Charles Dawson

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Academic Interests

My research aims to support the design and verification of cyberphysical systems in three ways:

1. *Design optimization:* optimizing the parameters of the system (e.g. control gains, neural network weights, etc.) to achieve good performance despite uncertainty in the system's environment.
2. *Safety verification:* characterizing a system's robustness to potentially adversarial environmental variation and predict corner cases where it is likely to fail (i.e. violate a constraint or incur a high cost).
3. *Closing the design-verification loop:* using the results from safety verification to inform design, e.g. by using predicted corner cases to guide future design iterations.

Education

Massachusetts Institute of Technology

Ph.D., Aeronautics and Astronautics (expected 2024). Advised by Prof. Chuchu Fan.
Ph.D. Thesis: *Glass-box formal methods for autonomous system design & verification*
S.M., Aeronautics and Astronautics (2020). Advised by Prof. Brian Williams.
S.M. Thesis: *Safe and Efficient Motion Planning through Chance-Constrained Nonlinear Optimization*

Harvey Mudd College

B.S., Engineering, *High Distinction, Departmental Honors* (2019).

Research Experience

Reliable Autonomous Systems Lab (REALM)

Ph.D. thesis advised by Prof. Chuchu Fan.

My research is inspired by the field of *formal methods*, which seeks to construct proofs about the behavior of a system using a formal mathematical model. Although many robotic systems are too complex to reduce to a set of equations, we instead often have access to a simulator (i.e. a computer program) that models the system's behavior. My research aims to exploit the rich mathematical structure embedded in simulators using *program analysis* methods like automatic differentiation, program tracing, and probabilistic programming.

- Developed a design optimization framework based on differentiable simulation to find robust solutions to robot design problems, achieving up to 20x speedup over gradient-free methods.
- Used adversarial optimization to identify counterexamples (cases where a robot fails to achieve its desired objective) and use those counterexamples as the basis for further design optimization.
- Developed a simulation-driven probabilistic modeling framework for robot behavior to efficiently explore the design space and predict a diverse set of high-likelihood, high-severity failure modes for a given robotic system. Feeding these failure modes back into the optimization process yields robot designs with 10x lower worst-case cost while maintaining good average-case performance.

Prior to working on simulation-based optimization and verification methods in REALM, I worked on problems at the intersection of control theory and machine learning, applying Lyapunov, barrier function, and contraction metric theory to guarantee the safety of learned control policies.

[1] Updated February 10, 2023 for submission to RSS Pioneers

Model-based Embedded and Robotic Systems Lab (MERS)

S.M. thesis advised by Prof. Brian Williams.

My research during my Masters degree focused on developing chance-constrained robot motion planning algorithms, using computational geometry and risk-aware nonlinear optimization to develop a fast motion planner that can navigate an uncertain environment with a guaranteed upper bound on the risk of collision.

Teaching Experience

Massachusetts Institute of Technology

AY 2022-23 Teaching Development Fellow (joint with Dept. of Aeronautics & Astronautics and MIT Teaching and Learning Lab)

- Supported and mentored TAs in my department by facilitating workshops on student-centered pedagogy, including scaffolding, active learning, and lesson planning techniques.

Fall 2020 Teaching Assistant, 16.413 Principles of Autonomy and Decision Making.

- Prepared and hosted weekly recitations on task and motion planning, search, inference, Markov models and decision processes, optimization, and constraint satisfaction problems.
- Hosted weekly office hours to support student success on problem sets and exams.
- Prepared and delivered lecture on linear programming.
- Student feedback:
  - "Charles' office hour sessions were always very clear and helpful"
  - "Charles was a great TA, really enthusiastic about the subject and put in extra work"
  - "I always left Charles's recitation with a stronger understanding of the course material."
  - "Clear, kind, and insightful!"

Spring 2021 Certificate, Graduate Teaching Development Tracks; MIT Teaching and Learning Lab.

- Completed workshops in Lesson Planning, Subject Design, Inclusive Teaching, and Teaching Practice

Harvey Mudd College

AY 2017-18 & AY 2018-19 Academic Excellence Tutor, E79 Introduction to Engineering Systems

- Hosted weekly tutoring sessions, answering students' questions on modeling, Laplace transforms, frequency response functions, and circuit analysis.

Industry Experience

Marble Technologies (Consulting Roboticist, 2022)

- Led a team of four engineers to build a robotic manipulation system for the food processing industry.
- Delivered an MVP within 3 months, supporting demos leading to pre-orders and a $10M Series A.
- Developed ROS2 system architecture and subsystems for vision, planning, and control.
- Coordinated efforts of multiple direct reports using GitHub issues and Asana for project management.

Pickle Robot Company (Intern, 2020)

- Led a team of two interns to build a collaborative robotic palletizing system for the logistics industry.

Riggs Fellowship in Manufacturing Engineering (2018-2019)

- Used Lean Manufacturing principles to help local manufacturers increase throughput by 156%, reduce work-in-process inventory by 86%, and save $80,000 in annual costs, working as part of 3-person team.

Professional Service

AeroAstro Graduate Application Assistance Program (GAAP)

In 2020, I founded GAAP with the aim of increasing the diversity of students pursuing graduate study in our department by assisting students from underrepresented backgrounds in applying to our graduate program. Specifically, GAAP aims to connect students from underrepresented backgrounds with current graduate students in AeroAstro to provide 1-on-1 mentoring and support, e.g. reading personal statements and providing feedback, answering questions about life in graduate school, etc..

- In 2020, I assembled an executive team of two other graduate students, secured support from senior faculty, obtained funding from our department, and successfully executed a pilot version of GAAP.
- In 2021 and 2022, I continued to serve on the GAAP executive board, but began to transfer ownership of the program to the next generation of student leaders to ensure continuity of the program. We expanded the 1-on-1 mentoring program and added office hours for small-group mentoring.
- To date, GAAP has connected 90+ students from underrepresented backgrounds with mentors in MIT AeroAstro and provided mentorship to 75+ additional students in office hours. 2021 data indicates that GAAP mentees had a **46% increase in application completion rate** and a **100% increase in admission rate** relative to a control group.

MIT LIDS Student Conference

Co-chaired the 28th Annual Laboratory for Information and Decision Science (LIDS) Student Conference with Ashkan Soleimani, Behrooz Tahmasebi, Feng Zhu, Xinyu Wu, & Andrew Fishberg (website).

Undergraduate Students Mentored

2022-23: Mukun Oscar Tong (Tsinghua University '22)

2021-22: Dylan Goff (MIT Aeronautics and Astronautics '22)

2021-22: Bethany Lowenkamp (MIT Mechanical Engineering '22)

2020-21: Aileen Ma (MIT Computer Science '22)

Awards

2021 **National Science Foundation Graduate Research Fellowship**

2019 **Tau Beta Pi Graduate Fellowship**: Awarded to only 35 engineering students in the United States.

2019 **Departmental Honors in Engineering**

2019 **Departmental Honors in Humanities, Social Sciences, and the Arts**

2019 **Harry E. Williams Mechanics Prize** for achievement applying mechanics to engineering problems.

2017 **Astronaut Scholarship**: Awarded to only 45 STEM undergraduate students in the United States.

Publications

Under review

2023 | **Charles Dawson**, Chuchu Fan, "Accelerating failure mode prediction and mitigation using sampling and automatic differentiation". In *Robotics: Science and Systems*, submitted Feb 2023.

Peer-reviewed publications

2023 | Mukun Tong, **Charles Dawson**, Chuchu Fan, "Enforcing safety for vision-based controllers via Control Barrier Functions and Neural Radiance Fields". In *IEEE International Conference on Robotics and Automation (ICRA)*, accepted Jan 2022. (preprint) (website)

2023 | **Charles Dawson**, Sicun Gao, Chuchu Fan, "Safe Control With Learned Certificates: A Survey of Neural Lyapunov, Barrier, and Contraction Methods for Robotics and Control". In *IEEE Transactions on Robotics*, published Jan 2023. (paper) (code)

2022 | **Charles Dawson**, Chuchu Fan, "Robust Counterexample-guided Optimization for Planning from Differentiable Temporal Logic". In *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, presented Oct 2022. (paper) (website)

2022 | **Charles Dawson**, Chuchu Fan, "Certifiable Robot Design Optimization using Differentiable Programming". In *Robotics: Science and Systems*, presented June 2022. (paper) (website)

2022 | **Charles Dawson**, Bethany Lowenkamp, Dylan Goff, Chuchu Fan, "Learning Safe, Generalizable Perception-Based Hybrid Control With Certificates". In *IEEE Robotics and Automation Letters*, published April 2022. (paper) (website)

2021 | **Charles Dawson**, Zengyi Qin, Sicun Gao, Chuchu Fan, "Safe Nonlinear Control Using Robust Neural Lyapunov-Barrier Functions". In *Conference on Robot Learning (CoRL)*, presented Nov 2021. (paper) (code)

2020 | **Charles Dawson**, Ashkan Jasour, Andreas Hofmann, Brian Williams, "Provably Safe Trajectory Optimization in the Presence of Uncertain Convex Obstacles". In *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, presented Oct 2020. (paper)

2019 | **Charles Dawson**, Philip D. Cha, "A sensitivity-based approach to solving the inverse eigenvalue problem for linear structures carrying lumped attachments". In *International Journal for Numerical Methods in Engineering*, published June 2019. (paper)

2019 | Xiaxin Ding, Bin Gao, Elizabeth Krenkel, **Charles Dawson**, James C. Eckert, Sang-Wook Cheong, and Vivien Zapf, "Magnetic properties of double perovskite Ln_2CoIrO_6 (Ln = Eu, Tb, Ho): Hetero-tri-spin $3d-5d-4f$ systems". In *Physical Review B*, published Jan 2019. (paper)

Pre-prints

2022 | **Charles Dawson**, Austin Garrett, Falk Pollok, Yang Zhang, Chuchu Fan, "Barrier functions enable safety-conscious force-feedback control". In *arXiv*, posted Sep 2022. (preprint)

2021 | **Charles Dawson**, Ashkan Jasour, Andreas Hofmann, Brian Williams, "Chance-Constrained Trajectory Optimization for High-DOF Robots in Uncertain Environments". In *arXiv*, posted Jan 2023. (preprint)

2020 | **Charles Dawson**, Ashkan Jasour, Andreas Hofmann, Brian Williams, "Fast Certification of Collision Probability Bounds with Uncertain Convex Obstacles". In *arXiv*, posted Mar 2020. (preprint)

Conference abstracts

2021 | Axel Garcia, **Charles Dawson**, Miles Lifson, David Arnas, Chuchu Fan, Christopher Jewison, Richard Linares, "Model Predictive Control and Safety Analysis for Satellite Collision Avoidance". In *AAS/AIAA Astrodynamics Specialist Conference*, presented Aug 2021. (preprint)

2020 | George C. Lordos, Caleb Amy, Becca Browder, Manwei Chan, **Charles Dawson**, and 15 others, "Autonomously Deployable Tower Infrastructure for Exploration and Communication in Lunar Permanently Shadowed Regions". In *AIAA ASCEND 2020*, presented Nov 2020. (preprint)

Contributed Talks

2022 | *Robust Counterexample-guided Optimization for Planning from Differentiable Temporal Logic.* Kyoto, Japan, International Conference on Intelligent Robots and Systems (IROS), Oct 2022.

2022 | *Certifiable Robot Design Optimization using Differentiable Programming.* New York, NY, USA, Robotics: Science and Systems, June 2022.

2022 | *Learning Safe, Generalizable Perception-Based Hybrid Control With Certificates.* Philadelphia, PA, USA, International Conference on Robotics and Automation (ICRA), April 2022.

2020 | *Provably Safe Trajectory Optimization in the Presence of Uncertain Convex Obstacles.* Virtual, International Conference on Intelligent Robots and Systems (IROS), Oct 2020.