



Envisioning Autonomy

Autonomous cars are just around the corner. These vehicles have no driver to make eye contact with, nobody to give you a go-ahead thumbs up or a warning honk.

We use many types of informal cues to get around our city safely.

What do you need to know about sharing your city with vehicles that see you as obstacles, not people?

Greg Martin
OCAD University
April 2022

Levels of Autonomous Driving

Autonomous driving technologies are in various stages of development.

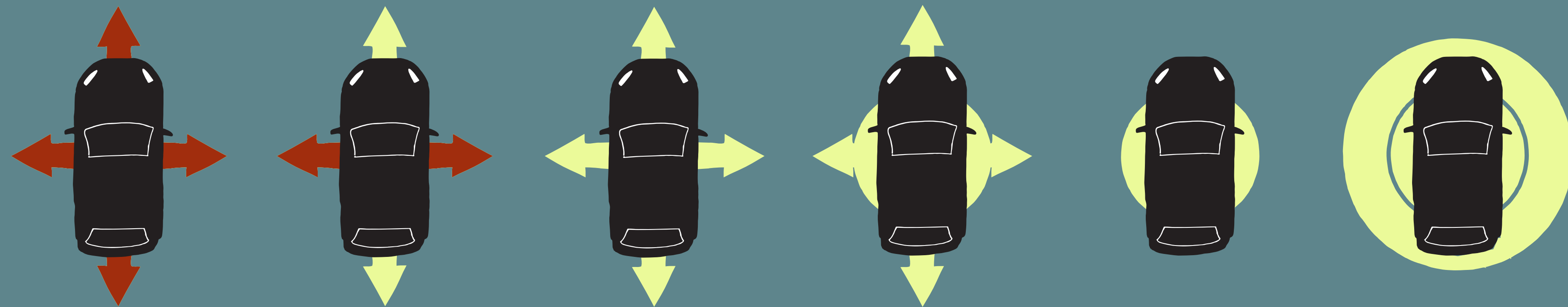
Some of these components are already commonplace in high-end modern cars. Vehicles advertising self-driving features today are offering autonomy at Levels One or Two.

To help regulate the transition, this taxonomy has been developed by the Society of Automotive Engineers (SAE). When you hear 'Level Three autonomy' in a commercial, this does not describe cost or age: it describes the circumstances under which the car drives itself.

Will we decide to skip one or more of these levels as self-driving vehicles become more popular? Would you be prepared to take over control of a Level Three vehicle, at high speed, at a moment's notice?

Human-controlled

Autonomous



Level Zero

The car may provide momentary assistance or safety warnings. You are always in control of the vehicle.

Level One

The car can assist either with acceleration and braking elements, or with some steering elements. You are always in control of the vehicle.

Level Two

The car can assist with acceleration, braking, and steering at the same time. At all times, however, you are in control of the vehicle.

Level Three

Under limited circumstances, the car can drive itself. At any time, the car may assign control to you. When the car is driving itself, you are not considered to be in control.

Level Four

Under limited circumstances, the car can drive itself. It will never assign control to you, but it may not operate under certain conditions.

Level Five

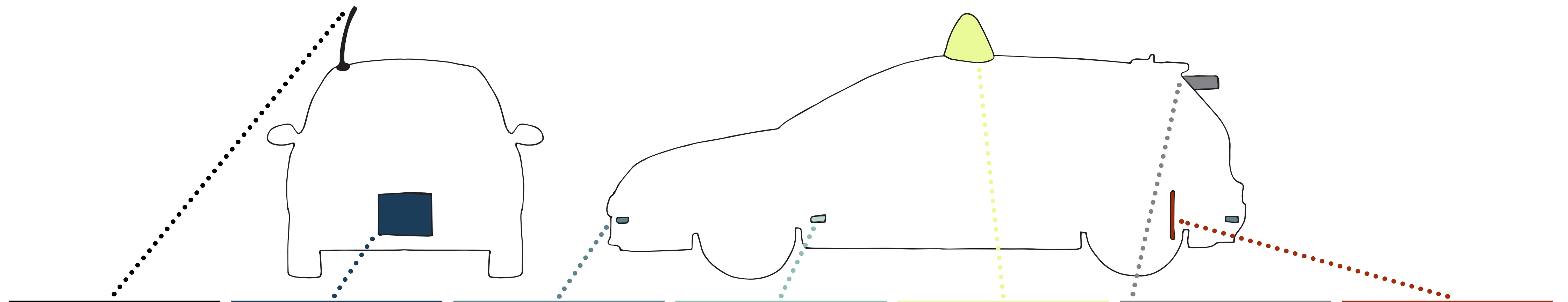
The car can drive itself under all circumstances. You are not permitted to drive, nor are human driving controls present in the vehicle.

Pritchard, Tom. Self-driving cars: Here's what the autonomous driving levels mean. Tom's Guide, 2021. <https://www.tomsguide.com/reference/self-driving-cars-heres-what-the-autonomous-driving-levels-mean>

How Do AVs Sense the World?

Autonomous vehicles use waves—at frequencies varying from long wave to infrared—to build up an instantaneous image of their surroundings.

Many of these sensors capture redundant data designed to mitigate complicating factors like inclement weather and low visibility.



GPS	DSRC	Ultrasonic Sensors	RADAR	LIDAR	Cameras	INS					
<p>The Global Positioning System is a network of US-owned satellites, circling the planet in medium earth orbit, forty to fifty times further out than conventional satellites.</p> <p>To calculate a position, the receiver—your phone, or your vehicle—makes contact with at least four satellites, which derive your position from the relative distances to the satellites.</p> <p>GPS has the potential to drop signal in 'urban canyons,' where reflective surfaces like the faces of buildings put satellites and receivers in indirect contact and add error to an object's GPS location.</p>	<p>While other components deal with determining the car's position, velocity and proximity to other objects, communication with other vehicles and traffic infrastructure (V2X) requires a dedicated short-range communications module, which uses its own custom frequencies.</p> <p>Some manufacturers and regulators have proposed using the existing LTE cell network as the main carrier for V2X, but the delays associated with frequent handoffs between cell towers mean that an eventual solution likely involves a combination of LTE and new DSRC technologies.</p>	<p>Already in common use for parallel and reverse parking tasks, ultrasonic sensors use the time of flight between the emission of sound waves and the reception of reflected waves to calculate objects' distance from the sensor.</p> <p>These sensors can generate sound pressure equivalent to a jet engine, but they operate outside the range of human hearing.</p>	<p>This device, originally developed for military use, detects the angle and distance to nearby objects by calculating the time of flight of radio waves.</p> <p>Autonomous vehicles use radar to detect blind spots and change lanes. Radar waves at these frequencies work well in all weather conditions, though they lack precision.</p>	<p>Similar to radar, LIDAR (Light Detection and Ranging) technology measures distances to nearby objects. Instead of radio waves, LIDAR calculates distances by bouncing pulses of infrared light against nearby objects.</p> <p>These components were prohibitively expensive for many years, but their accuracy has spurred huge investment in increased production.</p>	<p>Despite the extensive array of sensors in use in autonomous vehicles, visible-light camera systems continue to form a vital component of the vehicle's overall sensor package.</p> <p>Often, they are positioned in pairs at a fixed focal length, enabling a three-dimensional representation of the final image to be derived, similar to the principles of human vision.</p> <p>Infrared cameras are also used because of their resilience to sudden exposure changes and their ability to detect warm bodies like pedestrians and animals.</p>	<p>Positioning dropouts and inaccuracies, though inherent to many of these technologies, are not acceptable for the high speeds and low tolerances of autonomous vehicles.</p> <p>Inertial Navigation Systems mitigate the limitations of GPS by measuring the car's position and velocity with onboard accelerometers and gyroscopes and mixing these findings into the vehicle's external data streams.</p> <p>These readings, however, are themselves subject to error drift over time. Solutions involving neural network processing have been proposed to account for this drift.</p>					
19–25cm	1.2GHz	5cm	5.9GHz	less than 2cm	15.7GHz	2.7–4.0mm	74.9GHz	900–1500nm	199THz	400–750nm	399THz

Vargas, Jorge, et al. "An Overview of Autonomous Vehicles Sensors and Their Vulnerability to Weather Conditions." *Sensors*, vol. 21, no. 16, 2021, p. 5397, <https://doi.org/10.3390/s21165397>.

Xu, Zhigang, et al. "DSRC versus 4G-LTE for Connected Vehicle Applications: A Study on Field Experiments of Vehicular Communication Performance." *Journal of Advanced Transportation*, vol. 2017, 2017, pp. 1–10, <https://doi.org/10.1155/2017/2750452>.

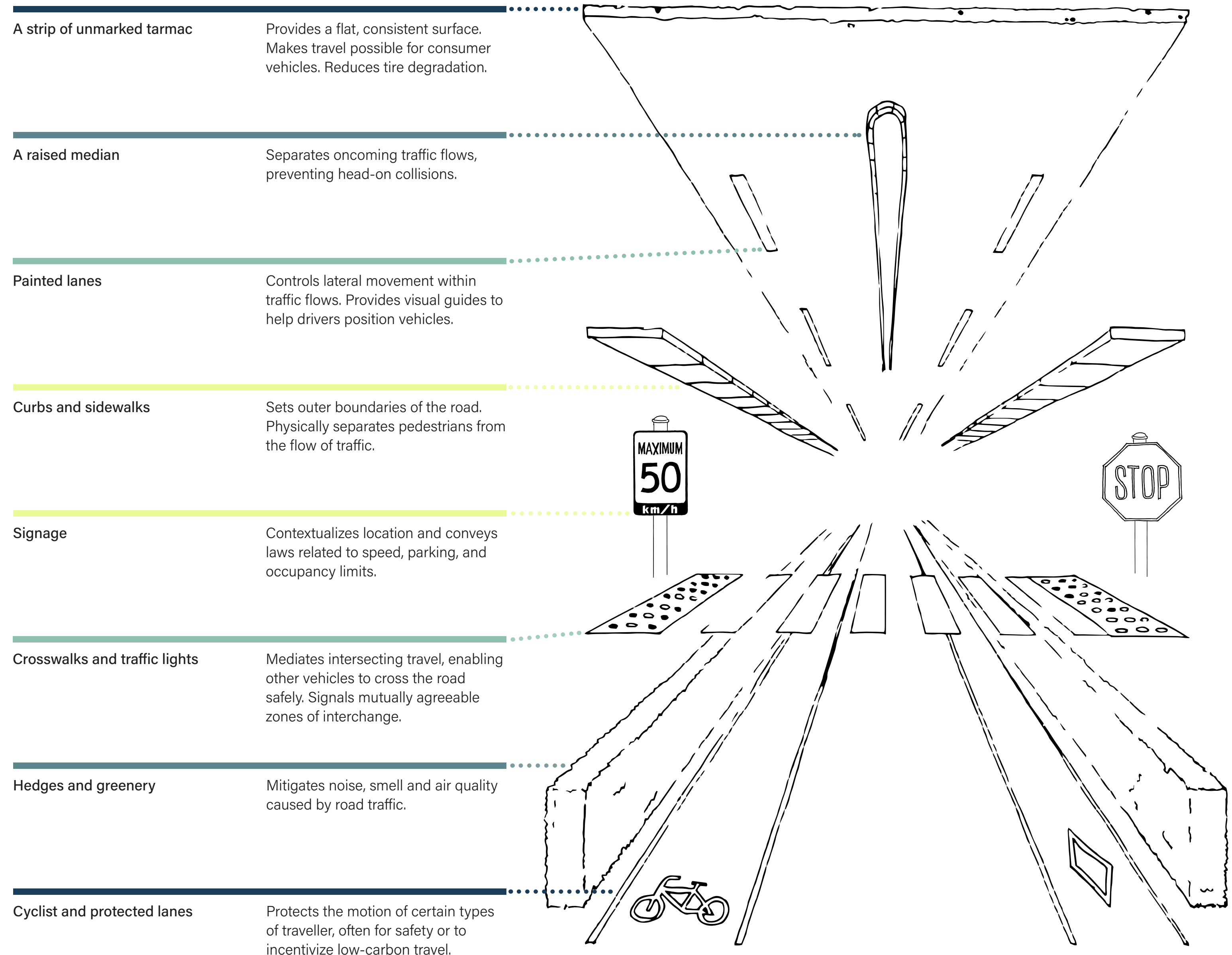
Rosique, Francisca, et al. "A Systematic Review of Perception System and Simulators for Autonomous Vehicles Research." *Sensors*, vol. 19, no. 3, Feb. 2019, p. 648. Crossref, <https://doi.org/10.3390/s19030648>.

What Makes a Road?

Before we consider what new infrastructure is needed to support autonomous vehicles on our roads, it is worthwhile to think about the components of an urban road.

Splitting a road into its constituent parts shows how a society implicitly favours certain types of traveller, as physical separations create implicit combinations of vehicles.

These elements are all built to be seen and understood quickly by people who use the road. Once we introduce a new type of vehicle operator, how do we ensure that it processes each of these elements as required?

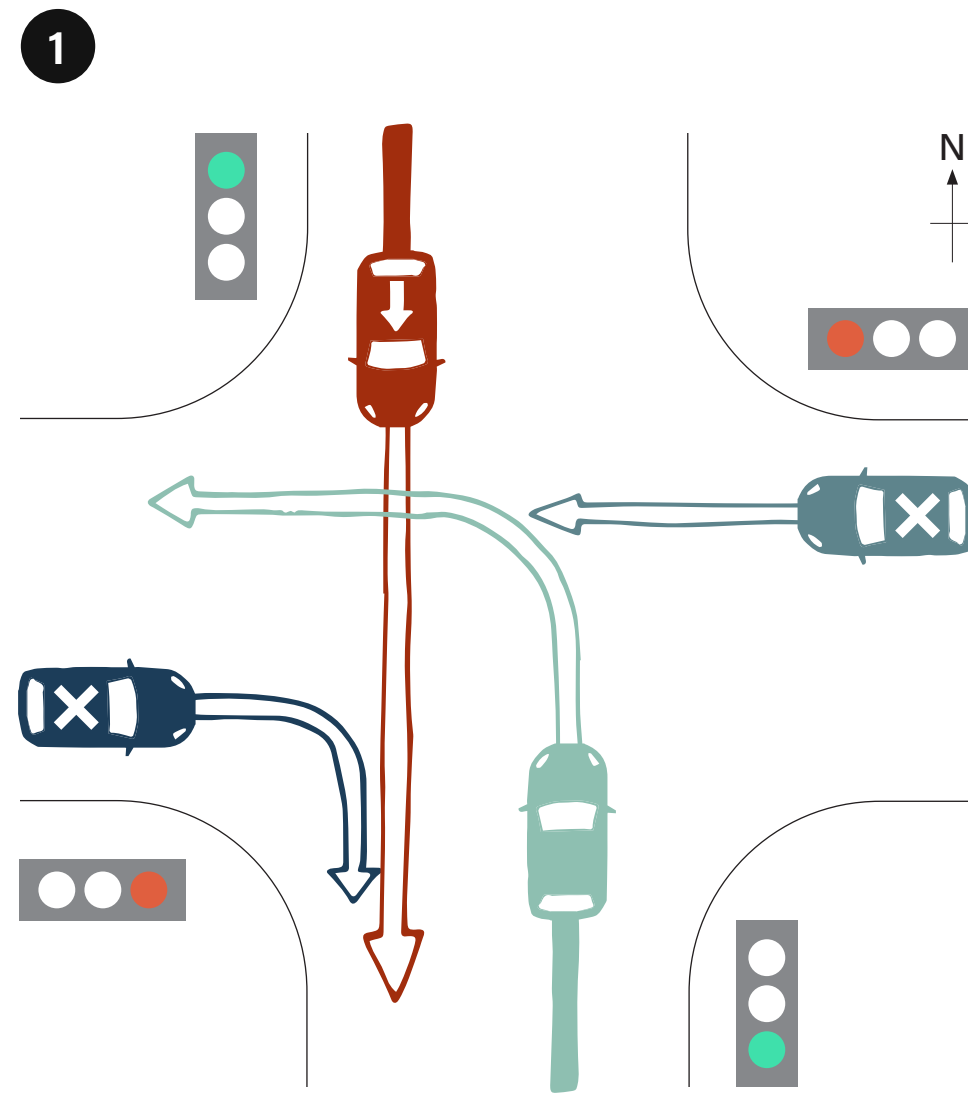


Intersection Management

Conventional Phased Crossing

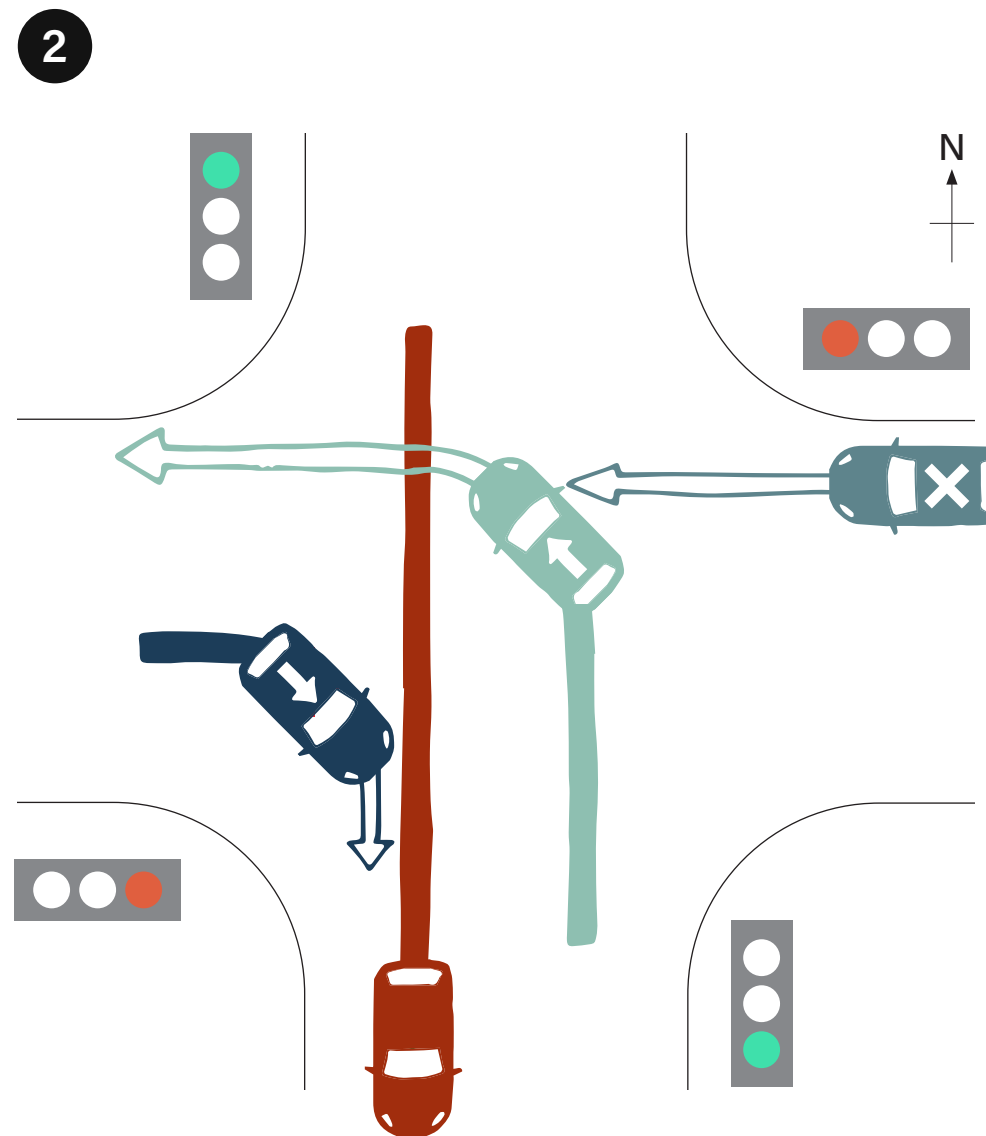
In a full autonomy environment, where all vehicles in a given area are fully autonomous and able to communicate with each other, multiple strategies emerge for the resolution of conflicting paths.

Prior to full autonomy, signalled intersections remain the most common way to satisfy the competing aims of drivers, prioritizing simplicity and safety at the expense of speed.



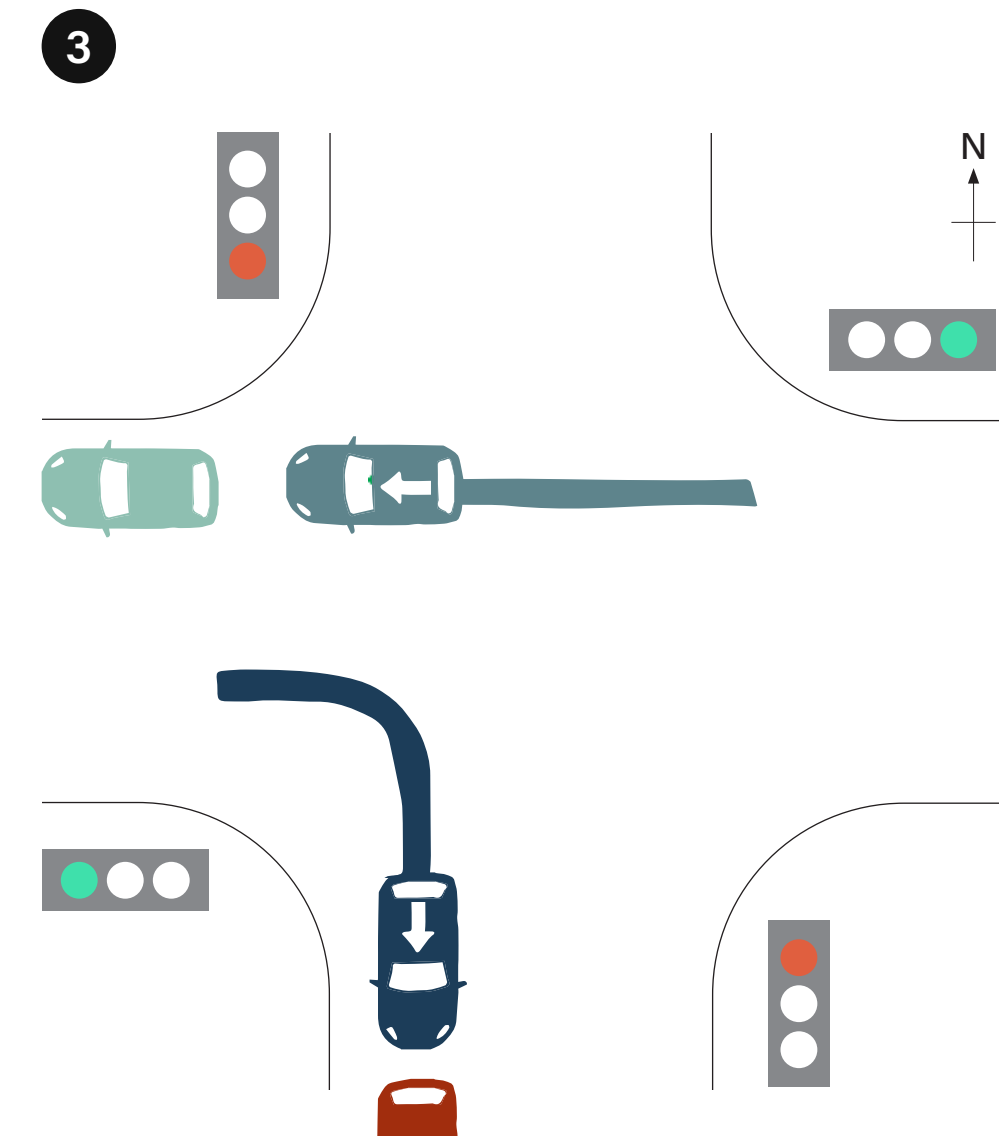
Modern traffic signals rely on the precept that vehicles in the intersection at the same time must never cross paths.

Here, vehicles originating from north or south get first access to the intersection. The southern car, turning left, must wait for the northernmost to clear the intersection.



In North America, vehicles may turn right at a red light when safe to do so except on the islands of Montreal (SAAQ) and Manhattan (NYCDOT).

Here, the westernmost car is able to complete their crossing early as a result. Within one signal change, three of four vehicles have completed their crossing.



Finally, the easternmost vehicle can complete its crossing. A complete cycle of traffic signals can take between 30 seconds and two minutes to complete, even if some origin directions have no cars waiting.

"Turning Right at a Red Light." SAAQ, Province Du Quebec, 25 Feb. 2016, <https://saaq.gouv.qc.ca/en/road-safety/behaviours/turning-right-at-a-red-light>.

"Right Turn on Red - Welcome to Nyc.gov | City of New York." Sustainable Streets Index, NYC Department of Transport, 2009, http://www.nyc.gov/html/dot/downloads/pdf/ssi09_rightonred.pdf.

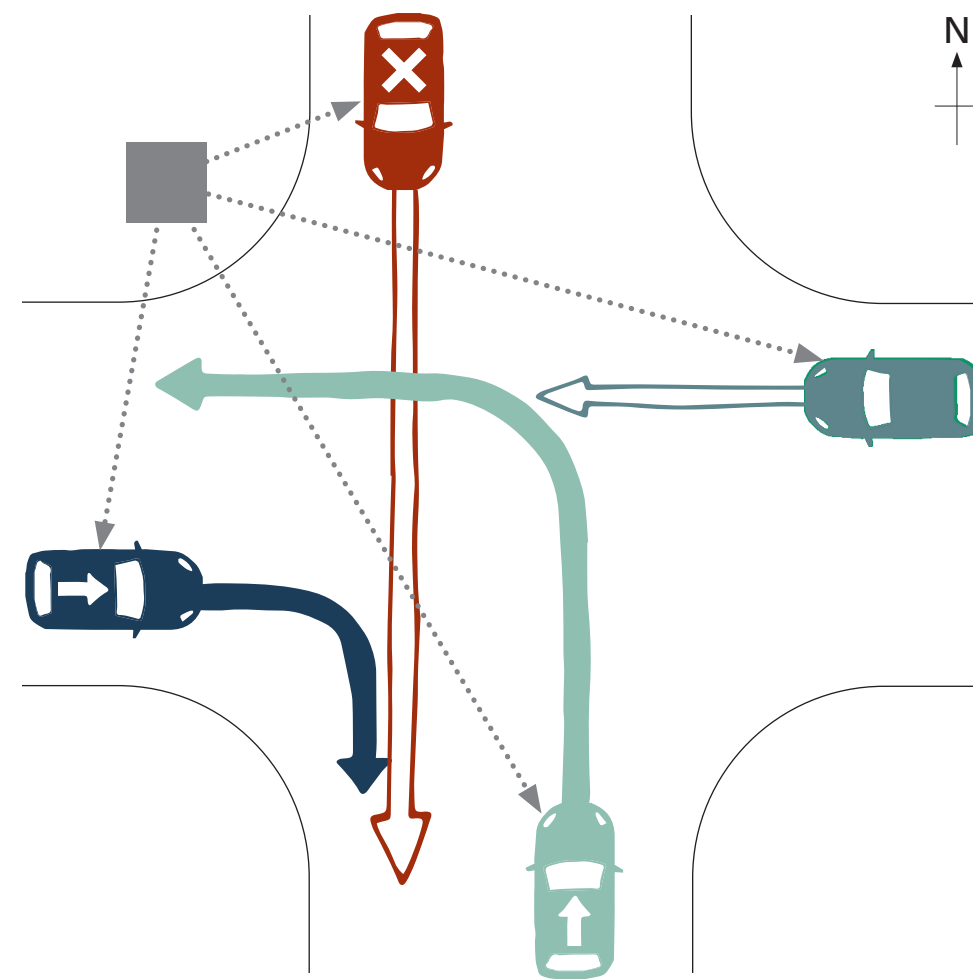
Intersection Management

Autonomous Techniques

Fully autonomous vehicles have the capability to communicate instantaneously with each other and with civic infrastructure. Because of this, traffic signals are not required in some scenarios.

Depending on implementation, the priority of cars through an intersection can vary wildly. The examples below show each of the four vehicles crossing anywhere from first to last.

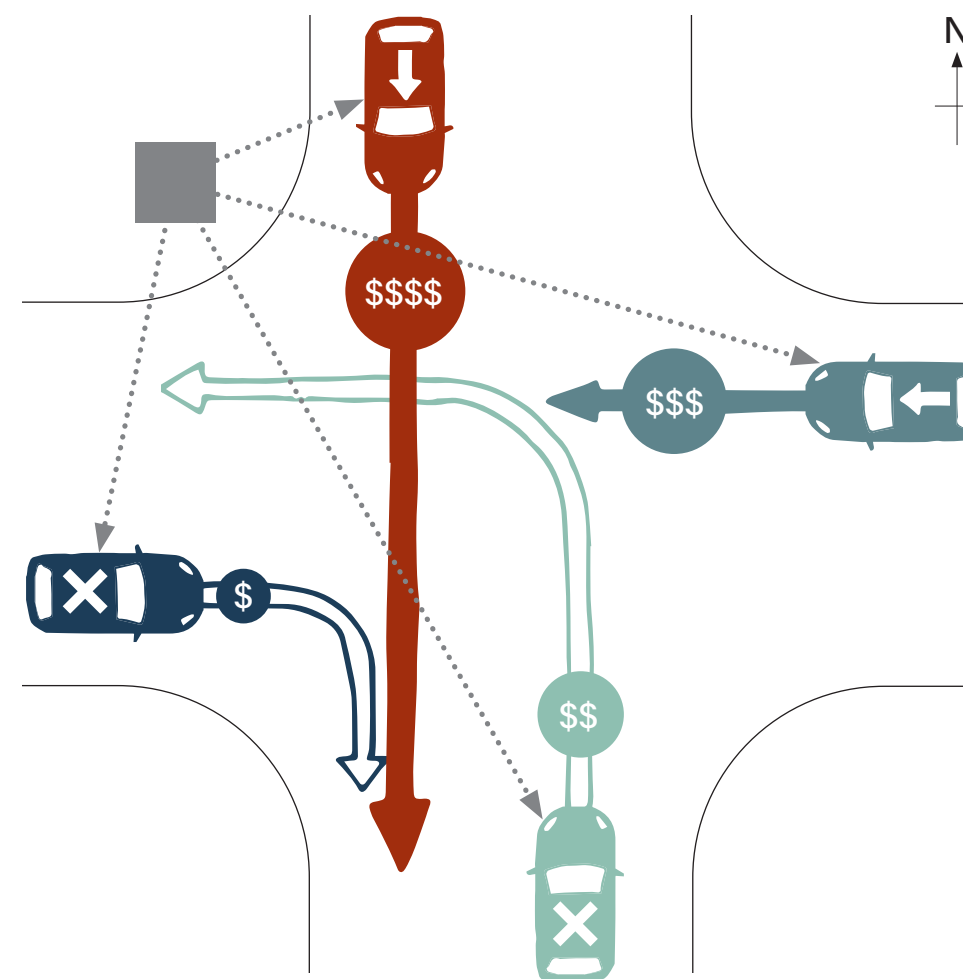
Centralized



A standalone "intersection manager" handles decision making in this scenario, either as an on-site element or as part of a central traffic management system.

Incoming vehicles communicate their intent, speed, and location to the manager. The manager converts these intents into a priority list before communicating this back to vehicles as a "flight plan". This approach is akin to the relationship between air traffic control and individual airplanes.

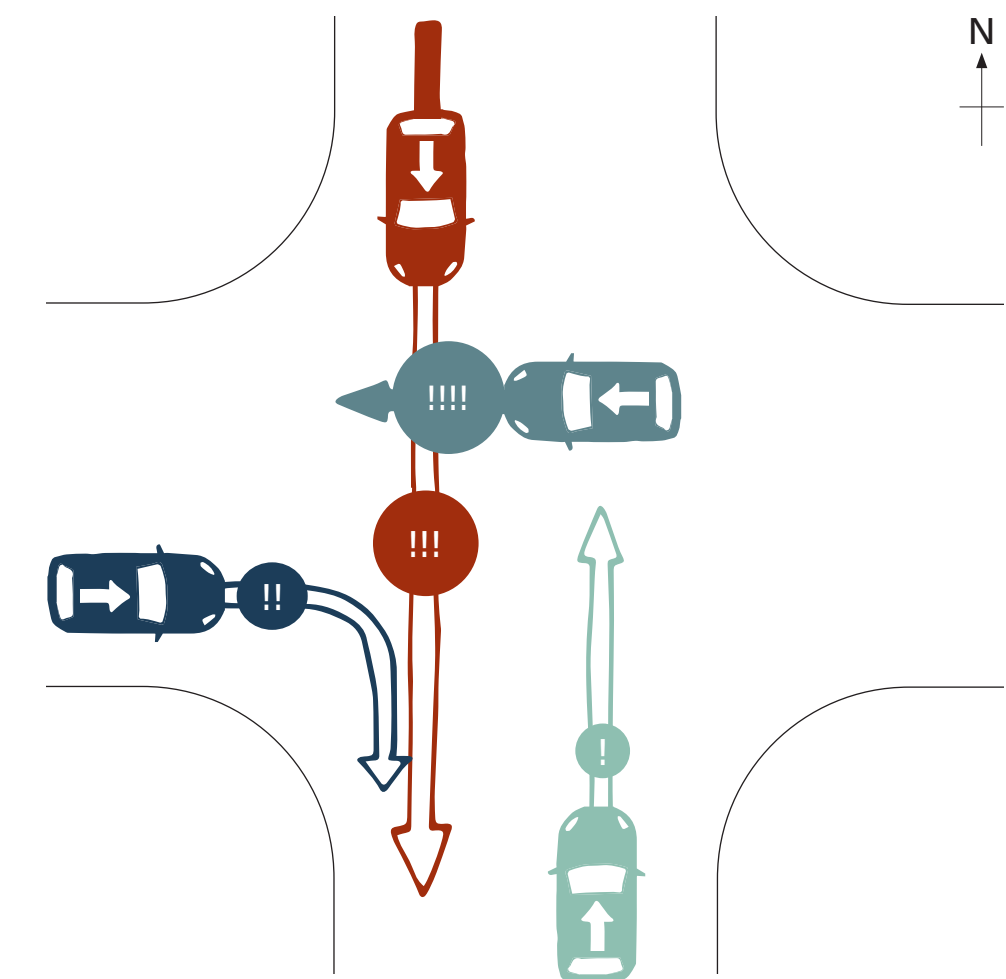
Negotiated



With this approach, vehicles actively participate in the protocol to decide crossing priority. This may be structured as an auction: each vehicle submits a bid to "buy" priority access to a travel path for a certain amount of time.

These bids may involve real money, or they might use "credits" disbursed according to emissions or an overall safety score. Equity issues arise with this protocol: cars can be "frozen out" of crossing indefinitely due to lack of funds.

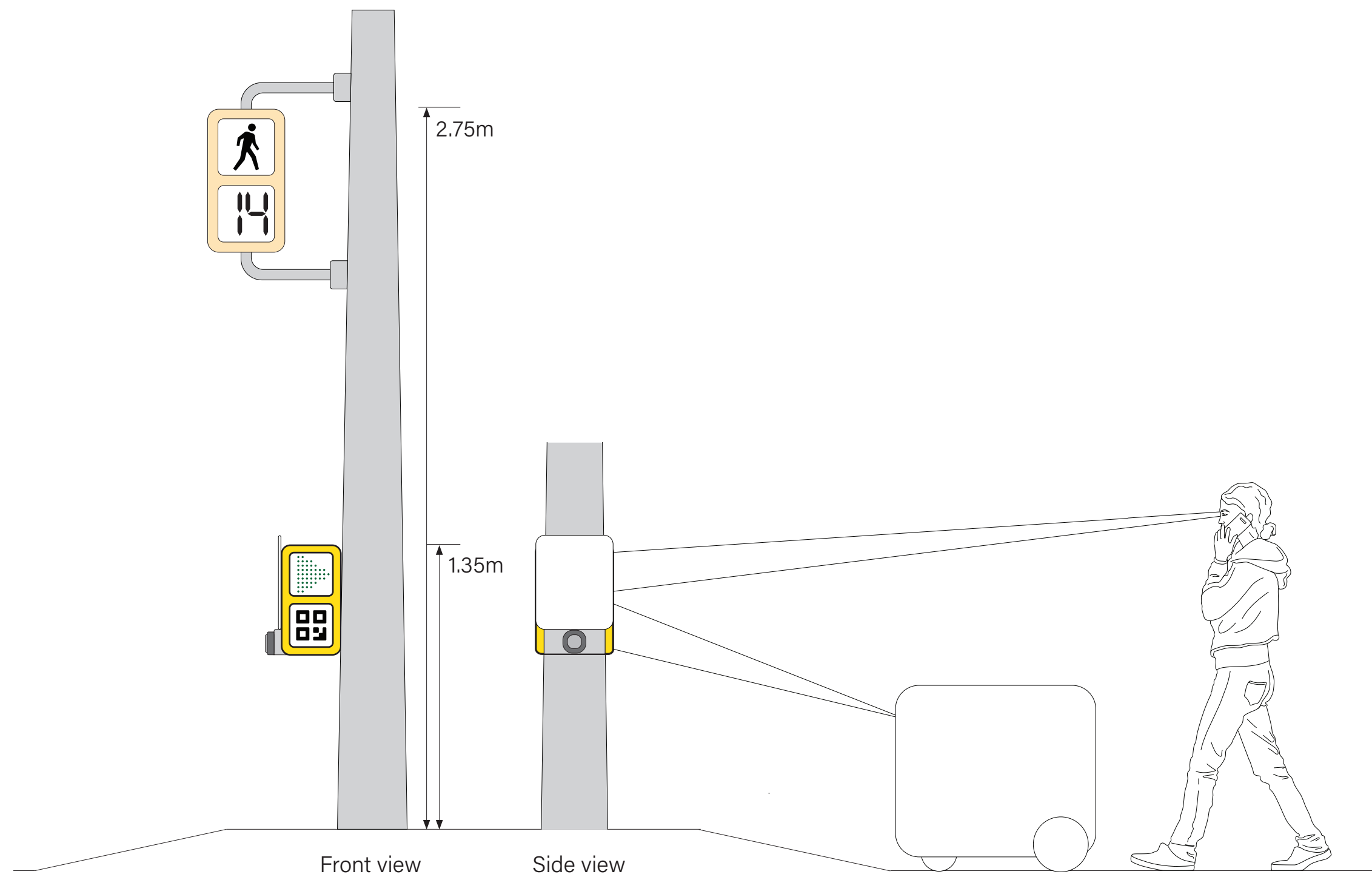
Emergent



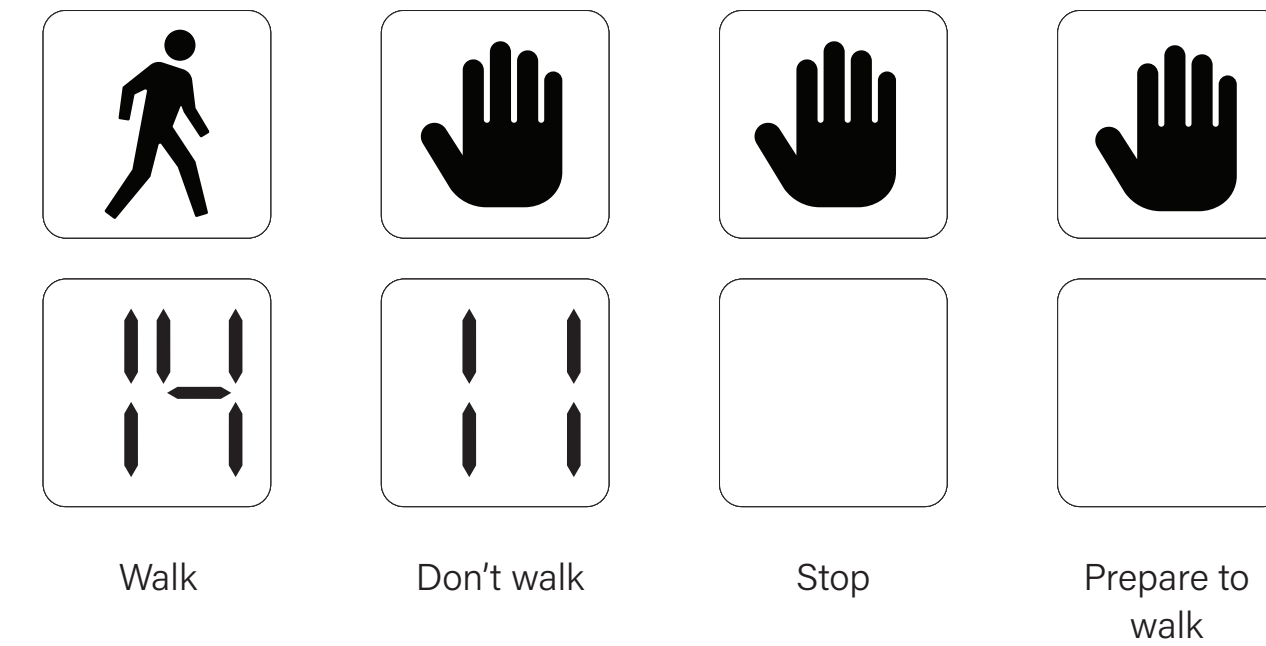
This protocol provides maximum flexibility on determining priority, requiring only that movement is safe and crossing times are reasonable for all vehicles.

The process borrows from game theory: vehicles do not communicate in a structured way. Instead, they perceive and signal intent with subtle movements. This approach is likely to remain a backup operation mode, for use when central infrastructure is unavailable.

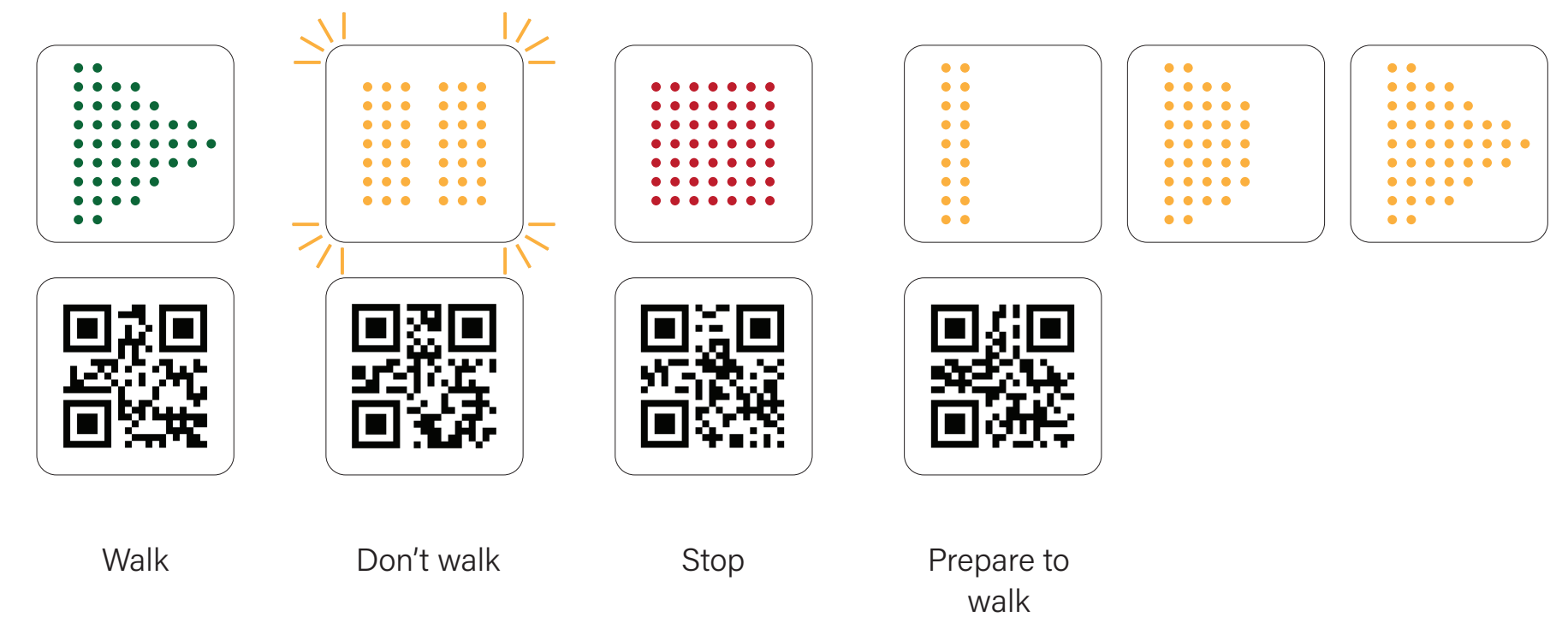
Pedestrian Signal Head for Autonomous Vehicles



Pedestrian signals



Autonomous signals



Design Intent

Although most autonomous vehicles will use roads, self-driving technology will also enable smaller autonomous vehicles that use sidewalks and crosswalks to complete tasks such as meal delivery or package couriating.

These smaller vehicles need their own set of crossing signals. Pedestrian crossing signals are usually placed nine feet above the ground, causing potential sightline issues.

These vehicles may also use different crossing phases than pedestrians for additional safety. This gives us an opportunity to design a signal head that is easily read and understood by human and machine alike.

Signal Iconography

This signal warns pedestrians of the expected behaviour and movements of autonomous devices. An additional phase between 'stop' and 'don't walk' help devices prepare to navigate and move across the intersection.

The signal head has two panels: a colour LED panel for human readers, and a QR panel for autonomous ones. The LED panel displays 'play', 'pause' or 'stop' to pedestrians to indicate what to expect from autonomous devices nearby.

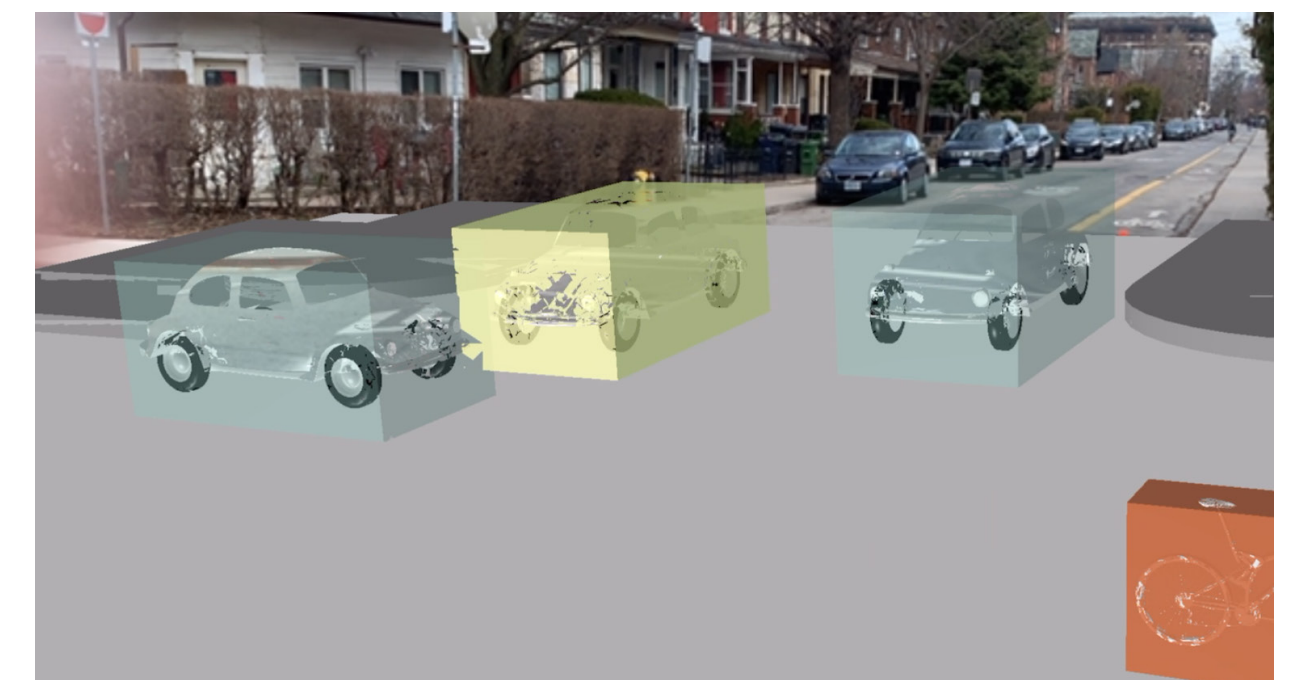
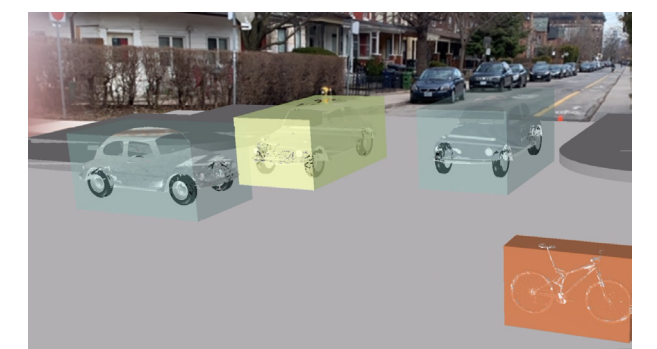
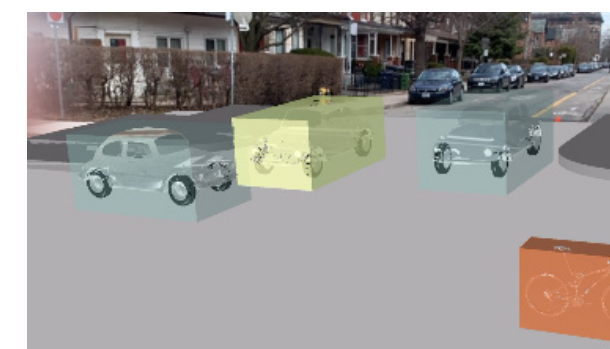
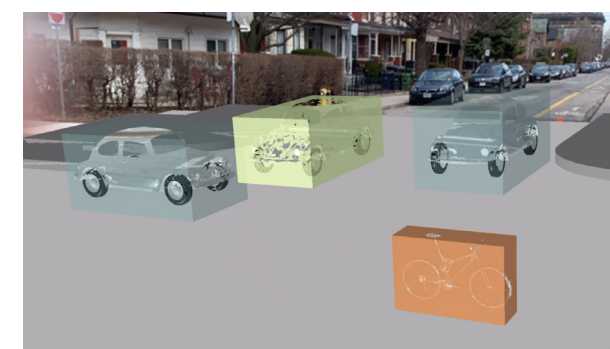
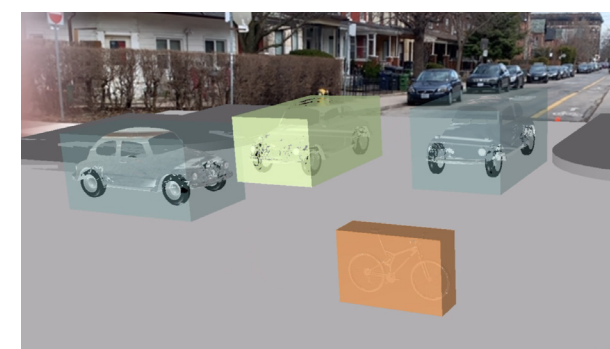
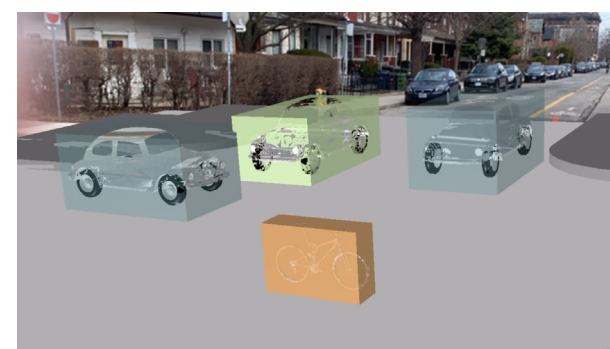
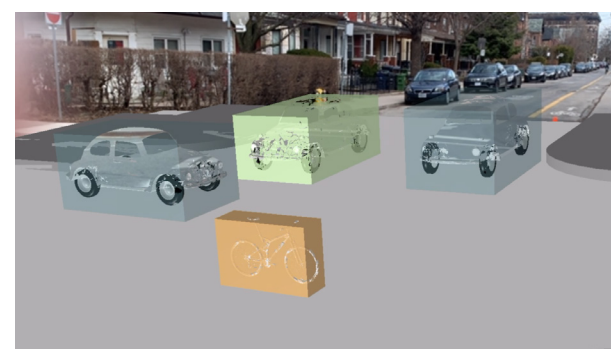
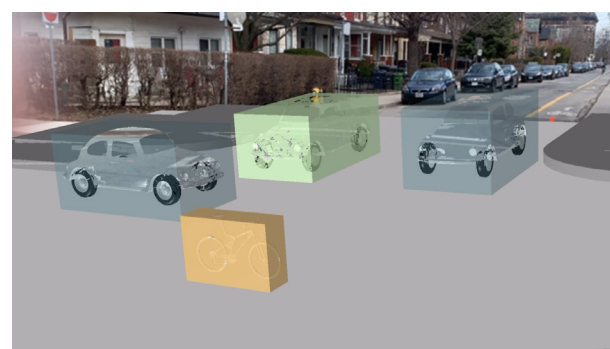
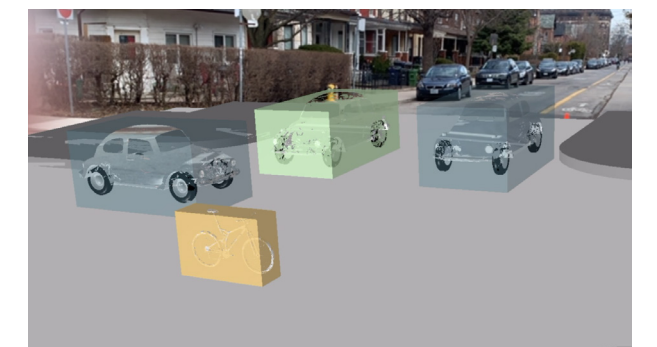
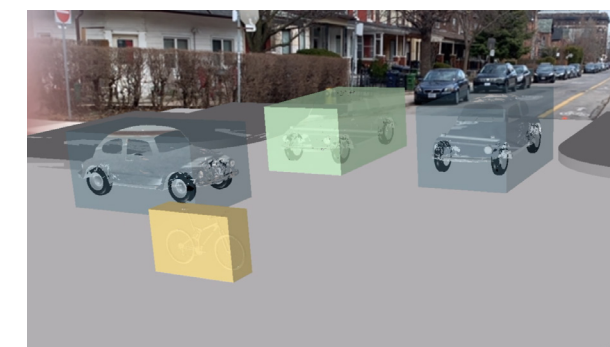
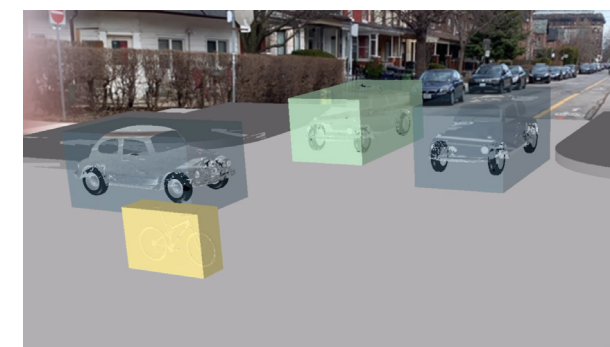
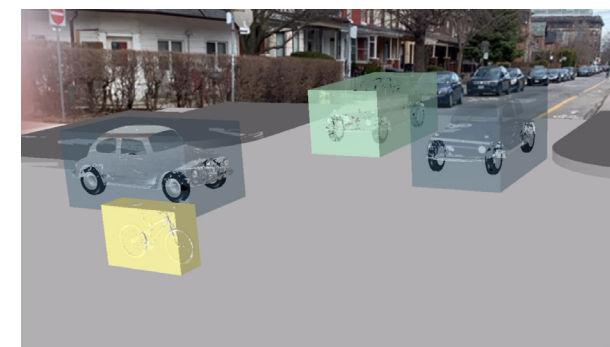
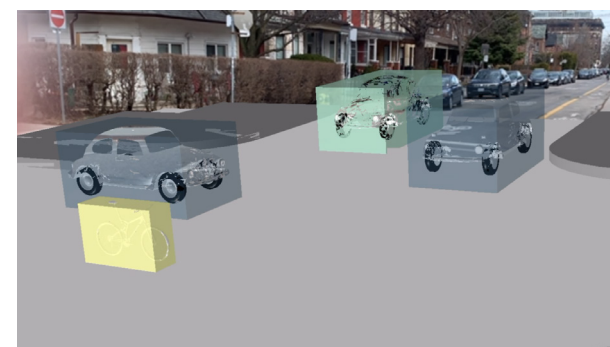
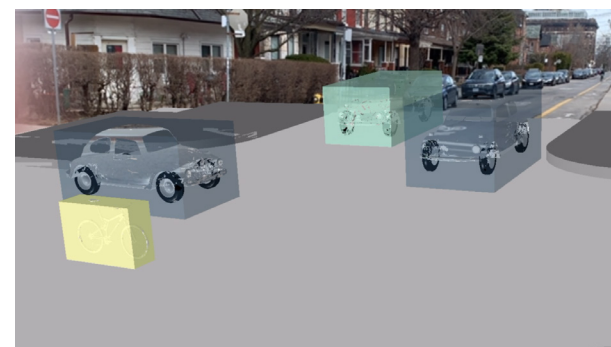
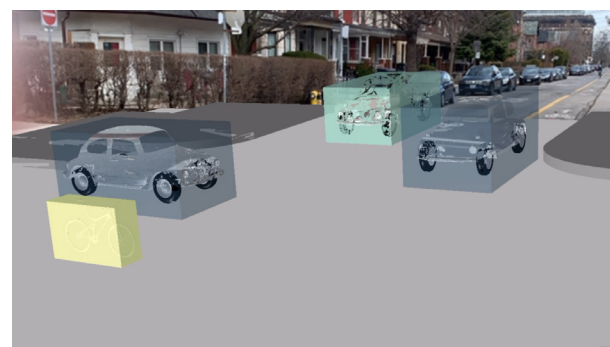
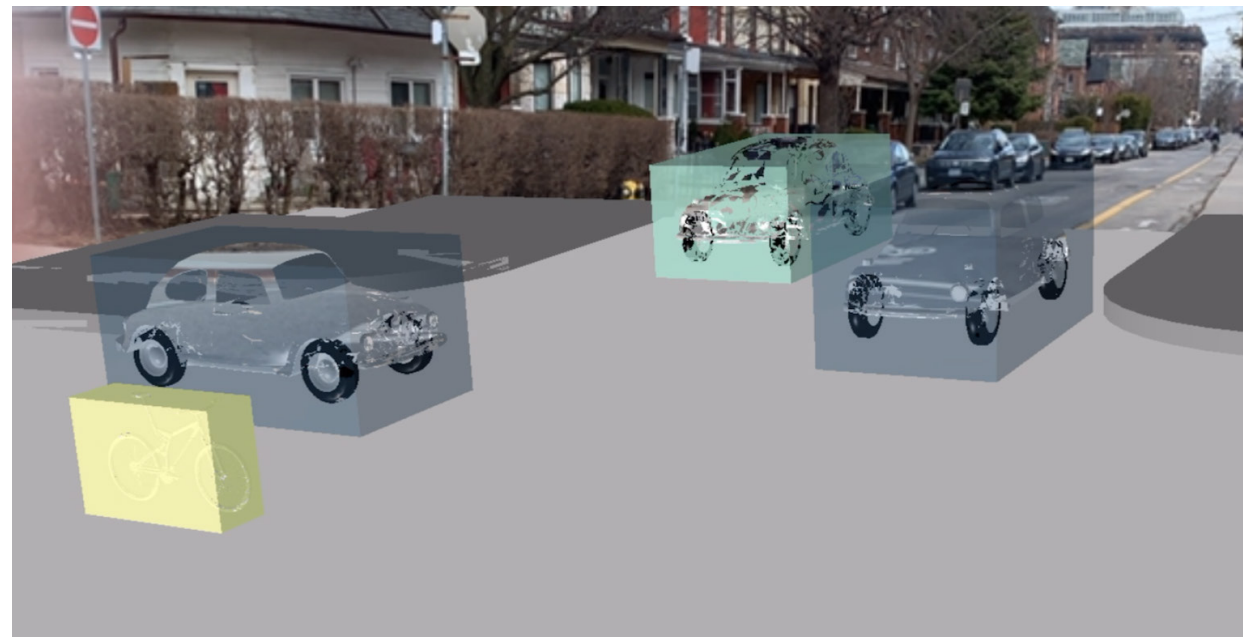
The QR panel beneath displays the same information in machine-readable format. This panel acts as mechanical backup if wireless communications from the wider traffic network fail at an intersection.

"Ontario Pedestrian Traffic Signal Construction Standards" The Road Authority, 2014. <https://www.roadauthority.com/Standards/?id=6cde695d-371b-46af-8df3-c020b2618099>.

Augmented Reality Visualizations for Pedestrian Safety

Although in its infancy, augmented reality will one day become our dominant mode of engagement with data in the real world. Sketches like these demonstrate the explicative potential of data overlays.

Vehicles in the field of view are colour-coded by their momentum. Human vision is evolutionarily adapted to notice warm colours like orange and red, allowing for quicker cognition of potential impacts.



Would My Car Save the Same People As Yours?

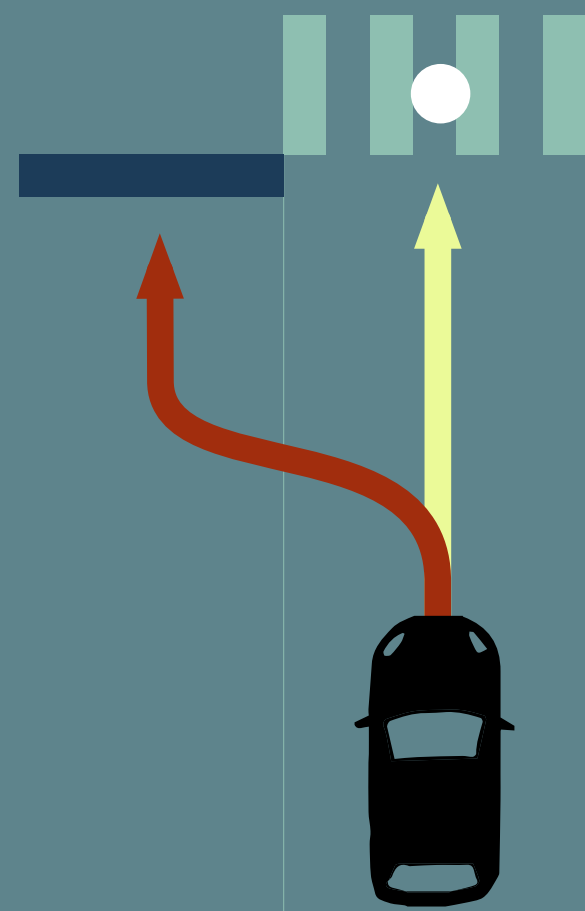
In the scenarios below, your self-driving car's artificial intelligence visually evaluates potential outcomes when harm is unavoidable. There are no right answers; in every case, somebody will be seriously injured.

As humans, these situations are handled with instinct, but these machines appraise ethical dilemmas using algorithms designed by human engineers. These systems are inherently reductive, trying to understand a complex situation from just a few frames of video.

As a passenger in an autonomous car, how would you want the car to react?

Your car is driving down a narrow, single-lane street. Just ahead, a pedestrian runs into the path of the vehicle.

Should the car swerve to avoid them, even if doing so kills you and other passengers?

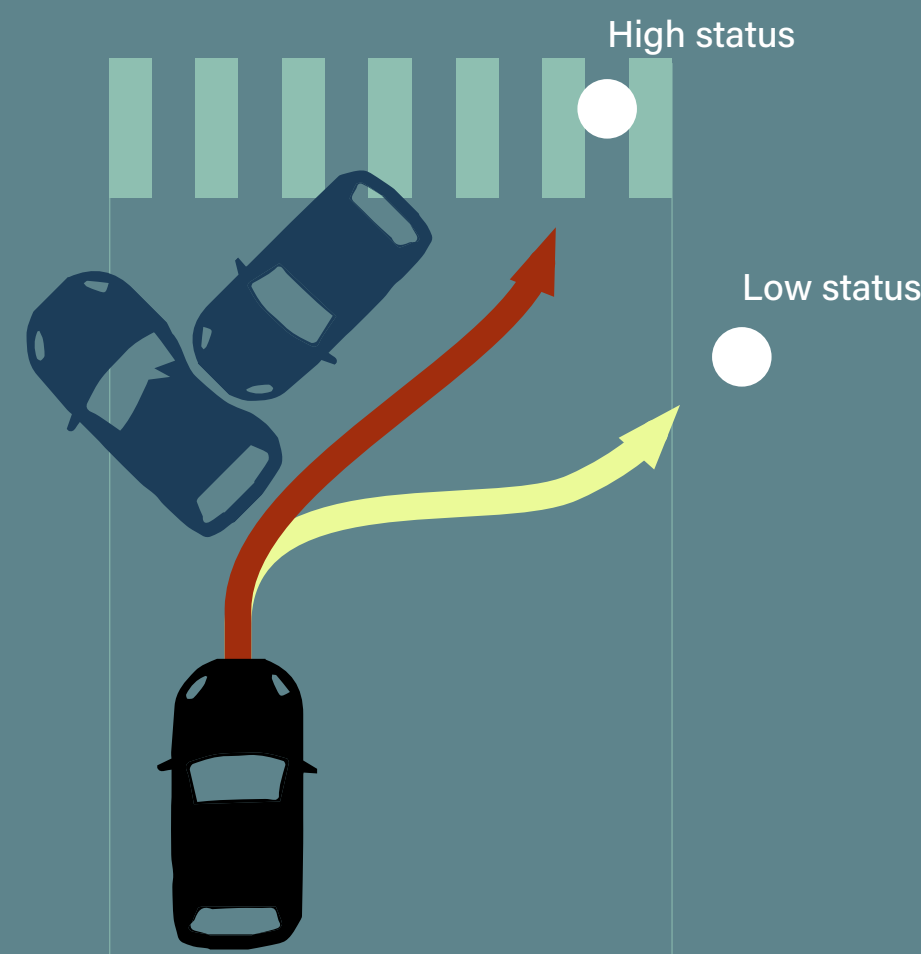


A
Save the pedestrian; hit the barrier and kill pedestrians

B
Save the passengers; hit the pedestrian

Your car must swerve to avoid an accident. Its vision module evaluates a person in expensive clothes in the crosswalk, and a person in old, damaged clothes sat on the sidewalk.

Should the car hit the person it deems high status or the person it deems low status?

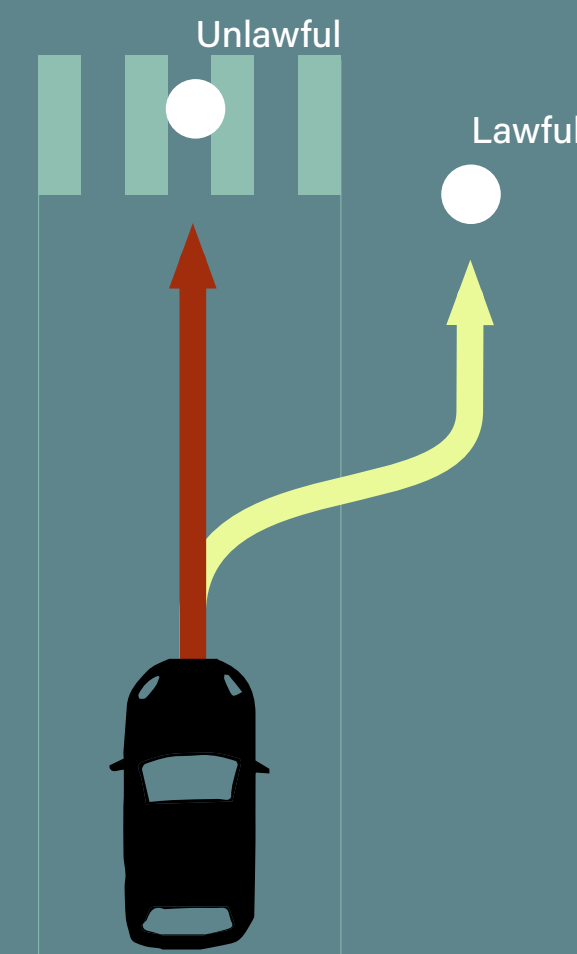


A
Save the person on the sidewalk; hit the high-status person in the crosswalk

B
Save person in the crosswalk; hit the low-status person on the sidewalk

Two pedestrians are waiting to cross the street ahead of you. Although you have right of way, one pedestrian misreads your car's speed and enters the crosswalk as you approach.

Should your car hit the lawful person or the person breaking the law?

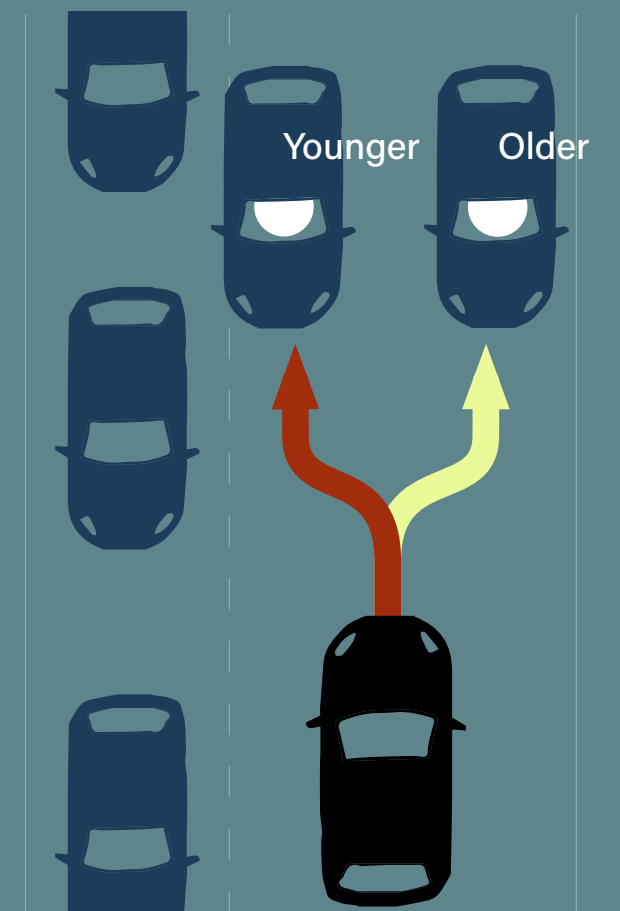


A
Carry on straight; hit the person who is jaywalking

B
Swerve off the road; hit the person waiting on the sidewalk

Two vehicles are trapped in your lane while overtaking traffic. Your car's vision module detects one passenger in each car: one who seems elderly, and one who seems young.

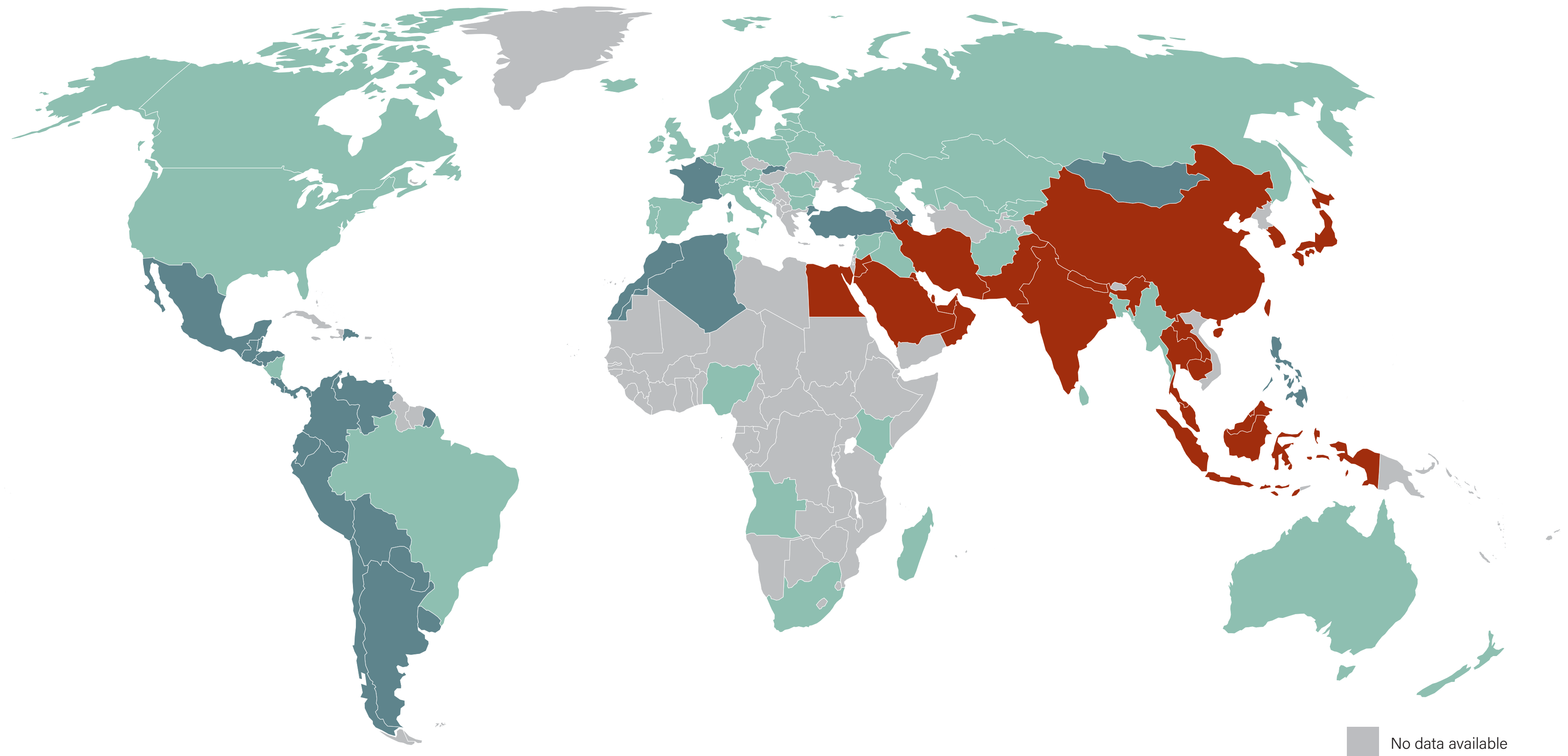
Should your car hit the older person or the younger one?



A
Spare the older person; hit the young person

B
Spare the younger person; hit the older person

The Moral Machine



A 2018 MIT study surveyed millions of people with the same scenarios you just saw. Strong geographic and cultural correlations emerged.

The researchers tried to understand general sentiment towards “no-win” scenarios by publishing an online survey with a random selection of multiple-choice scenarios. The survey quickly went viral, gathering more than 40 million decisions over its collection period.

Three distinct ethical schools emerged from the data. Discover what your answers above say about your autonomous driving ethics.

If you answered	Mostly As	Mostly Bs	A mixture of As and Bs	Global Preferences
Closest ethical school	Eastern School	Southern School	Western School	
Notable ethical preferences	Respondents in these countries tend to favour sparing law-abiding characters over those breaking the law. They also tend to favour sparing pedestrians over passengers, and sparing the old over the young.	Respondents in these countries favour sparing high-status characters - those who appear upper class - to those of lower status. They also favour sparing physically fit characters .	Respondents in these countries have few strong preferences in these scenarios. The only statistically meaningful preferences are for sparing the young over the old, and for preferring inaction over action - respondents generally instructed cars to continue along their original path .	Among all groups, certain preferences are shown that may provide the foundation for a global code of autonomous vehicle ethics. Universal principles included the preference to spare humans over animals and, whenever the number of potential victims varied, the preference to spare more lives over fewer.

Awad, Edmond, et al. "The Moral Machine experiment." Nature, vol. 563, no. 7729, Nov. 2018, p. 59. Gale Academic OneFile, link.gale.com/apps/doc/A573088418/AONE?u=toro37158&sid=-googleScholar&id=b76257e5.

Ongoing Research Approaches

Ethical research

- The German Federal Transport Ministry commissioned a team of philosophers, ethicists and technologists to assemble a list of principles by which regulators could operate.

The commission returned a list of 20 axioms from which they recommend autonomous driving technology should develop.
- The commission notes that although a human driver may not be culpable for killing a person in an effort to save others, such legal standards "cannot readily be transformed into general appraisals and thus also not into corresponding programming".
- 8

Dilemmas cannot be reduced to simple programming solutions.

The commission states that the manner of this information must be "sufficiently differentiated" from existing public communications.
- 12

The introduction of autonomous vehicles must include transparent public communications.

The commission states that the manner of this information must be "sufficiently differentiated" from existing public communications.
- 16

It must be clear to all nearby users when an autonomous vehicle is being temporarily controlled by humans.

For mixed autonomy cars where human drivers may operate under certain circumstances, data relating to timing and handover of control should be documented and stored.
- 20

General education should include the proper use of autonomous vehicles.

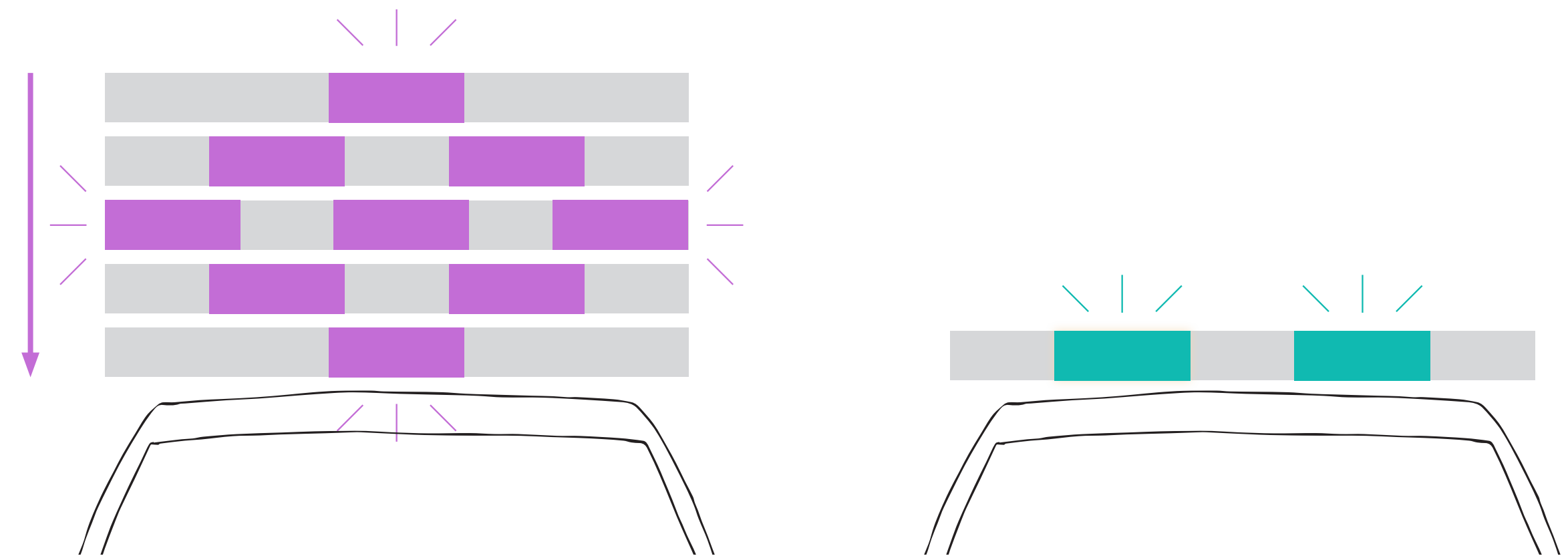
People should receive instruction on the proper use of automated systems as part of their "digital education", and proper handling of autonomous driving systems should be tested during driving tuition.

Visual research

Ford conducted research in Europe and the US on lighting systems that communicate active autonomous operation to pedestrians nearby.

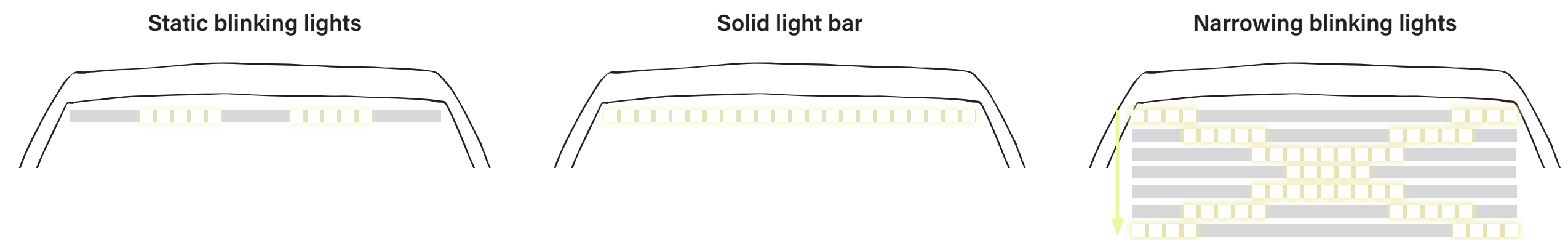
In Europe, 60% of people surveyed understood that the vehicle displaying the light sequence below was likely autonomous. Would you?

They found that turquoise was more noticeable than white and less easily confused with red than purple.



In the US, Ford tested a white light bar behind the front windshield glass with three operation modes. Try to guess which operation mode pertains to which light design.

- Vehicle operating autonomously**
- Vehicle coming to a full stop**
- Vehicle beginning to accelerate**



Solid light bar: vehicle operating autonomously
 Static blinking lights: vehicle beginning to accelerate
 Narrowing blinking lights: vehicle coming to a full stop

"Ford Tests Light-Based Visual Language That Could Help Autonomous Vehicles Communicate with Pedestrians." Ford of Europe, Ford Media Centre, 6 Feb. 2019, <https://media.ford.com/content/fordmedia/feu/en/news/2019/02/06/ford-tests-light-based-visual-language-that-could-help-autonomou.html>.
 Di Fabio, Udo, et al. *Ethics Commission: Automated and Connected Driving*. German Federal Ministry of Transport and Digital Infrastructure, 2017.

What Happens Next?



Technological

In the previous panels, you may have imagined your car choosing between outcomes in no-win scenarios and asked yourself: "How would my car know who is old and who is young? How sure can it be?" The algorithmic bias built into these machines' decision-making processors will be under scrutiny for years to come.

Despite progress in the perceptual technologies behind autonomous driving, the elements that provide the safety and efficiency benefits of autonomous vehicles are still in development.

The protocols allowing vehicles to communicate with each other and the world around them must be regulated. Civic infrastructure must be renewed and enhanced to adapt to a whole new category of user. Without investment in these auxiliary technologies, autonomous driving will remain a curious sideshow.



Ethical

We do not yet know how full autonomy will be implemented. Will owners have influence over the moral priorities of their vehicles at an individual level, or will those decisions be made at the ballot box?

The decision-making processes of these vehicles should be publicly codified and easily accessible. It must also be made clear that a significant decision space exists that cannot be analyzed in advance. The data produced by these outlying incidents must be recorded and analyzed for continuing safety improvements.

The researchers behind the Moral Machine survey and paper revealed strong correlations between a citizen's willingness to prioritize wealthy or male victims and the degree of income and gender inequality in their home country. Autonomous driving justice goes hand in hand with remedying unequal societies.



Communications

This project establishes a rationale for structured visual communication both around autonomous vehicles and in the built environment.

More work must be done to develop international standards for this information. The visual language of autonomous vehicles must be consistent the world over to maximize public safety.

These strategies must also be combined with techniques that aid blind people and the visually impaired, including auditory and tactile interventions. Improved consumer technology should allow users with accessibility issues to gain access to more urban space by providing them tools that dynamically appraise the safety of their immediate environment.

Awad, Edmond, et al. "The Moral Machine experiment." *Nature*, vol. 563, no. 7729, Nov. 2018, p. 59. Gale Academic OneFile, link. gale.com/apps/doc/A573088418/AONE?u=toro37158&sid=-googleScholar&id=b76257e5.

All images by author.