Computer History Museum

Oral History of Steve Mann

Interviewed by:
Dag Spicer

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Spicer: So it's December 14, 2017, in Mountain View, California. We're here today with Professor Steve Mann from [the] University of Toronto and Stanford, and Steve, welcome today to the Computer History Museum.

Mann: Hello. It's an honor to be here. It's great.

Spicer: Thank you. Before we begin our interview, you're wearing something on your head there. Why don't you take a few minutes and just tell us what that is, and what the theory or philosophy behind what you're wearing is?

Mann: Yeah, so this is an EyeTap. This eye glass is about 19 years old. This is in 1998, I guess, when we completed this. And it's an EyeTap device. Light comes into the eye like this, and it goes through a computer system processor, and then the processed light ... you know, it's reflected off the back. So the light, you can see, there's a 45-degree mirror, and the light comes in here. It goes into this. This camera here is pointed to the right, and what it does is it sees the exact same rays of light that would have gone into the eye if this apparatus wasn't there. And so the rays of eyeward bound light are intercepted and brought off this way, and then resynthesized on the other side as virtual light. So this is what I call real reality. You know, virtual reality is the reality of fiction, and real reality is the reality of truth.

So what I've been interested in, since my childhood, has been, sort of, seeing the world in new ways. Like, my grandfather taught me how to weld when I was four years old, and it was a crazy experience, you know, seeing everything through this dark glass and everything was almost completely black, except a little speck of light, and I thought, "Well, there's got to be a better way to see that." And the, sort of, experience of seeing and trying to see and understand over that kind of dynamic range led me to invent something called HDR, High Dynamic Range imaging, and so, you know, what you see here on these typical phones, you know, the HDR, that's my invention from the 1980s and 1990s, which, sort of, came out of this exploration in trying to see and understand the real reality of what's actually present. And so the eye glass gives us this reality, the ability to see sound waves, see radio waves, see HDR vision. To be able to see over a complete spectrum from the infrared to the ultraviolet, as well as to be able to see and understand the world in a, sort of, phase-coherent fashion, what I call phase-coherent HDR.

Spicer: Is it correct to call it augmented reality? Because, in a way, you're supplementing the world out there with an overly. Is that correct to say?

Mann: Maybe, in some ways. I mean, I've sometimes referred to certain aspects of it as phenomenological augmented reality, PAR, which means the physical phenomenology of the real world is overlaid back onto the real world again. Oftentimes, augmented reality is the reality of fiction, kind of like virtual reality, you know, pop-up caricatures and things like that. What I've been interested in is seeing truth, rather than fiction, and in that sense, maybe, real reality is a better framing. Or in some sense, "augmediated" reality might capture the spirit of this, in the sense that the reality can be augmented, as well as diminished or mediated. For example, when we're welding, what I am doing, essentially, is diminishing the bright areas of the scene and augmenting the dark areas of the scene, mediating or modifying, to help people see.

Spicer: Right.

Mann: The kind of mediated reality or modified reality is a reality that helps people see, not just adding more. So if you've got an already confusing scene that you can't see well, like the dazzling scene of an arc welder, what you don't really want to necessarily do is just throw more overlays on top of that. What you really want to do is tame it down to the point where people can see it first, and then add the overlays, and I call that augmediated reality. It's an augmentation of the mediation of reality.

Spicer: Right. I see. So what are you seeing right now through your glasses?

Mann: So what I see is just a computer screen of reality, and then ... so I see an HDR vision. So when I'm looking at really bright scenes, like bright lights or whatever, I can see the lettering on the lights, and so on.

Spicer: Oh, my goodness.

Mann: On the light bulbs...

Spicer: The lettering on the light bulbs?

Mann: Yes. So I can see the bright...

Spicer: Oh, my...

Mann: ...areas of the...

Spicer: ...gosh.

Mann: ...scene, down to the darker areas of the scene. And with some of the eyeglasses, I can see in complete darkness, pretty much, as well, so over this range of light. That's one of my inventions, is HDR, but it's also ... there's also this notion of phenomenology, phase-coherent HDR. So one of the things that I invented in my childhood was this, kind of, lock-in amplifier that allowed me to see sound waves and radio waves.

Spicer: Right. Is there anything more you want to say about this? How do you control the computer that modifies what you see, for example? Is that in your pocket? Or how do you ... is it just on a permanent setting, perhaps?

Mann: So some of the eyeglass ... well, I guess, this is, kind of, an old prototype, about 19 years old, now. But the ones we're building now are just like ... look like ordinary eyeglasses, and we're working on projects. I founded a company, InteraXON, you know, out of my house, originally, with my students and the company gradually grew, and now we're partnering with others. Together, we're making brain wave controlled eye glasses that just ... wearable computers that just look like ordinary eyeglasses, and have the world's most advanced brain computer interface in them, and then, we're working on a number of other things that help people see.

And the idea is there's a machine learning algorithm so that you don't need to do anything, really. You don't need to fidget with it, or whatever. There's a machine learning system that learns what you want to see and helps you see better by simply adapting to whatever's there and adapting to you, as well, and there's a principle that we call humanistic intelligence. Marvin Minsky is the father of the whole field of machine learning and AI. He's the one who invented the field of AI, and him and I together developed this conceptual framework, and Marvin Minsky together with Ray Kurzweil, Chief Engineer at Google, and myself, the three of us, in 2013, wrote a paper on the society of intelligent veillance. And in that paper, we introduced the concept of humanistic intelligence as a form of creating this, sort of, cyborg entity. It was this humanistic intelligence, this intelligence that arises by having the human being [in] the feedback loop with the computational process, and humanistic intelligence is human-in-the-loop AI.

And so there's a few things that we have. You know, the most advanced vision algorithms that help people see ... the most advanced HDR that runs thousands of times faster than anything that anyone else has, and at the moment ... we're developing this in hardware. We've got FPGA-based implementations of HDR that run real-time video, and we also ...have partnered with a company in China, where we manufacture the world's most advanced lock-in amplifier. And so with these technologies, we're able to use machine learning to help machines see, as well as to help people see. So we're looking at self-driving cars, putting cameras in self-driving cars to help cars see. One of the things that I really notice early on is that my vision system ... I had an active vision system at one time, and I've noticed I walk into a restaurant or something and I couldn't see properly because their surveillance camera was blinding my eyesight. They had an active surveillance camera with a ring of infrared lights, and it would swap my IR receiver and I wasn't able to see properly. So I had to boost the output of my infrared system, in order to see properly, and so in order ... whenever it encountered ... and I had this with machine learning. So whenever it encountered ... whenever it was blinded, it would automatically boost itself, and so the effect was whenever I'd walk into a place, it would white out all their surveillance cameras. When you look at the surveillance monitor, when I walk into a room, the screen would be all white because my system, in order for me to see, I'd have to blind their system. And so I started to realize that these active vision systems don't work too well ... they don't play too well with each other. They tend to blind each other. So these self-driving cars are great when there's only one of them on the road, but when there's a whole bunch of them on the road, I could foresee, or I could predict, the future where that's going to be a problem. So what I did is I developed the technology that would solve that problem, which I call phase-coherent HDR, phase-coherent High Dynamic Range imaging.

Spicer: Without getting too technical, what does that, basically do or mean, the "phase-coherent" part of it?

Mann: Well, one of the things that's fascinated me, since my childhood, since I was about, maybe, eight years old or so, I started building lock-in amplifiers to be able to see phenomenology. You know, different things, and I built ... when I was 12, I built what many people regard as the world's first wearable computer, back in 1974. It was a wearable computer system to pick up sound waves and radio waves and make them visible as an array of light, and one of the things I did in my high school class, physics class, is I showed a nice little experiment, where you can see the interference fringes of sound waves. So I had two transducers, and as I varied the spacing between the transducers, you could see the sound waves. As I brought the transducers closer together, you could see the interference fringes of the sound waves spreading apart. And so just this ability to see this phenomenology, like sound waves and radio waves, was a whole new world that opened to me, and I realized it holds the key to being able to see better, and that I had developed a technology that would help people see and understand their world, spatially, in a world that's more opaque.

I noticed in my childhood, you know, I'd look at a radio and there would be no back on the radio, and you could look inside and the lamps in there, the vacuum tubes were all transparent, and I could look in and see and understand everything about that radio, how it worked. Literally, the technology was transparent. In this transparent technology, not only were the tubes themselves transparent, so you could look into them, often these radios had the back that could easily come off, or some of them didn't even have a back. You could just look in behind the radio and see everything. Its complete principle of operation was laid bare, totally. Not only that, but the manufacturer used to put a schematic diagram in there on one side and a parts list on the other. So you could, literally, look in there and understand [the circuit] and you could mix parts. You could take tubes from a General Electric radio and put them in an RCA radio. You could swap parts between different brands. There was this great interoperability between components and there was this transparency of the technology. You know, my dad got me a Cathode Ray Oscillograph, RCA type TMV-122, in my childhood, I got this thing. It was about 40 years old when I got it. It's about 80 years old now. And it had a completely clear Cathode Ray tube, transparent. This was back in the 1930s before they put that Aquadag stuff on the inside of the tubes, and so you could see back in behind the tube exactly. You could see the electron beam structure there and then, you could look at the front of the tube. But you could look in behind and see everything backwards on the inside of the CRT. So it was just a totally transparent, completely understandable technology, and one of the things about that scope is that the time base didn't work on it. That's part of the reason I got it, because it was broken, and the time base didn't work, and the dot would only move up and down. And so what I did is I started pushing it along my workbench, you see, to make ... so that I could see a time base, and just did some long exposure photographs, or I'd take a picture of it while I was sliding it down the bench, to trace out a wave form. And what I discovered by accident was I had a transducer mounted to the oscilloscope, just screwed to the binding posts on the input, with a little amplifier. And so when I pushed it along my workbench, it traced out a wave form as a function of space, rather than time, and I, kind of, stumbled on this notion of sharing this space-time continuum in a set of coordinates in which the speed of light or the speed of sound is exactly zero, so that I could see waves sitting still, and I discovered something that I call sitting waves.

We all know what standing waves are. You know, when a violin string or a skipping rope, kind of, goes up and the aperture goes to zero and then, down and then up and down and then, there's certain fixed points, then in between it goes up and down. But a sitting wave is where the wave just sits perfectly still, for the most part. A little bit of statistical fluctuation, but otherwise, the wave's sitting still, and it was this concept of a sitting wave that I developed that allowed me to see, and so I developed this concept of a scientific "outstrument." An oscilloscope is a scientific instrument, you know, where you can see inside of it. It's all contained and you see things as a function of time on a time base. But what I did is took the wave outside of itself, and I call it a scientific outstrument, in which the phenomenology is out in the real world. So I'd be looking at my workbench, where I'd have an antenna here, and I'd see the waveform from the antenna. I'd see the electromagnetic waves from the antenna just, kind of, hanging there in space outside of itself. And so one of the things I do, you know, I build smart phones, and so I build these, as a fun little thing. I used to like to build radio receivers and radio transmitters, in my childhood, and build all these smart phones and everything, and so this is a smart phone here, homemade smart phone, and this is a replica of my wave machine. You can see...

Spicer: Okay.

Mann: And there's a wave there.

Spicer: Right.

Mann: And you can see the wave is stronger when I'm closer, weaker when I'm further away.

Spicer: Right.

Mann: And then, I don't know if this will show up on the video camera, because you need a shutter angle of more than 360 degrees to be able to see it really well. But anyway, the human eye sees it as this wave that's coming from the phone and, you know, if I go through something ... like, if you have a book or something, a nice thick book, even that note pad...

Spicer: A note pad?

Mann: ...would probably do it.

Spicer: Magazine?

Mann: Yeah, it might do it. So I've got this *New England Journal of Medicine* here. Maybe, I'll fold it over twice so there's two thickness ... well, actually, even just holding it like this. So you can see it's a little bit weaker going through that *New England Journal of Medicine*.

Spicer: Oh, yeah.

Mann: And versus here. But if I go through this bottle of water, what do you think we're going to see?

Spicer: Nothing.

Mann: If I hold my phone like this, if I block the speaker, it doesn't make much difference.

Spicer: Mm-hm.

Mann: Or if I cover up the microphone, it doesn't make much difference. But if I cover up the antenna...

Spicer: Oh, yeah.

Mann: You can see the signal's a lot weaker. In fact, if I put one finger over where the antenna is, it's quite a bit weaker. Two fingers...

Spicer: Yeah.

Mann: Three fingers, four fingers. So it tells me that you shouldn't hold your phone like this. Nobody can hear what you're saying. The smart people hold their phone like this. You can hear what they're saying. Otherwise, if you hold it like this, the transmitter...

Spicer: I remember...

Mann: Otherwise, if you hold it like this, the transmitter will go full power and it'll just waste a lot of energy, heating up your brain and your hand and running your battery down. But the other person's not going to hear very much, because you're blocking the signal.

Spicer: Yeah. That was like "Antennagate." You remember the Apple phone?

Mann: Uh-huh.

Spicer: That had the issue for a little while, and Steve Jobs came out and, basically, said exactly what you said. You can't hold ... you shouldn't hold it like that, this sort of death grip. <laughs>

Mann: Yeah.

Spicer: You should hold it a little more gently and delicately.

Mann: Yeah, and that's an important thing, is knowing where to put the antenna, and that's what this ... one of the things I could see in my childhood was to be able to see all these radio waves and sound waves.

Spicer: So this thing that you just showed us is what? How would you describe that to an observer on the street?

Mann: So this is a device ... this is an invention from my childhood, which I call the Sequential Wave Imprinting Machine, which I've got the original wearable computer here I can show you, and that's ... I call it the SWIM, Sequential Wave Imprinting Machine. As I used to say, "We're going to SWIM out that wave, you know, from that device, and we're going to sequentialize it and make it visible." And so it sequentially imprints the wave onto your retina or onto photographic film, and by virtue of persistence of exposure, it made these waves visible.

Spicer: Yes. So it's, kind of, within keeping of your overall life project of making things visible and improving how we see things in the real world?

Mann: Yeah, it, sort of, extends our vision down into radio waves.

Spicer: Right. So these waves that are being made visible, they are the actual radio waves from the phone?

Mann: Yeah, this is not a representation of the wave. People ask me, "How does it know where it is?" And it's just bound by the rules of physics, and as such, this thing updates at a rate of about 1.6 million times per second, and it's accurate to within, you know, maybe, nanometer accuracy, or whatever. It doesn't lag behind reality.

Spicer: Awesome.

Mann: See, all these virtual reality ... the fiction of virtual reality is laggy and it swims behind everything. The irony of the SWIM is it's perfectly in sync with reality because it's governed by the laws of physics. So it's operating at the speed of light, rather than at the speed of, you know, every once in a while updates.

Spicer: Right. Okay. So Steve, what have you got here? And can you tell us how it works?

Mann: So this is the world's first wearable computer. I built it when I was 12 years old in 1974, and it controls these lights. You know, it's a phenomenological augmented reality amplifier. It's a lock-in amplifier that picks up signals in sequence, as lamps, electric lights, in order to make real augmented reality, or phenomenological augmented reality. So I called it the SWIM wear. S-W-I-M stands for Sequential Wave Imprinting Machine. So it's a wearable wave machine and it has a little strap on it, and I used to wear this and walk around the lights and sequence and understand and see reality, and so there's a ... it's an amplifier that picks up weak signals. There's antenna terminals on the back, where you can connect rabbit ears to pick up television signals and amplify them and drive them to electric lightbulbs, and there's a gain and a sensitivity. So there's a bias here, which is overall bias. I can increase this bias here and decrease it, and then separately, there's a sensitivity adjustment and various other controls and sequencer, forward, reverse, automatic. It'll pass through different kinds of computed sequences, and it's a fairly simple structure and then, now, if I have a little bit of gain here on this, if I turn up the bias a little bit so there's a bit of a bias voltage on the amplifier, what happens is even when it's not picking anything up, it amplifies and gives you something on the light. Now, what this does is when I bring it in front of this surveillance camera, what you'll notice is the light gets brighter when it's in view of the surveillance camera. Because what it's doing is it's receiving television signals, even weak television signals, and amplifying them massively, massive amplification. So with a huge amount of gain, it's amplifying those television signals, and so if I hold this light here and block it with my coat, wherever the coat is blocking it, see, the light falls dim when the camera can't see the light. When the camera can see the light, it glows much brighter, and of course, if it's outside the field of view of the camera, it also falls dim. It only goes bright when it's within the field of view of the camera. So when the camera can see the light, it glows more brilliantly, and when the camera can't see the light, it glows less brilliantly. And so the idea here is it creates this phenomenological reality, in which it allows us to see these otherwise invisible signals. So this is meta vision. You know, if I tell you a meta joke is a joke about jokes. A meta conversation is a conversation about conversations. Meta vision is the vision of vision. This is seeing sight, visualizing vision, and sensing sensors and sensing their capacity to sense.

Spicer: Mm-hm. Can you think of an application where this might be used?

Mann: So one application is, say, in a new kind of eye test, where you can test people's vision and see, in a simple way ... like, right now, if you have eye diagnostics, they're all written. But I've got something called the "eyenograph." My students and I are working on a new kind of eye test that we call the eyenograph, which is a vision of the eye. It's an eye test where you end up with a photograph of what your eye can see. And so if you have a camera ... so for example, if we want to understand the Internet of things, we can finally see the Internet of things, because it's otherwise invisible. This sight field, if you will, of the camera, or its capacity to see, the capacity of humans to see, of cameras to see, and other sensors, sensing sensors and sensing the capacity to sense, allows us to quantify and to speak in quantified units. Meta-veillance or meta-vision are concepts that allow us to quantify and scientifically analyze the Internet of things, which is otherwise just, kind of, a general vague sense. People will say, "Well, you know, in lighting, we do lighting studies. We study lights and we see how much light. We measure how much light, how much amount of light is present in every part of the room." That's a scientific study that people value. Well, now, with surveillance cameras, that could measure how much veillance there is in each part of the room.

Spicer: Oh, now, you're using the word "veillance." I just picked up on that. Not in the chemical sense of bonds, as in covalent bonds...

Mann: No, no...

Spicer: ...but veillance as in surveillance?

Mann: Yeah...

Spicer: Correct?

Mann: Well, if you take the word surveillance, it has two parts to it, sur and veillance. Sur means over or above, as in surcharge or surtax, and veillance means sight or watching.

Spicer: Okay.

Mann: So the closest English translation to the word surveillance is ... it's a French word, surveillance. The closest English word is oversight. But the word oversight has a double meaning. It means to watch over, like surveillance, but it also can mean an error or omission on our part, and so we tend to use the French word. But what I'm talking about here ... this light bulb doesn't know anything about political hierarchy. So surveillance is like when police are watching citizens or a shopkeeper's watching shoppers or a cab driver's watching the passenger. The surveillance implies a political hierarchy. But this light bulb doesn't know anything about politics. This amplifier here and wearable computer doesn't understand politics. It merely measures scientific fact, and so in science, I introduced the concept of veillance as a non-political ... surveillance is a politically charged word. But veillance, if you take the word surveillance and remove the first three letters, you've removed the politics from it, and what remains is just a scientific phenomenology.

Spicer: Yeah. Okay. Got you. Okay. Now, Steve, you've got something very interesting there. Can you tell us a bit about that?

Mann: So what I did is I mounted 35 electric lights on this stick here, and they're connected together through these connections in a kind of pattern that's useful. And the way it worked is that these plugs plugged into this machine here and so this computer sequenced through the lights. And so the way it worked is that I would wear this and I was able to swing this around and capture the pattern of the phenomenology. So it's sequenced through these lights at high speed in different patterns, and I had a computational framework for optimizing the pattern so that it would search through. It conducted a search space through all possible ... through the different permutations to rapidly identify the veillance flux or the pattern in which we're seeing and understanding this world.

And so as I brought these lights through space, like this, I would swing these lights through space, and by persistence of exposure, either on the human retina or the human visual system as a whole, or by persistence of exposure on photographic film, I'd be able to see and understand the patterns. So if I started moving this back and forth in the space of reality, these lights would dance around in interesting patterns, and what they did was showed me the veillance flux. So I'd see the sight field of that camera as a cone of sight all in one go. Instead of having to swing a single light bulb back and forth like this, I had this whole brush that's like a giant paint brush that painted onto reality what was actually there and allowed people to see what was actually present. So one of the things that I did is meta-vision, meta-veillance, being able to see, for example, sight fields of cameras, and the other thing that I did was I took the world's first photographs of radio waves, with this apparatus, where I could see it has some antennae and one or more antennae, you know, like an antenna that was transmitting a video signal, and be able to see the wave forms of the electric or magnetic field coming from the antenna. So this was phase-coherent detection. Not just signal strength, not just a signal strength meter moving through space, but actually seeing the radio wave itself in a set of coordinates in which the speed of light was exactly zero.

Spicer: Mm-hm. Wow. Okay.

Mann: And so that was one of those things. So this wearable apparatus allowed me to walk around and explore large landscapes and spaces for waves and I was able to walk around in big open spaces and paint out the reality that I envisioned.

Spicer: Oh. Amazing. Is there a way to capture the experience?

Mann: Yes. So what I used to do, sometimes, a lot of times I would show people by just waving it around, they would see it. Because if I move this fast, now, of course, you can see those patterns.

Spicer: Right.

Mann: Especially, in a dark room, where your eye adjusts to the dark. When your eyes adjust to the dark, the apparent exposure time length is, and so you're able to see these patterns. And I would tell people, you know, "Don't let your eyes follow the light. Just look at a spot." So I often have a little "X" or something that we light up glowing so people could look at a little pattern, or dim the glowing bulb and say, "Just stare at that bulb, but don't let your eyes follow the light." I'd swing the lights around. Of course, they would see this image of this augmented reality overlay, and I used to ... you know, I could have large groups of people be able to see this without having to wear any special apparatus or anything. And then, I also did this on photographic film. So I would put a photographic plate or a photographic film into my camera, and then open up the shutter of the camera and sweep this out and let it go, and then I had a radio controlled shutter and I even had a camera, later when these motor drives became available, I had a motor drive to advance to the next frame. So I had this little cording keyer, actually, I could issue commands to my computer. So I could actually type ASCII characters on this thing by squeezing different combinations of these keys here and issue commands, and actually, control my computer and send messages to my computer and key out different messages. Like, each of these goes over one of the fingers, and then I'd get a whole bunch of different symbols and different permutations and combinations with keys...

Spicer: I've always admired people who can deal with cording keysets. <laughs>

Mann: Yeah, I call this a keyer, of course, because it's like a keyboard, but it doesn't have a board.

Spicer: Yeah.

Mann: You know, it's just in free space, as I'm swinging this thing around issuing commands to the computer, and it's controlling everything.

Spicer: Uh-huh. Oh, that's wonderful, and you made this when you were 12?

Mann: Yes.

Spicer: Wow. And so did you ... obviously, you didn't have the body of theory you do now, when you were 12. So what was going through your mind when you built this?

Mann: Well, as I was growing up, I was fascinated by certain things, and I found a television repair shop in my neighborhood, where I volunteered to help out.

Spicer: Oh, yes.

Mann: And you see, he became my mentor. Antonin Kimwell was his name. He became, sort of, my mentor to teach me all about television. Because I wanted to learn about TV, and so I talked to different people over the years, and I found somebody who could teach me the workings of television, and when I first showed up at his place, he said, "What can a young child do to ... what do you know? You know, how can I, a child, possibly know anything?" So when I first met him, he went into the back room and he closed the door and told me to wait, and then when he was ready, he opened the door, and he said, "There's a TV. Fix it for me." And he was just testing me, and so I walked over, and all the tubes were glowing. So I said, "Well, it's getting power." And I said, "Do you have a voltmeter?" And he said yes. So I started measuring. The horizontal oscillator wasn't oscillating. So, finally, I measured the voltage across the volume control, on-off switch, and I said, "Oh, the problem's the on-off switch." And, see, what he'd done is taken the set, taken the TV, and turned it to face the wall so that the front panel was pressed against the wall, and it was all open on the workbench, and he had simply turned the TV off. So the only thing that was wrong with it was that it was turned off. But within about two minutes or so, I identified the problem as the on-off switch.

Spicer: Right. <laughs>

Mann: Because there's was voltage across it. And so he just wanted to see if I could logically deduce or logically reason...

Spicer: Pretty amazing for a 12 year old.

Mann: Of course, in those days, when you turned TV's off, the tubes would still glow. There's a diode across the on-off switch, to keep the filaments kind of half on. So there is a, you know, partial...

Spicer: Instant on.

Mann: Instant on. So the thing, you know, certainly looked like it was on and it made an interesting little problem. But he was convinced that I wasn't totally stupid. So then, he said, "Hey, you know ... " so I volunteered to help fix sets and I learned a lot, and got a chance to play around with lock-in amplifiers and other things like that, that most children don't get access to.

Spicer: Now, a lock-in amplifier, can you explain what that is? If I'm correct, it's usually a fairly high-end piece of test equipment, is it not?

Mann: Yes. They're very expensive.

Spicer: Yes.

Mann: And it's an amplifier that provides that massive gain phase-coherently. So it has a reference input and a signal input, and so that's the fundamental principle of being able to phase-coherently detect something. And so I, kind of, became fascinated, in my childhood, with these kinds of ... concept of lock-in amplifiers and phase-coherent detection, and I kind of got into this notion of picking off radio waves and sound waves as they're traveling through space, and trying to freeze them and look at them in a set of coordinates in which the speed of sound or the speed of light is exactly zero.

Spicer: Yeah. So it's...

Mann: So I'd take a reference signal. If I had any radio transmission or I'd have an antenna fixed here as my reference signal, and I'd move the other one ... this is, kind of, what I discovered when I was sliding my oscillograph back and forth across the workbench that had the broken time base on it. The dot would only go up and down, and when I moved it back and forth like this, I noticed it would trace up this pattern. Because I had a sensor attached to it against the reference of another stationary sensor. And so I started to get this idea that I could pick off these waves, you know, with lock-in amplifiers as a way of massively amplifying very weak signals, picking up weak signals that are buried in noise. You know, any kind of thing that you're trying to do, whether it's sweeping for bugs or picking up really weak phenomenology and physics, cryogenics, you know, any ... there's many things in physics where we're trying to find a really weak signal, and a lock-in amplifier can, sort of, answer this fundamental question of what does it do to something else? You know, how much of this is due to that? You know, if you can get access to the thing that's causing something as a reference signal, then you can see how much of what you're observing is caused by the thing that your reference is to.

Spicer: Thank you for showing us the SWIM machine. I really appreciate that. It's quite amazing that you built that when you were 12. That's remarkable. And you can see the roots of your, sort of, life purpose, if you like, of extending the range of human sensing abilities or ability to see things we don't usually see began really early with you. And so let's just start with the, sort of, more formal part of the oral history, and talk about where you grew up, what your parents did, and what school was like. Did you like school? Did you have hobbies? Those kind of things.

Mann: Yeah, I guess, when I was growing up, you know, my father worked at a men's clothing company. So he was in the clothing business, and so, I guess, I learned a little bit about clothes and how clothes are designed. But he was also into tinkering and building things, too. So before I started kindergarten, we were often building things. I can remember, you know, building radio receivers and things like that with my dad, and my grandfather was, sort of, like that, too. He was into building things. He used to build airplanes, and sometimes he'd let me fly his airplane. He wouldn't let me take off or land it. But when we were in the air, you know, he would put his hands up on the bars to let me know I could grab onto the stick and take control of it, and I used to fly his little airplane around when I was a young child.

Spicer: This is a model aircraft; right?

Mann: No. Like a two-person aircraft.

Spicer: Oh, really? A real aircraft?

Mann: Just a small airplane.

Spicer: Wow.

Mann: He'd often fly in on these little airplanes.

Spicer: Well, that's fun. What was his job? What did he do...

Mann: He liked to build things. He was a refrigeration engineer and...

Spicer: Okay.

Mann: ...he fixed refrigerators. That was back in the days when refrigeration was fairly new as a field. People still had ice. The ice man would come around and you'd get a 25 pound or 50 pound or 100 pound block of ice. He made these mechanical refrigeration type things and he was kind of in that world, as a refrigeration engineer. But he also liked to build things, so he used to build Stirling engines in his garage, and he taught me how to build them, and I'd build these various engines. He also built airplanes. So he was a pilot and he also built airplanes ... helped others build airplanes, and a lot of his friends were pilots as well. So he was into that world of making things.

Spicer: Yeah. So you had some good role models when you were young.

Mann: Yeah.

Spicer: In terms of tinkering and working with mechanical ... working with your hands and so on, what was school like for you, generally, as an experience? Were you a happy student, or more often you were home?

Mann: School was kind of meaningless. I was always sort of teetering on the brink of dropping out of school when I was in high school. I really wanted to quit school and do something meaningful with my life, because I felt school was useless, or actually provided negative value in many ways. It's interesting, I met ... one of my math teachers, his name was Ron Lancaster ... I met him. He's maybe the only reason I stayed in school, because he sort of showed me that school can be fun and math is fun. Math was the only subject I really liked when I was in school.

Spicer: Okay.

Mann: If I had my way, I would have just canceled all the other classes and maybe had mathematics all morning and physics in the afternoon or something. But the other stuff, I didn't see ... it wasn't really interesting. Even the math that they taught in school was kind of dull and watered down and uninteresting. Really interesting mathematics problems didn't come my way. I remember when I was in high school, I think I placed second place in a math contest that was meant for university students. So I was okay in math, but then I was close to failing math, because I was just not ... my mind wasn't switched on. It was just ignoring what the teacher was saying or doing. I think maybe I upset a lot of my teachers by not paying attention, because it was kind of uninteresting. So the real mentorship I got was, you know, volunteering in a TV repair shop and learning about the real world.

Spicer: What kind of hobbies did you have at this time? I'm sure you had some. I know at 12 you built the SWIM, so you must have been somewhat into electronics or electricity at some point.

Mann: Yeah, I liked to build things, you know. I used to take television sets and turn them into oscillographs, you know. I'd turn the deflection yoke sideways 90 degrees and get the vertical oscillator going across as a sweep. Then in where the horizontal was, I'd drive an external waveform. A couple of times, the TV would not like it and it would start to smolder a little bit when you had the horizontal operating differently, so I realized I had to dummy load the horizontal side with another deflection yoke. I kind of just figured out, in my childhood, from television sets that people were throwing away, how to get the television sets to draw waveforms and make them into oscillographs. I was kind of interested in tinkering and playing, and something I call "tinquiry." Tinkering is a form of inquiry, this notion of exploring the world through experimentation.

Spicer: Right. I think there's huge value in what you say, in simply taking things apart when you're a kid.

Mann: Yeah.

Spicer: With no goal of putting them back together, necessarily, which is good, because often you can't.

Mann: Yeah. I would often take things apart and turn them into other things.

Spicer: Yeah.

Mann: Like I wasn't necessarily interested in just taking things apart for the sake of taking them apart, or for putting them back together. I mean, I did fix TVs. I had my own business. I was an entrepreneur in my childhood, and my entrepreneurial practice was to fix televisions for people and radios. So I had my own business repairing all the televisions and radios, mostly from different ... around the community. So I was kind of widely known as the guy to fix the TV, but that was just a way to make a little bit of money, you know, as an entrepreneurial pursuit. But I was more interested in kind of exploring reality.

Spicer: Mm-hmm. So let's just skip ahead. You got out of high school, which sounds like it was a blessing for you.

Mann: That I actually completed it is amazing. Got to thank Ron Lancaster for that, otherwise I would've probably dropped out, and I don't know, maybe I would have been an entrepreneur and been successful in that side. Who knows?

Spicer: Yeah. All it takes is one good teacher sometimes, to just keep you on track, you know.

Mann: Just to show by way of example that there is something of value there.

Spicer: Right, yeah. So I presume you went to MIT at this stage or to U of T [Toronto]?

Mann: Yeah, I took ... after I finished high school, I went to McMaster University and then I went to MIT. I took my wearable computing inventions to MIT. At McMaster, I did work on radar. I came up with a new way of ... a new mathematical transform called the chirplet transform. So the wavelet transform is pieces of waves, wavelets or little pieces of waves, roughly speaking. I invented something called the chirplet transform, which is a mathematical representation on little pieces of chirps. So a chirp is a waveform that varies in frequency. So a wave is like [monotone whistle], you know. If you look on an oscillograph, it's this wave, whereas a chirp is like [modulating whistle], you know. It varies in frequency, so it starts out with long waves and gets shorter, or vice versa as a down chirp. It would be like [descending whistle], down or up in frequency.

Spicer: Right.

Mann: So I created a new mathematical transform called the chirplet transform when I was at McMaster in Hamilton. I did a lot of wearables things there too. I grew up in Hamilton, Ontario, near Toronto, and I'd come into Toronto and do these wearables events, kind of like hardwear, H-A-R-D-W-E-A-R, kind of events and organize different things where we'd do different wearables. I did a lot of sort of phenomenological augmented reality performances, stupid and crazy things, as a cyborg performance artist.

Spicer: We'll get to that in a second, but just to pick up on the chirplet transform, has that been taken up by the community as an effective DSP technique?

Mann: Yeah, there's a lot of companies now using it. It's fairly widely used.

Spicer: Wow.

Mann: There's different hardware implementations of it, fast chirplet transform implemented hardware.

Spicer: That's pretty impressive.

Mann: You see, people have traditionally looked at waves and Fourier analysis, you know, Fourier transforms and waves.

Spicer: Right.

Mann: Waves hold the answer to things that are of constant pitch. Like in music, we think of something like [whistles tune], notes that have a certain duration and a certain frequency, neatly organized.

Spicer: Right.

Mann: But in nature, if you look at the song of the birds, you know, it's like [whistles birdsong]. It doesn't stay at these fixed frequencies.

Spicer: Oh yeah, right.

Mann: So if you look at the musical instruments, it makes sense to do Fourier analysis of notes that are sustained at a certain pitch. In human music, we have a note that's sustained at a certain pitch.

Spicer: I see.

Mann: Then another note that's sustained at another pitch and so on. But in nature, the song of the birds or bats when they're echo-locating, they chirp. Dolphins chirp. Just about anything in nature, even brainwaves and heart rate variability, people are looking at the chirplet transform for HRV, heart rate variability. They're looking at the chirplet transform for brainwaves. I started up a company, a brainwave company, and we're doing this sort of chirplet-based analysis of brainwaves and everything. So there's lots of different things where waves are not the right framing for it, you know. Even you look at a picture of something, like if I look up at the ceiling here, what you see is there's ceiling tiles. Although they may look like a periodic pattern, which would have a Fourier series, if you look at a camera photograph of it, the ones closer to the camera appear bigger, and the ones further away appear smaller, and that's a chirp. That's the frequency. If you just take a picture of railway ties, you've got wood, stones, wood, stones, with the railway tracks meeting. You know, parallel lines meet at the point, at infinity, if you project, or they never meet if you're not projective. But you look at the picture, as we get closer to the point at infinity, the spatial frequency increases. You've got wood and then stones and then wood and then stones. It gets closer and closer together in the picture.

Spicer: Right, right.

Mann: And that's a chirp. It starts out at low frequencies in one place and goes to high frequency [ascending whistle]. The frequency increases without bound towards infinity, when you go towards the vanishing point. So in nature, photographs, pictures, signals, bio signals from human as well as other animals, and just any phenomenology that we might observe in nature often has chirps in it. What I notice is that accelerating radar targets have chirps in it. Little iceberg fragments in the ocean chirp around as they bob around. I call those "warblets," where the frequency is periodic and it goes [modulating whistle]. The frequency goes up and down and up and down, as you've got this iceberg fragment that's accelerating. I was able to use the chirplet transform to detect small iceberg fragments in a way better than any other means of detecting them. These were harmful to ships, you know, little iceberg fragments about the size of a grand piano.

Spicer: Oh.

Mann: Too small to see on any existing radar at the time.

Spicer: Right.

Mann: But were immediately visible with my chirplet-based radar set.

Spicer: Right.

Mann: So I invented a new kind of radar vision that allowed people to see these somewhat hazardous objects that were otherwise invisible to every other radar at the time.

Spicer: So would this be expressed in the form of enhancement to existing radar or as an add-on?

Mann: Either way. I mean, the chirplet transform can be in its own right, or it can exist on top of existing radar sets.

Spicer: Right. I think the word chirp comes from radar as well, does it not?

Mann: Well, chirp is the sound that's a fairly common word. People will say the sound that a bird makes is a chirp.

Spicer: Sure.

Mann: Or the sounds of bats and dolphins, or swept frequency wave packets.

Spicer: Isn't in short wave listening, or ham radio, isn't the word chirp ... ? I forget where I've come across that. Maybe those old Soviet jammers used some kind of chirping?

Mann: Well, in radio, we often sweep across frequency ranges, and so that's fairly common to have a chirp. In sound systems, to measure the spectrum of a sound system, you may have a ramp input ...

Spicer: Sweep.

Mann: Sweep across frequencies.

Spicer: Right.

Mann: So a chirping phenomenology has been around for years, but what I did is invented the first mathematical transform that uses a swept frequency wave packets as its fundamental basis.

Spicer: Right. So that was at McMaster where you did a bachelor's and a master's in engineering, I think?

Mann: Yeah.

Spicer: Right. Electrical.

Mann: Yeah.

Spicer: Right. And then you went to MIT in the Media Lab?

Mann: Yeah, then I went to MIT. When I finished my master's in electrical, "oh, do I want to work as a radar engineer, or do I want to pursue my dreams?" So I asked myself, "what is it that I really love?" I asked myself the question that I always ask my students when they want to come and work with me. I say, "What is it that you did in your childhood, before anybody told you what you should be doing?" Because everybody told me I should get a good job, you know. My parents said, "Go into engineering and management, because that's where the money is." My parents were saying, "You should be an engineer or a doctor or a lawyer, a dentist or something." Somebody who makes money, you know?

Spicer: Right.

Mann: I kind of rebelled against that and I said, "Well, what is it that I liked to do in my childhood before anybody told me what I should do, before any teachers told me what I need to do for an assignment, before any employer or prospective employer told me what I should do to make myself ready for the job market?" I said, "My true passion in life is to see phenomenology, my sequential wave imprinting machine. So I applied to only one place. I applied to only MIT because that's the place that I thought was right for my ... what I wanted to do at the Media Lab. I put in my portfolio of the sequential wave and printing machine, the SWIM, this thing here basically.

Spicer: Right.

Mann: And I said, you know, "What I want to do in life is this wearable computing and seeing and understanding the world." So I got accepted into the MIT Media Lab, and I brought all these inventions down there with me, inventions from my childhood, the true passion, the true things that I wanted to do. Not necessarily make a lot of money, but I started to realize that deep down inside, I'm an "inventrepreneur." It's a word that I made up. An inventor and entrepreneur. You see, it occurred to me, the people who just try and make money, often get by in a mediocre sense. They kind of get by. You can say, "Okay, I'm going to set out to make money," and you see musicians do this. Sometimes they say, "Well, I'm going to just try and make some money." But there's a lack of "authentegrity." I call it authentegrity, the integrity of authenticity. There's an authenticity to doing what ... to pursuing your own dreams, because I think when you do that, you become much deeper. You can't help but succeed if there's depth to what you're doing. Look at the best musicians. They're the ones who are really doing it because they love it. I think the best engineers ought to be the ones who are doing it because they're really in their passion, they're really in their zone.

Spicer: Mm-hmm.

Mann: So this is kind of what I ask my students. I've attracted some really great, super bright students, by asking these fundamental questions. I say, "What is it that you really like to do." I seem to attract these super brilliant students who are really into following their dreams. When our dreams and visions align, I say, "Well, that's great. That makes sense."

Spicer: Okay. Can you give us a year that you started at MIT, for example, and when you graduated, just to give us a framework?

Mann: Yeah. It was like 1992 to 1996 I was there. A little bit off, because I spent a little bit of time at HP Labs. I went down to MIT. I founded the MIT Wearable Computing Project there, as its first member. In the words of the Media Lab director, Nicholas Negroponte, he said, "Steve Mann founded a new discipline." He recognized early on that what I had brought to the lab there was the seeds of a new discipline, a new field of research. You see, HP Labs was really interested in that, so they brought me out to California for a little while, during my time at MIT. So HP Labs was a sponsor to the Media Lab. I worked there for a little while, and I lived in Palo Alto, you know, in the early '90s, for a short time period, working at HP Labs, kind of bringing this vision out to the west coast. Then I went back and finished my PhD at MIT. What I did was explore these new ways of seeing, new ways ... I kind of also got a little bit of a following there. I applied to the New England Spectrum Management Council for 100 kilohertz spectral allocation for this sort of community of cyborgs. When I arrived there, I put this antenna on the roof of the building of the Media Lab, originally, then I put it on the roof of the tallest building in the city, you know, [the] Green Building. Got my antenna up on the roof of that building, and had the signals beamed back by microwave downlink to the roof of the Media Lab building. I had a piece of coax running down there, some RG-58 coax running down the side of the building into a 19-inch relay rack I had full of equipment in my office. Because back in those days, there was no wireless service like there is today, you know. So I was my own service provider, of course. So I had this coverage throughout most of the city, of my own doing, but I wanted to expand that and bring in a community of cyborgs, and kind of get that idea of a small community of people wearing it, using these computers to stay connected. So I sort of started exploring a lot of these ideas there.

Spicer: Can you tell us a bit about the wearable computing as a field, as a discipline? Who the major players are, besides yourself, and a bit of maybe a capsule history of the discipline. It's maybe 20 or 25 years old?

Mann: Yeah, there's a lot of companies in this space now. Woodrow Barfield collaborated with us a little bit and wrote quite a bit about augmented reality. It's interesting that the world of wearable computing is at a certain stage now where it sort of ... I kind of thought there would be a big industry around it, because Nicholas Negroponte said, "Oh, Steve Mann founded a new discipline." So I was expecting kind of a big explosion of this material. In 1998, I made the world's first smart watch, and it was on the cover of *Linux Journal* in 2000. Then I sort of got this idea, well, a smart watch is kind of limited, because you've got to keep looking at it. I thought, well, it really should be eyeglasses that are the thing. When I was at MIT, a guy named Mark Spitzer came and started talking to me. He said, "Hey, those glasses look pretty cool. I could build something like that." Like he wanted to make something like what he'd heard about my work, I guess. So he made this eyeglass and he showed it to me. He brought it and he showed it to me and he said, "Hey, I got this eyeglass. What do you think?" I said, "Oh, that's great. I can see letters on the screen," but I said, "How is that connected to reality?" He said, "What do you mean?" He didn't understand what I was trying to do. I said, "How can this ever help people see if it doesn't have any kind of camera or sensing in it? It's just a display. It's just going to show me stock quotes while I smash into walls when I'm walking around," you know.

Spicer: Right.

Mann: I said, "The fundamental purpose of eyeglasses is to help people see." I said, "Imagine a wristwatch that could not tell time. Wouldn't that deserve the sledgehammer award?" I sort of told him, your glasses deserve the sledgehammer award.

Spicer: Uh-oh.

Mann: Because they can't help people see.

Spicer: Yeah.

Mann: And then he put a camera in there, just a little camera off to the side and I told him, "Well, you know, that camera's off to one side. I did that in 1978 and it made me throw up, you know." Because it's dizzy, it's disorienting to have your eye taken out and placed over to one side.

Spicer: Right, right.

Mann: Then his company got bought up by Google and they called it Google Glass.

Spicer: Oh my goodness.

Mann: It's funny how people say, "Oh, is that Google Glass?" I say, "Well, this is like built before Google even existed."

Spicer: Yeah, but you can see there's kind of a lineage maybe? Archeological, some DNA that's the same?

Mann: It's one piece that goes all the way around with no hinges, piece of metal frame, you know.

Spicer: Right.

Mann: So it's just kind of interesting. But the difference is that, in some sense, the Goo-Glass, as we call it, is kind of a bad copy of this. It's interesting, because when you look in my eye, you see a reflection of this camera in the mirror. It sort of looks like I have a glass eye, you know.

Spicer: Okay.

Mann: So people call this the Eye Glass, or the Glass Eye or just Glass for short. So people used to call this Glass, and it's funny, Google used the same term. They call it Glass, but theirs isn't really glass, because it doesn't give you the glass eye effect, because the eye itself is not the camera.

Spicer: Mm-hmm, right.

Mann: I think what I saw happening over and over again is, a lot of my inventions were misunderstood, or understood in kind of a shallow, superficial way. So I felt sort of disappointed that the industry ... I realized I could not just be an academic and invent these things and expect industry to do it right.

Spicer: So you started your own company.

Mann: So then I said, oh, we've got to start our own company. So I got together with my students and we started this brain computer interface company, InteraXON, started in the back of my house, in the back room there, and then expanded to the whole main floor. I've got a house in kind of a commercial mixed residential area, so it's kind of an industrial building and it works as a business.

Spicer: Oh.

Mann: It's kind of my incubator of sorts for entrepreneurial pursuits.

Spicer: Well, what's your ultimate fantasy as far as your life's work? What would you love to see happen?

Mann: I guess I'd like to see things done right. I'd like to see technologies ... I like the IEEE slogan. I really like to live by the IEEE slogan, which is "Advancing technology for humanity." I figure that's a slogan we should all embrace. And what I think is missing is the humanity. So what I've come up with is something I call humanistic intelligence, which is intelligence arising from the human being, the feedback loop and the computational process.

Spicer: Mm-hmm.

Mann: A sort of a human loop intelligence.

Spicer: Right, because aside from the technical sort of engineering part, you have a sort of philosophy behind your work.

Mann: Yeah.

Spicer: Can you share a bit about that?

Mann: Yeah. The philosophy is that really, the human should be in the loop. What I think it really comes down to is veillance. Surveillance is when machines are sensing us. What I see a lot of is that machines sense us, but they don't reveal their own internal intent. Something as simple as a television, for example. In the old days, I could click the switch on and immediately I knew it was on. Up is on, down is off. Now you've got a button that you push, and sometimes it's not even a button. You just touch it somewhere and it goes off. So I touch it, and there's a bit of a delay. So then I touch it again and maybe I've turned it off and then back on again. Everything is very slow about delaying it giving its feedback. So these systems, they're all sluggish in terms of their response. I call that sousveillance, when we can see and understand our world. So surveillance is when something sees and understands us, and sousveillance is when we see and understand.

Spicer: Now does part of sousveillance also involve what you might ... what I'm just going to call countermeasures, that is, you filming the people filming you?

Mann: I think a lot of people mistake sousveillance for counterveillance, but it's not.

Spicer: Oh, okay.

Mann: Because a person can be in favor of both sousveillance and surveillance. You can actually ... I like to think of a veillance compass. Like, let's say surveillance is in one particular direction like this, the X axis, let's say, and sousveillance is maybe like the Y axis. You can have a combination. A person in favor of both veillances might be along the diagonal. A person more in favor of sousveillance but still somewhat in favor of surveillance might be up this way. Let's say you're walking down a dark alley late at night. If you're wearing a camera, it might deter thieves. But you might also welcome additional surveillance cameras under those circumstances. There might be other times when you don't want the surveillance. So you can have people who are in favor of both veillances, people who are opposed to both veillances, people who are in favor of one but not the other. I call it Mcveillance, like when you're in favor of surveillance, but you don't allow people to have their own cameras, like a McDonald's restaurant where maybe they have surveillance cameras watching you, but they don't allow you to use a camera to translate the menu from one language to another, you know, that kind of thing. So you can have different veillances. So you think of a veillance compass maybe, like the cardinal directions on the veillance compass and you can look at it that way. But I think in order to have an effective machine learning system with human in the loop, you need both veillances. So if we're going to have a technological universe that works properly, you need to have both veillances. If you only have one of the veillances, you've broken the loop, because for example, oftentimes we're sensed. The TV has a camera in it, watching us, recognizing our hand gestures, but it's rather slow to reveal its internal state.

Spicer: Yeah. I like your idea of a spectrum, of a graph, along which people can choose their own spots because, for example, in the web, it's very ambiguous. People share information on social media that they would never share with the government or other institutions. There's a great saying. I don't know who said it, maybe you've heard of it, where basically something like, "Orwell got it wrong. What he didn't predict is that we would buy the cameras ourselves and be disappointed that no one was watching."

Mann: Yes. It's so true because you see it's a matter of choice. If you think of choice, you know, all of these things come down to a violation of personal space versus choice. Like there's a lot of things that we would do to ourselves happily, or allow others to do to us by choice, that we'd object to if they were done forcibly.

Spicer: Mm-hmm.

Mann: You know, even simple things, like you might go for a swim and be prepared to take your clothes off and have a shower and not think anything of it. But if somebody stripped you down to check for weapons or whatever, you'd be really upset and filing a lawsuit against them.

Spicer: Right.

Mann: So a lot of things that are done by choice, it's really a matter of self-determination and mastery over our own destiny.

Spicer: Right.

Mann: That's really important, I think.

Spicer: Yeah. Interestingly, a report just came out on the use of police body cams, showing that they don't appear to be changing the behavior very much, which is, I guess, a good thing. Maybe there wasn't much to record in the first place. Or they've all of a sudden gone on their best behavior, which doesn't seem statistically likely. But that's another example of bringing cameras more and more into the daily life of our citizens.

Mann: Yeah, and I think really in terms of machine learning, which is really where my focus is, we need to think about a new kind of intelligence. That is, take something simple like a television. You see, in the old days, I would plug my TV in, this TV screen, or the BNC connector. I'd connect it, and immediately, I would see if the camera was connected to it. Say I'm connecting a camera to a television, or I'm connecting my computer to a TV display. I plug it in. Within less than a sixtieth of a second, I know exactly ... even one millisecond, I can see a little flicker when I plug it in, so I know right away that I've connected it. But with something like HDMI, when you plug it in, it goes into this long negotiating process.

Spicer: Yes.

Mann: So I've got like three different HDMI connectors on my computer, and four different HDMI inputs on my TV, and I'm not sure which one to connect. So I plug the first one in, then I go to the next one. I try all 12 permutations and none of them work. Well, the thing is, I didn't wait long enough ...

Spicer: Yes.

Mann: ... when I plugged in. I plugged it in and then figured, oh, it's probably not working. I'd better unplug it and try a different one. What you have to do is plug it in, wait a really long time for it to show you that it's worked, and then try the next one and wait a really long time. Now, that's only 12 permutations, but what if you have three cables and you're not sure which one's working? That's now 36 permutations.

Spicer: Yes.

Mann: And what if the cable's a little loose and you've got to wiggle it? You see, in the old days, you would wiggle the cable and immediately see that there's a little blip there on the screen, telling you that it's the right thing to do.

Spicer: Yes.

Mann: But now you wiggle the cable, it doesn't. It waits a long time, you see. So what we're seeing is, what I would say is that feedback delayed is feedback denied.

Spicer: Well, some things just should not have a microprocessor. Cables. Cables shouldn't have a microprocessor. <laughs>

Mann: Whether it has a microprocessor or not is the means. But I'm talking about the principle.

Spicer: Yeah.

Mann: The principle is that feedback delayed is feedback denied.

Spicer: Yeah, yeah.

Mann: We should see immediately what the effect is. As a joke, I put a light switch in my office, push on, push off and I wrote above it, "digital light switch." So I had a random three to five second delay when you push it. Then I had a random 10 percent packet loss.

Spicer: That's funny.

Mann: In some versions, I had people push it, and then push it again, and it'd say, "Hey, you idiot, you turned me on and back off again."

Spicer: Yeah.

Mann: So there's this notion of veillance. These machines are watching us ever more intricately, collecting more information about us, but revealing less about themselves.

Spicer: Right.

Mann: So something like HDMI is a curse, because it's so slow to reveal information about itself. So I gave HDMI the sledgehammer award, which is with a big anvil, and gave it a smash, the connector. So there's something ... there's certain things...

Spicer: Yeah. As you know, Negroponte wrote that great book, "Being Digital," which was pretty groundbreaking, I thought.

Mann: Hmm?

Spicer: Do you know his book, "Being Digital?"

Mann: Yeah, I read it when it first came out and I wrote a response to it called "Being Undigital."

Spicer: Did you like it or not like it?

Mann: I love Negroponte's original work.

Spicer: But what it reminded me of is that everything that was analog, including simple wires, are now digital. Like the little lightning cable even has a little chip inside it.

Mann: The thing that bothered me though, about "Being Digital" is that it's not whether it's digital or analog, whether the word length is finite or infinite. In "Being Undigital" I wrote a paper called Being Undigital. HDR is kind of using digital cameras to be undigital, to recover the original continuous analog spirit of the world. It's not about whether it has finite word length. That's not the issue. The issue is really about being connected. So if you can unlock the underlying analog continuous signal of, say, HDR, get the full dynamic range, then that's really what you want, not a quantized version of it. So quantization is not, in my mind, the thing you want. In fact, the digitalness is the undesirable attribute. What we'd love to do is be undigitally connected, continuously, fluidly connected.

Spicer: We did have the old phone system.

Mann: Hmm?

Spicer: The old analog phone system, switched-circuit phone system. That was pretty awesome, probably the largest technical system ever built.

Mann: Yeah.

Spicer: All analog, simple switches and so on.

Mann: Yeah.

Spicer: Yeah. Anyway, is there anything else you'd like to chat about today? About your work or your thoughts about your work over the past few decades?

Mann: Yeah, I guess. Yeah, you know, now I'm teaching this course I call inventrepreneurship, invention and entrepreneurship. What I want to do is continue to attract really bright students and co-invent, file patents together, create companies, start things. I think the idea of inventrepreneurship, taking inventions, taking ideas ... the idea of inventrepreneurship is to take ideas from the idea stage into product development and forward. You know, being able to take things from an initial idea into a product I think makes a lot of sense. So in many ways, I want to bring these things to the world.

Spicer: That's great. It's much easier too to be a hobbyist nowadays ... well, it's easier and it's harder. On the one hand, we have surface mount, which is impossible to use for people with somewhat shaky hands, or just poor eyesight, whatever. As you get older, you know, it gets more challenging. But on the other hand, you have PCB manufacturing shops that will do three circuit boards for you for 50 bucks.

Mann: Yeah.

Spicer: Two sided and drilled and solder mask and everything. So it's kind of an exciting time to be doing what you're doing and inventing new things.

Mann: I think it's a less exciting time. It's more difficult for the individual now. For the individual hobbyist, it's more difficult, but for the connected hobbyist collective, it's much simpler. So, you know, if you have a small collective ... and this is where I think I can really serve hopefully as a role model and help people. Much of what we do is from, you know, these really bright collaborators. Like, all the people who've collaborated with me, I really reach out to, you know. People, we've co-authored papers together [with]. Much of the people I've collaborated with are really wonderful. We've co-authored papers together, done things together. This is really where I think the future is. For the individual hobbyist, it's a lot tougher now, because everything's all kind of larger in scale. But I think for the small collective, small to medium size collective, the opportunities are more than they ever were, because you can get circuit boards made so cheaply and easily. You can have things fabricated, 3D printed. So for the individual, it's harder to understand the world, but once you do understand a little bit of it, it's a lot easier to bring your vision to reality.

Spicer: What would kids, for example, these days if they want ... we don't have any old vacuum tube TV sets around anymore. So how would they learn? What advice would you give to a young person that's, say, ten or 12 and is sort of interested in electronics?

Mann: You know, I would say the same advice that I would think of before is, I think nowadays a lot of people turn to software without understanding how anything works. We say those people have gone soft, you know. They've lost touch with any fundamentals. I think that's a big mistake. I think that people should learn, try to learn as much as they can about math and physics, [the] fundamentals of things. That's what I try to teach with, is phenomenological, real reality, is to teach how things work, fundamental concepts. In my courses, I try to teach fundamentals of how things work. You can always learn software and add that layer on top of everything, but it's really important to have the foundation to understand why these things are.

Spicer: Right. So your advice is for them to stick to their basic sciences and math.

Mann: Yeah, math and physics is my answer.

Spicer: Worry about programming later.

Mann: Yeah, don't go soft.

Spicer: Spoken like a true hardware engineer. Okay, well thanks so much, Steve, we really appreciated today.

Mann: Right.

Spicer: Thank you.

END OF THE INTERVIEW

