Looking into **the Future**

Picture credit: Astrid Eckert/TUM

Link
www.ce.cit.tum.de/air

Preventing accidents is the number one priority in the development of autonomous vehicles. With this in mind, Professor Matthias Althoff is working on a procedure to make autonomous vehicles up to 100 % safe. His software can anticipate traffic situations within a fraction of a second – thereby ensuring that the car avoids collisions with other road users.

Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung-28

Blick in die Zukunft

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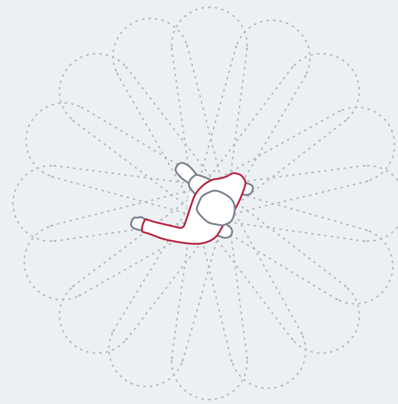
Autonom fahrende Autos dürfen andere nicht gefährden. Um Unfälle und Kollisionen zu vermeiden, müssen sie auf alle möglichen Verkehrssituationen vorbereitet sein. Prof. Matthias Althoff will mit seinen Forschungsarbeiten die Interaktion von autonomen Fahrzeugen mit anderen Verkehrsteilnehmern sicherer machen. Seine Software trifft in Echtzeit eigene Entscheidungen und kann so – Sekunden im Voraus – Gefahren ausschließen. Dazu erfasst das Programm permanent die Verkehrsdaten, analysiert im Millisekundentakt während der Fahrt das Geschehen und prognostiziert den weiteren Verlauf. Die Software berechnet dann für alle Verkehrsteilnehmern die Menge aller Möglichkeiten, ermittelt verschiedene Optionen und kalkuliert gleichzeitig mögliche Notmanöver. Nur wenn eine Route ohne voraussehbare Kollision befahren werden kann und zudem ein Notmanöver möglich ist, darf das autonome Fahrzeug die Strecke befahren. □



Plenty of things can surprise you when driving a car. From a vehicle in front braking sharply to a cyclist suddenly veering into your path or a pedestrian stepping directly onto the road, the range of hazards that can arise in road traffic is just about endless.

In most cases, a person sitting behind the wheel can make an adequate assessment of hazards as they occur and react accordingly. They can anticipate how other road users will behave and preempt their intentions, such as the possibility that a pedestrian standing on the curb might suddenly step into the road.

In their current stage of technological development, autonomous vehicles cannot keep pace with human cognition. For the most part, they rely on patterns they have learned and stored in their memory, driving according to rigid rules – which limits their flexibility in complex traffic situations and increases the risk of accidents. Above all, they need to be prepared to handle as many different scenarios as possible so that they can react appropriately.

Achieving that, however, is anything but simple. Given the gargantuan number of potential combinations of variables, it is simply not possible to determine all possible scenarios in advance. The sharpness and shape of a bend, the width of a lane, the number of other vehicles on the road, directions of travel, different speeds – the possible variants of these central driving parameters generate a vast number of combinations that cannot all be tested.

“Testing alone is not enough to validate an autonomous car,” explains Matthias Althoff, Professor of Cyber-Physical Systems at TUM. “If you wanted to ensure that an autonomous car drives just as reliably as a human with a 95 % degree of certainty, it would have to complete around 440 million kilometers – which would be inefficient.” And, as Althoff points out, a car will never experience the vast majority of scenarios and combinations of potential traffic scenarios.

Real-time decisions

Together with his research team, Matthias Althoff is hoping to help autonomous vehicles react in a similar way to humans. Instead of rigidly following rules they have been taught, the researchers hope to enable autonomous vehicles to make decisions independently in future, thereby eliminating hazards seconds before they occur.

For this to be possible, cars will need the ability to think ahead when driving and anticipate traffic situations, just as people do. “To achieve this goal, we look at everything that other road users could do,” says Althoff. Before a self-driving vehicle sets off, Althoff’s software system calculates the multitude of possible situations that could occur fractions of a second later. This “set of reachable states” is the heart of the entire concept.

The procedure behind it is called reachability analysis. It involves calculating, for example, which positions a car or a pedestrian could feasibly occupy in the next few seconds. “Determining these sets of states and reconciling everything with motion planning for other vehicles is not easy," explains Althoff. Moreover, because determining a set of states requires sophisticated calculations, Althoff makes do with simple models that are easier to capture mathematically.

At the same time, the set of states is used to design an emergency maneuver. This could be to brake sharply or speed up so that the vehicle can be guided to a safe place without endangering other people. "We always have an emergency maneuver to hand that can take us to a safe state," says Althoff. "The vehicle can only drive a given route if no collisions are foreseeable and an emergency maneuver can be performed."

> *"Testing alone is not enough to validate an autonomous car."*
>
> Matthias Althoff

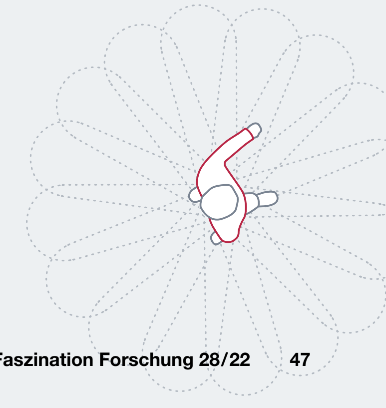
Better reactions

Together with his team, Althoff has translated this theoretical concept into a software module that constantly analyzes and predicts incidents while a vehicle is driving. In the first step, the program uses camera and radar data to capture all nearby road users at millisecond intervals.

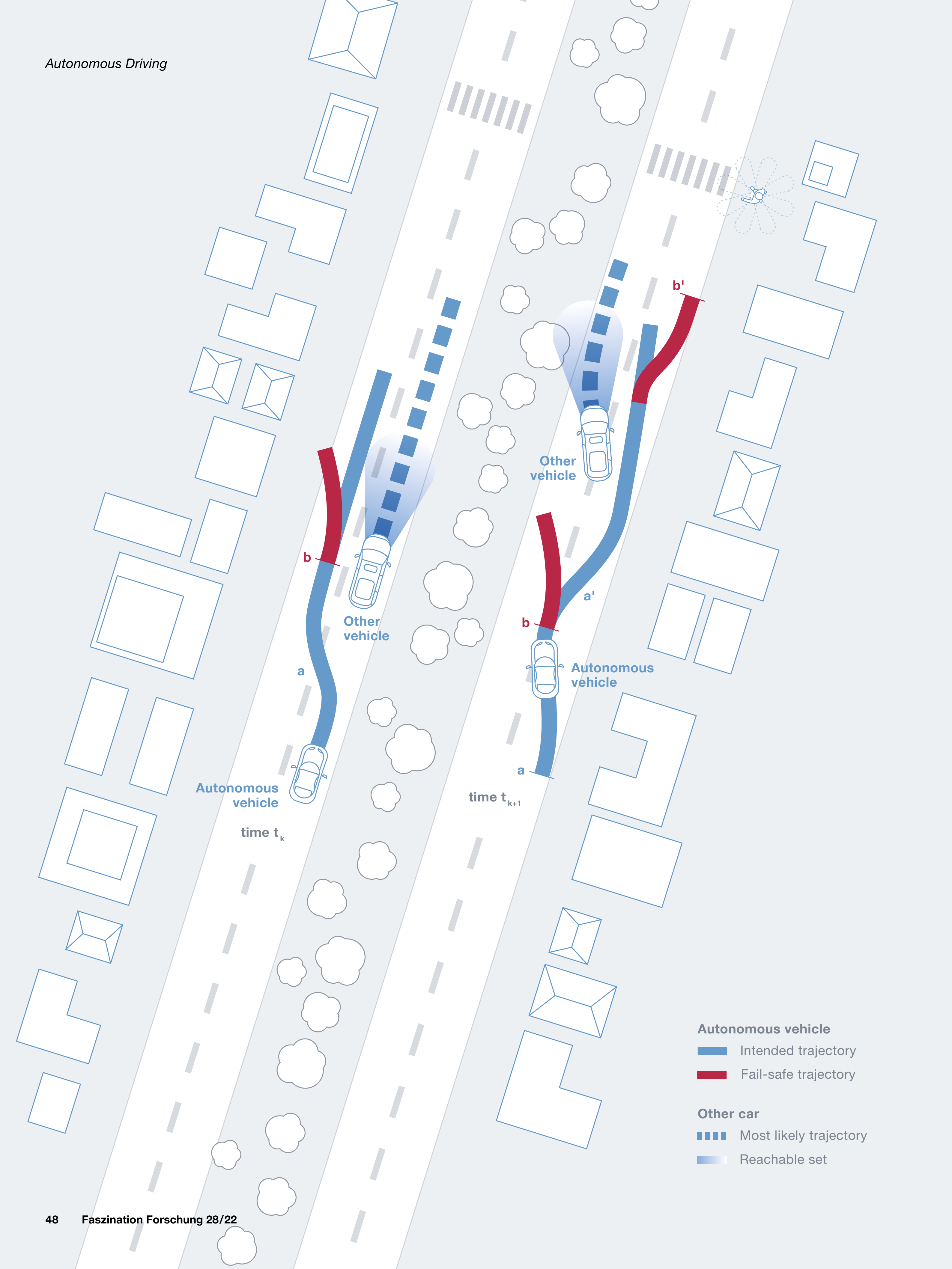
Based on this data, it calculates the set of reachable states – that is, the potential movements of the other road users in the next few seconds. This analysis allows the software system to look three to six seconds into the future. Using these calculations, the program then defines several motion options for the car's maneuver – including the emergency maneuver. However, there is one limitation to this. The vehicle's actions must also comply with road traffic regulations at all times.

This new approach could usher in a paradigm shift for autonomous vehicles. Althoff's software enables cars to react more effectively to unexpected road traffic incidents not foreseen by manufacturers. Not only has the Munich-based research team shown that real-time data analysis and simultaneous simulation of future traffic situations is theoretically possible, they have also delivered the mathematical proof that it achieves reliable results. Real-world road testing is currently underway.

■ *Klaus Manhart*



Graphics: ediundsepp


b
Other vehicle
a
Autonomous vehicle
time t_k
b'
Other vehicle
a'
b
Autonomous vehicle
a
time t_{k+1}
Autonomous vehicle
Intended trajectory
Fail-safe trajectory
Other car
Most likely trajectory
Reachable set

Prof. Matthias Althoff

received a diploma in Mechanical Engineering in 2005 and his PhD in Electrical Engineering in 2010, both from TUM. From 2010 to 2012, he was a postdoctoral researcher at Carnegie Mellon University in Pittsburgh, USA, followed by a stint as Assistant Professor at the Technische Universität Ilmenau from 2012 to 2013. Since then he has been a professor in computer science at TUM. His research interests include the formal verification of continuous and hybrid systems, reachability analysis, planning algorithms, non-linear control, automated vehicles, and power systems.

◁ **Planning for the unexpected**

The graphic illustrates the software module developed by Matthias Althoff to achieve safe autonomous driving. In the initial scenario, the autonomous blue car wants to overtake another slow car in front of it. Just like a human driver, the autonomous vehicle assumes that the other car will stay in the same lane and continue to drive at the same speed.

Althoff's concept involves analyzing the behavioral scope of the car to be overtaken – that is, its range of potential behaviors. This is known as the set of reachable states. In the example, a and a' are two sections of the planned movement. At the same time, the system designs an emergency maneuver (b and b'). This maneuver becomes important if no future safe behavior can be found. In this case, the autonomous car must execute the emergency maneuver to return to a safe state.

Only when a and b have been verified does the autonomous car start the maneuver, at time step t_k in the diagram. At time step t_{k+1} the other car makes an unexpected and sudden lane change. The original emergency maneuver, b, remains safe – but the autonomous vehicle does not need to brake unnecessarily and come to a halt.

This is because a new solution, a', has arisen dynamically along with a corresponding emergency maneuver, b' – both of which must be safe, taking the behavior of the other vehicle into account. Once this solution has been verified, the autonomous vehicle can follow this new route.

Picture credit: Astrid Eckert/TUM; Graphics: ediundsepp (source: TUM)