Eliminating unexplained traffic jams

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Everybody's experienced it: a miserable backup on the freeway, which you think must be caused by an accident or construction, but which at some point thins out for no apparent reason.

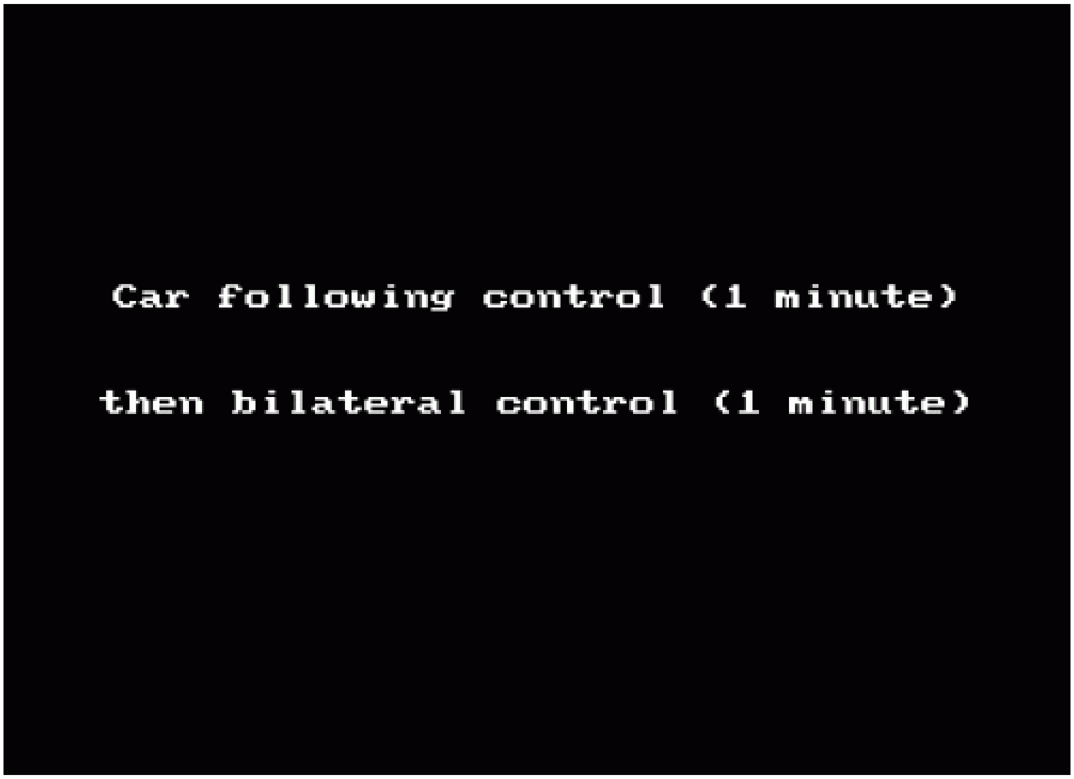
Such "traffic flow instabilities" have been a subject of scientific study since the 1930s, but although there are a half-dozen different ways to mathematically model them, little has been done to prevent them.

At this month's IEEE Conference on Intelligent Transport Systems, Berthold Horn, a professor in MIT's Department of Electrical Engineering and Computer Science, presented a new algorithm for alleviating traffic flow instabilities, which he believes could be implemented by a variation of the adaptive cruise-control systems that are an option on many of today's high-end cars.

A car with adaptive cruise control uses sensors, such as radar or laser rangefinders, to monitor the speed and distance of the car in front of it. That way, the driver doesn't have to turn the cruise control off when traffic gets backed up: The car will automatically slow when it needs to and return to its programmed speed when possible.

Counterintuitively, a car equipped with Horn's system would also use sensor information about the distance and velocity of the car behind it. A car that stays roughly halfway between those in front of it and behind it won't have to slow down as precipitously if the car in front of it brakes; but it will also be less likely to pass on any unavoidable disruptions to the car behind it. Since the system looks in both directions at once, Horn describes it as "bilateral control."

Traffic flow instabilities arise, Horn explains, because variations in velocity are magnified as they pass through a lane of traffic. "Suppose that you introduce a perturbation by just braking really hard for a moment, then that will propagate upstream and increase in amplitude as it goes away from you," Horn says. "It's kind of a chaotic system. It has positive feedback, and some little perturbation can get it going."



A sample run of Horn's traffic simulator. The bilateral-control algorithm is switched on at the one-minute mark. Credit: Berthold Horn

Doing the math

Horn hit upon the notion of bilateral control after suffering through his own share of inexplicable backups on Massachusetts' Interstate 93. Since he's a computer scientist, he built a computer simulation to test it out.

The simulation seemed to bear out his intuition, but to publish, he needed mathematical proof. After a few false starts, he found that bilateral control could be modeled using something called the damped-wave equation, which describes how oscillations, such as waves propagating through a heavy fluid, die out over distance. Once he had a mathematical description of his dynamic system, he used techniques standard in control theory—in particular, the Lyapunov function—to demonstrate that his algorithm could stabilize it.

Horn's proof accounts for several variables that govern real-life traffic flow, among them drivers' reaction times, their desired speed, and their eagerness to reach that speed—how rapidly they accelerate when they see gaps opening in front of them. Horn found that the literature on traffic flow instabilities had proposed a range of values for all those variables, and within those ranges, his algorithm works very efficiently. But in fact, for any plausible set of values, the algorithm still works: All that varies is how rapidly it can smooth out disruptions.

Horn's algorithm works, however, only if a large percentage of cars are using it. And laser rangefinders and radar systems are relatively costly pieces of hardware, which is one of the reasons that adaptive cruise control has remained a high-end option.

Digital cameras, on the other hand, have become extremely cheap, and many cars already use them to monitor drivers' blind spots. "There are several techniques," Horn says. "One is using binocular stereo, where you have two cameras, and that allows you to get distance as well as relative velocity. The disadvantage of that is, well, two cameras, plus alignment. If they ever get out of alignment, you have to recalibrate them."

Time to impact

Horn's chief area of research is computer vision, and his group previously published work on extracting information about distance and velocity from a single camera. "We've developed monocular methods that allow you to very accurately get the ratio of distance to velocity," Horn says—a ratio known in transportation studies as "time to contact," since it captures information about the imminence of collision.

"Strangely, while it's, from a monocular camera, difficult to get distance accurately without additional information, and it's difficult to get velocity accurately without additional information, the ratio can be had." In ongoing work, Horn is investigating whether his algorithm can be adapted so that it uses only information about time to contact, rather than absolute information about speed and distance.

"This is a beautiful paper," says Mohan Trivedi, a professor of electrical engineering and computer science at the University of California at San Diego, and director of the school's Laboratory for Intelligent and Safe Automobiles. "It's a welcome addition to our literature, and I'm looking forward to other people picking up on this and pushing it forward."

The real obstacle to the system's adoption, Trivedi says, is not technical but psychological. "Generally, drivers really worry about what is good for me, rather than what is good for the whole platoon or the community of vehicles that are moving on this road with me," he says.

But, Trivedi adds, his own group is investigating the use of rearview cameras for safety applications, rather than applications that address questions of collective welfare. "A lot of times, we might be intending to change lanes to overtake, to exit, to merge, and in those cases, we may not be aware of things that can come from behind us," he says. "We are developing these large, wide-angle field-of-view systems that look behind and can fuse motion cues and appearance cues to look at those surrounding criticalities." If such systems catch on, Trivedi says, Horn's algorithm could piggyback on top of them, without increasing cars' sticker prices.

More information: "Optimization of Lyapunov Invariants in Verification of Software Systems" ieeexplore.ieee.org/xpl/articl … tp=&arnumber=6416001