Stanford eCorner

Self-Driving Cars for Everyone [Entire Talk]

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Tim Kentley-Klay and Jesse Levinson, co-founders of autonomous-vehicle startup Zoox, detail a not-too-distant future when we'll get into their cars and do nothing other than say where we need to go. In conversation with Stanford Professor of the Practice Tina Seelig, the two entrepreneurs explain how self-driving cars work and how their fleet of electric vehicles could make owning a ride obsolete.

Transcript

- So, we have our CTO and our CEO of this company. Can you give us a little story of how you got here? Maybe each of you can give us a little bit of time to tell your story of how you ended up here, sitting here on this stage. - Sure. I think for me, my journey in robotics started around 2012, when I was watching from Melbourne, Australia, from one of my animation studios, what Google was doing with their self-driving car program. Sitting here today, looking back, they kind of lied to us. They made it look a little bit easier than what it actually is. But for me, at the time, had the insight that AI and mobility, autonomy and mobility is about much more than just incremental adaptation to the automobile. It's more than an autopilot feature for a freeway. This technology is going to reboot mobility as we know it. The previous mobility age, before the automobile, was of course the horse and carriage.

And we were actually in that age for around six thousand years. So it's around four thousand BC, we domesticated the horse, put the axle on the wheel, and got coach building. So what let us switch from one mobility age to the next? Arguably, it was the invention of the internal combustion engine. Where we got to a technology level on this planet where we could mechanize the horse's biomechanical power. What was the right exploitation of that invention? Well, it wasn't to put it in the coach and keep the horse. People tried that, but it didn't work particularly well. The right exploitation was to get rid of the horse. Change the architecture of the coach, quite radically. To get through to something like the Model T Ford, right? And so they people that won, weren't the coach builders. It was people who understood mechanical engineering, and then importantly, how to industrialize it.

The insight we have at Zoox, is that AI mobility will take us from the age of the automobile into the next mobility age. And we think that's robotics. Because what we're really doing is bringing a narrow AI. Sort of a horse-level intelligence, if you like. We created horse power, now creating horse-level intelligence to the vehicle and taking the human out of the loop. And if that's true, Zoox was founded to ask the question well, what would the full realization of AI mobility be? Can we imagine that? And if we can, can we build it not in 10 years but today? - [Interviewer] Right. - So everyone who works at Zoox likes to say he works 10 years in the future. And that's the journey we're on, is to be focused on what is the full realization of this technology, and let's see if we can make that today. - I love this idea of bringing the horse intelligence to the car. I'm gonna look at my car differently.

So Jesse, you've been thinking about this a long time. What brought you to this stage? - Yeah, so I got to spend a bunch of time at Stanford. I actually specifically came to Stanford, in large part, because Stanford started working on self-driving cars. And it seemed to me that of all the application of computer science and AI, self-driving cars had, by far, the most potential to impact society in a whole variety of positive ways. Economically, environmentally, and socially. So, it also is kind of cool. And seemed like it'd be fun to work on. So, I started working on it with Sebastian Thrun just in time to start working on the DARPA

Urban Challenge, which was in 2007. And it was the first time that we'd sort of gotten some level of actual interaction between autonomous vehicles and other dynamic objects in the world. Which was really exciting.

I got to work on a really small team and be part of that. And I kind of stayed in academia for a bit, instead of going to Google or one of the car companies. Because, although I really-- - [Tim] Because you love tennis. - Well, a little bit of tennis, some photography. But I really wanted it turn into a product, but I wasn't really convinced that the car companies saw the future. Like how is this technology really gonna actually make it to the market? And Google is doing super cool stuff. I have a lot of friends there and they were doing amazing technology. But also, it just didn't seem like they quite knew what was the product going to be, right? And I didn't know either. So, I was sort of like, "Well I'll just keep working on this research." And I met Tim about three years ago. And he sort of came up with this idea for how would you actually come up with a whole new platform, a new business model.

Way more ambitious that anything I'd heard anyone else talking about. And so, my first reaction was, "Well this is probably nuts, right?" Because it's so different. I spent an hour with Tim, and I was like, "Well, actually sounds pretty amazing." And it seemed like it probably was the future of transportation in cities. So, we spent a few months getting to know each other. And I got really excited because I felt like I could take the work that some of my team and I had been doing at Stanford, and actually start to apply it to what I thought would in fact be the full realization of that technology. So, we got started, yeah about almost three years ago now. - So, okay. Paint a picture of what the future of autonomous vehicles are. So, okay. Think about five years from now.

Hopefully you'll be launched by then. Ten years, maybe even twenty years. What's the vision that you guys have for the future? - [Jesse] Not to run out of money by then. (laughing) - We have your investors in the room, so. We hear them laughing. (laughing) - Well, not to be making too much money by then 'cause we want to keep the blue sky. But hopefully customer adoption. I think, Jesse and I, we really started Zoox 'cause we thought it was the best application of our time and talents. You know, we didn't do this 'cause we want to flip the business. We did it 'cause we want to found the future.

And so, I think for me, what we're working to at Zoox, we're on a five year vehicle development program. Kicked off in 2015. When I said kicked off, I mean kicked off like two guys, one laptop. And we're having to conclude that in 2020 and be ready to scale a fully autonomous mobility service in cities. And so what I think we're both working for is being up at the Ferry Building, hopefully in San Francisco, eating at a burger joint and watching one of our ground-up robots going down Embarcadero, picking up a customer, and taking them to where they want to be. I think that's the reward that we're looking for is to create that magical moment. - So, Jesse, is this true? This is like you're looking at, essentially mobile robots that are gonna pick me up, anywhere I want, and take me where I want to go? - That's the idea. They're actually quite intelligent. They have a lot of computing power, a lot of sensors. And I actually hope that they'll be a little smarter than horses.

Somewhere in between horses and people. - Okay, maybe they'll be even smarter than some people. - Well. - I mean that would be great (laughs) or maybe some drivers, smarter than some drivers. - They'll certainly be a lot more attentive. - So, what are the trade-offs that you're considering right now as you're developing this technology, right? The hope is to launch when? When are we gonna see these on the road? - We've already launched on our private test track. Actually in 2015, the first seven months, we actually created an on-demand, point-to-point, electric autonomous mobility service. - [Interviewer] Wow. - A lot to say, isn't it? That from an app on my phone, you can push a button and the robot will come on that facility, find you, and take you where you want to go. And then we have a very detailed roadmap from now until 2020 where we roll-out things.

Jesse, we already have Toyota Highlanders that we've hacked into and taken paracytic control of the ECU and put our own computing sensors on. We have our license from the state of California. So they're out testing in the field, in Menlo Park, actually. And, you know, by 2020 we want to create the full thing. - So, I want to paint a picture. I had a chance to chat with you at another time and so I have this image in my mind of these vehicles that you're creating. And I understand that they're not like anything that we currently see on the road, right? Because if no one's ever, ever, gonna drive them, they don't need a steering wheel. They don't need a dashboard. They don't need windows. They don't need mirrors.

How do you design a product like that from the ground up, when you really are not comparing it to something that already exists? - Well, that's half the fun, right? Is if you have a legacy product and you have a steering wheel in there, and you're trying to retrofit what I call roof racks. You know, there's a lot of developers out there just putting sensors into the car architecture. You know, I think you're taking a complex product and making it more complex. And then that structure of that vehicle is designed for human vision. So if you take that constraint out and say, "Well, the passenger never has to take physical control "of this vehicle." That's on us, right? It actually gives you more degrees of freedom to optimize for machine vision, rather than a hybrid architecture, while actually removing complexity from the vehicle. By getting rid of the steering wheel, the instrument panel, side mirrors, windscreen wipers, we actually get rid of a lot of hardware out of the vehicle, which is really important for a startup to reduce the building materials and help us get to market faster. - Super interesting. So, can you paint a picture of what this user experience will be when this thing comes up and picks me up at the Ferry Building? - No.

(laughing) - Okay. Now, this is really important because you actually are in stealth mode, right? I'm gonna guess it's not because you don't know.

It's because you just don't want to tell us. - Yes. - Okay. (laughing) And why is it that you're in stealth mode? A lot of companies choose that decision for very important strategic reasons. And I think it's important to understand why are you choosing not to tell us what this experience is going to be like? - Yeah, that's a really good question. Sometimes there's a bit of media saying, "This super-secretive startup called Zoox," right? It's not that we're secretive at all. Within the company, we're very transparent with everyone about what we're doing. We don't compartmentalize too much 'cause we want everyone to understand what we're doing 'cause it's very holistic. You have to be able to see how everything works to solve this. For me it's really just a question of focus.

We've bitten off a lot, like we've got a lot of work to do. And so for me, by being stealth mode, we can just focus on perfecting the fundamental art and science of what it means to create this technology. Without the distraction of going to too many, you know this is the first one we've done actually, going to too many conferences. Or having to have a rinky dink website or anything like that. To me that stuff's just a distraction. We really want to focus as a company on what we're doing. We also have a point of view on what we're doing. And so part of it is we don't want to say with a megaphone to our competitors, "This is how we think this can work." Because that's part of our competitive advantage. It might be so crazy that they wouldn't do it anyway. But that's part of it.

- Well, so this is really important, right? A, your competitors aren't seeing it, but also, your potential customers aren't seeing it and able to give feedback, right? So how do you get feedback? And how do you set up the ability to pivot, right? To make some changes if you're going in the wrong direction. If you're not actually out there sharing what you're doing with the world. - Yeah, so within the company, we do do user testing. We make interior models of the, we make models of the interior, and we bring in people, and we have UX researchers that come in and take notes without me there so I can influence it. Right? All this kind of stuff. So we got through that diligence, but there's also some pretty good heuristics as well. I think, you know, as over in Europe we've actually built a one to one version of the vehicle with the industrial design. And you know, unsolicited, when people stand around it, look at it. You can tell from their reaction that we have something here. Whereas it's very clear when people don't like something 'cause they're just not as interested, or they feel awkward about it.

So, we're super excited about what we're building. It's really fun. It's really different. The industrial design, by the way, is not what's on the internet from what I designed a couple years ago. The DNA is the same, in terms of the architecture we're building, but we're actually creating what we call a microbus at Zoox, which is a compact four-seater for urban mobility. - So, Jesse as the CTO, and with all of this deep technical knowledge, how much are you actually having to build yourself versus buying off the shelf? Is this something that okay, all the technology actually already exists, and it's just piecing it together in an interesting way? Or are you actually reinventing the wheel? Haha. (laughing) Or inventing the wheel. - Well, it does have wheels but they're not steering wheels. You know, tires. - [Interviewer] Yeah, yeah, yeah.

- It's a mixture. But I think one of the things that makes Zoox challenging is that nobody has solved this type of problem before, right? There's a big gap between autonomous sort of features, that you can get on a car today, and then true Level 5 mobility, which means you get in a vehicle and it takes you where you want to go. And you really don't have to do anything. In fact, you can't even do anything other than say where you want to go. Or, "Hey, I want to get out of the vehicle." From a startup's perspective, one of the really exciting things is that we get to do the hardware and the software and the service jointly and holistically. I think people sometimes don't appreciate how big of an advantage that is. If you look at what Apple did with the iPhone, they didn't just write a new operating system and put it on a Motorola Razr or Blackberry. And they also didn't make a new hardware device that was running Windows Mobile Phone from 2006. They could have done either of those things, but I don't think it would have made nearly the impact on the market that they were able to achieve with the iPhone. Now, I think with autonomous vehicles, especially fully autonomous vehicles, I think that integration between hardware and software and the user experience is even more important than it was with cell phones, right? And so, one of the fun things that we get to do but also the very difficult things is we get to think holisicaly about where do we put sensors? What type of sensors do we need? How much computing power do we need? It's probably more sensors and more computers than you're going to be able to buy on a car in the next couple of years.

Because our business model is very different. We don't actually sell these vehicles to customers. We own and operate this fleet and then you can use them the way you use Uber and Lyft. They'll just hopefully be much better and even cheaper to operate 'cause you're not paying the driver. So, we do need to develop our own software, our own AI, our own algorithms. We're not using, you know, Mobileye or anybody else's AI technology. It's completely developed in-house at Zoox. When it comes to computers and sensors we, as much possible, buy things off the shelf or work with technology partners to get access to their upcoming products. And then when it comes to the sort of physical mechatronic layer of the vehicle, it's also really powerful that we get to design a level of robustness and some amount of fail operational into that design that cars today are not built for. Cars today are not built to drive a hundred thousand miles a year, for four years.

And they're also not designed to be necessarily safe when a whole bunch of components might fail. The good news is we don't have to reinvent, for example, the entire concept of an electric car. The way Tesla had to do. What Tesla did 10 years ago, from a vehicle engineering perspective, was quite amazing. Very, very difficult. And there was really no supply chain for EV technology then. In the last decade, Tesla, and now a bunch of other companies, make electric cars in quite some scale. So if we're looking for batteries,and motors, and steering columns, and these sort of things, sometimes we might need to innovate a little bit with the supplier but for the most part, it's about building a new architecture but not reinventing every single hardware component in the vehicle. - So, what do you guys see as the biggest risks? Are they technical risks? Are they market risks? Are they regulation risks? This is a really complicated product and experience and environment. What are the things that keep you up at night? - Well, I don't mean to be cute, but I think the biggest risk is actually unknown unknowns, in the abstract, right? - [Interviewer] Yeah.

- 'Cause they're the things you don't see that really hurt you looking back, right? And so, one thing I've been learning sort of leading with Jesse, Zoox, it's really important, the game almost in a way when you're starting a business is to bring into the company, as fast as you can, domain experts to expunge those unknown unknowns, right? That's really important work 'cause it'll not only let you go faster, it'll stop you from colliding into something you didn't see coming. So I think, you know, for me that's really important is the culture of the company. Who do we have around it? Not just the board level, but advisors. We have tremendous advisors around Zoox. We have people like Carl Bass, who was recently the CEO of Autodesk. We have Gonazalo Rey, who's the CTO of Moog. We have Andrew Howard, who's a senior software engineer down at Spacex. People that have shipped a lot of product, in very advanced systems, that are giving really good advice to what is a young team at Zoox. We have over 60 doctors, PHDs, post-docs from around the world working on the computer science aspects of what we're doing at Zoox. And so I think that's really important in the abstract is to get rid of the unknown unknowns as fast as you can.

And part of that is also being pragmatic. You know, rather than having a lot of conversations based on first principles, or that's rational and academic, it's like, "well, let's just put something on the vehicle "and go out and test it and get some data "and let the data speak to what's important "and de-risk the business." - So, even though you're not telling us what you did, you've certainly told investors and they have given you a lot of money. You have been able to raise a tremendous amount for the vision that you've sold. How did you inspire people to get behind this very radical idea? That really, essentially, jumped over a lot of things that people are now developing. - Yeah, it was pretty crazy raising our series A. Jesse and I really had to go out to the market and ask for an unusually large amount of money because the complexity of what we're doing, you know we're creating a full stack next generation autonomous mobility experience that's vertically integrated, is not cheap. All our competitors, their budgets are one billion plus in this marketplace. And yeah we're entering a market that is a 10 trillion dollar market, right? And it is about to disrupt. And we'll be incumbents, we'll be a new entrant. And so for the investment community, they get the size of the opportunity.

And Zoox is in a very unique position. Because as far as we know, we're the only startup and even compared to some tech giants and OEM giants that are actually trying to do the whole thing under one roof, right? And so we're a big bet, but the outcome can also be a big reward as well. And so, to find a group of investors that, more or less, five years out from a product, a customer, with a lot of technical risk, a lot of regulatory risk, right? Who would put in 250 million dollars into our series A, which is one to two orders a magnitude of what is normal, and for less than 20% of the business as well, that's a very special set of investors. And we were able to find them. We were able to have the right set of conversations with them. And I'm sure Jesse would agree, we have just brilliant investors around this company. You know DFG, of course have been early stage seed investors through to our A round and helped lead that. Companies like 10 Cent, Lux Capital , Blackbird, really high caliber venture capitalists that are not looking for a quick exit. They're looking to work with founders who want to create something big. And so we were able to find those people.

- That really is a moonshot. If it works, it's gonna be amazing. And it's remarkable. Now, who do you see as your biggest competitors? Is it folks who are already working on autonomous vehicles, like Google? Or is it folks who are doing something totally radical that you might not even know about? - That's an interesting question. It's actually a little hard to say at this point, right? Because nobody has Level 5 technology on the market, right? - [Interviewer] Can you do us a favor and describe what that is? What Level 5 is? - Yeah, absolutely. So, the SAE came up with this series of autonomy sort of rankings. Level 1 is cruise control, basic stuff. Level 2 is you can do sort of adaptive cruise control and lane keeping. All right, so sort of like the Tesla autopilot system that you can get today. Level 3 means sort of a fully autonomous vehicle, but you still have to be sitting behind a steering wheel, paying attention.

Because at any point in time, it might decide it doesn't really know what it's doing and you have to take over. But other than that, it can get through intersections, through traffic lights, and sort of do almost everything. Level 4 means that the car is fully autonomous you don't even have to pay attenetion. But it's only able to operate in a certain domain. So, maybe it's fully autonomous but only during the daytime. Or fully autonomous, but only in this particular chunk of the city, right? And then Level 5 means it's sort of fully autonomous, and it can drive anywhere. And pretty much anything a human can drive, it can drive. So

of course that is the goal. That's what we're trying to get to at Zoox. - So, I'm curious though.

It's really different if all the cars on the road are autonomous, and they all have the same rules, and the same etiquette. But when you have a car, an autonomous vehicle on the road, that is not being controlled at all by a person, and you also have human controlled cars, there's got to be some mismatch. I heard the other day about the concept of bullying autonomous vehicles, right? The people who know that, well they know the autonomous car is gonna be very polite, so you can cut it off. (laughing) Don't try that. Okay. - Yeah, this really speaks to what we call social robotics. - Yeah. - And at Zoox, we talk about the car becoming a character, right? And this is why we think a car if it's autonomous, wouldn't actually work in the marketplace 'cause it actually doesn't have the lighting and sound actuation that we think you need to deal with social scenarios like that. We actually have a personality for our vehicle and we call it friendly but fierce. So it can be nice, but it can also dial up certain attributes if you're being a pest.

And then our vehicle, it has some super cool features. So, you know, if you're driving through the Tenderloin, 2:00am and someone comes out in front of the vehicle and is messing with it. Well, most autonomous vehicles would just be stuck. Either with no one in it, and so the customer's waiting. Or someone's in it, and they're freaking out. Well, our vehicle has special features. It's actually symmetrical. It's what we called bidirectional with electric motors that can drive either way equally well. And we use active LED illumination to define dynamically what the front or the rear is. And so we have this neat little maneuver where if someone were standing in front of the vehicle, messing with it, we can actually flip our lights, and flop over to the other side of the road and drive away.

I call it the French maneuver. (laughing) - Does the car also signal whether it's being friendly or fierce? Does it change color? Does it send out signals? Does it do something to say, "Hey, I'm going from my friendly mode to my fierce mode?" - All of that. - All of that? Okay. So, it really does have a personality. Okay. I'm not gonna ask some rude questions about what it does. Okay. When it gets mad. So, what is the business model, here? You eluded to the fact that this will be a fleet that will be out there. Is this a fleet that you'll control? You said it would be like Uber.

Would Uber buy these and use them? Is this something or something that you're gonna be managing centrally? - Well, I mean, companies like Uber, traditionally, don't like capex on their balance sheet. So, that's something for them to answer. But I think there's two ways to look at this. One is through technology and one is through social. I think on a social level, there's clear trend lines in mega cities that young people or people who live in cities don't want to own a car. It's a pain. I don't want to have to park it. I don't want to have to deal with insurance. And what I really want is on-demand mobility where I push a button, it picks me up, and takes me where I want to be, and that's it. And that's really the mission statement of our company.

Is connecting people and places, right? We love connection, and we want them to have a physicality to how that is. And so I think people don't want to own the vehicle. They just want to pay for what they use. And we actually like that as a company because what's happening is with these advanced AI systems, they require continuous improvement, by a large team of software engineers, and a lot of computation happening in the cloud, and a lot of data coming off them, and that costs money. And so if you have the automotive model, which is if you're a tier one like Bosch, and you work on a rack and pinion steering system, then you might spend four years writing some carefully coded firmware that goes on that system. And you sell it once to an OEM, who then sells it to a customer once. And they monetize once. If you need to continuously update that software, you've got no way to pay for it. Whereas, these vehicles will have over-the-air updates going out to them at quite a high frequency. And so, you actually need the subscription model, of getting paid per mile, to actually fund the updating of your robots 'cause they have almost like living code on them.

And so it's good in that people don't want to own cars that live in cities, they want on-demand, and pay per use. And that's great for us, because that helps us make the product better. - They're just going to keep evolving. - And it's also a much better use of materials, right? Because we all know, well you don't all know, but people who work in the industry know that cars are actually driven 4% of the day on average. So 96% of the time, all the resources put in that product, sit idle. And so I love the idea that if you're not using this product, someone else is, right? And so, again, this is why you do ground up 'cause you need to solve a product that's going to drive 16 hours of the day, 365 days of the year. As Jesse mentioned, that's a hundred thousand, hundred and thirty thousand miles. And so, if you think you're going to get that just by retrofitting a car, good luck to you, right? You need to create a purpose built architecture and product experience to solve for that. - And to add to that, this technology changes very quickly, right? People are used to buying a car and owning it for 10 years or so, right? The technology that people are putting into autonomous driving today, you know in 10 years, is gonna be pretty obsolete, right? If you look at the cell phone you had 10 years ago. It certainly wasn't an iPhone 'cause they actually didn't have iPhones 10 years ago.

Although I'll only be able to say that for another month. (laughing) But, it's kind of crazy, this idea that you buy a car and you buy a 50 thousand dollar car, or a Tesla 80, 100 thousand dollar car, right? And you know it has several thousand dollars of computers and sensors in it, and it's super cool, right? It's by the far, the best system on the market. But, in five years, 10 years, it's not gonna be very useful anymore. That's one of the things that we're excited about, is that if we own and operate our fleets, we can continuously upgrade the technology as it changes every year or two, which would be very frustrating if you

bought a car and then a couple years later you're like oh not so much. - Is this dependent upon any changes in the ambient infrastructure? Changes in the roads, or changes in the communication networks, that you're dependent upon? - Yes, when Zoox launches, we need to ban all cars from America. (laughing) That would make our job a lot easier. 'Cause the problem is not really us, it's people hitting us, right? And so, Jesse can speak to this, but the technology is designed to work in a mixed mode environment in cities, and we're not really looking to the local mayor to roll out the bank check to change the infrastructure of the city. That would be prohibitive. And so, if your goal is to create a self-driving vehicle for like a car park, you know Disney Land, or a campus, you could really lightweight the vehicle. And in fact, Zoox built that in 2015.

Our ambition, is to create a ground-up vehicle that will have five star crash safety, will have airbags in it. It will go from a surface street to a freeway and it'll deal with harsh weather. So this is a full stack hardware product. That if we get right, can scale on the marketplace very quickly. - Interesting. In a few minutes, I'm gonna open up for questions from the audience. So start thinking about the hardest questions you have for these guys. - I'll just add one extra thought to that. Sometimes, people say, "Wouldn't your problem be so much easier, "if you had vehicle to vehicle communication. "Or vehicle to infrastructure? "You know, what if cities were willing to spend "hundreds of millions of dollars "and add all these fancy features?" And the reality is, well first of all, that's just not happening in the next few years.

No matter what, even if we wanted it. And then second of all, it wouldn't make our lives as much easier as you might think. Because even if every other car on the road had V-to-V technology, and even if cities had all this fancy infrastructure, your vehicle still needs to see bicyclists, and pedestrians, and all these other dynamic entities in the world, that definitely aren't gonna have this type of technology on them. So, no matter what, you have to build a perception system that can see the world around you and make sense of it. So, you need the sensing, and the AI, and the understanding. And if you sort of need to understand that anyway, then understanding cars is just sort of one extra thing you need to understand. - Now, we know that with all technology there's a dark side, right? If you think about cars in general, it lead to urban sprawl and air pollution. Are you thinking about the dark side, the downside, the consequences of this technology? And how are you, or are you doing anything to try to mitigate that? So what are the things you're concerned about and how are you thinking about that? - Yeah, I'm personally pretty optsmistic about the technology. Otherwise, I wouldn't be doing it. It is true that the car was seen as clean, and solving the problem of a lot of horse pollution that was happening in town because there was so many horses.

But, this is one of the reasons, some of our competitors for example, are fielding vehicles that have internal combustion engines. I mean, we're pure EV. 'Cause for us, in our most dense urban areas, and the United Nations predicts that in 2050, 75% of the world's population are going to live in dense urban areas, and so we want that to be safe. We want it to be clean, we want people to be able to jog and not be getting tailpipe emissions, right? And we want it to be access for the whole community. Low cost. And we want it to be a wonderful product experience which is something we're also very passionate about at Zoox, as well. And so, I think for us, there's a lot of positives. I think some of the negatives, are as you said, there's always a yin-yang to life, right? And so, when you have a new technology it is gonna displace some other incumbent industries. And in Silicon Valley, I've been living here for two and half years, it's called disruptive technologies, right? But I kind of react against that term because I'm like, "I'm not really creating a disruptive company. "I'm creating a constructive company." For a new business to get up in the marketplace, I think it has to be an order of magnitude, at least, better and ahead of the competition, right? And so, you're actually making things better but there's also loss in that.

And so, you might have some unemployment from professional drivers, like taxis and this sort of thing, but you need to look at the entire system of a city, for example. If you're able to make that city drive more efficiently, be more safe, and a better service, for a city of four million people, then that's a win. And by creating that technology, you create new stratas of jobs. And this is something that people often don't see. They just that jobs are being lost, but they don't see that jobs are being created. When was the personal computer invented? - [Jesse] 1976. - 1976, right? And we employ over a hundred computer scientists. So those jobs didn't exist when that thing was invented, right? And so, you also need to look at, there will be displacement, but they'll be new economies created. They'll be cottage industries, so people cleaning these vehicles, recharging them, right? And even though, they're more utilized, you're gonna be making more of them. There's a lot more cars made today than horses and carriages were ever built.

And it'll be the same with these robotic systems. They will increase the size of the market. - Do you anticipate this essentially obliterating the traditional car industries? Will people still have a car? - I think you'll see personal car ownership dropping. It's actually been dropping for decades in any event. Because people that live in cities, the big mega-cities, they don't want to own a car. It's a pain, right? And so we're helping solve that problem. You know, I think on a time horizon of multiple decades, yeah, people won't be able to drive a car. It'll be considered too dangerous. And people won't have those skills anymore. Just like, how many people in this room, and this might be a bit biased because Woodside's not too far away, but how many people in this room actually know how to ride a horse? Okay, that's a lot.

(laughing) Next question. - Yeah, how about a pogo stick. I don't know. But, okay. Let's get some burning questions. And I'm gonna focus on students first, okay? Great. Back in the corner. Back corner. - [Audience Member] I have two questions.

First, when you're in the car, if you have an accident or if you have somebody coming, you have the human who just stops, who has reactions.

Your car has two modes. A human being has more than two modes when he drives. So, how do you, if it's with like a human being behind the wheel in your car, how do you stop the impact if there's an accident that can be created? - So, is the question how do you deal with an accident or how do you prevent an accident? - [Audience Member] How do you prevent it because when there's two human beings behind wheels, they have emotions, reactions. A robot, has no emotion. - Okay, so what do you do to prevent accidents? - Well, so the good news is that 96% of accidents are caused by human error, right? - [Tim] I don't know how that's good news, but-- - Well, the good news, well I mean-- (laughing) It's good news for autonomous technology, right? And actually to add onto the previous question, we're talking about what is the dark side. The fact is 40 thousand Americans are dying every year in car accidents. More than a million are getting injured. And then globally, you have over a million people dying. So, when that's your starting point, right? There's a lot of ways to improve that technology. The self-driving vehicles have 360 degrees sensing coverage.

They're able to detect, not only with cameras to see sort of visually what things are, but they also have depth sensing. So you might have radar, you might have lidar. These are technologies that can see where things are in 3-D space. And so when you combine this 3-D reconstruction that you can do, with the semantic understanding that you get from your cameras, you actually do understand what's going on around you, and you can react to it much, much faster than a human can. So, in those situations where somebody else is doing something strange, somebody's making a weird turn, or they're speeding, or a person is jumping out and they're not paying attention. This type of technology will be able to react significantly, significantly faster than a human would. And it also won't make stupid mistakes the same way people do, because it's not texting or drunk, right? (laughing) So, right? So, although there are very, very rare circumstances where some of this, sort of emotional stuff might come into play. I think we can get rid of probably around 95% of accidents, just by being attentive, and not doing stupid things. And then for that last 5%, then you start looking at really advanced AI, and do you understand people's gestures and emotions. That's a bit farther out, but I think we can make, at least, an order of magnitude improvement before we get to that level of AI.

- Great. Back there. Yes. - [Audience Member] Hi. So, the system that you're building from the vehicle, to the sort of app platform, has a lot of complicated pieces. If there was one technology that you would most want to see mature, if it could just get like 10 thousand percent better, what would you pick? - So the question is, this is a very large multi-dimensional problem. If there was one technology that you could put the gas on and really have a vast improvement, what would be your dream? - That's a good one. There's a whole bunch. - No, one. - Yeah, number one, I would say if somebody could make extremely good solid state lidar that could see out to 150 meters in all directions, and be a couple hundred dollars, that'd be pretty great.

There's a whole bunch of companies working on it but nobody's figured it out yet. But that would be pretty cool. - [Interviewer] For those who don't know what lidar is. What is it? - It's like a, it's basically a laser. It shoots out the beam of light, and then it measures how long it takes to bounce back. And then, you know the speed of light, so you can figure out how far away things are, right? And so what people have traditionally done today, is they've used a technology called mechanical spinning lidar. And it's these little things that go like this. And they shoot a few million points per second into the environment and then measure how long they take to get back. And you get what's called a 3-D point plot. It's a really good way of knowing where things are in 3-D space.

The technology is still fairly expensive and it's not automotive grade yet. So, there are a whole bunch of people working on this, but it hasn't quite materialized yet. So that would be pretty cool. - Great. Lidar. Over there, back there. Yup. - [Audience Member] So, if the car is gonna be completely autonomous, we have to deal with the problem of security of the car. How will you deal with cybersecurity threats? - So, how will you deal with cybersecurity threats? - Yeah, that's a really good question. So, I think there's sort of two answers that are sort of technical and then one that's social.

And the social one is that messing with these things is a pretty bad thing to do. And I think there will be a series of laws, I mean there already are laws, but I think there will be even more laws that make it extremely undesirable to mess with this stuff. But from a technical perspective, there's sort of two things you can do. The obvious one is just to have extremely good encryption, right? And just have a top tier security team, as well as you can actually pay hackers to try to break into your system, and then they find vulnerabilities and you fix them. So that's the sort of obvious thing. I think the less obvious thing is the way you actually build the architecture. So that these vehicles will be on a network, and able to do some communication, but you want to make sure that it's actually physically impossible to command them to do dangerous things. So when we build the sort of network and communication infrastructure, we're making sure that even if somebody were to try to instruct the vehicle to do something really dumb, it would just simply refuse to do that. All of the computation is actually happening locally on the vehicle, all right? All of the sensing, it's all happening locally, right? It's not like you're sending your sensor data over the network, and then it's deciding what to do, and then it's sending that back, right? And so, the vehicle is basically going to refuse to obey any type of a dangerous command, even if a hacker were to intercept it. So, that would be how it would handle it.

But it's really obviously, an important topic and it's one we take very seriously. - Right there. - [Audience Member] Yeah, I

have a question about the autonomous driving strategy ecosystem. So, actually I think there are quite a few autonomous driving startups been founded in the past two years. And actually, it's quite a complicated thing to do, like when it's driving, it needs time, talent, and a lot of money, and resources. So Zoox's quite lucky, you had extreme talent, and you are well funded. But what do you think about those other small startups that started, just starting to do autonomous driving? What's their future, or what's their chance? Or is it a good chance to do that anymore? - So the question is, there are a lot of other small companies that are popping up, trying to tackle the same problem. What do you think about this ecosystem of other competitors? - Go for it. This is robotics, AI, mobility, safety, the environment, zero emissions, product architecture experience. This is at the intersection of I think everything that's super compelling.

These are companies that are on the vanguard of what's possible on this planet. And, I think the more people that are looking at the problem and trying to understand it, as an industry as a whole, pushing it forward, is a great thing. - Yeah, it's literally now like every two weeks there's a new self-driven car startup. Which is fun, right? Obviously, not everybody's gonna pull something off. I think one of the reasons there's a lot of excitement is that there's also a lot of acquisitions in this space. I think that's partly driving it. But, you know, if you take a step back, like Tim said, ground transportation is a 10 trillion dollar market. So, for all the money that VCs are putting into self-driving technology. And all the money that automakers are spending on it. It's a minuscule fraction of 1% of the overall market.

So, even if some of those things don't actually pan out, I think that overall if you look at the market in 10 years, you'll see that there was a pretty good return on investment there. - [Interviewer] Good. - But it has changed. I think when Jesse and I incorporated Zoox, it was just Google. And I think Uber reached out to Jesse, like a month after. Luckily, I co-founded the business with him 'cause they were starting their program, right? And now there's been a proliferation post that. But if you look at what these startups are doing, they're trying to slot, they're trying to solve a slice of the pie. And I think what makes Zoox unique, we're 240 odd people at the moment. About, over two and a half years in. Is that we are trying to do full stack vertical integration and under one roof we have product architecture, software, and hardware integration.

And so I think that makes us unique, not only in the startup community, but also like WeMo has decided not to build its own vehicle, you know. And so, it's definitely ambitious. Zoox is not for the faint of heart. And we have a real maker, invertor culture at the company. And it's hard work. But it's crazy fun at the same time. - Do you think that some of the traditional automakers are gonna try to jump into this space? - Eventually. - Well, I mean they are. I mean it's this is a real Black Swan event. Who knows who wins? I'm as interested as anyone else to see what happens.

- [Interviewer] We'll wait for the movie. - There's very historical markers, like when we did go from the automobile, from the horse and carriage to the automobile. It wasn't the coach builders that figured it out. And they were the titan industries and the companies of their day. It was people like Ford or Porsche or Benz who understood mechanical engineering, not how to stable a horse and leather. And today, the problem really is a computer science problem. It's vision. And it's AI. And it's semantic scene understanding in a way that's robust and gives us, gives the vehicle, the ability to drive through the environment with a degree of competency that the vehicle can actually bill for its own time, right? And so, if you can create that, and wrap a vehicle around it, then you just might have something. And you could argue whether automakers, which are about vehicle dynamics, and internal combustion engines, and bending metal at high volume, whether they're well-placed to look at the computer science AI challenges that are actually the key to unlocking this new era of mobility.

- [Inteviewer] Cool. Okay. - [Audience Member] Directly to that point about training the AI, getting to the level of reliability you need. It's been widely rumored that Zoox is using three reconstructions of the real world as video game simulations to train the AI. - Widely rumored? - Wow, I didn't know there were rumors. - [Audience Member] Yeah. - So there are all these-- Oh, go ahead. - [Audience Member] So tell us about your thoughts on the strengths and limits of using simulation. Something that WeMo says publicly on their websites that they use simulations to do training. It was reported by Bloomberg that WeMo, and Ford, and others are using simulation.

- So the question is, are you using simulations to train these vehicles? - Yes, we are. It's actually really exciting because there's two things you can get out of simulations that you don't get out of real life. And, by the way, you still need a lot of real life data. So, we're collecting lots of real life data. We have a remote team of 150 people just labeling data full-time using tools we've built. So, we've labeled a whole bunch of data. But there's only so many cars you can see before you kind of learn what a car is, right? If you've labeled 10 million examples of cars in images, it's pretty obvious what's a car and what's not a car, right? And so, one of the reasons why companies like WeMo drive so many miles, or one of the things that Tesla has going for it, is they have these big fleets, they're getting lots of miles. It's not that they want to see 7 billion cars instead of 2 billion cars. It's they want to see what happens in these corner spaces, right? What happens when something goes super, super wrong? And they want to get examples of that. The interesting thing is not a very efficient way to get corner cases, right? I think WeMo's driven a few million miles so far, and they've seen, I think, they've publicly mentioned a few dozen examples of really weird stuff that they've seen.

But another way to get really weird sensor data is actually to simulate it. And so one of the things that we're investing really

heavily in, is this idea of sort of building the matrix for self-driving cars. And when we talk about simulation, we don't just mean the planning level simulation. We mean down, as you, it has been widely rumored apparently, right? Actually recreating 3-D models, and sort of dynamic models of cities, where you can generate synthetic lidar data, synthetic camera data, synthetic radar data. And you actually run your entire vehicle's AI driving software in that virtual world, and you can see how all of the software interacts. Because usually when something goes wrong, it's not just one thing failing. It's usually, there's some weird object and some sensor failed, and this other thing happened. It's usually two or three things interacting that caused the problem. And so, we can simulate a lot of those things happening at the same time, and then we can see how the vehicle would react. And then we can try to change the software and make it better.

So we believe very heavily in simulation combined with lots, and lots of real world data. And I think, putting those together, you can build something really safe. - It's also a really important, at market, at scale tool. If you think about if you have 10 thousand autonomous vehicles in the city, and you want to update the code, it's not practical at that point in the technology's curve to go an manually drive a million miles or something like that. And even if you did, it might not even reveal something. And so, you really need to have a very advanced simulator that's able to run a lot of regression testing, a lot of structure tests, a lot of virtual tests, to give you the confidence that the change that you're making is performing to the system that you can roll out. - Back there. - [Audience Member] Who? - The two of you. One-- With the red sweater first and then the next one. - [Audience Member] Okay.

So, from what it sounds like you're saying what Zoox is planning in confidence have, like a line, basically building a line of taxi vehicles, autonomous system, and for the current moment a full simulation. Almost kind of a full game in that it has a full cityscape, for which to test the vehicle, which is very, very large undertaking for a small, for a company of two hundred or so. How do you think, what do you think put Zoox as an advantage to do this? Especially as you mentioned, other competitors are focusing on more specific things. And yeah, how would you-- - So the question is, this is a very complicated process, what make you, what's given you an advantage in this very complicated problem? - Well, I mean I think we've spoken to that a little bit. It is complex. But our aggressive bet is that if we can keep that complexity under one roof, it gives us a competitive advantage. If you're like Mobileye, a tier one, a supplier to an OEM, and you're developing a system, then you have to go to an OEM and say, "Hey, we want to talk about how to integrate into your car." And then they have to go through all their procedures and manufacturing the car, and produce, and put it on the marketplace. These large companies, it's very slow progress. Whereas, if you setup very strong recursive frameworks in one entity, the ability to field a vehicle, get all the diagnostics and data off that vehicle, train on it, and put it back in the vehicle. And that is happening in one entity, that becomes very powerful in our view.

And so, that's what we're really trying to do is setup these recursive frameworks. You know, simulation is actually a recursive framework, a fractal framework, that gives us that performance. - So, I'm curious. Maybe you could tell us the types of engineers you have working there, because and that'll give us, sort of , the sense of the range of types of problems you're trying to solve. - Yeah, it's actually really fun. One of the things that makes me super excited to go to work everyday, is that there's such a diverse group of people. Even within engineering, but obviously, broader than engineering. But within engineering, there's a lot of, there's a lot of computer scientists. But even then, you have people from the gaming industry, you have people from motion piling, from computer vision, other types of machine learning. You have people, we have an amazing infrastructure team.

We realized about a year ago, crap we sort of need almost Google-level infrastructure if we want to do this stuff serious now. We're not literally building Google-level infrastructure, but we're also building a lot more infrastructure than you'd typically see at a startup, right? So we're building a computing cluster with many, many hundreds of Nvidia Pascal Titan X GPUs. Stuff like that, right? So we have a whole infrastructure team of people used to building that kind of stuff. We have mechanical engineers, we have optical engineers, all kinds of different types of electrical engineers. Pretty much, we're doing enough stuff that if there's a type of engineering, there's a good chance we have one of those, or a few. - [Interviewer] Great. Super. - [Audience Member] Can I talk? - Could you stand up so we can hear you? - Could you talk about a defining moment that has shaped who you are today, whether it be professionally or tempremently? - Great, I love that question. A defining moment in your career that's shaped who you are today. - Oh gosh.

- Well, I want to just say, for Tim, this is interesting, right? You came from a very, very, very different background-- - It was probably when I was in my grade two at school. - [Interviewer] Yeah, what happened? - I was kept down a year because I spelt cat with a K. (laughing) - [Interviewer] That's because you have all these K's in your name (laughs). - Yeah, well that's part of it actually. But, yeah, so my take home message there was well Tim's just dumb, right? But, maybe I am, maybe I'm not. We'll find out. But that was, that sort of really got me thinking about how things work on deeper levels. Why did that happen? - And did you feel like you had to prove something? Or just was, did you come away thinking you were a creative thinker? - Yeah, definitely, I think through my younger years. You definitely have something to show and something to prove when that happens. - [Interviewer] Did you back and talk to your second grade teacher? - I don't think she particularly wanted to talk to me.

I was (laughing) not the most well disciplined child. - Ah ha. Okay, well. We know a lot of those in this room, too. So, Jesse a defining moment. - Hmm that's a tough one. I think one that stands out for me was the night before the 2007 DARPA Urban Challenge. We were a very small team at Stanford. I think there were only four of us who actually wrote the code for our vehicle, and DARPA had told us that they were, they weren't gonna give us the digital map file until the morning of the race. But then they decided the night before, they'd give everybody the map file just to make sure there's no surprises, right? But we had frozen our code several days before and we weren't touching anything.

And they gave us the map file and it turned out that it had about 20 times more of these sort of digital waypoints than we thought it would have. 'Cause every file they'd given us previously, if there was a straight road, there would just be one waypoint at the beginning and one at the end, and that was it. And all of a sudden, this file had every meter there was a waypoint. And so we tried to load it and it was just too slow and the entire thing didn't work. It was like 11:00pm and the race was the next morning. And we're like, "Well this is, this is not good." So, it was actually just a really fun three hours because we had to come up with a whole new set of algorithms. - [Interviewer] Sounds really fun. - It was super fun. (laughing) We had to come up with a whole new algorithm to parse that file and search the road network. And then sort of test it, and then hope it would work the next morning.

And it was actually fun 'cause we had sort of all of these technical arguments. Like, "Well should we do it this way or that way?" And I sort of made my case, and Sebastian, my advisor said, "Okay, I think yours makes sense. "Let's go try it." So I coded it up, and it seemed like it worked, and then we ran it the next day. And it actually worked and then we got to watch our robot car drive for six hours and not screw up at all and come back to the end. To me, that was really exciting, 'cause I think before that race, it was like, "Is any of this stuff even gonna work, or is it just too hard?" And then you see it do those six hours, and you see it come back, and you're like-- That was the first time where I felt like, obviously there was tons of work to do, but it was the first time where I felt like, "Hey, this is really possible "and it's coming at some point in the future." - That's great. Well, so let's then talk about the business for a few minutes. You guys are co-founders. You come from really different backgrounds, different areas of expertise. How do you work together as co-founders? Especially if you have different point of view about something. How does that work out? - Well, one sort of neat thing I learned from Jesse is he has this really cool way of communicating.

If we're discussing something, he'll go, "Yeah, I don't feel strongly about that." I'm like, "Cool." Or sometimes he'll say, "I feel quite strongly about that," and we'll talk about it. And sometimes it's, "I feel very strongly "about this is not the right thing to do." And so, it's kind of nice there's this sort of scale. And, when we both feel very, and it's not often that we actually feel very strongly that this is the wrong thing to do with each other. So the first thing I think you need is mutual respect, so you can listen to the person. And then I think when you do get to that situation, where you both feel very strongly about something, you really need to go back to first principles and decompose the problem and why it is. And fortunately for me, Jesse's one of the most rational people that I've ever met. And so, that's a good way to process it. And sometimes, sometimes the answer is, "Well, let's just go and explore that thing, "and if we're wrong, it's not the end of the world." Or, let's go and get some data to see how that works. - So Jesse, that is a very mature thing. That idea of sort of making it clear what things are important and not important.

Where did you learn that? - That's a good question. I don't know. I think I've had pretty good role models. Both of my parents. My mom's here, hi. Were pretty at encouraging me to be inquisitive. I think that's part of it. It comes from being inquisitive and also part of it comes from just trying to be reasonable, right? And not saying, "Okay, I have to get my way all the time." I think, sort of my answer to that question, I like your answer, but for me, as well, it's about actually genuinely respecting each other, right? And respect doesn't mean that you always defer to the other person. Or you assume they're always right. It doesn't mean that at all.

And it doesn't mean that you're both equally skilled in all areas. But it means, I think, in our case, if we do disagree, we assume a couple of things that are important. So first of all, that we're both being genuine, right? I never question Tim's intentions or why is he saying something or is he being misleading? Sometimes I'm like, "Hey, I don't agree with you on that." But, I don't have to worry if there's some ulterior motive or any of that kind of crap. 'Cause I think if you have to deal with that level of uncertainty, or distrust, I don't think you can make something like this work. And then the other is, Tim's a super smart guy. And it only took me about an hour of meeting him to realize that even though he didn't come from the sort of traditional engineering background, it doesn't really matter at the end of the day, right? A lot of what we're doing is about coming up with new architectures, and coming up with creative solutions to technical problems. And if you can reason from first principles, which Tim is extremely good at, it doesn't necessarily matter if he can't code up something in C plus plus. That's a little bit beside the point. So I think one of the reasons why we're able to work together is even in very technical areas, we can have a fun three hour conversation back and forth. And I think Tim is sometimes frustratingly good at keeping up (laughs).

And he doesn't sort of take anybody's, anybody's statement just verbatim. He's always thinking for himself. Which again, every once in a while that's frustrating. But it's actually an amazingly good quality in a CEO, so. - One thing I'd add to that is it's

okay for there to be conflict. It's how you process it, right? What Zoox is doing has never been done before. It's basically a group of people who don't know what they're doing, consequently, right? And so, for me, when I see people locked in an argument, I actually enjoy it 'cause I love the passion. And you need that passion. If people aren't arguing fiercely about how to do something that's never been done before, then you've got the wrong people. And so on a high level, it's actually quite a good signal.

But you do want to balance that and keep it healthy. - [Interviewer] We call that creative friction. - Yeah, I call it being comfortable with being uncomfortable (laughs). - So I have a thousand more questions, but I'm gonna just ask one more. Because we just are gonna run out of time. And I would love to know what really motivates each of you? This is a really big, hard, problem. Something with a very long deadline. Long, sort of vision into the future. What is it that drives you in this very big endeavor? - Want to go first? - Sure. Yeah, I think for me, it's seeing people being able to use something that they don't necessarily understand, but they find to be amazing and they find to make their life better in some meaningful way.

I love solving technological problems and coming up with creative solutions to them. Not for the sake of just writing a paper. I've done that. It's fun. I like going to conferences. But at the end of the day, when you can actually create something that somebody can use, and they don't understand how it works but they can tell that it's amazing, that's super rewarding for me. And that's actually why I wanted to work with Tim on Zoox, because I knew that at the end of the day, there will be other companies that figure out autonomous technology, right? We're not going to be the only one that ever figures this stuff out, right? And at the end of the day, the customers getting into these vehicles, are going to care a lot about the product, and the experience, and what is it like, and how do they work? And of course it has to work and be safe, and I love, obviously, the technology element of that. But, getting in a Zoox vehicle and thinking that it's kind of magical, I think that's really important. And Tim brings all of that, and a lot more, to the table, and that to me seemed like something worth working on. - [Tim] We also have to make the vehicle work.

- I'm trying. (laughing) And so yeah, for me it's that you're connecting people and places. But for me, it's also, you know I have a background in animation. And what we're really doing here is animating matter. And we're animating in a way that it becomes independent from us. Silicon Valley was founded on computation. Silicon Valley, right? In a way, that computation now has been plugged into sensors and algorithms that can make sense magically of what's happening around it. And that's going down to electromechanical actuation. And that feedback loop can drive a device through the environment and that's robotics. And so, I find that fascinating as an animator and a creative person, is to figure out spatially and geometrically how to solve that product.

And ultimately, I think that's important for cities today. But it's also important for expanding possible, of what's possible in this planet. At Zoox like to say, "We're gonna create autonomous mobility, "and then explore the universe." 'Cause ultimately, I think that's where intelligent robots go. - Wow. Thank you so much for animating us. (applauding)