hantao Zhang, **Meng, Baoluo**, and Yiwen Liang. Sort Race. *Software: Practice and Experience*, 52(8):1867–1878, 2022

3. **Meng, Baoluo**, William Smith, and Michael Durling. Security Threat Modeling and Automated Analysis for System Design. *SAE International Journal of Transportation Cybersecurity and Privacy*, 4(11-04-01-0001):3–17, 2021

4. **Meng, Baoluo**, Daniel Larraz, Kit Siu, Abha Moitra, John Interrante, William Smith, Saswata Paul, Daniel Prince, Heber Herencia-Zapana, M Fareed Arif, et al. Verdict: A Language and Framework for Engineering Cyber Resilient and Safe System. *Systems*, 9(1):18, 2021

Conference

1. **Baoluo Meng**, Joyanta Debnath, Sarat Chandra Varanasi , Emanuel Manolios, Michael Durling, Saswata Paul, Saif Alsabbagh, Richard Haadsma, Craig McMillan, Chi Zhang, and Tim Oates. "Towards a Correct-by-Construction Design of Integrated Modular Avionics." In *Computer Aided Verification International Conference, CAV 2023.* (**Under Review**)

2. Abha Moitra, Paul Cuddihy, Kit Siu, David Archer, Eric Mertens, Daniel Russell, Kevin Quick, Valentin Robert, and **Meng, Baoluo**. RACK: A Semantic Model and Triplestore for Curation of Assurance Case Evidence. In *Computer Safety, Reliability, and Security: 42nd International Conference, SAFECOMP 2023, Toulouse, France*, 2023 (**Under Review**)

3. Sarat Chandra Varanasi, **Meng, Baoluo**, Christopher Alexander, and Szabolcs Borgyos. UAV Compliance Checking Using Answer Set Programming and Minimal Explanations Towards Compliance (Application Paper). In *Practical Aspects of Declarative Languages: 25th International Symposium, PADL 2023, Boston, MA, USA, January 16–17, 2023, Proceedings*, pages 250–260. Springer, 2023

4. Michael R Durling, Abha Moitra, Kit Y Siu, **Meng, Baoluo**, John W Carbone, Christopher C Alexander, Krystel K Castillo-Villar, and Gabriela F Ciocarlie. Model-Based Security Analysis in Additive Manufacturing Systems. In *Proceedings of the 2022 ACM CCS Workshop on Additive Manufacturing (3D Printing) Security*, pages 3–13, 2022

5. Sarat Chandra Varanasi, **Meng, Baoluo**, Christopher Alexander, Szabolcs Borgyos, and Brendan Hall. Automating UAV flight readiness approval using goal-directed answer set programming. *arXiv preprint arXiv:2208.12199*, 2022

6. Abha Moitra, Paul Cuddihy, Kit Siu, **Meng, Baoluo**, John Interrante, David Archer, Eric Mertens, Kevin Quick, Valentin Robert, and Daniel Russell. A Semantic Reference Model for Capturing System Development and Evaluation. In *2022 IEEE 16th International Conference on Semantic Computing (ICSC)*, pages 173–174. IEEE, 2022

7. **Meng, Baoluo**, Arjun Viswanathan, William Smith, Abha Moitra, Kit Siu, and Michael Durling. Synthesis of Optimal Defenses for System Architecture Design Model in MaxSMT. In *NASA Formal Methods: 14th International Symposium, NFM 2022, Pasadena, CA, USA, May 24–27, 2022, Proceedings*, pages 752–770. Springer, 2022

8. **Meng, Baoluo**, Saswata Paul, Abha Moitra, Kit Siu, and Michael Durling. Automating the assembly of security assurance case fragments. In *Computer Safety, Reliability, and Security: 40th*

International Conference, SAFECOMP 2021, York, UK, September 8–10, 2021, Proceedings 40, pages 101–114. Springer, 2021

9. Jennifer Barzeele, Kit Siu, Mike Robinson, Liana Suantak, John Merems, Michael Durling, Abha Moitra, **Meng, Baoluo**, Patrice Williams, and Daniel Prince. Experience in designing for cyber resiliency in embedded DOD systems. In *INCOSE International Symposium*, volume 31, pages 80–94. Wiley Online Library, 2021

10. **Meng, Baoluo**, Abha Moitra, Andrew W Crapo, Saswata Paul, Kit Siu, Michael Durling, Daniel Prince, and Heber Herencia-Zapana. Towards developing formalized assurance cases. In *2020 AIAA/IEEE 39th Digital Avionics Systems Conference (DASC)*, pages 1–9. IEEE, 2020

11. **Meng, Baoluo**, Meng Li, Benjamin Beckmann, Yoshifumi Nishida, John Carbone, Dan Yang, and Michael Durling. Towards Developing Trusted Smart Contracts in Simulink. In *PoEM Workshops*, pages 35–46, 2020

12. Nikita Visnevski, Teresa Hubscher-Younger, Akshay Rajhans, and **Meng, Baoluo**. Automatic Synthesis of Information Flow Driven Execution Managers for Embedded Software Applications. In *2020 AIAA/IEEE 39th Digital Avionics Systems Conference (DASC)*, pages 1–9. IEEE, 2020 **(Best of Session)**

13. Heber Herencia-Zapana, James Lopez, Glen Gallagher, **Meng, Baoluo**, Cameron Patterson, and Lakshman Maalolan. Formal Verification Tool Evaluation For Unmanned Aircraft Containing Complex Functions. In *2020 AIAA/IEEE 39th Digital Avionics Systems Conference (DASC)*, pages 1–9. IEEE, 2020

14. Ahmed Irfan, Kyle D Julian, Haoze Wu, Clark Barrett, Mykel J Kochenderfer, **Meng, Baoluo**, and James Lopez. Towards verification of neural networks for small unmanned aircraft collision avoidance. In *2020 AIAA/IEEE 39th Digital Avionics Systems Conference (DASC)*, pages 1–10. IEEE, 2020

15. James G Lopez, Liling Ren, **Meng, Baoluo**, Robert Fisher, Joel Markham, Michael Figard, Richard Evans, Ryan Spoelhof, Michael Rubenstahl, Scott Edwards, et al. Integration and flight test of small UAS detect and avoid on a miniaturized avionics platform. In *2019 IEEE/AIAA 38th Digital Avionics Systems Conference (DASC)*, pages 1–5. IEEE, 2019 **(Best of Session)**

16. Meng Li, **Meng, Baoluo**, Han Yu, Kit Siu, Michael Durling, Daniel Russell, Craig McMillan, Matthew Smith, Mark Stephens, and Scott Thomson. Requirements-based automated test generation for safety critical software. In *2019 IEEE/AIAA 38th Digital Avionics Systems Conference (DASC)*, pages 1–10. IEEE, 2019

17. Kit Siu, Abha Moitra, Meng Li, Michael Durling, Heber Herencia-Zapana, John Interrante, **Meng, Baoluo**, Cesare Tinelli, Omar Chowdhury, Daniel Larraz, et al. Architectural and behavioral analysis for cyber security. In *2019 IEEE/AIAA 38th Digital Avionics Systems Conference (DASC)*, pages 1–10. IEEE, 2019 **(Best of Track & Best of Session)**

18. **Meng, Baoluo**, Andrew Reynolds, Cesare Tinelli, and Clark Barrett. Relational Constraint Solving in SMT. In *Automated Deduction–CADE 26: 26th International Conference on Automated Deduction, Gothenburg, Sweden, August 6–11, 2017, Proceedings*, pages 148–165. Springer, 2017

19. S. Bhattacharyya, S. Miller, J. Yang, S. Smolka, **Meng, Baoluo**., C. Sticksel, and C. Tinelli. Verification of quasi-synchronous systems with Uppaal. In *2014 IEEE/AIAA 33rd Digital Avionics Systems Conference (DASC)*, pages 8A4–1–8A4–12, 2014

Patent

1. Han Yu, Michael Richard Durling, Kit Yan Siu, Meng Li, **Meng, Baoluo**, Scott Alan Stacey,

Daniel Edward Russell, and Gregory Reed Sykes. System and method for test generation from software specification models that contain nonlinear arithmetic constraints over real number ranges, January 1 2019. US Patent 10,169,217

2. **Baoluo Meng**, Saswata Paul, Michael Richard Durling, Szabolcs Borgyos. "System and Method for Constraint Solving-based Strategic Aircraft Conflict Detection and Resolution" submitted on June 29, 2022. (**Submitted**)

PROJECTS

- **Project:** PrOof Engineering for SYSTEm ARchitecture Design Model (OYSTER)
  - **Role:** Principle Investigator (PI)
  - **Funding Agency:** Defense Advanced Research Projects Agency (DARPA)
  - **Time:** February 2022 - August 2023
  - **Description:** GE Research (GRC), in collaboration with the University of Maryland at Baltimore County (UMBC) and GE Aviation Systems (GEAS), proposes "PrOof Engineering for SYSTEm ARchitecture Design Model (OYSTER)" to develop innovative theories and prototype tools that combine Machine Learning-(ML), Satisfiability Modulo Theories (SMT) and model checking to improve formal proof construction, evolution, and repair for system architecture design model.
- **Project:** Formal Verification of AI-based Autonomy
  - **Role:** Co-PI
  - **Funding Agency:** Air Force Office of Scientific Research (AFOSR)
  - **Time:** 2022 - 2025
  - **Description:** GE Research (GRC), in collaboration with Stanford University (Stanford) and the Air Force Research Laboratory (AFRL) /ACT3 in Dayton, Ohio proposes a 3-year program to perform basic research to support Test and Evaluation (T&E) of Artificial Intelligence (AI)-based spacecraft applications. The team will create an approach to mathematically formalize requirements and perform formal analysis of AI algorithms implemented as neural networks.
- **Project:** Safety Assurance in Complex Aerospace Digital Systems that include AI/ML
  - **Role:** Co-PI
  - **Funding Agency:** Federal Aviation Administration (FAA)
  - **Time:** October 2022 - October 2025
  - **Description:** The objective of this research is to assess alternate means of compliance using Overarching Properties and conduct use case studies of safety assurance of complex aerospace digital systems including AI/ML implementations. The results of this research will be used to develop recommendations and assurance criteria for future guidance, standards, and certification; and to explore safety risk mitigation approaches.
- **Project:** Cyber-Resilient Architecture for Manufacturing
  - **Role:** Co-PI
  - **Funding Agency:** The Cybersecurity Manufacturing Innovation Institute (CyManII)
  - **Time:** September 2021 – February 2022
  - **Description:** The goal of this program is to develop tools, methods and building blocks that will be shared by the CyManII community to secure manufacturing architecture. General Electric proposes to deliver an open-source tool and methodology that supports architecture-level modelling of automation components used in modern manufacturing along with formal security specifications, then performs cyber resiliency analysis of the components connected as systems. GE will extend the VERDICT (Verification Evidence and Resilient Design in Anticipation of Cybersecurity Threats) tool originally developed on the DARPA Cyber Assured Systems Engineering (CASE) program. VERDICT enables System Engineers to develop architectural models in AADL and annotate them with formal security specifications. The VERDICT analysis engine creates an attack-defense tree for the archi-

tectural model, calculates a likelihood of successful attack figure of merit, identifies relevant Common Attack Pattern Enumeration and Classification (CAPEC) vulnerabilities, suggests NIST 800-53 controls to implement as defenses, and provides formal proof evidence that the system is cyber resilient to common threat effects. VERDICT was developed to support embedded control systems for critical infrastructure and military systems. The technology is well aligned with embedded automation used in manufacturing. The CyManII Secure Manufacturing Architecture program will extend VERDICT to specifically support energy efficiency and manufacturing by creating a library of components commonly used in manufacturing, adding an energy efficiency term to the optimization cost function, and developing a suite of example formal security specifications for the manufacturing domain.

- **Project:** RACK Engineering Change Proposal – Secure Assurance Fragment Evidence
  - **Role:** Co-PI
  - **Funding Agency:** Defense Advanced Research Projects Agency (DARPA)
  - **Time:** January 2022 - March 2022
  - **Description:** DARPA recently kicked off the Automated Rapid Certification of Software (ARCOS) program. The goal of ARCOS is to automate the evaluation of software assurance evidence enabling certifiers to determine rapidly that system risk is acceptable. GE is leading the TA 2 Evidence Curation technical area, which will ingest assurance case fragments from the Evidence Generation performers and curate the information in a database that the Assurance Generation performers will query and create validated assurance cases with confidence scores. On the existing contract award, the GE team plans to include data provenance for all the evidence under curation in a secure database. In order to make the evidence more secure, GE and Guardtime Federal (GTF) propose this Engineering Change Proposal effort to explore application of KSI Distributed Cryptography (similar to blockchain) technology to capture and manage development and certification of artifacts. KSI Distributed Cryptography enables the participation of digital artifacts of the state of a file (or files) in a recurring set of cryptographic calculations such that verification of authenticity, authorship, and time of state changes can be immutably verified. Applying KSI data integrity to the evidence itself will ensure that the implementation and certification artifacts have not been tampered with over the life cycle of the system.
- **Project:** Evaluation of Verification & Validation Tools in a Ummaned Aircraft System Runtime Safety Assurance System
  - **Role:** Co-PI
  - **Funding Agency:** National Aeronautics and Space Administration (NASA)
  - **Time:** January 2020 - December 2022
  - **Description:** GE is developing an embedded avionics system for hosting flight safety critical functions for unmanned aerial systems (UAS). In order to ensure safe operation of UAS in the national airspce, we include a runtime safety assurance (RTSA) system. In year 1, the goal of this project is to evaluate Validation & Verification (V&V) tools on the RTSA system. We will start by detailing and base-lining a traditional V&V process of the RTSA system, capturing metrics at each step of the process. Then we will perform the same V&V process for the RTSA system but will use formal methods based tools at appropriate steps in the process. We will use formal tools such as FRET, AdvoCATE, AGREE, CoCoSim, and ASSERT developed by NASA, DARPA, Virginia Tech and GE. At the end, we will perform a comparison of the two approaches. In year 2, we evaluate the usability and effectiveness of the Adaptive Stress Testing (AST) tool (AdaStress) in an industrial setting, and clarify the role for AST artifacts to support software certification. To achieve this, we will work on integrating NASA Adaptive Stress Testing (AST) tool with GE next-gen product testing tool – Continuum to detect rare failure events in trajectory prediction done by GE Aviation's Flight Management System (FMS).
- **Project:** VERDICT: Verification Evidence & Resilient Design in anticipation of Cybersecurity
  - **Role:** Major Contributor

  - **Funding Agency:** Defense Advanced Research Projects Agency (DARPA)
  - **Time:** February 2018 - December 2021
  - **Description:** The goal of this project is to develop the necessary design, analysis and verification tools to allow system engineers to design-in cyber resiliency and manage tradeoffs as they do other nonfunctional properties when designing complex embedded computing systems. Cyber resiliency means the system is tolerant to cyberattacks in the same way that safety critical systems are tolerant to random faults—they recover and continue to execute their mission function.
- **Project:** Robustness Verification of Deep Neural Networks (DNNs) Representation of Airborne
  - **Role:** Major Contributor
  - **Funding Agency:** GE Aviation
  - **Time:** February 2019 - August 2020
  - **Description:** The Airborne Collision Avoidance System X family has been adopted for manned (ACAS Xa), unmanned aircraft (ACAS Xu) and small unmanned aircraft (ACAS sXu) to reduce the risk of mid-air collisions or near mid-air collision. Traditionally, the decision-making logic of ACAS X is created using a large numeric lookup table (LUT) requiring hundreds of GB storage, which makes it difficult for certification. In this project, we will use a new storage-efficient approach to represent ACAS sXu, which leverages the deep neural network (DNN) to learn a robust nonlinear function approximation of the lookup table. We will leverage the SMT solver – Marabou to verify the DNNs of ACAS sXu behave smoothly, i.e., small input perturbations should not cause major spikes in the network's output. We hope to form a formal proof that the entire network always behaves as intended.
- **Project:** ASSERT: Analysis of Semantic Specifications and Efficient generation of Requirements
  - **Role:** Contributor
  - **Funding Agency:** GE Aviation
  - **Time:** Summer 2015, Summer 2016, Summer 2017
  - **Description:** The size and complexity associated with software that monitors, controls, and protects flight critical products continues to grow. Thus, maintenance, verification and validation of those software requires significant amount of money, time and manpower. To reduce the cost and time associated with the process, we propose a new tool suite for requirements capture and analysis, and test case and test procedure generation for requirements. We introduce a Requirements Capture language developed for use by a requirements engineer that is as close as possible to English, allowing her to write requirements using terms and concepts from her domain, yet is formal enough that requirements written in this language can be analyzed using formal methods. After the requirements analysis, we obtain a set of unambiguous, conflict-free, and complete requirements. Then we will generate test cases and test procedures by leveraging SMT technology to validate that the software implementation satisfies requirements.
- **Project:** CVC4: An efficient open-source automatic theorem prover for satisfiability modulo theories (SMT) problems
  - **Role:** Contributor
  - **Funding Agency:** Multiple Funding Agencies
  - **Time:** 2017 - 2018
  - **Description:** CVC4 is a state-of-the-art, efficient, open-source automatic theorem prover for satisfiability modulo theories (SMT) problems. It can be used to prove the validity (or, dually, the satisfiability) of first-order formulas in a large number of built-in logical theories and their combination. In this project, I designed, implemented and tested a finite sets/relations theory solver. Combining this new solver with the finite model finding features of CVC4 enables several compelling use cases. For instance, native support for relations enables a natural mapping from Alloy, a declarative modeling language based on

first-order relational logic, to SMT constraints. It also enables a natural encoding of several description logics with concrete domains, allowing the use of an SMT solver to analyze, for instance, Web Ontology Language (OWL) models.

- **Project:** Formal Analysis and Verification of Unmanned System Autonomy Services (UxAS)
  - **Role:** Major Contributor
  - **Funding Agency:** United States Air Force Research Lab (AFRL)
  - **Time:** 2017 Summer
  - **Description:** Software architecture plays an important role in the software development, because system characteristics such as functional correctness, robustness and maintainability depend on the architecture. However, it is not easy to verify if the final software product complies with the original software architecture specifications, especially in the absence of a formally described and documented architecture design, and lack of a formal verification framework to verify the implementation against the original specification. Based on previous experience of extracting design information from legacy software, we use a similar and extended methodology to support formal capture of software architecture models captured in SADL and scalable analysis and verification of UxAS architecture by using an SMT solver – CVC4.
- **Project:** CoCoSim: Automated analysis and compilation framework for Simulink/Stateflow
  - **Role:** Major Contributor
  - **Funding Agency:** National Aeronautics and Space Administration (NASA)
  - **Time:** 2017 – 2018
  - **Description:** CoCoSim is an automated analysis and code generation framework for Simulink and Stateflow models. Specifically, CoCoSim can be used to verify automatically user-supplied safety requirements. In this project, we develop a translator from the intermediate representation (JSON) of CoCoSim models to Lustre programs, and leverage the Kind2 model checker to verify if CoCoSim models satisfies their contracts.

PROGRAM COMMITTEE EXPERIENCE

- Program Committee Member, FMCAD 2023
- Program Committee Member (Artifact Evaluation), CAV 2023
- Program Committee Member (Artifact Evaluation), TACAS 2023
- Program Committee Member (Artifact Evaluation), VMCAI 2022
- Reviewer for 41st AIAA Digital Avionics System Conference, 2022
- Session Chair, Reviewer for 40th AIAA Digital Avionics System Conference, 2021
- Session Chair, Reviewer for 39th AIAA Digital Avionics System Conference, 2020

AWARDS

- GE Research Technical Awards 5 Under 5, GE Research, Niskayuna NY, 2022
  - Recognized each year at the GE Research Technology Award event, these nominations are proposed by the GE Research Senior Leadership Team and hand selected by our Chief Technology Officer. Recognizes an early career professional who brings curiosity, tenacity and a fresh perspective to deliver technical impact across their work. The individual is often sought after for their innovative mindset and ability to execute on their ideas. (5 awarded; less than 5 years with GE)
- Control & Optimization Rookie of the Year, GE Research, Niskayuna NY, 2019
- Outstanding Beijing Olympic Games Volunteer Leader, Beijing, 2008

MENTORING

- Sarat Chandra Varanasi, PhD Student, University of Texas, Dallas, 2022 Summer
- Soumyabrata Talukder, PhD Student, Iowa State University, 2019 Summer
- William Smith, Undergraduate, Cornell University, 2019 Summer, 2020 Summer
- Saswata Paul, PhD Student, Rensselaer Polytechnic Institute, 2020 Summer, 2021 Summer
- Arjun Viswanathan, PhD Student, The University of Iowa, 2021 Summer
- Joyanta Debnath, PhD Student, The University of Iowa, 2021 Summer, 2022 Summer
- Emmanuel Manolios, Master Student, The University of Northeastern, 2022 Spring

PERSONAL TRAITS

Highly motivated and eager to learn new things.

Strong motivational and leadership skills.

Ability to work as an individual as well as in group.