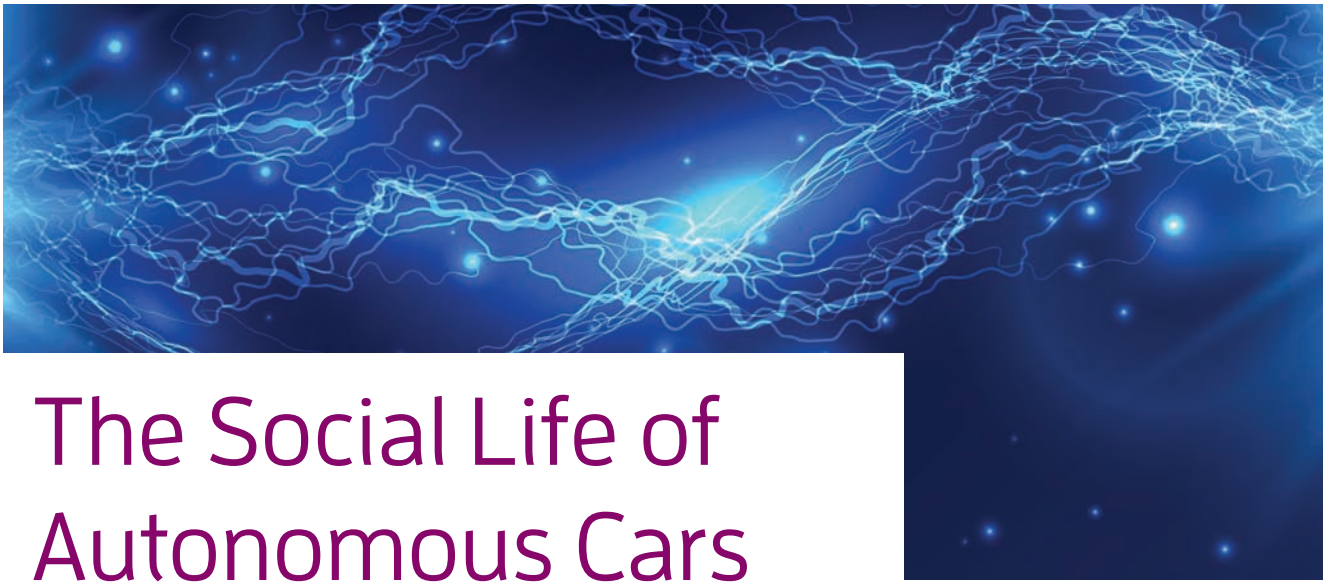

The Social Life of Autonomous Cars

Barry Brown, Stockholm University

Until the day comes when all vehicles are fully autonomous, self-driving cars must be more than safe and efficient—they must also understand and interact naturally with human drivers.

Cars such as the Tesla Model S and the Volvo XC90 now feature advanced self-driving functions, with tens of thousands of these vehicles on roads worldwide and more appearing every year. In addition, Tesla and other companies like Delphi and Google are testing fully autonomous cars, which have traveled millions of miles on American roads.

We're in the midst of a global field test of autonomous driving technology, yet results from these tests are proprietary, with little publically available data. Occasionally, flaws in the technology are exposed by videos taken by in-car dashcams and passengers' mobile phones and uploaded to social media sites like YouTube, prompting media discussion and sometimes controversy. For example, in December 2016, on the first day of a trial launch of a fleet of Uber self-driving cars with human monitors in San Francisco, a motorist's dashcam captured one such car driving through a red light and narrowly missing a pedestrian. Hours after the video appeared on YouTube, California authorities forced Uber to cease testing until it had obtained proper permits.[1]

At Stockholm University, we've developed a new method that provides a quick, partial view of self-driving systems using public videos.[2] These videos reveal some of the challenges of adapting autonomous cars to human social activity on the road.

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REPURPOSING ONLINE VIDEOS

YouTube is the world's largest repository of third-party videos. For our first study, we used a range of terms to search this repository for clips involving both semiautonomous cars with driver assistance functionality and fully autonomous test cars. We mostly excluded promotional videos and instead focused on reviews and travelogues, many of which contain long stretches of silent driving and commentaries on system actions.

We collected a corpus of 93 video clips—totaling 10.5 hours—recorded in the US, the UK, Germany, France, Sweden, Hong Kong, Iceland, and Canada. The average length is 9 minutes, with 7 of the clips over 30 minutes. Most illustrate Tesla's driver-assistance system, Autopilot, and three show similar systems in the Volvo XC90

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(a)

(b)

Figure 1. "Rude" behavior by Tesla's Autopilot system after the driver signals his intention to move to the left lane to make room for a pickup truck merging onto the highway. (a) A silver car approaching from behind in the left lane slows to allow the Tesla driver to move over (left) as the truck enters the right lane ahead of the Tesla driver (right). (b) The silver car's driver, thinking the Tesla driver has rejected his polite offer, accelerates into the gap (left), but Autopilot executes the lane change anyway, cutting off the other driver (right). (Source: Garth Woodworth, "Tesla Autopilot Lane Changing," 12 Nov. 2015; www.youtube.com/watch?v=el4OdwtgzNk.)

and a Honda Civic. Nine videos, totaling 11 minutes, recorded Google's self-driving cars. In addition, a South by Southwest (SXSW) presentation on the Google project shows several interesting incidents.

THE SOCIAL ROAD

We drew upon well-established linguistic and sociological methods that analyze unobtrusive video recordings of humans to better understand driving behavior and some of the potential problems posed by autonomous vehicles. Perhaps the most interesting revelation comes from interactions between such cars and other drivers.

Consider Tesla's Autopilot system, which has three main functions:

- adaptive cruise control, which relies on distance to the car ahead to accelerate and decelerate;
- auto-steering, which uses road markings and, if that fails, the vehicle ahead, to maintain lane position; and
- lane-change assistance, which moves the car to an adjacent lane if it's safe to do so after the driver activates the turn indicator.

These functions are far from fully autonomous driving, but the Tesla can travel for considerable periods of time in autonomous mode.

In the YouTube videos we collected, most of the time Autopilot drives without incident. Yet, due to its simple mechanics, Autopilot sometimes misunderstands other drivers' actions. While people can often discern other drivers' intentions as well as mood or character—aggressive, hesitant, selfish, unpredictable, and so on—based on changes (or the absence of changes) in their car's speed, direction, and so on, Autopilot lacks this ability.

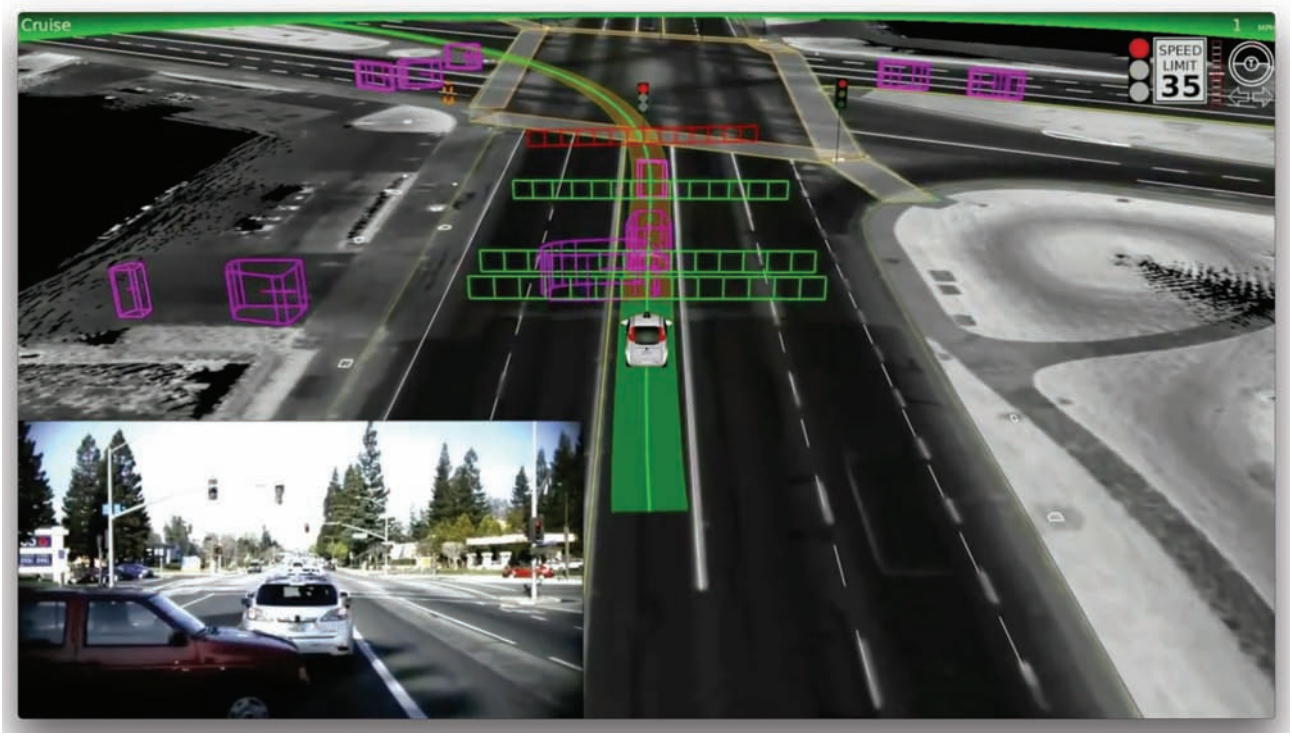

Figure 2. Human driver confused by self-driving technology. A driver in a red vehicle crosses a highway and tries to squeeze into the narrow space between two Google self-driving cars to enter the left-turn lane (inset). The driver might have mistakenly perceived the gap, which the second car left to maintain a safe following distance, as an offer to enter the space. (Source: SXSW, "Google Self-Driving Car Project/SXSW Interactive 2016," 12 Mar. 2016; www.youtube.com/watch?v=Uj-rK8V-rik.)

Consider, for example, the fairly common situation depicted in Figure 1. On a divided highway with two lanes in each direction, a Tesla driver is in the right lane in heavy traffic. Ahead on his right he sees a pickup truck merging onto the highway from a connector road. The Tesla driver activates his left-turn signal, indicating his desire to move to the left lane to make room for the truck. A driver in a silver car approaching from behind in the left lane sees the signal and stops accelerating, offering a space for the Tesla driver to enter (Figure 1a). Autopilot, however, doesn't recognize this polite "gesture" and continues to maintain the Tesla's position. The silver car's driver, concluding that the Tesla driver has rejected the offer, starts accelerating again. Autopilot, determining the lane change to still be safe, directs the Tesla to move over (Figure 1b).

The action produced by the Tesla's robotic coordination might not "bother" another autonomous driving system, but the silver car's driver understandably perceives this as doubly rude: The Tesla driver first apparently spurns his offer and then cuts in front of him at the last second. The Tesla driver acknowledges this rudeness in the video: "Well, we pulled in ahead of that guy and from what I saw it wasn't something he was exactly encouraging."

This example demonstrates that, even if autonomous cars can be safe and reliable, they fail to recognize the social nature of the road. Human drivers aren't always "in tune" with one another, but they're not just algorithmic agents—in most cases they can detect the same kind of subtle cues that we exhibit in personal interactions.

SEEING A GAP AS JUST A GAP

In addition to not understanding what others on the road are doing, autonomous driving systems have trouble recognizing what their own actions might communicate to human drivers. This problem is highlighted in Figure 2, which is extracted from a SXSW 2016 talk narrated by Chris Urmson, principal engineer of Google's self-driving car project.

In this example, a human driver crosses a four-lane highway and then enters a left-turn lane just before an intersection, wedging his red vehicle in the narrow space between two self-driving cars. Prompting laughter from the audience, Urmson mocks the driver's behavior: "And of course, we have people who do I don't know what sometimes on the road, like this guy pulling out between two self-driving cars. You have to ask, what are you thinking?"

Yet, while the human driver might not show the best judgment, his behavior is understandable. As drivers, we learn the importance of maintaining a safe distance behind the car ahead. This principle is likewise incorporated

into autonomous driving systems. In this case, the second self-driving car slowly approaches the intersection and leaves a gap between itself and the first self-driving car. However, as the Tesla example shows, gaps in the road aren't just safe following distances—they can also be interpreted by other drivers as offers to enter the space. The human driver might have perceived the gap between the self-driving cars as such an offer.

The driver might also simply have tried to force his way in. People don't always drive sensibly or legally, especially in situations that can lead to anger or confusion such as in construction zones or heavy traffic. On busy roadways, some drivers will exploit any space they can find. In this case, the self-driving car approaching the intersection dealt with the human driver's action appropriately, slowing down and allowing the red vehicle to enter the space.

SOMETIMES IT'S GOOD TO BE A CREEP

Human drivers also interpret other drivers' *inaction*. This too can cause problems for autonomous driving systems, as Figure 3 shows.

In this example, a Google self-driving car arrives at a four-way stop just before a driver in a white car on the cross street. Research on four-way stops underlines the importance of creeping into the intersection to let other drivers know that you're attentive to the situation and ready to take your turn. Although the Google car edges forward, the motion is insufficient to signal an urgency to proceed. The driver on the cross street interprets this as hesitation and accordingly moves into the intersection first. This causes the Google car to brake abruptly, much like a novice driver, which in turn causes the driver behind to also stop quickly to avoid a rear-end collision.

Our videos also show drivers, apparently annoyed by the Google's car slowness, tailgating the vehicle to "urge" it forward through intersections.

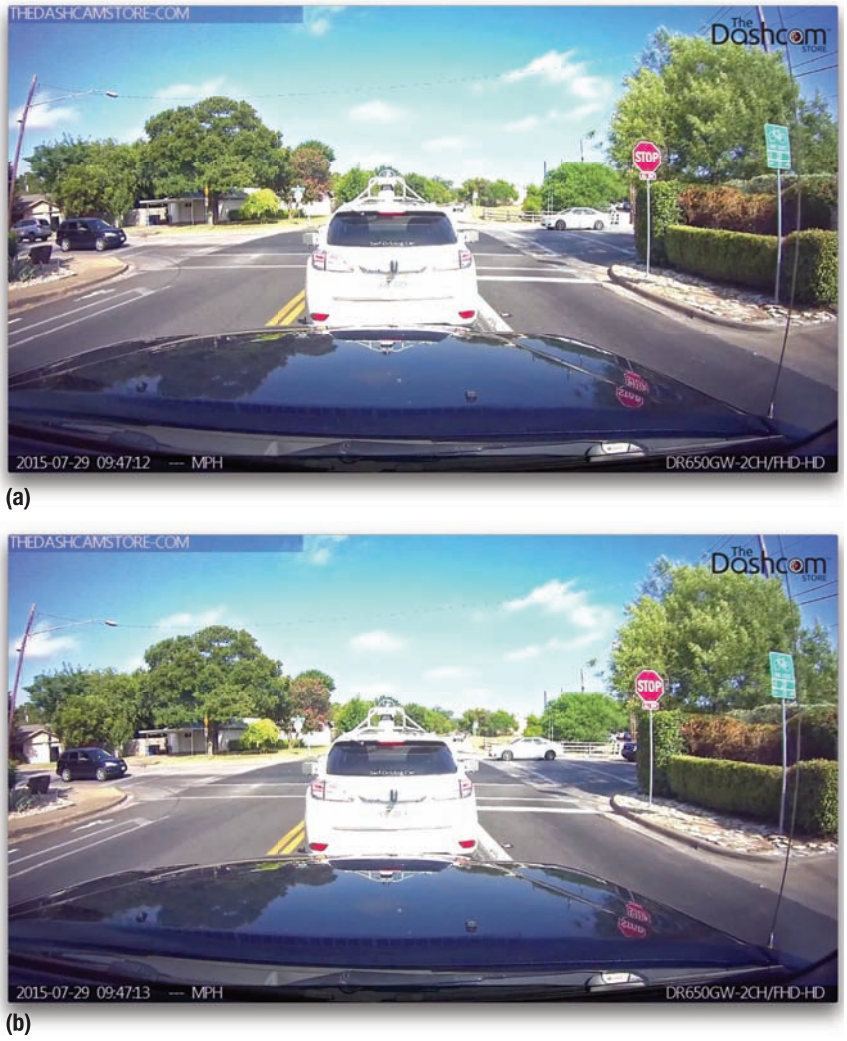

Figure 3. Aggressive driving prompted by self-driving technology. (a) A Google self-driving car arrives at a four-way stop just before a driver in a white car to the right on the cross street. (b) The self-driving car's seeming hesitancy to proceed motivates the driver to jump his turn, causing the Google car to brake abruptly and nearly cause a collision with the vehicle behind it. (Source: The Dashcam Store, "Google Self-Driving Car Spotted in Austin, TX—Dashcam Video," 29 July 2015; www.youtube.com/watch?v=FbSQm3YaAzA.)

THE UNCANNY VALLEY OF AUTONOMOUS CARS

Research on human social interaction has revealed that many of our actions—complaints, invitations, and so on—are preceded by "pre-actions" that communicate our intent and thus prepare others for what we're about to do. For example, placing a hand on a stand-up microphone is a pre-action to making an announcement. Because of the driving environment's complexity and the intricate rules of engagement, drivers carry out many pre-actions to avoid potential collisions or to assert themselves in congested conditions.

Programming autonomous vehicles to execute and recognize often subtle pre-actions is challenging, which poses a dilemma for designers akin to the "uncanny valley" problem in computer graphics and robotics. As computer-generated human figures and humanoid robots become less

cartoonish and more realistic, their residual shortcomings become more visible, sometimes evoking unease or revulsion. Similarly, as self-driving cars become better at the mechanics of driving, yet still not "behave" exactly like human drivers, they could arouse feelings of anger or frustration. For example, always slowing down to avoid a collision—a statistically safe but not always the best response—could encourage drivers to cut off or zoom past an autonomous car, ironically increasing the risk of a collision.

In the early days of the automobile, a person walked ahead of a car with a red flag to alert other road users. Until autonomous vehicles can navigate the social road as well as actual roads, should they likewise be equipped with a system to warn human drivers or to signal their intent in ambiguous situations such as four-way stops? This prompts the question of how identifying a vehicle as autonomous would influence human drivers. Would they be more cautious and patient, or try to take advantage of a "dumb" artificial driver?

My goal here isn't to critique the current generation of self-driving cars, which are still in the early stages of development. Rather, it's to point out that driving isn't just a mechanical operation but also a complex social activity. Until the day comes when all vehicles are fully autonomous, self-driving cars must be more than safe and efficient—they must also understand and interact naturally with human drivers. So long as most vehicles on the roadway continue to be operated by people, self-driving car designers must consider how their choices impact other drivers as well as their own vehicles' passengers. If not, the social road could get a lot bumpier.

REFERENCES

1. J.F. Rodriguez, "Video Appears to Show Uber Self-Driving Car Running Red Light in SF," *San Francisco Examiner*, 14 Dec. 2016; www.sfexaminer.com/uber-self-driving-vehicle-appears-launch-red-light-first-day-sf.
2. B. Brown and E. Laurier, "The Trouble with Autopilots: Assisted and Autonomous Driving on the Social Road," to be published in *Proc. 2017 CHI Conf. Human Factors in Computing Systems* (CHI 17), 2017.

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