Shengfan Cao

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Research Interests

My research focuses on integrating safety constraints, optimization, and learning to enable reliable long-horizon decision-making for embodied AI systems under uncertainty.

Education

University of California, Berkeley *Aug 2022 — May 2027*
Ph.D. in Mechanical Engineering

- **PI:** Francesco Borrelli
- **Coursework:** Advanced Control Theory and Systems, Model Predictive Control, Nonlinear Systems, Convex Optimization, Deep Learning, Reinforcement Learning, Computer Vision, Natural Language Processing.

Tsinghua University *Aug 2017 — Jun 2022*
B.S. in Mechanical Engineering; B.A. in Japanese Language and Literature

- **PI:** Chuxiong Hu (Mechanical Engineering); Rong Zhao (Japanese Language and Literature)
- **Thesis:** Path Generation for Rapid Filling of Planar Areas with Optimized Parallel Curves

Major Research Experience

Trusted Autonomy for Rapidly Prototyped Uncrewed Ground Vehicles, Project Lead *Sep 2024 — Present*

- Engineered a rapidly deployable autonomous ground robot capable of exploring, mapping, and navigating previously unseen terrain with minimal setup and low hardware cost for expeditionary missions.
- Developed an interpretable autonomy stack that converts multi-modal sensor data into human-readable terrain and uncertainty maps to support both autonomous decision-making and operator trust.
- Learned and maintained a continuously updated latent world representation combining geometry, semantics, and uncertainty to support long-horizon planning and human-interpretable decision-making.
- Developed a Python data access layer over ROS2 bag files (SQLite), enabling SQL-style queries for efficient extraction and analysis of logged autonomy data.
- Deployed and maintained the full autonomy stack on embedded onboard compute under real-world constraints, and collaborated with NIWC Pacific human-factors researchers through regular technical reviews.
- **Tech:** PyTorch, ROS 2, SQL, SLAM, YOLO, Semantic Mapping, CasADi, Jetson Orin

Sampling-Based Constrained Policy Optimization, Principal Researcher *Sep 2025 — Dec 2025*

- Introduced a scalable, training-time constrained optimization framework for large neural policies, enabling safety guarantees without test-time shielding or policy rollback.
- Formulated policy optimization as a convex projection in parameter space, with theoretical guarantees that projected updates preserve objective improvement.
- Derived a sufficient stability condition linking weight updates to closed-loop constraint satisfaction, and embedded it directly into the optimization pipeline.
- Empirically demonstrated complete rejection of harmful supervision and safe performance gains in regression and imitation learning under adversarial experts.
- Paper submitted to IFAC WC 2026: "*Constrained Policy Optimization via Sampling-Based Weight-Space Projection*".
- **Tech:** PyTorch, Convex Optimization, Reinforcement Learning, Safe Learning.

Safe Imitation Learning at Handling Limits, Principal Researcher *Nov 2024 — Feb 2025*

- Designed a constraint-aware imitation learning framework incorporating an actor-critic structure for explicit safety modeling.
- Improved training efficiency by 150% and reduced collision rates by 60% at the vehicle's dynamic handling

limits in CARLA simulation.

- Integrated reachability-based safety filters into the training pipeline, enabling safe policy generalization.
- Oral presentation at IEEE IROS 2025 for this work: "*A Simple Approach to Constraint-Aware Imitation Learning with Application to Autonomous Racing*".
- **Tech:** PyTorch, CasADi, CARLA, RL, MPC, optimization, safety-aware learning.

Vision-based End-to-end Control for Racing, Principal Researcher *Nov 2023 — May 2024*

- Developed a CNN-based end-to-end controller for high-speed autonomous racing using RGB camera input and velocity feedback.
- Trained using imitation learning from MPCC expert trajectories and deployed on a 1:10 Jetson-powered vehicle with onboard ROS stack.
- Designed and executed systematic policy evaluation in CARLA under various conditions (e.g., weather, lighting), measuring success rates and failure modes across diverse initial conditions to assess robustness near dynamic handling limits.
- Achieved long rollouts (80 laps at high speed) without constraint violation and improved consistency in performance compared to traditional SLAM-based pipelines across 10+ field tests.
- **Tech:** PyTorch, CasADi, ROS, OpenCV, SLAM, RL, NVIDIA Jetson, real-time control.

Additional Project & Research Experience

Goal-Conditioned Learning MPC, Independent Research *May 2023 — Sep 2023*

- Explored a goal-conditioned, data-driven MPC pipeline using feasible closed-loop trajectories to learn transition costs between feasible states via imitation learning.
- Investigated a two-layer hierarchical architecture: short-horizon reference generation in a planning layer, tracked by MPC in an execution layer.
- Demonstrated improved long-horizon efficiency in simulation compared to a single-layer MPC baseline.
- **Tech:** Gurobi, CasADi, MPC, Python.

Autonomous Rover for Solar Panel Fields (Terabase), Team Member *May 2023 — Aug 2023*

- Co-implemented a perception stack on ROS 1 to identify object locations and types around the rover.
- Assisted in connecting perception outputs with an MPC planner and low-level controller on ROS 2 to enable evasive maneuvers.
- Debugged on the physical rover and delivered a field demo in Davis.
- **Tech:** ROS 1/2, MPC, YOLO, Python.

Corner Smoothing for Additive Manufacturing Toolpaths, Research Assistant *May 2021 — Aug 2021*

- Proposed a corner smoothing method for additive manufacturing toolpaths to achieve uniform coating while constraining maximum curvature.
- Refined the original formulation into a convex optimization problem to enforce continuous curvature and even area coverage.
- Implemented an iterative solver (gradient-based) in Python and integrated it into a parallel-curve toolpath planner.
- **Tech:** Convex optimization, Python.

Path Planning for Rapid Filling of Planar Areas with Optimized Parallel Curves, Research Assistant *Mar 2021 — May 2021*

- Proposed and implemented an algorithm to generate non-self-intersecting parallel curves that cover the area enclosed by an arbitrary boundary curve.
- Built a net-like linked list representation to compute normal vectors and curvature pointwise using central differences.
- Improved motion stability by converting contour-like paths into spiral-like paths using offsetting methods.
- **Tech:** Computational geometry, Python/C++.

Publications & Preprints

- **Cao, S.**, Joa, E., & Borrelli, F. (2025). *A Simple Approach to Constraint-Aware Imitation Learning with Application to Autonomous Racing*, Oral presentation at IEEE IROS 2025.
- Prignoli, F., **Cao, S.**, Falcone, P., Borrelli, F. (2025). *Real-Time Regulation-Aware Game-Theoretic Motion Planning for Head-to-Head Autonomous Racing*. Under review at IEEE TCST.
- **Cao, S.**, & Borrelli, F. (2025). *Constrained Policy Optimization via Sampling-Based Weight-Space Projection*. Under review at IFAC WC 2026.
- Liu, Y., & **Cao, S.** *State-Conditional Adversarial Learning: An Off-Policy Visual Domain Transfer Method for End-to-End Imitation Learning*. Under review at IFAC WC 2026.

Teaching

Supervisor for Undergraduate Research Program, UC Berkeley — Jan 2025 — Present

- Led a team of four undergraduate students on vision-based off-road vehicle dynamics modeling and path planning, guiding research efforts, technical documentation, and successful interim presentations to faculty and industry stakeholders.

Graduate Student Instructor, UC Berkeley — Jan 2024 — May 2024

- Led discussions 10 hours per week for 40-student sessions.
- Held office hours 2 hours per week that helped more than 20 students.
- Developed labs and exams on Python, MATLAB, and numerical methods to prepare students for advanced engineering classes.

Graduate Student Instructor, UC Berkeley — Jan 2025 — May 2025

- Developed a vehicle dynamics simulator based on dynamic bicycle model, with standard gymnasium APIs.
- Implemented a CARLA connector in the gymnasium wrapper and a shell script for quick installation.

Students Mentored

Yuxiang Liu, UC Berkeley	Jan 2023 — Present
Yun Chung Chang, UC Berkeley	Jan 2025 — Present
Parham Sharafoleslami, UC Berkeley	Jan 2024 — Dec 2024
Ethan Kou, UC Berkeley	Jan 2025 — May 2025
JongHoon Ock, UC Berkeley	Jan 2025 — May 2025

Academic Services

Invited Reviewer, IEEE — Apr 2025 — Present

- Reviewed three submissions for IFAC World Congress 2026, one submission for the IEEE Conference on Automation Science and Engineering (CASE 2025) and one IEEE RA-L journal submission, upon invitation from the program committee.

Awards & Honors

- Scholarship for Academic Excellence (Top 10%) sponsored by AEON
- Scholarship for Art Excellence
- Scholarship for Social Services
- First Honor Roll, 8th U.S. United Young Musician International Piano Competition

Skills

- **Programming**: Python, C/C++, MATLAB, HTML, SQL, Java.
- **Software**: PyTorch, NumPy, Pandas, ROS, CARLA, CasADi, Linux/bash, NVIDIA Visual SLAM, Docker, Solidworks, Git, Pytest, LaTeX.
- **Hardware**: Raspberry Pi, NVIDIA Jetson Orin Nano, Arduino.
- **Languages**: Japanese (JLPT N1); English (fluent); Chinese (native).