Research Challenges in Automotive Control Software

Rance Cleaveland

Professor
Department of Computer Science
University of Maryland

Executive and Scientific Director
Fraunhofer Center for Exp. Software Eng.
University of Maryland

October 21, 2008

1. Introduction

Over a century has passed since the invention of the automobile, and yet the social and economic benefits of this innovation continue to be felt around the world. As an enabler of personal mobility, cars provide people with flexibility in where they live, work and shop. Their popularity continues to grow, both in the developed world, where the ratio of vehicles to people can approach 1:1, and in developing societies, where rising levels of car ownership are a sure indicator of economic growth.

The very popularity of automobiles also presents great social challenges, among which environmental disturbance, dependence on fossil fuels, and road congestion feature prominently. Addressing these issues in a cost-effective and business-sensitive manner is arguably one of the biggest long-term technical problems facing the automotive industry; succeeding at doing so will have tremendous benefits, both to society and to the companies that are successful in devising well-engineered solutions.

Software will be a key enabler in whatever solutions emerge to these challenges. Software already constitutes approximately 15% of the cost of an average automobile, according to statistics widely cited in the automotive press. For advanced hybrid vehicles, this figure is significantly higher, approaching 40%. Moreover, new-feature content – the source both of industry profit, driver satisfaction, and social benefit – is reckoned to be 90% software-based, according to sources in General Motors. The thesis of this position paper is that anticipating, and addressing, the software needs of the automotive industry must be a key and urgent item on the national research agenda in order for the industry, and society, to continue to reap the benefits of automobile ownership while addressing the concomitant concerns of widespread car ownership.

2. Grand Challenges for Automotive Cyberphysical Systems

This section presents two grand automotive challenges whose solutions will entail fundamental research in software for cyberphysical systems.

The 500-miles-per-gallon car. The environmental and geopolitical impacts of automobiles both derive from automobiles' reliance on petroleum-based fuels. While research on alternative fuels shows promise, the next 20 years is unlikely to see a dramatic departure from the current gasoline / diesel paradigm. Revolutionary improvements in the fuel efficiency of such engine platforms would have huge social benefits over the coming decades.

Meeting this grand challenge will require advances in software development. As noted earlier, current best-practice fuel-efficiency technologies are largely software driven, and new technologies will likely require the complex control that software enables. In particular, future advances will likely require decentralized power distribution (electric motors on each wheel, for example), as well as great improvements in energy-recovery during braking and steering. Implementing these sophisticated distributed control systems will require research in control theory, systems engineering, and especially software modeling and implementation. Current limitations in software development that must be overcome include a lack of standardized modeling frameworks for distributed control software; a lack of automatic code generation for networks of electronic control units (ECUs); and tractable verification and validation methodologies for distributed control systems. These three areas represent research opportunities that, if addressed, will provide automotive engineers with necessary tools to revolutionize automotive fuel efficiency.

Driver-less driving. Road congestion is a growing drag on the economies and quality of life of developed countries, and current and future considerations for developing ones. An appealing approach to addressing congestion is to automate the task of driving itself, so that vehicles can safely travel more closely, more safely and at higher speeds than possible with humans at the controls.

This vision is not new, and several research efforts are underway that focus on this problem, but significant fundamental research, especially on the software side, needs to be undertaken to realize its promise. In particular, advances are needed in the area of real-time ad-hoc networking (since neighboring vehicle clusters will change); methods for simulating such systems; and verification technology for assuring their safety and robustness.

3. Architectures for Automotive Cyberphysical Systems

Software architectural issues will also feature prominently in future automotive design. Current design strategies rely on so-called federated approaches: suppliers provide OEMs with integrated subsystems (braking, steering, central locking. etc.), each of which includes its own ECU. This approach has worked well in the past, when automotive subsystems were largely independent and suppliers could be relied upon to be expert in the control functionalities of these subsystems. However, safety and performance imperatives are driving carmakers to consider vehicle designs in which independent subsystems (e.g. suspension and braking) interact in order to provide improved vehicle functionality. These concerns are driving reconsideration within the industry of vehicle computing architectures, among other things: many OEMs have an expressed desire to dramatically reduce the number of microprocessors in a vehicle as a means of easing inter-system communication and also reducing cost. Achieving this vision will, among other things, require substantial revisions how current automotive control architectures will be designed. Research needs include the following.

- **Software architecture analysis.** As the number of ECUs decrease, current system architectural design will be replaced by software architectural design. Current initiatives in the automotive industry (AUTOSAR in Europe and North America, JASPAR in Japan) are focused on developing reference architectures for automotive software. However, the issue of ensuring that reference architectures are adhered to in implementations remains an open problem, and one that research should be focused on. The development of formalisms for modeling and simulating distributed control-software architectures will also require research.

- **Compositional reasoning for control systems.** Developing coordinated, distributed control systems will require frameworks for reasoning about the behavior of such systems. Distributed cyberphysical control is particularly problematic because the environment ("plant") in which such systems operate is shared, and hence offers avenues for subtle and unintended interactions among different controllers**.**

Biographical Information. Rance Cleaveland is a Professor of Computer Science at the University of Maryland at College Park, where he is also the Executive and Scientific Director of the Fraunhofer USA Center for Experimental Software Engineering, an applied-research institute. Prior to joining the Maryland faculty in 2005, he held professorships at the State University of New York at Stony Brook and at North Carolina State University. He also co-founded Reactive Systems, Inc., in 1999 to commercialize tools for model-based testing of embedded software; Reactive Systems currently has numerous customers worldwide in the automotive and aerospace industries. In 1992 he received Young Investigator Awards from the National Science Foundation and from the Office of Naval Research, and in 1994 he was awarded the Alcoa Engineering Research Achievement prize at North Carolina State University. He has published over 100 papers in the areas of software verification and validation, formal methods, model checking, software specification formalisms, and verification tools. Cleaveland received B.S. degrees in Mathematics and Computer Science from Duke University in 1982 and his M.S. and Ph.D. degrees from Cornell University in 1985 and 1987, respectively.

Contact info
Rance Cleaveland
Department of Computer Science, AV Williams Building
University of Maryland
College Park, MD 20742
Tel: 301-403-2065
E-mail: rance@cs.umd.edu