

**KRISTEN:** So our next keynote speaker is Alex Lorman. He is an engineer, but he has also been a professional photographer. And he's going to tell you what's inside the camera, and all the physics behind it, and some cool things cool he's done with his own cameras. So I'm going to turn it off to Alex. Thank you.

**ALEX LORMAN:** I promise to bore you all to death with physics. It will be great, I promise.

So like Kristen mentioned, I currently work as an engineer. I build robotic boats right now, which is all kinds of fun. But I used to build cameras and take pictures in a former life. It's OK, you guys can all have two careers, too.

This is what I do. I play with sunken ships, and now I build them. It's great. It's good times. So also for cameras, helicopters are really useful if you ever want to take cool pictures. You should go out and ask your parents for one.

So this is actually a camera I built. And that shot-- the picture on the left-- and before you all say, no, you didn't possibly shoot that picture-- I did, and I can show you the raw feed from it. So it's actually a really old style of camera that used to use film. How many of you actually loaded a film camera. Awesome. Wow. That's actually more than I would have expected. So film is the thing, we'll get into that in a couple of slides.

This was a digital film hybrid camera. So actually the whole front unit is a film camera and it had a platen glass, which is what you used to use to focus the image. So before auto-focus and before fixed focus, you actually had to focus a picture, which involved moving pieces of glass around. It was super fun. And then the thing at the rear takes a picture of that. So it's a really weird set up, but it also worked, and I made it in my basement.

So you guys can, too. Honestly, it's kind of fun to go to a camera store, or eBay, or Amazon, or wherever, and pick up old used large format camera gear. And you can do some fun stuff with it. So this did shoot the image on the left. You see it has a really sort of odd, dreamy quality to it. That was in 2008. But it can do some interesting stuff. Most of the Secret Service will think you have a bomb. But that's OK.

So I've built some other cameras as well. You can build time lapse cameras. This is taking apart go pros and soldering things onto them so that microcontrollers-- similar to the Raspberry Pi's-- actually, a lot simpler than the Raspberry Pi's-- could control them and take a picture every-- I think this was taking a picture every half an hour, something like that. So it actually turned the GoPro on, take a picture, and then turn it off again. And you guys are actually building something much more sophisticated than that, so if you guys can all do your stuff today, you're way ahead of where I was a couple years ago. It'll be great.

So that was also solar powered. That was fun. That was-- why is my clicker not working? There we go.

So this shot this. It will give you a minute of time lapse. That stayed on the top of a mountain on a project I was working on for-- it stayed up there for like six or eight weeks or something. I only give you a minute of it. It worked out pretty well. It was a fun little project. Time lapses are cool when they actually show something. In this case, they're not actually showing very much. So there's one or two cool shots where you get a nice sunrise. There we go. Isn't that pretty?

All right, we won't bore you with any further details.

So, cameras and how they've developed. I'm sure there are further notes on this, and this is not an exhaustive history of cameras, so don't quote me on any of it. In fact, I might even be making it up. I probably am.

Apparently in 1839, photographs were on paper that probably had something to do with chemicals that reacted to light. I'm just guessing. But in 1861 they seem to have gotten it in color. Now the thing with both color, digital cameras, and film cameras, is suddenly you need to capture three different sets of light. And that's much more key with digital cameras-- and you'll see that-- you need to capture red, green, and blue to make color. So then apparently in 1884 they made photographic film. They seemed to have had a pretty good run of that for about the next 125 years, 150 years. And in 1936 SLRs. We'll get into exactly what SLRs do, and how, and why, in just a second. That's OK.

Instant photography. Has anyone actually shot a Polaroid camera, where you've got

like a little thing that you have to shake? One. Cool. OK. Polaroid used to be a lot more popular. Remember I was talking about large format cameras before? You used to check how they shot by shooting a Polaroid, and then waiting for the Polaroid to develop, and then putting the proper large format film-- which was about this big-- into it. So your subjects couldn't really be going anywhere fast.

So instant photography was a thing. A little bit before my time, but it definitely was a thing. I've heard about it.

Auto-focus, we'll get into auto-focus as well. People used to actually have to manually focus their cameras. They had all kinds of cool things called split screens, where you could-- the image would suddenly snap into focus when you had it right. Those were fun. You can actually get them for modern cameras if you want.

Kodak digital camera. So they basically took a-- I think it was an Icon F5-- and just stripped the entire thing out and put electronics in it. They were horribly, staggeringly expensive, slow, and didn't work all that well. And really the only people who used them were newspaper photographers because they needed to get their images out as fast as possible. They were also about-- the first ones were like one megapixel, maybe not even that. They were horrible.

And that continued for a while, until 1998 with modern DSLRs. Modern DSLRs are really amazing, and what you can get for a couple of hundred dollars is unbelievable. So, a 2012 is the gigapixel camera. Apparently-- I'm told-- that is a camera that has like 92 lenses that all shoot at the same time and creates a gigapixel image. If any of you can tell me what a gigapixel image is, that would be great. Because I don't know. But I can tell you about DSLRs. So-- even have a few here. This looks pretty familiar to everyone? Cool. Great. Ahead of the curve so far.

This bit, too? Lenses? Great. Let's see if they'll actually couple together. So, yes? Still with me so far? And the make clicking noises? Fabulous.

So in this wonderful diagram, which I stole from the internet, the light path goes in and we get lens elements. So if you see through lenses, they have bits of glass in them. We'll get into much more about how they work. And I'm probably making half of that up, anyway. It might just be black magic coming through. It's fine. It's not a problem.

The aperture. So I'll pass around a manual lens for you, and you can see what the aperture is. Who can actually-- oh, come on. Lord.

Who can actually tell me what an aperture is? Anybody? Yes, please fire away.

**AUDIENCE:** [INAUDIBLE] small hole that lets light in.

**ALEX LORMAN:** Yes. That is an accurate summary.

So-- here, I'll pass this around. The aperture ring is on the front. You hear it click. Look through the lens, you'll see it change. Please pass it around. Just don't lose it. Awesome.

So she's exactly right. The aperture controls how much light is coming through. You say, why on earth would you want less light to come through? Can anybody tell me? Please, the back.

**AUDIENCE:** [INAUDIBLE] picture doesn't get overexposed.

**ALEX LORMAN:** Good. Why wouldn't I just want an obscenely fast shutter speed instead?

It would freeze everything nice and you could get exactly the right freeze frame. Anybody else? It is-- you're right, you have a correct answer, though.

Please.

**AUDIENCE:** [INAUDIBLE]

**ALEX LORMAN:** That's true.

The other one is depth of field. So if I'm shooting with that wide open-- and you can sort of see it when you look through the camera-- you get a really shallow focus point. And that's great if you're shooting romantic portraits. But if you're not, you can actually stop it down-- make it smaller-- and your focus area will increase. So suddenly I'll get the first three rows of you guys in focus instead of just one.

So apertures are really important. Then it comes in, and bounces up, and then bounces around five times, and out. Anybody have a reason why bounces around five times? Why don't I just put a mirror right there and call it a day?

Great. I had to look this one up, too. So it bounces around five times because otherwise it would be upside down. And who wants to look through an image upside down? Personally I don't, but a lot of old view cameras you do have to look at the image upside down, because they don't have any optics to flip it over. It's really easy when you have a developed film to just do that. But you have to actually focus and compose the camera upside down. These were challenges I learned when I was building cameras.

So the sensor and the shutter are two different things. So you will notice that the light is not actually going to the sensor or the shutter right now. We'll get into this in a minute. Anyway, that whole shebang flips up and allows light to get to the imager, and then flips down, in all the time it takes you to press the button. It seems complicated, and honestly it really is complicated. There are many simpler ways of doing this. And the cameras you're about to build are simpler. And thank god, they don't have all these moving parts to them. It's great.

So we go into parts of the camera a little bit. We've got a lens. We talked about shutters. We'll get into shutters in a second, they're actually kind of fun. Flashes, batteries, sensors, LCDs. This looks pretty familiar to everyone, right? Great.

Lenses. This is fun, right? Come on, we're having fun, aren't we? Excellent. Good.

So lenses. Here's a lens. We can pass it around. Don't drop it. It's already been dropped about five times. Don't do it again. It will be unhappy.

So we have wide angles and long lenses, right? Anybody have any idea why the lenses have different sizes in the front? Please.

**AUDIENCE:** So you can see more-- [INAUDIBLE]

**ALEX LORMAN:** No, no. I see what you're getting. And the answer is, sort of. I don't mean to call you out. But, it's sort of.

So this over here is an 8 to 15 lens. Who can tell me what a focal length is? Nobody. Great. Fantastic. That's fine. Don't worry.

So focal length is how wide the lens is. 8 millimeters is really, really, really,

shockingly wide. Like, it's like this. In fact, that's a fisheye lens. It's a really nice little lens, but it's hugely wide. And over there we have a 300 millimeter lens, which is about this long, costs more than all of your first cars will, and shoots-- focuses somewhere over there to begin with, and you can't really focus any closer. But they're really beautiful lenses for doing certain things.

So we've covered what focal length is between 8 and 200. But the aperture is a big thing. We talked about the aperture and the iris in the lens. You will not be able to see through the lens even if you look through it. I promise you you'll never get it to focus. But it's a fun try.

So the big expensive lenses let a ton of light in, and that's why they're big and expensive. Seriously. No, that is exactly why. In terms of optics as well, you'll notice none of these are 8 to 200 because you can't actually produce good optics that do that. It is not within the realm of physics. People try, and they make really bad lenses that do like 8 to 200. And they're about this big, and they're not very good. That's OK. Your lenses on the Raspberry Pi's are moderns of marvel engineering-- of- - you know what I meant.

All right. So here's a fun bit. Here's a video. So shutters-- we talked about shutters briefly, right? They expose the imager to light, and then stop, and they do it in a very precise timing. So same thing as film.

So we're watching this at 10,000 frames a second. And I think someone is coming to talk about high speed cameras, which are their own really awesome thing. So we'll watch this again with more narration, if that's OK. If you all can tolerate 30 seconds again.

So we talked about the mirror flipping up. There goes the mirror. This is in one exposure. Now we see these are all different exposure times, so they let different amounts of light in. And you'll see that. Watch the size of the shutter as it rolls by. There we go. See one's much bigger, one's much smaller. Lets much more light in versus much less light in. And now the mirror is coming back down.

So you see how phenomenally fast this processes is. And modern DSLRs can do this on the order of 10 to 14 times a second. Which is really cool, and sounds like a machine gun. That's OK.

So the imagers. These are the imagers. Yeah, they're we go. See? That's roughly 8 to 10 frames a second. They go quickly. So in film, 10 frames a second would last you about three seconds. And they actually invented big, high capacity basically magazines for stuff like sports photographers, that had 250 shots in them. And you'd have a roll of film that was about this big. And they were horrible. And some cameras got away without the mirror snapping up and down by having something called a split mirror, and let some light through and some light up at the same time. So you basically got a bad image in both places, but you didn't have to flip the mirror up every time, so you could just shoot the film through like there was no tomorrow.

Sports photography is hard. If you want to start in photography, sports is probably not the place because you need thousands and thousands of dollars of equipment. Don't worry about it.

This is a CCD. I am not the right person to tell you exactly how they work. I'm sure one of the other people that does this for a living can, and can tell you how to make them in your basement. Which would be really cool. But essentially they convert light photons to electricity. And then the computers in the cameras convert that to a picture, and then write it to an SD card, and we go from there.

So the cameras you're going to building, like I said, are marvels of modern engineering. All of that-- lens, shutter, focus-- all of that is built into something that is absolutely tiny and costs like \$25. It's amazing. And actually, all of the image processing is on-board the camera as well. And it sends it over a communication bus called SPI, which is a standardized communication bus. So it's actually incredible what these little cameras can do. And no, they're never going to shoot as nicely as the giant piece of glass that's flying around. But they're also on a chip.

How many of you use your iPhones over a different camera? Like a smartphone instead of an actual camera? Most of you? Don't be shy. It's OK to admit it. There you go. See? So the marvels of cell phone technology have brought us to this. And that's why you can buy it for \$25 or \$30, which is still pretty incredible. And the volume of production for that is unbelievable.

There is a fun trick with that lens, if you want. If you can hold a smartphone behind

it, you might be able to get the image to focus on the smartphone camera and shoot some kind of weirdly distorted, and probably upside down, picture. It will probably be upside down because the light is probably crossing as it goes through to focus. Maybe. You can do it with a set of binoculars, too, actually.

**AUDIENCE:** [INAUDIBLE]

**ALEX LORMAN:** Nope. Everyone's welcome to try it. In fact I'll pass around another lens and we can do that, too.

Again, they're all heavy because they are really fast lenses. Here. That's another fun activity. Go for it. Just don't drop that one, please. I really like that one. If I have to pick one lens, that's the one I go around with.

All right. OK. And please, you can play with smartphones and try to get a picture if you desperately desire.

Like I said, the Raspberry Pi cameras are really stunningly amazing, and you can do really fun stuff with lots and lots of them because they're so cheap. And I think someone's going to show you how to do photogrammetric scanning with them, which is really cool. But that concludes cameras. Who has questions about any part of that? Because we really breezed over like several hundred years of development and science in 20 minutes.

Who can explain how a shutter works, roughly? I clearly didn't do a very good job.

Oh, no-- please-- save me. No? All right.

What does a shutter do?

**AUDIENCE:** [INAUDIBLE]

**ALEX LORMAN:** Please.

**AUDIENCE:** It lets light in.

**ALEX LORMAN:** Yeah. Exactly. Perfect. Detector. It's 10 points for the scientific words. Very good.

All right. Excellent. And apertures, again?

**AUDIENCE:** [INAUDIBLE]

**ALEX LORMAN:** Yep. Perfect. All right. Fabulous.

I think I'm going to hand it back to whoever else is running the show here, because it's clearly not me. And hopefully you have enjoyed it. And hopefully I get all of the lenses that I passed out back at the end, otherwise I'm going to sit and cry in the corner. I promise you, there will be tears.

**KRISTEN:** Let's give him a big round of applause.

[APPLAUSE]

**ALEX LORMAN:** Thanks, guys.

If anyone does have questions, please fire away. No? Yes, please.

**AUDIENCE:** Why is that camera called a Raspberry Pi?

**ALEX LORMAN:** That is a question for the Raspberry Pi foundation, who's based in the UK. And I honestly don't know.

No, but seriously, the Raspberry Pi Foundation is a nonprofit that makes Raspberry Pi, and they started making the Raspberry Pi camera. And that's what they do. I don't have a better answer than that, unfortunately.

Anybody else? No?

If you really wanted to get into like boards produced by nonprofits, literally the BBC-- like the news organization-- just came out with a tiny little ARM based Linux board, which they're giving away to all school children in the UK. Which is pretty cool, actually, when you think about it. Better yet, they've included tools to actually do things with it.

All right. Thank you all. Appreciate it.

[APPLAUSE]