Demetri Kofinas:	00:00:00	Today's episode of Hidden Forces is made possible by listeners like you. For more information about this week's episode or for easy access to related programming, visit our website at hiddenforces.io and subscribe to our free email list. If you want access to overtime segments, episode transcripts and show rundowns full of links and detailed information related to each and every episode, check out our premium subscription available through the Hidden Forces website or through our Patreon page. And remember, if you listen to the show on your Apple Podcast app, you can give us a review. Each review helps more people find the show and join our amazing community. With that, please enjoy this week's episode.
Demetri Kofinas:	00:00:50	What's up, everybody? I'm Demetri Kofinas and you're listening to Hidden Forces, where each week I speak with experts in the fields of technology, science, finance and culture to help you gain the tools to better navigate an increasingly complex world so that you're less surprised about tomorrow. And better able to predict what happens next.
Demetri Kofinas:	00:01:13	My guest this week is Thomas Reardon, CEO and cofounder of CTRL-Labs, a company working at the intersection of frontier disciplines including computational neuroscience, machine learning and biophysics that builds transformative neural interfaces which can easily be confused with something straight out of science fiction. You gotta see it, to believe it. Reardon's career before starting CTRL-Labs is no less impressive. A founding board member of the World Wide Web Consortium, he's famous for having created Internet Explorer at Microsoft, which at its peak, represented 96% of all web browsers in existence. Over one billion people on earth have used his software. After leaving Microsoft, Reardon decided to go back to school, receiving his undergraduate degree in Classics from Columbia, gaining fluency in Latin and Greek and followed that up with a PhD in neuroscience, split between Columbia and Duke.
Demetri Kofinas:	00:02:15	It's hard to capture the paradigm shifting nature of the innovations stemming from the work being done at CTRL-Labs without seeing it for yourself. Anything that I can say is insufficient to capture the awe of watching someone type on a screen without moving their fingers, use their intentions to pick up and finally control objects in three dimensional space or play a video game while remaining visually motionless. The implications of this technology are perhaps rivaled only by the practical genius of its implementation. By focusing their attention on translating only the final, neuronal output of our brain's commands as expressed through electrical impulses sent

directly to our muscles, the team at CTRL-Labs has managed to create a device that can capture the brain's intentions noninvasively through the use of a simple armband that you can wear like an article of clothing, a wristwatch, or a fancy bracelet. It's not an exaggeration to say that this technology turns yesterday's future into today's reality, blowing wide open the world of immersive computing and expanding our sense of possibility beyond our wildest imaginations. And with that, let's get right in to this week's episode.

Demetri Kofinas:	00:03:34	Thomas Reardon, welcome to Hidden Forces.
Thomas Reardon:	00:03:36	Thanks for having me.
Demetri Kofinas:	00:03:38	It's awesome having you on. I told you this was one of the most difficult and easiest episodes to prepare for. Difficult because this is really … What you do is at the intersection of technology, information science, neuroscience and robotics.
Thomas Reardon:	00:03:58	And beyond.
Demetri Kofinas:	00:03:59	And beyond, so there are a lot of fields that it covers and it's so new that what you're doing, the field in general, I think, the people that are doing this that are putting in the pieces together but there's not much information about it out there so, there wasn't much I could do so I didn't get too anxious about it.
Thomas Reardon:	00:04:15	I'd say we're creating the field as we go. I don't think there is a field quite yet.
Demetri Kofinas:	00:04:20	In that spirit, because I do want to get into your background also but before we do that, maybe you can give us a background of what it is that CTRL-Labs … First of all, maybe you can tell us why the name CTRL-Labs and what is CTRL-Labs?
Thomas Reardon:	00:04:32	Well, it's control and it's CTRL just like it's on your keyboard. It was really meant to be a tip of the hat to the hacker that I grew up as. The idea that we wanted to increase human control, that we'd spent decades letting machines increasingly dominate our lives, letting digital experiences dominating our lives, but we haven't gained more control over them. If anything, the last decade or so in the post-iPhone era has been a regression for humanity of less and less control.

Demetri Kofinas:	00:05:02	Now, do you mean control in terms of the server side or in terms of the client side on the user interface and user experience?
Thomas Reardon:	00:05:09	Control broadly writ from the human subjective perspective. Do I feel like I have control over these machines that are around me or do I feel like they have control over me?
Demetri Kofinas:	00:05:20	That's very interesting. It's interesting. I didn't realize that that was part of the mission. I was thinking about it much more in terms of UI and UX.
Thomas Reardon:	00:05:28	That's a piece of it but it's really much more about how we want to change the rules by which we extract information from people or more importantly, allow people to express their intentions to machines, to computers, to robots and have those things do what people want.
Demetri Kofinas:	00:05:47	That's sounds amazing. That sounds way better than we have now. We're going to circle back to that. You mentioned you were a hacker growing up. You were also, as I understand, the youngest of 10 biological siblings and one of 18 kids total?
Thomas Reardon:	00:06:00	That's right, yeah.
Demetri Kofinas:	00:06:01	Did you grow up on like a farm? Where did they fit all these people?
Thomas Reardon:	00:06:04	No. We grew up in a midsize city in New Hampshire. Believe it or not, there are cities in New Hampshire and I grew up in one of the two real cities in that state.
Demetri Kofinas:	00:06:11	Were you guys half of the state?
Thomas Reardon:	00:06:13	Just about. It felt like that. It certainly felt like that way mentally.
Demetri Kofinas:	00:06:17	That's really cool. What was that like growing up in such a huge family home?
Thomas Reardon:	00:06:22	This question comes up in so many different social context and I try to explain to people. I can't give you what it was like because it's just so different than any other family experience. So much so that I don't actually believe it happened to me.

Demetri Kofinas:	00:06:33	Do you have to go like with anthropologist and visit aboriginal tribes to get a sense of what is similar? Do you think that's closer to what your family was like?
Thomas Reardon:	00:06:41	Maybe, closer to like a collective experience.
Demetri Kofinas:	00:06:43	New Guinea.
Thomas Reardon:	00:06:44	Yeah, just most of the way you experience families in the world is through other friend's families. Your own if it's aberrant relative to the way the rest of the world works. It suddenly doesn't even feel like it's real. It was a crazy way to grow up. We were highly incented to get jobs. I'll just say that so I left home when I was 15.
Demetri Kofinas:	00:07:03	As a result of the fact that you were in such a large family or-
Thomas Reardon:	00:07:05	Yeah, pretty much. I think there's just a lot of pressure to move up and out quickly.
Demetri Kofinas:	00:07:11	Pressure that was exerted from the top down or just part of the collective of all the different siblings because I imagine, for me, thinking about it is that there will be a culture within your family that is far more difficult to direct from the top down in such a large family than there would be, let's say, in your typical two child home.
Thomas Reardon:	00:07:29	Yeah, I would say, it's more of a … Most of us in my family I think had a sense of having to get out of the house because of what we'll call resource scarcity. You got to go make your way quickly. You got to make room for the one's behind you. I think that was the attitude.
Demetri Kofinas:	00:07:45	The other questions that I would love to ask maybe in your time. I can ask you about those because it is such a fascinating thing to think about. In some sense, it seems inviable. I know everything has their pros and cons but there seems to be something really awesome about that especially as you get older that you have all these siblings.
Demetri Kofinas:	00:08:00	One practical question though is how did that experience impact who you are today? How did it shape who you are and how did it shape the type of leader you've become in business?
Thomas Reardon:	00:08:11	Boy. I had this really crazy experience, not only in my rear in the sense I'm one of 18 but the way that it happened so I was the

		baby of these 10 and when I was 11, 12 years old, we adopted eight kids that were scattered around the foster homes across-
Demetri Kofinas:	00:08:30	All at once?
Thomas Reardon:	00:08:30	Massachusetts. Yeah, all at once and they were all just younger than me and then all the way down. The oldest of them was three months younger than me and it was this crazy transition where I went from being the baby who gets to make the baby demands to be the older brother who has to tend to the flock and it was a really odd switch in my life that both made me feel like nothing is permanent.
Thomas Reardon:	00:08:54	Nothing is stable, but also, I don't know how to describe it. I don't know many people on earth who've gone through that switch in family roles that it put me in a position where I think I'm a fairly empathetic leader although I would also say, many of the people who work with me say I tend to tune them out too easily.
Demetri Kofinas:	00:09:11	Tune them out too easily.
Thomas Reardon:	00:09:13	Yeah.
Demetri Kofinas:	00:09:13	What? What does that mean?
Thomas Reardon:	00:09:14	It means I have built up filters to interruptions.
Demetri Kofinas:	00:09:19	Interesting. You know how to create solitude for yourself amidst the noise. Also, it sounds like you know how to scale pretty well.
Thomas Reardon:	00:09:26	Yes. Nice.
Demetri Kofinas:	00:09:27	You double your family size in overnight. That's pretty fascinating.
Thomas Reardon:	00:09:30	It went from one baseball team to two baseball teams.
Demetri Kofinas:	00:09:33	That's amazing. Did you guys play baseball? Did you actually play family baseball?
Thomas Reardon:	00:09:37	No, I wish we had. I don't think we ever pulled off a single game but we should've.
Demetri Kofinas:	00:09:41	That's so interesting. Okay, so that's fascinating. Another fascinating thing that I heard about you. Less remarkable than some of the other things. Remarkably enough, less remarkable.

You were taking graduate courses in mathematics at MIT when you were in high school and as I understand it, you didn't go to college initially, right?

Thomas Reardon: 00:09:58 I didn't, so I was doing … I don't know, mathematics. I did take classes at MIT when I was very young, comically young, 13, 14, in computer science, like that's where I first learned Lisp, about way back in the day.

Demetri Kofinas: 00:10:10 What year was this?

Thomas Reardon: 00:10:11 That would've been '83, '82, '83. I was quite young. I was able to do that because that's really where the hacker culture was born, was in Cambridge and in Massachusetts. Also, obviously, it happened in the West Coast, around Berkeley, et cetera. There's just this great inviting culture around hacking at MIT and I want to make clear.

Thomas Reardon: 00:10:34 When I use hack here or hacker here, I'm using it in a very reverential way. I'm not talking about that contemporary term, hackers. We think of somebody who breaks into systems. The term hacker as I grew up was a, as I say, a term of reverence and it really was about classifying somebody's skill like the most skillful programmers were hackers as I was growing up.

Demetri Kofinas: 00:10:56 Autodidacts, able to navigate creatively.

Thomas Reardon: 00:10:59 Yeah, absolutely.

Demetri Kofinas: 00:11:01 What made you decide not to go to college? That's a risky move.

Thomas Reardon: 00:11:05 That's another part of a … I did one year away that was a failure. Like I said, I left home when I was 15 and then ended up moving to North Carolina after that. Basically, I was just not socially mature enough at 15 to really-

Demetri Kofinas: 00:11:17 You were working on your own, supporting yourself at the age of 15, living away from home?

Thomas Reardon: 00:11:23 Yeah. That's crazy. What's funny about that is I actually had to forge my birth certificate to pull it off.

Demetri Kofinas: 00:11:30 You had to forge your birth certificate?

Thomas Reardon: 00:11:31 I did. I'm fortunate because the year, I was able to make a slight change in the year because the working age at the time in New

		Hampshire was if I get this history, that was 16 and I was 15, so I forged it to say I was 16 so I could get a job.
Demetri Kofinas:	00:11:42	Did you look your age? It's one year but that's a big-
Thomas Reardon:	00:11:46	I was six feet tall. I was 14 so I was able to like … I think I was baby face but I could sneak through and hide alone. Like I said, that's the thing that was sponsored out of my family which is resource scarcity so therefore, pull out whatever tricks you need to get done the thing that will get you out of the house and get you thriving so forge your birth certificate. No big deal.
Demetri Kofinas:	00:12:07	Modern day pioneer so just going off into the software wilderness.
Thomas Reardon:	00:12:11	Yeah.
Demetri Kofinas:	00:12:13	As I understand, so you didn't go to … I suppose in the context of what you're saying there. It's not that surprising or meaningful that you didn't go to college because you were not even living at home. You were already out on your own and you … As I understand, you started a company before you went to Microsoft, right?
Thomas Reardon:	00:12:29	Yeah. I started a company in North Carolina with some other folks. We ended up selling it to Ann Winblad or really, to another company but Ann was tightly involved in the deal and Ann introduced me one-off to Bill Gates afterwards though I had a miserable time after that company had bought, but Ann redirected me to Microsoft.
Demetri Kofinas:	00:12:50	You had a miserable time because you didn't know what to do?
Thomas Reardon:	00:12:52	No, because the company that acquired us didn't know what to do.
Demetri Kofinas:	00:12:55	That's frustrating.
Thomas Reardon:	00:12:56	That's quite a long time ago and I was young and like I said, like I left that after about six months and ended up at Microsoft in a two-step.
Demetri Kofinas:	00:13:07	She introduced you to Bill when?
Thomas Reardon:	00:13:09	She introduced me to Microsoft is probably the more accurate way of saying it and I would say, that was 1990.

Demetri Kofinas:	00:13:14	1990.
Thomas Reardon:	00:13:16	That's when I ended up going to Microsoft.
Demetri Kofinas:	00:13:18	We did an episode on the history of the early web which started pretty much or at least our episode started with Tim Berners-Lee and then quickly moved to Andreessen and Mosaic and Netscape and you guys came up in that godfather meeting, like this popular describe. I didn't know how accurate that is but I'm curious how and there was a memo that I had in that rundown where I had pulled that Bill Gates had sent to all the employees at Microsoft once he got the internet.
Demetri Kofinas:	00:13:50	I'm curious how you went from going to Microsoft to leading. Basically, being the first person on the Internet Explorer team. You're generally credited with creating Internet Explorer. How-
Thomas Reardon:	00:14:02	Like I said, I started the project. Of course, like in a big piece of software. It grew to be a huge number of people and another person was brought in to manage it as we went to shipping it but I did get it started and as part of that really, I took on a role as the overall architecture, internet client software at Microsoft so that was everything from the browser itself and all the languages that are embedded in the browser like CSS and HTML and XML.
Thomas Reardon:	00:14:32	As part of that, that's how I became friends with Tim Berners-Lee. I was one of the founding board members of the W3C when we got W3C started in 1994. Then, yeah, I was there from the day zero of IE all the way through to the antitrust suit.
Demetri Kofinas:	00:14:50	That must've been difficult too. We don't have to get to all that but one of the things that I do want to get into because, for me, I'm trying to get into your head and think about you as an entrepreneur and as a creator and when we're talking about CTRL-Labs. You created a piece of software. You led the team or you were part of this herculean effort to become the dominant browser on the internet.
Demetri Kofinas:	00:15:10	You guys, at some point, I believe had 96% market share, right? Over a billion people were using Internet Explorer. That's enormous scale. That's like very few people in the history of humanity have ever experienced anything like that. What was that like?
Thomas Reardon:	00:15:27	That was a thrill. It's a thrill that's hard to not want again.

Demetri Kofinas: 00:15:32 That was my next question. You read my mind.

Thomas Reardon: 00:15:35 When you're building software, you want people to use it. Why else would you be building it? I guess you can do some things for your own meditative happiness but I cared about people using the software that we wrote and I cared about making it excellent and winning by some measure. We said that we called it browser usage was the metric we were going after. It's a thrill like you just-

Demetri Kofinas: 00:15:59 Talk to me.

Thomas Reardon: 00:16:00 It's a thrill not just because of that crazy scale but like it's humbling. It's just really humbling to learn how people interpret something at scale like that when it really goes to fuse around the world when it leaves your own local culture and goes out to say, to the American culture broadly, and then it goes from that across the world.

Thomas Reardon: 00:16:17 You start to see like how you imagined it being used is not the way it's actually getting used right away. Then it mutates into some other thing. You're able to live right at the center of that. Not so much controlling it as it is that you just get to absorb so much information that it changes your thinking so rapidly. It's the most thrilling learning experience you can possibly go through.

Thomas Reardon: 00:16:41 I imagine people who've worked on like massive political campaigns like for a president or something like that have had that experience where it's hard to give up that buzz.

Demetri Kofinas: 00:16:51 I was going to use that example because that's the closest thing I can think of where let's say you're the candidate's number one guy or girl, right? You're the person that's been with him or her from the very beginning when this was literally just a dream and now, you're in the last year of a presidency that has transformed the country or whatever else.

Demetri Kofinas: 00:17:09 You said something earlier and this is what resonated with me that you had an idea of how it would work and it's not at all how it works or how people are using it. Rather, just this idea that you had a private relationship with something before anyone else knew about it and then it had just become this leviathan that the whole world had a relationship with.

Thomas Reardon: 00:17:29 One good thing about going to Microsoft when I did like I got there before Windows had happened. I make the joke that I was

		hired. This was actually the truth. I was hired to work on a project called Windows '93.
Demetri Kofinas:	00:17:39	Yeah. I didn't know that.
Thomas Reardon:	00:17:43	You're a little bit late. That was like the end of '90, beginning of '91, and the thing that happens inside of that culture is at least then, it was a really self-critical culture. There's a lot of dark parts to that but I found that self-criticism and humility like really, again, humbling. We always had this idea that like you're going to start in one place but there's always this confidence.
Thomas Reardon:	00:18:05	We're going to do a version two. We're going to do a version three like what's the dialogue we want to have with the market? How do we want to set ourselves up to learn and respond? How are we going to learn as this thing mutates, as people actually use it? Microsoft's a pretty magical place with the way it listens to developers, listens to creators.
Thomas Reardon:	00:18:23	It doesn't always get it right but it really is a really fascinating process of just culture for talking to developers and learning what to go do next.
Demetri Kofinas:	00:18:31	How so do you think that's reflected because the fact that Bill Gates has often said that if you open up his brain, inside, it would just be software because he was at his-
Thomas Reardon:	00:18:39	Bill's a developer.
Demetri Kofinas:	00:18:40	Yeah.
Thomas Reardon:	00:18:40	At heart and the very first things that Microsoft shipped were like development tools. There wasn't an operating system. It wasn't DOS. The first things were development tools. The basic language and things like that. It was just a very developer focused company and believe it or not, at one point in time, was a very hacker ethos company.
Thomas Reardon:	00:18:59	Now, that has completely transformed into something else. When I was there, we had this saying that like the software that you're working on right now is the coolest thing ever created until the day it ships and then it's the biggest piece of shit you've ever seen. If you can't digest that and live on that and thrive off of that, you have to have unbelievable confidence to do the next one and unbelievable humility to move past it.
Demetri Kofinas:	00:19:29	Wow. That's great.

Thomas Reardon:	00:19:31	Anyways. I think of that a lot when I think about what we're building today with brain machine interfaces which, my goodness, couldn't be more different but the ethos of building could be … It's pretty much the same.
Demetri Kofinas:	00:19:42	That's fascinating. That's great. You left Microsoft eventually. You started another company. We don't have to go into that but eventually, you got tired of, as I would say, crushing the internet and you decided to go back to school. This, I also found, equally fascinating. You decided to major in Classics and as I understand it, you're fluent in Latin.
Demetri Kofinas:	00:20:00	I don't know if you're fluent in Greek but you obviously would've studied Greek. How did you decide to go study Classics? Let me just tell you this. There's almost like in my mind, you scaled the heights of success in technology and software and it's almost like you went in the exact opposite direction. You wanted to see how advanced was civilization at the beginning when we had the most advanced civilizations and we had the ancient world.
Thomas Reardon:	00:20:22	You have great insight into how I was thinking. Yeah. That but yeah. I would say, that combined with the fact that I had grown sick of the web in almost every possible way. It had, in no way, lived up to Tim Berners-Lee's dream. It's founded out of CERN, a big physics research institute. It was how we were going to go create network machines to go help us think through the next, the evolution of information and knowledge and the acquisition of knowledge.
Thomas Reardon:	00:20:50	Instead, the greatest successes on the internet were sports and porn and the technology battles we were having were just not interesting scientific or computer science arguments. They were about how to increase ad revenue the fastest. Those technology problems were utterly disinteresting to me.
Demetri Kofinas:	00:21:11	As the web had scaled, you're saying because you'd already solved the major technological hurdles. Now, you were focused on the monetization, how to squeeze more out of it.
Thomas Reardon:	00:21:20	Not so much that I was or that Microsoft. It was just, that's where the world had gone and I just wasn't interested in those questions. I just needed both a break and something to really rewire my brain and I went and did the thing that I thought would be the furthest possible thing from a tech career.

Thomas Reardon: 00:21:36 That was move to New York. Register at Columbia and put my head down and study Classics which is what I did.

Demetri Kofinas: 00:21:42 Have you had any experience or familiarity with the Classics before that you made that decision?

Thomas Reardon: 00:21:49 I had this really embarrassing encounter with one of my idols, with Freeman Dyson, the legendary physicist. I had a lunch with him when I was struggling with what I should do next and I asked him about some of the things he had done in his life and he mentioned reading Classics regularly and reading Tacitus and I was really interested in that and I said, "My Latin isn't that good. I've tried to teach myself a little bit but I'd really like to read Herodotus."

Thomas Reardon: 00:22:18 He said, "That's great. You do know Herodotus was Greek?" I was like, "Shit." I should've known that. That's embarrassing but as I said like, "Okay. Next time I see Freeman Dyson, I'm going to know Latin and Greek."

Demetri Kofinas: 00:22:35 You read Herodotus in Greek?

Thomas Reardon: 00:22:37 I did.

Demetri Kofinas: 00:22:37 You read Tacitus, I'm sure.

Thomas Reardon: 00:22:39 Herodotus is hard. Tacitus in Latin, also very difficult as authors go.

Demetri Kofinas: 00:22:43 You get a real sense of dysfunction when you read Tacitus.

Thomas Reardon: 00:22:47 Just as language, he writes in this spectacularly dense Latin way like the Greeks don't write this way. The Latin authors write in this very, very compressed fashion but he's the most compressed of all. At least of all the prose writers. What you'd get it out of dysfunction is political dysfunction because Tacitus is obviously writing about Rome-

Demetri Kofinas: 00:23:07 Comical. Very funny-

Thomas Reardon: 00:23:09 Rome, and he's dry and fascinating, but you mentioned something which is absolutely true which is what you learn about what the common questions were then and now, and the common questions of political organization and family and they have a very different conception of family, relative to my family like family is much adopted as born in the Roman mind.

Thomas Reardon: 00:23:36 Those ideas were really, really comfortable to me. There's a lot to learn there. I don't know whether it is actionable other than things haven't changed much in 2,000 years.

Demetri Kofinas: 00:23:47 How did you feel, what you started in college? How did it help you, both personally and professionally? Are there ways in which studying those Classic works has advanced your ability or increased your creative capacity or anything like that?

Thomas Reardon: 00:24:03 I wouldn't say it's done any of that. I was trying to put a smile on my face and read as much as I could and read it with a lot of other brilliant people and see if I enjoyed the simple process of learning alongside other critical thinkers. I loved that process and that frankly led me to grad school and a whole other field.

Demetri Kofinas: 00:24:23 Right, so you were part of the early web and then you moved into doing Classics at Columbia. Then you decided to go take your, to do your PhD in neuroscience. I think you were split across Columbia and Duke.

Thomas Reardon: 00:24:36 That's right. That's right.

Demetri Kofinas: 00:24:37 What drove you to do that? You had your period where you were baking and like you did your four years or whatever where you just let your mind go somewhere else, then you came back and decided, what it was that you really were interested in.

Thomas Reardon: 00:24:48 Yeah. I needed that time to be able to stew and find out whether or not the problems I had worked on up to that point in my life were really the problems that I cared about or they're just the ones that allowed me to get a paycheck the fastest. I did the biggest reset I possibly could and tried to be much more deliberate about the next investments I was going to make with my life.

Thomas Reardon: 00:25:09 I started to become attracted to questions of the brain. Like a lot of people, these were more questions of the mind and consciousness and that led me to, during my times doing classics, just to volunteer to work in the lab at Columbia and expose myself to contemporary neuroscience and down at the level of single neurons.

Thomas Reardon: 00:25:26 Not the psychology of the neuroscience but the deep biophysics end of neuroscience. Once I started hanging out with those people, I started to realize like they were the kinds of people that I was fascinated with in the early '80s who were hackers. These were like very big minded people who had … They were able to bring to me that we had started to crack part of the code of the brain.

Thomas Reardon: 00:25:52 Not the code of consciousness but really about how the brain works at an almost mechanical level or an electromechanical level.

Demetri Kofinas: 00:25:59 Would you say that that was the common thread or the theme that what attracted you to the work you did in the early years of the web was that you are. You've said this a few times, a hacker, and that hacking was, for you, what was your passion, what drove you, that you found a new place where you could hack in you.

Thomas Reardon: 00:26:17 That's why I had fun doing the PhD. I did a bunch of molecular biology which was absolutely what they called genome hacking. I did a bunch of work on neurotropic viruses that was really fascinating to me and not commercially viable but fascinating work. It was all in that hacker spirit and I think the best young scientist have that spirit. You can be very formal and over-proceduralized in science and God knows.

Thomas Reardon: 00:26:43 I say the vast number of PhDs frankly are the transferal of bones from one grave to another. The best are creative hackers who rewrite the rules of … Yeah, the rules that they received. I don't want to say that there was this clear arc to go into neuroscience but what's more interesting. I think what really happened is that by studying Classics, I gave myself the confidence that the academy wasn't locked away from me because I had skipped college when I was younger.

Thomas Reardon: 00:27:14 That, boy, once I was in the academy, I was like, "Okay. What's the most interesting problem happening in this entire place?" I do mean the neuroscience and now, I had that confidence. Both piece, my Microsoft arc and then having actually studied something more seriously undergraduate that I could actually go and do something productive there.

Thomas Reardon: 00:27:32 A lot of that is just having that confidence that where you came from is not a limitation but where you're going is the only limitation.

Demetri Kofinas: 00:27:40 Right. It's also interesting that you broke out of that box. A lot of people, they get stuck in one domain and they try to innovate within that area but I find that the greatest innovations come from as much interdisciplinary context as possible.

Thomas Reardon:	00:27:54	Good lord, is that true in neuroscience. I want to emphasize. Neuroscience, as we know, like it was barely a term 20 years ago. It's not this well-understood cohesive field with like a monolithic text that you're just going to read like neuroscience is the ultimate interdisciplinary science. It just requires like end-to-end-
Demetri Kofinas:	00:28:13	Why is that?
Thomas Reardon:	00:28:13	Because we're trying to understand the complex behavioral output of you, this 15 billion neuron computer, all the way from the scale of individual synapses up to speech. Like we're scaling across so many different phenomenological levels. It just requires, basically, all of science as we've known it to date. The amount of people like statistical mechanics is a hugely important thing from physics that now comes in models that are used in solid-state physics.
Thomas Reardon:	00:28:49	Are used to model neural behavior today, like the borrowings into neuroscience come from chemistry and biochemistry and physics and particle physics and computer science and psychology and cognitive psychology and sociology. It just comes from so many different places. It comes from applied math. It comes from some crazy places in pure math.
Thomas Reardon:	00:29:10	There's just so much because ultimately, we're trying to figure out how thought happens.
Demetri Kofinas:	00:29:17	What's at stake is more important. Perhaps also, your focus is going from outside of yourself. Building these machines. You're building these computers or software to inside, to saying, "How do I work? How does this brain that I have work? How does this all come together?" I'm sure that that's intrinsically fascinating. I'm going to pull … This is a hodgepodge that I put together of a description of CTRL-Labs from various different parts, from your website, other areas.
Demetri Kofinas:	00:29:44	Then I want to ask you something about it and that'll be, I think, a good way for us to get into this. CTRL-Labs is a startup that develops devices capable of translating electrical muscle impulses into digital signals. The company dedicates itself to answering the big questions in computing neuroscience and design so creators can dream.
Demetri Kofinas:	00:30:05	The teams work to build a transformative brain machine interface, spans research and challenges at the intersection of computational neuroscience, statistics, machine learning,

biophysics, hardware and human computer interaction so there at the end, what you were just saying, but my question for you and then we can see where this goes, that stuck out for me was answering the biggest questions. What are the biggest questions that you and CTRL-Labs are trying to answer?

Thomas Reardon: 00:30:33 How much control you're capable of? How much output you're capable of?

Demetri Kofinas: 00:30:37 Explain. What does that mean?

Thomas Reardon: 00:30:39 Here's the thing and this is really born out of my PhD and the learning I did in that that was seven plus years in my life. Human input is incredibly rich. Your ability to absorb information is unbound whether it's visually, auditorily, via touch and per perception-

Demetri Kofinas: 00:31:00 You're including also scientific instruments that you can use to obtain further information?

Thomas Reardon: 00:31:04 No. I'm just talking about your natural-

Demetri Kofinas: 00:31:06 Sensory-

Thomas Reardon: 00:31:06 To take in … Yeah. To take in information is extraordinary. You can process a crazy amount of information in parallel, all towards a goal of a final behavior. Ultimately, a movement. What's crazy is when you actually go to move, when you actually want to output from a human, you have to do it via your muscles. Your muscles transduce the electrochemical output of the brain into forces and movements.

Thomas Reardon: 00:31:36 That is an incredibly slow process and is low bandwidth, high latency and error-prone. Our brain is a remarkable evolutionary, I'll call it invention. Our muscles, I think, I'm broadly speaking, less impressed by. We're working on that problem to make the output from you match the input to you. We want to extract as much information out of your nervous system as possible, such that you can have the control over things in your life that mirrors how well you perceive all the things in your life.

Thomas Reardon: 00:32:14 Today, you mostly express control with your hands. You do that, I'm watching you with a pen as you write notes on that piece of paper. I'm just going to say, "That is a comically low bandwidth output." Comically low bandwidth, using a pretty old technology there. Your ability to read in all the information, read that thing in front of you. Watch me be aware of them around you-

Demetri Kofinas:	00:32:35	It took a lot of practice.
Thomas Reardon:	00:32:36	Complain about the temperature in the room, all this stuff. It's because you're always integrating all this information simultaneously, but your ability to do something is incredibly limited. There's no reason why five fingers is the natural output of your brain. It's just an evolutionary … I'll call it a stump. What is exciting to us is this idea of giving you 30 fingers on a hand or the ability to rotate your hand 360 degrees.
Thomas Reardon:	00:33:03	Like there's no reason to be limited by what your body can do. Your ability to actually do things.
Demetri Kofinas:	00:33:08	That just freaked me out, what you just said. I'm sorry. I'm just thinking of my wrist turning inside towards my arm.
Thomas Reardon:	00:33:14	I don't want your hand to do it, but I want your virtual hand to do it. Your robotic extension to do it.
Demetri Kofinas:	00:33:19	There's a phantom loop, so this is, to me … We're now getting to the part. Like I said, there's not much information there so I had to do a lot of just imagining on my own but this is where, what I find most exciting and also most interesting and fascinating how you've done it. Your decision so this is probably … I'm not sure where we'll go here.
Demetri Kofinas:	00:33:39	There's an interesting point about in your plasticity, I'd like to go to, but there's also an important distinction between two particular modalities. I know you call them electroencephalography and electromyography. You've decided to use EMG which is electromyography as opposed to EEG. I found your explanations about this fascinating.
Demetri Kofinas:	00:33:59	I found the practical nature of the decision to do that and its implications to be probably the most interesting thing that I read about. What was your original vision when you decided to create what is traditionally called a brain-machine interface or a brain-computer interface? I know you don't like those terms.
Thomas Reardon:	00:34:18	Yeah, we prefer the term neural interface because brain-machine interface has too much of a connotation of cortex and what's up there on the top of your skull. Of course, your brain is a giant organ that starts at the top of your skull and cortex. Goes all the way through the old brain, if you will, and then down into the spinal cord. Your spinal cord is still part of the brain, although it-

Demetri Kofinas:	00:34:40	The old brain is the base of the brain?
Thomas Reardon:	00:34:42	Sure. We'll call it there or you can have things from the mesencephalon up. We call it … The telencephalon is the very top of the brain that are the evolutionary new structures like cortex. Then as you go down from cortex, you go into evolutionary older things and arguably, the spinal cord is the oldest of all. The spinal cord is the output port of the brain. This is where your brain actually sort of does its final act. Your question is, why did we go in this path of EMG?
Thomas Reardon:	00:35:12	It came down to something where we said a couple of first principles, one, boy, it was sort of odd to us that there wasn't really much happening in the world, or had happened to commercialize all of the great discoveries of neuroscience. I make the comparison to sort of Genentech in 1975 where they sat at the end of 30 years of pure bench science that had been investigating DNA and RNA, and the structure of proteins, and how proteins are created. All of these molecular biology, the restriction enzymes, et cetera, but nobody have sort of put it altogether and said, "Okay, we can now start to create novel forms of life.
Thomas Reardon:	00:35:51	Like we're going to create a company that does genomic engineering and creates, synthesizes new protein," and that's the birth of biotech. They basically took 30 years of bench science that have been totally unexploited and rolled it all up into one company. I thought there was a similar opportunity for us to do something that epic, that there are decades of neuroscience that are sort of unexploited, a lot of experimental tools, a lot of experimental results that we could go and do.
Thomas Reardon:	00:36:19	Now, the second part of that would be, how could you do it in a way that would matter to eight billion people? Because from my perspective, one of the problems with academic neuroscience right now is not the practitioners. They are some of my favorite people in the world. It's the practice itself which is really focused on pathologies. If you go into a typical academic neuroscience lab, they are funded because they're working on Parkinson's or they're working on ALS, or they're working on schizophrenia.
Thomas Reardon:	00:36:46	What you don't hear people say is like, "I'm working on human happiness. I'm working on empowering people. I'm working on giving people new extraordinary abilities." I want to be on the other side of that. I didn't want to create technology that was for 100,000 people or million people. I wanted to create technology that was for eight billion people-

Demetri Kofinas:	00:37:06	Right. It goes back to-
Thomas Reardon:	00:37:06	… and that really reaches back to my Internet Explorer-
Demetri Kofinas:	00:37:08	… Internet Explorer.
Thomas Reardon:	00:37:09	… experience. I really said, "I want to turn this on its head and make a run at creating a technology for eight billion people." Now, in the neural interface world, you have to make a decision right away. Are you going to be invasive or noninvasive? What that means is are you going to require surgery or not? We said, "Of course we're not going to require surgery." What technologies are available to us to go get signals from the brain, from the nervous system that don't require surgery?
Thomas Reardon:	00:37:36	One of them is EEG. There are others. We are broadly speaking skeptics of EEG as a-
Demetri Kofinas:	00:37:43	Explain EEG just sort of superficially for those listening.
Thomas Reardon:	00:37:47	EEG is a technique for reading out what they'll call brainwaves. I'll tell you sort of in by an analogy. Imagine you had a microphone and you are standing outside of giant stadium during the football game and you held it up, and you could basically tell whether or not a touchdown had been scored. You might be able to tell which team scored. Beyond that, you have no idea.
Demetri Kofinas:	00:38:09	Signal to noise ratio is extraordinarily low.
Thomas Reardon:	00:38:12	Yeah. You have to go through the skull and scan, and more importantly, all the muscles themselves around the head are generating electrical fields. You're just getting basically kind of a global state of the brain and it turns out that things like surprise or fear writ large, are giant signals in the brain, so you can kind of detect those. I wouldn't want to drive my car with EEG. I don't want to do anything more subtle than say like I'm in a panic but that's about what EEG is good for. It tells you global-
Demetri Kofinas:	00:38:39	No one knows where-
Thomas Reardon:	00:38:40	… brain state.
Demetri Kofinas:	00:38:41	No one knows the pattern or the signal for type the letter P on a keyboard.

Thomas Reardon:	00:38:46	Yeah. I say we're working on the problem of a microphone that in some sense, sits kind of right up against the stadium, but I can tell what somebody in section 34, row 12, seat five, is saying to the person right next to them-
Demetri Kofinas:	00:39:03	Right.
Thomas Reardon:	00:39:03	… directly. That was our big bet. We couldn't do it when we started the company. It took us two years to be able to do that but the idea is noninvasively to be able to listen to single neurons inside the body. That was the great, big proposition. Can you hear, virtually speaking, a single neuron without putting a probe into the brain? It took us several years to pull it off and we can do that now, and that is the kind of core breakthrough that we've bet on. We've pulled off and that's what we're building on now.
Demetri Kofinas:	00:39:38	Between the mapping part of this and the hardware part or the being able to actually extract the messages noninvasively, was there one challenge that was more difficult than the other or do they kind of go together? Is it-
Thomas Reardon:	00:39:51	I would say this. The getting the signal out is a hard problem. The signal that we get allows us to see thousands to tens of thousands of neurons, and we need to disambiguate all between them. We have to be able to tell which one is which from kind of a mathematical perspective. We can separate them out into their constituent signals. All the neurons together, all shouting together, create a big, huge electrical pulse, but we can break that down into each of the little component neurons.
Thomas Reardon:	00:40:19	The harder problem for us actually was, and remains, and will always be the machine learning side of this. Most of the company, we are 65 people now. Most of the company work in what I'll call modeling and machine learning, what in the field we call it computational neuroscience. We build this spectacularly subtle, complicated models that allow you, as a person, to quickly focus down on just a few neurons that are effectively talking to this machine learning algorithm to translate the activity of those neurons into action somewhere.
Thomas Reardon:	00:40:57	Like I want to be able to pick up that pen that you're holding in your hand and write down some letters with it, and I want to be able to do that, I'm not even going to move to do that, and this is something we can do today. Basically, typing without moving by generating little pulses of electrical activity through the nerve that don't provoke movement.

Demetri Kofinas:	00:41:16	Okay. Invariably, I'm getting lost here, but hopefully I thought that once I start getting lost, well, we'll need to get back on the trail because I don't want to lose the audience. How does that relate to the two regimes of control that you have? Is that neuro control what you're describing?
Thomas Reardon:	00:41:32	That's what we call neuro controls-
Demetri Kofinas:	00:41:34	Myo control is kind of right out of the box?
Thomas Reardon:	00:41:35	Yeah, we didn't introduce those terms earlier. We talked about two kinds of control, myo control and neuro control. Myo control is basically just us working at the level of what we call gross EMG or basically muscle activity. Imagine anything you do today by moving, swiping on a screen, typing on a keyboard, using a mouse. These are all movement-based and myo control is our ability to read out the electrical input to the muscle, the synaptic activity onto the muscle from neurons, and recreate the movements what would have been there.
Thomas Reardon:	00:42:08	Once I know those movements, I can redo kind of virtually whatever you would have been doing. For instance, I can have you type without the keyboard actually being there. We call all of that myo control. That's not properly what a neural interface technology. It's more of a-
Demetri Kofinas:	00:42:23	Mimic.
Thomas Reardon:	00:42:23	… muscle interface technology and we broadly call that biomimeticism or biomimetic action. Things that require you to move or do things as if they were your regular natural task, like writing.
Demetri Kofinas:	00:42:36	I'm curious about something, so the other thing is this is I was thinking about when I was reading this stuff and looking at some of these videos. You have to see this stuff, A, B, I had reached out, this is a last minute thing, but I would love to come by your lab at some point and test these out, because I feel like the next level is actually testing it.
Thomas Reardon:	00:42:54	Yeah.
Demetri Kofinas:	00:42:54	I've seen for example you or other people typing on a table-
Thomas Reardon:	00:42:58	Yeah.

Demetri Kofinas:	00:42:58	… just with your fingers and that translate directly to the screen. It wasn't any cameras. That was literally the electrical impulses that were being read, that were being translated into code on a screen.
Thomas Reardon:	00:43:09	Yeah.
Demetri Kofinas:	00:43:10	Is that where you've mapped specifically like this movement for like the letter Q or whatever? You've mapped that particular movement or is it to a level of sophistication where the software can actually read the nuance of the movement, so if you're slightly off it's not … I mean, what's-
Thomas Reardon:	00:43:24	That's what makes it so great. I tried to talk about this. Now, imagine you have a keyboard and you're always adjusting. If you go up to a new keyboard you've never done before, you adjust where you type so your hands fit the keys properly. Imagine instead of you adjusting with the keyboard, imagine if you are the keyboard and maybe you start by typing like it was a regular QWERTY keyboard, and instead, let's say you're like, "I keep screwing up the P key."
Thomas Reardon:	00:43:55	One of two things can happen here. Either you, the human, can learn how to hit that awkward P key. I happen to have a weak right pinky and that's hard for me to hit a P key accurately. If you don't learn it, then the machine has to learn it. Now, if it's just a dumb keyboard, it's not going to learn, but a machine can learn if we teach it to learn and that's exactly what we've done.
Demetri Kofinas:	00:44:16	That's the neuro control? That's separate-
Thomas Reardon:	00:44:17	This is part of myo control and the neuro control. It's just we use those terms to talk about the signal level that we're talking at. This is at the level of muscles. Neuro control is at the level of individual neurons but they both involve this what we call coadaptation, the ability for a machine to learn and give you feedback, and have you collapse down. You sort of approach each other on agreement about what's right and what's wrong.
Thomas Reardon:	00:44:39	Now, you're typing and you know what? Forget it. Like you just said, if I'm just doing a very subtle movement with that rate pinky, that's fine for a P.
Demetri Kofinas:	00:44:50	How does the machine know that that's a P?
Thomas Reardon:	00:44:52	We train it pretty rapidly.

Demetri Kofinas:	00:44:54	You're training. This is something where you sit and you would train?
Thomas Reardon:	00:44:57	When I say train, I am talking about things that take less than 60 seconds. It's not days of training. It's not like the first time you learn to type like between months.
Demetri Kofinas:	00:45:04	This is kind of like sitting in a car seat and adjusting the seat?
Thomas Reardon:	00:45:08	I would say that but I would say it's more like if you are adjusting the seat but not like because you put your hand down there and moved the seat, and said, "I like it right here." It's more like-
Demetri Kofinas:	00:45:16	Perfect.
Thomas Reardon:	00:45:16	… every single time you got into a car, it's like, "Oh, I know you. I'm going to adjust here. By the way, the environment you are in is slightly different, so I'm going to move you over a little bit." Just by watching the way your body suddenly shifts, it changes the seat automatically.
Demetri Kofinas:	00:45:30	Fascinating.
Thomas Reardon:	00:45:31	You don't have to explicitly move that P key to make it more approachable to you. We just nudge it along in that direction.
Demetri Kofinas:	00:45:41	Holy shit.
Thomas Reardon:	00:45:42	That's kind of the coolest part of this. We call it coadaptation. We're not the inventors of that idea but we are the biggest exploitative of it.
Demetri Kofinas:	00:45:48	Just to kind of put a little small summary on that point, your vision in this particular example that you're giving is that you'd throw in a keyboard, right now, we're all using one thing. We're all going to a keyboard. We're using a keyboard. The keyboard, we structure ourselves to this device.
Thomas Reardon:	00:46:05	Absolutely.
Demetri Kofinas:	00:46:05	You're basically inverting that. You're saying, we all get our own keyboard and adjust to us.
Thomas Reardon:	00:46:11	Correct.
Demetri Kofinas:	00:46:12	That's fascinating.

Thomas Reardon:	00:46:13	Not just is it sort of adjusted to you, it is the most personalized technology in history, and I am not overstating that. You cannot be more personalized than this. This is personalized to your nervous system.
Demetri Kofinas:	00:46:27	All right, so I don't know exactly now where to go in this conversation, so I want you to continue. All right. You're talking about the keyboard, walk me through … Like I said, this distinction of the myo control and neuro control stuck out to me but I didn't fully understand it. A lot of really fascinating things seemed to be what is myo control. I don't know how you want to approach this conversation but I'd love to hear more about this sort of innovative stuff you're doing here and how you're doing it.
Thomas Reardon:	00:46:53	We're neuroscientists and the great question of neuroscience is, how do neurons ultimately do their work and lead to behavior? Everything from as I said earlier, speech to twiddling my fingers, to tapping on a table, to eating, to whatever, all of that is done by neurons. Neuroscientists ask the question, how did information get into the brain, i.e. how did you sense it? What happens to the information to the brain and then how do you output it? Turn muscles on and off.
Thomas Reardon:	00:47:23	Neurons are at the heart of that and we spend our entire lives as neuroscientists trying to figure out what happens in between that input and that output. We want to do that at the level of a single neuron. That's ultimately the goal or now we collect them together. No one single neuron does everything for you but they altogether collectively regulate your behavior. We have these very complicated models that talk about different parts of behavior and how some collection, we call them ensemble of neurons, accomplishes that.
Thomas Reardon:	00:47:54	Neuro control is where we meet that level of neuroscience. Think of myo control more as sort of control theory and human computer interaction work, and kind of changing the games but we're not talking about physical devices. We're talking about always morphing devices, these virtualized devices. Neuro control is the same goal but at the level where we're using signals from individual neurons, what's important about that is that you don't have to move in anything like the way you move today.
Thomas Reardon:	00:48:25	In a lot of our demos, you don't have to move at all because you're actually generating an electrical pulse, an action potential, down a motor axon. It terminates on the muscle. It's a single neuron and the activity of a single neuron is unlikely to

		provoke actual muscle action, the contraction of the muscle. It takes a lot of neurons firing a lot of signals for the muscle to actually contract. When you're down in that regime where you're not really moving at all, you can still control things like you call it using the force.
Thomas Reardon:	00:48:57	It's a little bit a joke in our part but we really mean it. That's what it feels like. We have some games that we have people play and really you will sit there and play the game-
Demetri Kofinas:	00:49:04	I've seen one of them, Asteroid, what is it, Asteroid Hunter?
Thomas Reardon:	00:49:07	We've done Asteroids. We've done some like goofy, our preference has been '80s arcade games actually.
Demetri Kofinas:	00:49:13	Well, I've seen one demo where you have the person has his hand. I don't know if that was you or I think it was your cofounder maybe in that one.
Thomas Reardon:	00:49:18	Yeah.
Demetri Kofinas:	00:49:19	He has his hand right next to the smartphone on which the game is being played and he is controlling the spaceship.
Thomas Reardon:	00:49:26	Yeah, and that's a high degree of complexity-
Demetri Kofinas:	00:49:28	Not moving his hand at all.
Thomas Reardon:	00:49:29	That's two and a half degrees of freedom in that game. Those are the technical control games.
Demetri Kofinas:	00:49:32	During that time, neurons are firing-
Thomas Reardon:	00:49:35	Absolutely.
Demetri Kofinas:	00:49:35	… from the spine.
Thomas Reardon:	00:49:36	Yeah. Sometimes that results in some of his muscles twitching. Sometimes they don't but we don't care about the movements. All we care about is the neuro signals.
Demetri Kofinas:	00:49:43	That seems like … Help me understand how I would know what-
Thomas Reardon:	00:49:49	Yeah. You don't know right away because you've spent your whole life learning how to be you and how to use your hand. I want to emphasize this. You're a human being. You have the most extraordinary motor skill of any life form, extraordinary.

You think a cat doing its little flip when it gets dropped is extraordinary? It's nothing compared to what you can do with your hands. The fact that I can close my eyes and touch my fingers together with my eyes closed, all based on per receptive information only, the way that I take a sip of water from this bottle and compensate for all that complicated motions of the liquid, something a robot can't do-

Demetri Kofinas: 00:50:27 And do that without even thinking.

Thomas Reardon: 00:50:28 Without even thinking.

Demetri Kofinas: 00:50:29 Right.

Thomas Reardon: 00:50:29 I just do it. Like this is what we're evolved to do. We have extraordinary motor output capacity. The job of control labs is to take that unbelievable learned capacity that you have and apply it to the way you interact with machines, the way that you interact in life effortlessly. That's what we wanted to be like to work with a computer. I want to get to this thing about when I said it's about learning. When you were born, you didn't have this ability. You spend the first year of your life just waving your limbs in the air, what we call motor babbling.

Thomas Reardon: 00:51:00 As you try to find out how your body worked, it turns out you were probably doing the most important learning you'll ever do in that first year. All you were trying to do is figure out very actively how to move your hands and limbs. We give you feedback at control labs to let you in some sense go through that process all over again, what's it like to be a baby, and do those kinds of exploration. Basically, we give you feedback and it takes for the kind of game you saw for Asteroids, it takes about five to eight minutes of training to figure out how to control it without moving.

Thomas Reardon: 00:51:36 That's because what's really happening is we're not just trying to take a signal form you and make the machine do something. We're trying to get you and the machine to negotiate. For instance in that game, there's left and right, not just left and right buttons, but how much left, how much right? There's go forward, go reverse.

Demetri Kofinas: 00:51:56 Man.

Thomas Reardon: 00:51:56 How much forward, how reverse? We're trying to get you and the machine to rapidly agree on what makes the spaceship go forward, what makes it go back? What makes it go left? What makes it go right? How to go fire missiles from the virtual space machine? That is coadaptation and that's kind of one of the most important, if not the most important thing, we're working on.

Demetri Kofinas: 00:52:19 Well, you talk of there's nothing, another thing that you bring up in your sort of what I read, a distinction between adaptability and plasticity-

Thomas Reardon: 00:52:27 Sure.

Demetri Kofinas: 00:52:28 … which I found super interesting. You're saying that all of this is happening on the level of adaptability-

Thomas Reardon: 00:52:33 Absolutely not but-

Demetri Kofinas: 00:52:34 This does not require any change in your brain?

Thomas Reardon: 00:52:37 No. You have this capacity today. Now, I'll say, as you do increasingly complex things, it probably does require plasticity but in the same way that like learning to play the violin requires plasticity.

Demetri Kofinas: 00:52:47 Right.

Thomas Reardon: 00:52:47 When you learn to play the violin, you're taking in a bunch of information about how much pressure to apply through which fingers, on which strings, and how to coordinate the rhythm across the bow. We're trying to … How you go through that experience now with a machine that's much more abstract but faster.

Demetri Kofinas: 00:53:03 Is the distinction between plasticity and adaptability in this example about skill level and also about remembering how to do an action?

Thomas Reardon: 00:53:12 No. I'd say at a neuroscience level, when plasticity generally implies something structural in the brain, so something happened at a synaptic level that changed the connection between two neurons. When we say learning and plasticity, we mean it in that context. There is a bunch of other adaptation that can occur without a structural change in the brain. In other words, think of it this way. You've learned, as I said, when you pick up that bottle of water and you take a sip, you don't have a program that has been prewritten to pick up that bottle of water and bring it, and take a sip from it.

Thomas Reardon: 00:53:45 Because that bottle of water is different every sip you take, you have to constantly adapt and change your hand shape, the amount of load that you have to compensate for in the bottle, et cetera. You can't make new synapses to do that on the fly. You've sort of have a menu of these commands that are embedded in your brain that you can quickly swap in and out adaptively, and that's what we mean by adaptation, using a bunch of the capacity that's already learned in your brain for a wide variety of tasks.

Thomas Reardon: 00:54:16 Plasticity is something that we don't really work on or depend on, which is the structural change on the brain that allows you to learn and consolidate the learning of something you've never done before. It turns out most of the motor things we're talking about are things you have done before.

Demetri Kofinas: 00:54:32 Let's say I wanted to learn how to type without a keyboard and without actually typing-

Thomas Reardon: 00:54:36 Well, that's the easiest one in the world because I did that and it took me zero minutes.

Demetri Kofinas: 00:54:40 Well, not the example I gave before, I mean, without actually using your fingers to type. Is that what you're talking about?

Thomas Reardon: 00:54:47 What ends up happening, that's why I love the technology slope that we got on, we didn't plan for this. It's just been an unbelievably positive outcome for us, is people start by doing what they do naturally. The way I learned it was I just let the machine watch me type, and then I just took my hands off the keyboard and continued to type, and the letters just kept coming because it was like, "That looks like what you were talking before."

Thomas Reardon: 00:55:11 It basically mapped the movement on my fingers to what I had done on the keyboard. Then, what I noticed was I didn't have to move as much to get the same keys. In other words, I didn't have to reach all the way up for the P. I could just reach a little bit less and less, and what ends up happening is-

Demetri Kofinas: 00:55:28 Just the intention?

Thomas Reardon: 00:55:30 Yes. You relax and you move significantly less all the way to the level of effectively not moving. I want to be careful there because somebody who is measuring EMG would … what is movement? Is there a muscle contraction or not? It's sort of irrelevant. Your subjective experience is you are not moving no more than you are moving when you breathe.

Demetri Kofinas: 00:55:50 You learn how to type with physical feedback, right? That's how you learned originally how to type?

Thomas Reardon: 00:55:55 Yeah.

Demetri Kofinas: 00:55:55 How important was the physical feedback and being able to do that? The question is, once you learn this other way of typing that's overwriting the previous sort of function, how does that effect … Does that deteriorate your skills that were associated with traditionally typing? Do you have to be careful on it versus of larger way of asking, do you have to be careful and choosy with what you map to what behavior and that's something you'd-

Thomas Reardon: 00:56:17 We're not far enough along now to answer that question. it's an awesome question.

Demetri Kofinas: 00:56:21 You're still just hacking?

Thomas Reardon: 00:56:22 We are still just hacking. It's an awesome question you're asking, and it really gets to the question of like … In some sense, your question implies that even just asking the question implies like that you think there's a limit that the nervous system is at its peak when it's typing. An argument is that can't possibly be true. If anything, it's a kind of stereotypy of movement, stereotypy, I guess that's word, that way underuses the amount of skill you have in your hands, and that the amount of skill you have in your hands is five orders of magnitude more than typing can capture.

Thomas Reardon: 00:56:58 Therefore, the idea that doing this more subtle version of typing without moving would erode the really simplistic thing that you learned before. You may think it's complex but relative to what your hands can do, it's nothing. Now, that's our first principle's response. We have no data to back that up right now and whether or not there are skill erosion in the natural tasks.

Demetri Kofinas: 00:57:18 When I'm dreaming and I'm like flying around or doing something totally off the wall that I probably can't even remember-

Thomas Reardon: 00:57:25 Yeah.

Demetri Kofinas:	00:57:26	… there's a very few dreams I can remember like that, but I think most of us can remember some dreams where we're doing something that's physically impossible. Is that basically saying, "Look, the only reason that I can't do that is because I'm constrained by my physiology not by my imaginative capacity in my brain and by the … " Well, in this case, there's also the neurons and the spine that have an impact here. I mean, how much more potential, you're talking about we're output-constrained, we're not input-constrained, 10X, 100X?
Demetri Kofinas:	00:57:55	How much more … I mean, obviously you don't have an answer. You don't know exactly but is there some general idea you can give me for just how much more potential we have to act on our environment?
Thomas Reardon:	00:58:04	Well, at least using the way they were doing it right now, which is an individual neurons, I would say there are 14 muscles in the arm that control the hand. The hand itself is kind of dumb but the forearm is what actually controls the hand. Those 14 muscles again have more nerve dedicated to any part of the body, by far the most nerve. We have a picture here this, this thing called the motor homunculus. That shows you how much nerve is dedicated there. Even for that, there's only about, we're estimating on the low end, probably 15,000 neurons that collectively control the hand.
Thomas Reardon:	00:58:39	That's assuming a thousand neurons per muscle or so. That's coming down from a brain of 15 billion neurons. Well, you can think of this as sort of your brain collapses down from a crazy place of complexity down to really relatively low complexity, still 15,000, but low complexity, and those 15,000 in turn drive 14 muscles to move your hand. There's this crazy collapsing down of complexity on the output side.
Demetri Kofinas:	00:59:04	Right.
Thomas Reardon:	00:59:04	That's not true on the input side. If we say 15,000, I'd say, "Well, that seems to be the limit." Today, you've got 14 muscles you seem to be able to control not quite individually but close enough, I'll say, that avoiding questions of just what we call synergists, but extensor and flexor activity across those 14 muscles. Potentially, you go from 14,000 to 15,000. That's quite a big expansion. More intriguing for us is being able to do that without stopping movements, like the cases that we care the most about are what it would be like to be moving and doing this, and like looking at my watch.

Thomas Reardon:	00:59:41	Also typing on it without moving. In other words, using neurons that aren't necessarily required for movement to do all of this other form of control, but then allowing them to help you move as well whenever you need them too. That's a really kind of obstruct concept but that's ultimately what we're trying to get you to learn how to do, is to use neurons in ways that you've never used them to move before.
Demetri Kofinas:	01:00:03	You guys have already released your SDK, right?
Thomas Reardon:	01:00:05	We are sampling right now.
Demetri Kofinas:	01:00:07	January, was that when you started sampling? I mean, it's very recent event.
Thomas Reardon:	01:00:11	We were sampling a little bit last fall but we were just really sampling right now.
Demetri Kofinas:	01:00:15	Where you at right now and also what are some of the most immediate used cases that you think can be applied or will be applied in this technology?
Thomas Reardon:	01:00:23	This technology is for everything in the end, but that's a terrible business plan. You got to start somewhere and it has to be incredibly focused and have high utility. I mean, you have to solve a problem. I think we're solving this problem of human sadness in a digital world. Again, that's a great vision statement. It doesn't get you the first couple of checks. Our first-
Demetri Kofinas:	01:00:45	That's your first line in your slide deck.
Thomas Reardon:	01:00:49	The first thing we talk about is opportunities in immersive computing, so this is VR and AR, where all this work was done to create new ways of getting information into you so that you feel like you're in a virtual environment, or that the virtual environment is all around you in the augmented reality case, but nothing was done to make it easier for you to interact. The first Oculus Rift shipped with an Xbox controller, I mean, that makes no sense. That's completely absurd.
Thomas Reardon:	01:01:18	I know the people in that field, the best thinkers in that field agree with me, and they think like, "We need to do much deeper things to have rich interactions between people and these immersive computing spaces." We feel like we saw the fundamental problem that's so fundamental in VR and AR that it can ungate those markets today. Those are not usually

exploding markets. A lot of people have a lot of belief in them but they're not happening right now.

Thomas Reardon: 01:01:42 Virtual reality is not a real deep market right now. We think we solved the big unstated problem about virtual reality, which is, how does a person actually do something?

Demetri Kofinas: 01:01:53 Long term, does this kill enhanced voice? Because one of the big-

Thomas Reardon: 01:01:56 Voice is a terrible controlled technology. Of course voice is there. Voice is the most exquisite thing for human to human interaction. I don't want to drive a car with my voice. I don't want to fly a jet with my voice. I use my voice for kind of low bandwidth just in time, ad hoc, queries and interactions, it's a great way to ask Alexa the weather. It's a great way to dictate an address into Google Maps. It is a terrible way to do control but your day is saturated by control problems not by, how do I get out phrase into Google Search to be able to get something back?

Thomas Reardon: 01:02:37 I feel like voice, we've comically overhyped the utility of voice as a means of machine interactions. It has a role but it has nothing like the role that real control, continuous control into speak control that we offer we'll have in the future.

Demetri Kofinas: 01:02:54 Reardon, I want to get more into your product, into some of these used cases, like VR especially, and I also want to talk to you a bit more about your team and sort of how you hire. I think you mentioned this conversation, I've heard it from others, you've got arguably the deepest bench of machine learning talent in the county. You compete with Google and Facebook for talent. I'm really curious sort of how the challenges you face as a business person in this field, and also ask some philosophical questions for you based on the kind of work you do.

Demetri Kofinas: 01:03:20 I'm curious what your thoughts will be on that. For those listening, you can find out more about our subscription through our Patreon page or go to hiddenforces.com and check out the subscription page, and you can learn how to listen to our overtime. Reardon, thank you for spending this full episode with me.

Thomas Reardon: 01:03:37 Thanks so much.

Demetri Kofinas:	01:03:38	That was my episode with Thomas Reardon. I want to thank Dr. Reardon for being on my program. Today's episode of Hidden Forces was recorded at CMD Design Studio in New York City. For more information about this week's episode or if you want easy access for related programming, visit our website at hiddenforces.io and subscribe for a free email list. If you want access to overtime segments, episode transcripts and show rundowns, full of links and detailed information related to each and every episode, check out our premium subscription available through the Hidden Forces website or through our Patreon page at patreon.com/hiddenforces.
Demetri Kofinas:	01:04:27	Today's episode was produced by me and edited by Stylianos Nicolaou. For more episodes, you can check out our website at hiddenforces.io. Join the conversation at Facebook, Twitter, and Instagram at hiddenforcespod or send me an email. As always, thanks for listening. We'll see you next week.