Challenges for Certifiable Software for Autonomous Vehicles
Position Paper

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Abstract: Autonomous (self-driving) cars, as full-fledged examples of cyber-physical systems (CPS), are expected to be available for customers around 2020. They are to be more dependable than a human driver and allow for more sustainable mobility to match the pace of urbanization. Even if several widely recognized international competitions during the recent years demonstrated the feasibility of such a technology under controlled conditions, the safety and the commercial viability of such systems remains challenging. Particularly problematic are issues surrounding the software that implements autonomous functions in such vehicles. This paper identifies key challenges in the development, testing, and certification of such software, and puts forth an approach to addressing them.

Introduction

The availability of unprecedented computational and communication capabilities is transforming the transportation landscape. These capabilities can be effectively used to render traffic accidents practically impossible, increase accessibility to disabled and elderly travellers, and reduce pollution, negative environmental impact, and the cost of transporting goods. Well-designed cyber-physical systems (CPS) [Lee08] must orchestrate the interplay between mechanical, electrical, and software-engineered solutions for systems supporting comfort, assistive, and even mission-critical processes in the real world. We can find CPS realizing subsystems like an adaptive cruise-control function in today's vehicles, or interconnected, semi-autonomous vehicle platoons in tomorrow's systems. Our interest is in autonomous vehicles, which are reported to be available for customers around 2020 [Hir13]. As vehicles and transportation systems make increasing use of the sensing and computational capabilities, increasing levels of autonomous operation will be necessary both to reduce the cognitive load on drivers as well as to assist with the vast spectrum of decisions that will be made by such systems.

Autonomous cars have been increasingly gaining public attention following the large international Grand Challenges organized by DARPA in 2004, 2005, and 2007 [BM+09], as well as events like the Grand Cooperative Driving Challenge in 2011 [SP+12] and the European ELROB events [ELR13]. While these events put engineering challenges in the limelight for the research community, their primary function was to explore feasibility. The technology's robustness and reliability in the context of day-to-day use has not yet been achieved. For example, in the 2007 DARPA Urban Challenge, the following aspects of inner-city driving were explicitly excluded:

1. vulnerable road users like pedestrians and bicyclists,
2. driving during reduced visibility due to rough weather conditions or at night,
3. long-term system reliability and robustness, or even
4. an acceptable customer comfort-level.

In the years following this competition, the Grand Challenge research community began addressing the listed challenges mentioned before [BR12].

Although the sensing capabilities of the experimental and prototype vehicles used in these contests were comparable, success in these competitions rested primarily on the unique software employed by the competing teams. Software plays a prominent role in autonomous vehicles, since it is responsible for implementing control, planning, and sensing functions. It must also be reliable enough to perform not just for a one-day demonstration, but to meet the day-to-day uses and expectations of customers.

The development, validation, and verification processes of these systems--and especially the software engineering for these cyber-physical represent a great challenge [Ber12]. In what follows, we outline key challenges towards certifiability of CPS using the example of autonomous vehicles, as well as promising research directions to realize reliable self-driving cars for a safer and more sustainable urban mobility in the future.

Key Challenges

While autonomy enables previously unimaginable levels of performance, it increases the costs of potential failures. Because autonomous software functions expand the intrinsic complexity and coupling in systems, they complicate design and testing. Current development processes, starting from requirements analysis to certification, appear to be fundamentally inadequate for systems that have higher levels of autonomy than what is already commercially available. In particular, a new methodology, processes, and tools are needed to support the development and validation of software in general, and algorithms for autonomous functions in particular. The most pressing challenges in this area are:

1. Large-scale field testing with human drivers on real roads is practically impossible. The difficulties include risk to human life, road time, scale needed to evaluate coordination functions, repeatability, and cost.
2. Human behavior in terms of attention, sensing, and cognition is difficult to model.
3. Certification standards and a methodology applicable to autonomous functions are lacking.

All three of these challenges must be addressed in order to advance beyond the currently attainable levels of autonomy.

Proposed Approach

High fidelity virtual prototyping and testing is the most promising approach for overcoming these challenges and enabling the development of provably safe and commercially viable autonomous vehicles. Areas of particularly high potential impact are the development of methods and tools for:

1. Physics-based modeling, simulation, and testing of sensors,
2. Empirical model validation,
3. Rigorous, automated, and model-based end-to-end testing, and
4. Human-in-the-loop virtual prototyping and testing.

Research at both the engineering and the foundational levels is required to develop such methods. In addition, success in this undertaking will require close coordination between partners with diverse academic and industrial expertise.

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