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Compositional Design and Operation of Society-Critical Autonomous Systems

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Abstract—Complex engineered systems can no longer be designed by optimizing components in isolation. In domains such as autonomy, mobility, and other society-critical infrastructures, system-level performance emerges from tightly coupled choices across hardware, software, control, operations, infrastructure, and policy. Moreover, these choices are distributed across abstraction levels and stakeholders, and the same subsystem is often both a system in its own right and a component of a larger one. This calls for a compositional approach to design: one that can represent interdependence, capture trade-offs across scales and disciplines, and remain computationally tractable.

In this talk, he will present a framework for the compositional co-design of complex systems, drawing on optimization, control, and applied category theory. The central idea is to model components and their interconnections in a modular way, so that large design problems can be assembled, queried, and solved systematically from smaller ones. This perspective gives rise to a new class of compositional optimization problems, in which design trade-offs are expressed structurally and solved through algorithms that exploit interconnection and feedback, rather than collapsing everything into a monolithic formulation.

He will illustrate the framework through examples spanning autonomous systems and future mobility, showing how it supports task-driven design across levels: from the choice of algorithms and components in autonomous vehicles to the co-design of services, operations, infrastructure, and policies in intermodal mobility systems. These examples highlight how compositional design can unify heterogeneous models and objectives, enable collaboration across disciplines, and provide quantitative tools to reason about the societal impact of emerging technologies.

He will conclude by outlining ongoing efforts that extend this framework toward uncertainty-aware and adaptive design, including distributional formulations of co-design problems, online learning with embedded black-box components, and broader questions at the intersection of compositional optimization, strategic interaction, and multi-stakeholder system design.

Bio—Gioele is the Rudge (1948) and Nancy Allen Assistant Professor at Massachusetts Institute of Technology, where he is a Principal Investigator in the Laboratory for Information and Decision Systems (LIDS), a faculty member in the Department of Civil and Environmental Engineering (CEE), and an affiliate faculty member with the Institute for Data, Systems, and Society (IDSS). Since joining MIT in Fall 2024, he has been building a research program at the intersection of optimization, control, autonomy, and complex systems design.

Driven by societal challenges, the goal of his research is to develop efficient computational tools and algorithmic approaches to formulate and solve complex, interconnected system design and autonomous decision-making problems. His interests include the co-design of complex systems, all the way from future mobility systems to autonomous systems, compositionality in engineering, planning, and control, and game theory. He is also the lead PI of an AFOSR Center of Excellence on compositional optimization. He is also the knowledge manager of the World Infrastructure Forum.

He received his doctoral degree from ETH Zurich in 2024, where he had previously earned both his B.Sc. in Mechanical Engineering and his M.Sc. in Robotics, Systems, and Control. Before joining MIT, he was a Postdoctoral Scholar at Stanford University for 6 months and held visiting positions at nuTonomy Singapore (later Aptiv, now Motional), Stanford, and MIT.

He is the creator of Autonomy Talks, an international seminar series fostering broad and diverse exchange on autonomy research, and has organized influential workshops on compositionality and architectures at CDC, ICRA, and ITSC. He is the recipient of the ETH Medal for his doctoral thesis, the 2025 DARPA Young Faculty Award (YFA), the 2026 Maseeh Excellence in Teaching Award in CEE at MIT, a paper award at the 4th Applied Category Theory Conference, the Best Paper Award (1st Place) at the 24th IEEE International Conference on Intelligent Transportation Systems (ITSC), DoE, MIT, AFOSR, SIDARA, and Amazon awards.

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