**Afternoon discussion with Sunny Bains**

00:00:18 → 00:01:25

**Ralph Etienne-Cummings:** Let's take a seat, please. So the next part of the agenda has to do with essentially the afternoon discussion. We are fortunate to have Dr. Sunny Bains, who is a journalist, scientist and a professor at Ucl. London. So she's been listening to all the discussions today, and she's been digesting it and synthesizing questions, and trying to get a sense of where you know folks who have spoken this morning, where they think are the important questions and where things are going. And hopefully, now she'll be able to kind of flip it back now to the audience, and basically gain some conversations between the various speakers this morning as well as the audience, and start getting things moving. So Sunny did her Phd in Physics at Imperial College, London.

01:27 → 07:12

**Sunny Bains:** After Imperial threw me out of my undergraduate degree, I finished my Physics degree at Queen Mary College, then went on to Boston University, did an Msc. In journalism, and then went back and got a Phd. Called Physical Computation and embodied artificial intelligence. So that's my background. Okay, so I would like to do this in a systematic way. So what I want is to really get a lot of discussion, to have lots of topics of discussion. I'm going to start the ball rolling in a minute. But I have this proposal for you for how we're going to operate. I have this. I'm pretty loud anyway. I have this proposal for you for how we're going to operate. So if you want to participate in the discussion that's going on at the moment, then use the two microphones on either side, so just go up and queue up and those, and we'll just keep the discussion going. If you want to start a new topic, if you think we're missing the point, there's some different direction you want to go. Come, sit next to one of the microphones, and then, as soon as I think, the current topic has kind of reached a plateau of productiveness, then we'll move on, and we'll take on a new topic. Okay? And if nobody, if nobody's willing to come and sit here, well, I might have to call on some people. So yeah, you can tell, I teach undergraduates all day long, can't you? Okay? So what I wanted to do, the way I wanted to start. It is in the panel discussion and through these sessions actually. Oh, maybe for a seat. We should probably not close the door. in the discussions we kind of got. I think we didn't crystallize things, and I'd like to try and do that a little bit. I think there are 3 things going on here that we're interested in. We are interested in doing more science to understand how the brain works and how we can most effectively send signals into the brain into the body to do the things that we want to do right. So, for instance, we had the example of the Eeg signals, and we were saying, Well, but we're only looking at a small proportion of the Eeg signals that we could be looking at right. So there's science to be done there. So that's sort of one piece of it. Now that science may be much bigger than what you would want. If you were actually using an operational chip that you're going to live with for many years. Right? So the constraints that we've talked about in terms of size constraints in terms of battery life. They may be very different if you're on the one hand, on that path to optimizing a particular process, or on this other path to actually implanting something that somebody's going to use. And you want to be able to forget about it. Now, I can see that neuromorphic would have a place in both of those. Maybe in the science place it might be more on the sensor side, and then you might end up doing lots of communication, because at the moment you're just trying to understand what you're looking at. So it seems to me there's that science side. And then on the chip side. Obviously, you want the lowest possible power. Highest possible computation for the smallest space and neuromorphic seems to me, would have a place there, too. Another thing that we got to was personalization right? And that seems to me to fit very slightly in a space that could go in either direction. So it could be that you have a personalization calibration step that involves bigger computers that are not in, you know, implanted in your brain. But then, once it's implanted, it's all good, or it could be that you have a certain number of circuits inside that are adaptive, and where you need a little bit of overhead in terms of as things change over the years, you know, as your own brain changes or or just to customize a little bit more after you do a customization step. And it seems to me again that neuromorphic could have a place there. So that was one of the things that got me thinking is that we have these different spaces and to fulfill the kind of things that people have said that they want to be able to achieve neuromorphic could have a space in all of those. So I wanted to sort of put out that little thesis and have you pick holes in it or expand it further, so that we can see whether that's a good way of breaking up the space of implantables, which is mostly what we've talked about. We haven't really talked about medical imaging yet. I guess that we're doing that tomorrow, aren't we? So? So and and also we were talking about. The difference between AI, which I think we all agree can be a tool in understanding whether it's Eeg or whatever, but not something that you would want to be using with a patient on a daily basis. So it's just separating out these things so that we know what we're talking about. So would anyone like to chime in? And I'm going to try and shut up for a while. You can either go up to the microphone, or I can pass you a microphone. I can. I'm mobile. I can do this.

07:13 → 07:40

**Elisa Donati:** I have a burning question from the last session that I didn't get a chance to ask, and it had to do with Eliza's comment. There's variability even within an individual that you can train someone on a prosthetic, and then 2 weeks. It doesn't work again. And because, you know, maybe the electrodes move, the neurons have changed. So I'm wondering, how do you know? How would neuromorphic help in that particular instance?

07:51 → 08:58

**Grace Hwang:** So something that I briefly mentioned is, and also some that we kind of agreed is that something that is well known is in the brain. From the neuroscience point of view. There are some kinds of latent dynamics. Right? So. And there are some studies that show that if you have these latent dynamics they are stable across even years. Okay? So if you measure the did your brave recordings one day and the week after they are completely different. Okay? And if you are based on these recordings. You need to retrain and calibrate your system. But if you go in a latent space, so in a low dimensional space, you can actually have something that is more stable. Am I correct? Maybe not. But then something that you can. You can use it. The neuromorphic, for example, is good to go in this dimensional space. Again, you can use that, for example, strutting features or slutting some dynamics underneath dynamics. And you can actually work on this. And now let's see what is.

09:00 → 09:34

**Audience:** No, no, no, no, not at all, actually, not at all. I was asking for the mic before you came to this point, so no worries. But I wanted to follow up on what Grace said. And your answer I had a similar question. And that goes actually more to the panel. But maybe, and the panels that were earlier there on neuroprosthetics, decoding, encoding was mentioned as if and you just put it in the context of.

09:36 → 09:55

**Sunny Bains:** I'm going to assert some control here. So is this related to Elisa and Grace's topic, because I'd like to just let us have a conversation about one thing before we move on to another thing, it is related to that topic is degeneracy effectively.

09:57 → 11:15

**Audience:** Something we are struggling with enormously is, in general, dangerously. Which means the same individual. Yeah, I can find different ways of generating the same behavior, which is actually a huge issue. When you get imaging signals. Yeah, how do you interpret them? Because they may be generated in different ways mechanistically, which is great. When you have an injury. Then you can actually start to adapt. Yeah, it provides you with redundancy, and you can reorganize and rewire. But these are huge challenges for encoding, for decoding, etc. How do you deal with that? That sounded also straightforward. And for us, when we interpret these signals. Yeah. Now, coming from imaging. There are so many different ways of generating the same signal, which is great coming from the perspective of inference. And you look for identifiability. There is a huge non-identifiability. So we are. How do you deal with these issues of coding decoding in light of its not just intra subject variability. There are many other issues, can you? So if this connects any one of you?

11:17 → 12:03

**Audience:** I mean, I guess I would just say that I like to tie it back to the brain and Normurfic. Yeah, whatever. I mean this. This is how the nervous system works right? So like even in gate, right people talk about this idea of goal equivalence manifold. So there's aspects of the behavior that don't affect your actual performance in the task. And those are the dimensions in which humans have more variability. If you put them in a situation where, like reducing that variability is important for task performance, they will just simply do it right? So what we want are systems that allow us to slop in the ways that don't matter right? And just like, you know you, I could switch and hold the microphone with one hand or the other hand, and just adapt right? So I just think this is how biology works. And we would probably, if we want people to be dependent on artificial systems. We want them to have that same degree of robustness and flexibility.

12:04 → 13:04

**Audience:** So my thought was along the same lines. Right. So it comes down to. For me. It's a question of kind of what is the fidelity at which you are modeling the system? Right? So your brain twin that you talked about this morning, Victor, when I looked at it. The question that came to me is, what degree of resolution are you talking about here? Are you doing down to the single channels? Are you thinking about astrocytes? Are you thinking about neurons? You know at what level of abstraction? Because that's going to ultimately lead to the various degrees of, you know, reproducibility, and and so on, and so forth. That's going to happen with your system right. So when you present you know what? What level of abstraction were you looking at here? And could you reproduce, you know, all the personalized behaviors that you know, that is that is important to capture a person's pathology.

13:05 → 15:00

**Audience:** Okay? The virtual brain twin is a special type of digital twin where we are on the level of resolution of millimeters. So I explicitly made the connection from individual neurons to the population of neurons, molecules, molecular motion to navier-stokes, equations of fluids or of airflow, etc. We had a discussion earlier about that in the brain simulator. You do not model molecular motion of air effectively. Yeah. So we are on that level of description. And for us in particular, there is as long as we stay in the clinical imaging domain. This is where we want to stay for other reasons. If you start asking questions about epileptogenesis.We want to go deeper and traverse scales of operation, but for the clinical applications at the moment we wish to stay there, addressing issues of in the context in which you pose the questions fidelity effectively. And that links a little bit to the question I asked to the panel, and James responded. There are issues, no, you need to quantify when you have absolutely no idea. This is very important. Yeah, this is the reason why we chose inference, because it provides us with posterior probability distributions, and if the probability distribution of the parameters we wish to estimate is flat. It simply means it's non-informative. Yeah. And these things happen all the time. If I ask you, what is the square root of 4? Actually give me? Give it a try.

15:02 → 15:03

**Ralph Etienne-Cummings:** Plus minus 2.

15:03→ 15:37

**Audience:** Bravo, is it? Plus 2 or minus 2. You don't know. You don't have enough information in order to address this issue. Now you can generalize this in a higher dimensional space, etc, etc. We are dealing with this all the time, and this links also to my question in terms of degeneracy on one thing is non-identifiability, because you don't have enough information. The other element is degeneracy. It's not non-identifiable, but there is. There are multiple solutions to the same question, not because you don't have enough information, but because it's degenerate.

15:38→ 15:42

**Ralph Etienne-Cummings:** Because basically, the problem is your pose. You have multiple potential solutions.

15:43→ 15:52

**Sunny Bains:** But that's not a bad thing. Right? I think we should point out that as long as you can find one of those solutions it doesn't matter whether there are lots of them.

15:53→ 16:06

**Audience:** This is why I was asking the question earlier, because it's actually very important, because the brain is using this explicitly, this redundancy in order to adapt or to recover from injury, etc.

16:08 → 16:13

**Sunny Bains:** So I'm gonna go to Elisa. And then I want to hear from someone on this side of the room. No, no, you go ahead.

16:17 → 17:10

**Elisa Donati:** So I've something that I'm curious about because you were describing this twin. Right? So but then you were talking about high level, right like this top down approach right? So you have like this big model of your brain. And then you said that you are not looking at exactly the behavior of each Ionic channel of each parameter. Right? So it's more like a top down approach to me. So then I want to ask you, how do you think that is neuromorphic, because what I presented before was more like an approach for using neuromorphic. So you can actually make your system matching the behavior of neurons and whatever synapses or even unique channels. And how do you see these 2 coming together? Because before you even mentioned that you tried using spina care and brain scale. But you failed if I understood correctly. So can you just give me a comment about that?

17:11 → 18:38

**Audience:** I should qualify the response when I say we failed is the systems spinnaker and brain scales. There are at least the way we have them implemented. They are optimized to use spiking neuron systems. And these are because we are on the mean field level. It's not spiking neuron systems. It's the mean field statistics. So the mathematics is different. And it's not straightforward to adapt. So then there are other issues, time delays, and so on. But that's more technical elements. How can we get these bottom up and top down approaches together? There are multiple possibilities. One would be, for instance, hybrid simulations or co-simulations, where you actually use for regions of interest spiking neurons a simulator, such as nest, for instance. Yeah, together with a virtual brain simulator, and then timing issues, you do a deal with different quantities, etc. But these are things you can do, and that people are working on. Yeah, so core simulation is a possibility. And then you can simulate the system at high resolution where you ask high resolution questions such as about spiking neurons, for instance, sprouting of the connectivity, etc. So these are ways of doing it. Otherwise you can. This would be a 1st approach.

18:40 → 19:16

**Sunny Bains:** Okay, I want to get off the digital twins just for a minute, because it's not. I mean, it's not been the focus of today. Right? Although, although it was one of the elements, I'd like to get back more to implants and stimulators. And that kind of thing? Can we have someone venture an opinion from this side? Is this the non opinionated section? Is this like the equivalent of the back of the class where everyone's trying to hide and be anonymous. Yay. Oh, wait! You're in the middle. Hold on!

19:18 → 20:02

**Ralph Etienne-Cummings:** I'm on this side of the room now. So my, you know, listening to the session on prosthetics. Right, I came out of it thinking all right. If there's any application where neuromorphic is relevant and ripe and ready to go. It is the prosthetic scenario, right? Because it goes all the way from the recording, the decoding, the encoding, the understanding the control. All that entire loop you know, and the fact that it's a closed loop system. Typically, you know, that is the place where neuromorphics would play a big role. So I wanted to ask that question to the panel and say, You know, what's your thought? You know. How do you see that? Am I completely off my rocker? In other words. Oh, I have one from

20:07 → 22:18

**Nitish Thakor:** So that's what I mentioned in my 2Â min that one is, start with the receptors. We need science of modeling, tactile and other receptors at a very high precision level. Then you go up the chain, and how nerves with their fascicles and fibers encode, and they're mixed. All nerves are mixed, sensory motors are mixed up. What are they encoding and taking it up? The chain is tactile. Then there's the kidney nucleus. So there is that model that is being ignored, although it has been paper by Odo and others. Then you go up to the cortical level. Right? So you have an entire neuroscience chain the neurosciences have looked at. But we have not precisely modeled that. So that's the upward part. Right now we are doing stimulation, and then I'll come to the electrode point. Right? So do you stimulate directly to the cortex? I think Luke had a paper recently, and so he can talk about it. Do you stimulate the nerves to create a percept and then answer quickly, so I don't take too much time electrodes? So the problem is, we have a massive development in cortical electrodes. I was talking to people who are, you know, one panelist. Others are doing hundreds and thousands of electrodes. What about the peripheral nerve? It's a stretchable, flexible few 100 micron nerves utop micro race lantern. It doesn't work. Cuff electrodes have been going around forever, and they don't have the resolution, stretchability, or flexibility. Although there's a world out there. So we're not able to get into the fascicles and fibers to do sensing and recording and stimulation. So the nerve is a sort of ignored cousin of the brain. You know, there's a brain initiative. Darpa puts money into the brain. So the peripheral part in sensory prosthetics left. Or now it's happening in modulation of the vagal and other areas. So there is some crossover that needs to occur between people who work on vagal neuromodulation and other neuromodulation. So yeah, I think, yeah, it's an entire chain. And there is a gap in technology, I think, at the peripheral level of the liver side spinal cord. It's even worse in organization.

22:20 → 23:05

**Audience:** So like, agree with all those points. But I guess I would just like to bring up again that idea of like, what is the technology readiness level of some of these concepts? Right? I mean. So like, there's a big distinction between working on the fundamental interfaces and computer infrastructure versus things that are going to get into the clinic and impact people in the next decade or 2 decades. And so really keeping in mind the things that are most impacting people, I think, is really essential and neuromorphic for its own sake. I mean, it's kind of very intuitive when someone has limb loss to be like. Oh, let's make all of these as human-like as possible. But that's not always the best engineered solution to our current set of problems and then I just wanted to. Also, at this point loop back to one of your original points, which was talking about, perhaps using the AI to train a system, but not using any AI and deployment. So I think.

23:05 → 23:16

**Sunny Bains:** In conventional AI not using the meaning neuromorph. I mean, AI is going to be there one way or another, but it doesn't have to be off site. It communicated AI right right.

23:17 → 23:40

**Audience:** But so like I think I would. Also, just because Helen's not standing up, shout out to her work right where she, you know, probably on a more powerful computer, infrastructure trains, these Rl policies. But then these are then learned and distilled AI systems that run online and then try and realign the kinematics to be more neuromorphic in the sense of being more like an intact limb. And I think so we have some examples already of these things being out there.

23:46 → 24:32

**Audience:** It's something that I think. I'm very excited about looking at the combination between neuro regenerative therapies and pharmaceuticals with closed loop stimulation. Whether it's in the periphery or the central nervous system, I'm inspired by work done by the team in Switzerland, led by Gregoi and Jocelyn, where they have these chemical cocktails that they inject into the spinal cord, and they do closed lip stimulation. And the reason why I'm very inspired by that is. I think that you need to promote both the neural healing and the appropriate signals for the body to know what to rewire again to what?

24:36 → 25:22

**Audience:** Yeah, let me take a slightly different and maybe intentionally disruptive answer to your question. So if you think of that loop that you outlined which makes it simpler. You know you have some output from the nervous system. You do something with it, and you get an actuator putting it back in. I would argue that the 2 ends of that loop or semi loop need to be neuromorphic or physiomorphic or encephalomorphic or whatever you want to call it, because they're interfacing with the nervous system. But the other thing in the middle there which is where maybe all the neuromorphic computing. And a lot of these sort of more purely engineering issues come in again as a clinician, as a scientist, as a user, I don't care. Use whatever works best.

25:23 → 25:27

**Sunny Bains:** But you care about the latency. If there's a big one.

25:27 → 25:43

**Audience:** There's nothing about. You could come up somebody in this room who knows a lot more than I do, which is basically everybody can come to me and say, I've got a computing structure computer algorithm, a computer architecture that is totally not related to anything that the brain could possibly do, and it is really fast and really efficient, and I'll say, great. Let's get it into my patients.

25:43 → 26:13

**Sunny Bains:** But that's fine as a clinician to say. But I mean, if if people are going to build stuff for you, you have to look at what is the thing that's going to get you what you want with the low latency, and if it's going to be implanted with low power and small size, and all of those things at the moment we're here because a lot of us think it's neuromorphic. Everybody gets that. No, nobody with an application cares about the technology answer for a different reason.

26:14 → 26:30

**Audience:** In other words, you're saying it's neuromorphic. Why? Why? Why is the answer neuromorphic? But what I'm saying is that at the ends where we're interfacing with the brain. It has to be somewhat neuromorphic. You don't have a choice.

26:32 → 26:56

**Sunny Bains:** Well, you could argue that way. It won't work. But you could argue that just as you said about the middle bit that if you could do something just as well as neuromorphic, using a different kind of technology. Then why would it have to be neuromorphic? All you're doing is simulating a kind of neuro. So I don't see why you're willing to be precious about the ends, but not about the middle, because.

26:57 → 27:00

**Audience:** I'm precious about it, because that's actually biology at the end.

27:01→ 27:01

**Sunny Bains:** Okay.

27:02 → 27:02

**Audience:** Go ahead. Sorry. Sorry.

27:03 → 27:51

**Audience:** Jump in as a former still recovering engineer. Okay, So whenever I presented a solution to management, I was guaranteed that would not be realized if I said, Hey, it's got to be neuromorphic. Okay, number one principle was, always you present 3 options. The middle option is the one that you actually want, you present the best, and you present the most expensive, okay? Right? And then, oh, yeah, well, you, we don't want to spend as much money, and we want it to be quicker. So okay, go for the middle one job. I gotta echo, though. The point is what we are focused on. Is it the solution that has to be neuromorphic? Let's find out work backwards to justify it. That feels really odd to me.

27:52 → 29:00

**Sunny Bains:** I didn't say that, I said the opposite. I said, if you can, I would say that the argument that the computer doesn't have to be made neuromorphic could be also extended to any bit of the chain. If you can do it just as well with something that's not neuromorphic, which is not because I don't believe in neuromorphic, because I'm here because I believe in neuromorphic. It's just that I think it's illogical to be kind of dogmatic because it's well, this emulates the biology more closely or in a specific way. And that I don't think it's illogical. We should be as engineers or as people who are looking for solutions to problems. We should be pragmatic about what the technology is, and if it can do the job, then it doesn't really matter to most clinicians. I think what's in the box is you know. It doesn't matter, but there's some paper that says that it works, and we can afford to buy it. So it's fine.

29:00 → 29:44

**Audience:** So I don't think doctors really care whether it's neuromorphic or not. So I think one of the best presentations I saw today from Dr. Donati was sort of hey. We did it this way. We got, you know, quick. Result, 8%. Some people spend a lot more time, a lot more effort, a lot more. Gpus got 6%. Okay, go back to 1st principles. What can we get out of linear regression? What can we get out of classic CNN transformers? Just test both ends of the spectrum and then present objectively. Right here is what we advocate. Here's why we advocate it. Here's 1 solution. And why that was better or not. That seems like a really productive path to keep going down. It's not necessarily present, but to take the time and the diligence to go try and see what the other methods are, and then present the data from the other methods.

29:45 → 29:45

**Sunny Bains:** Sure.

29:46 → 30:42

**Roger Miller:** Here's the other corner. Hi I'm Roger Miller. I'm program director at Nih for neuroprosthesis development at the deafness and communication disorders institute. So we have some experience with the cochlear implant and I think what Sid said was very interesting. And that is, he said, the inputs needed to be physiologic and that's what we've learned with the cochlear implant. If you put in an electrode and you get the, it's very easy to recapitulate the physiological signal, but just by using bandpass filters to different locations. But if you don't get the electrode in deep enough so that the 2 kilohertz is up at the 4 kilohertz or the 8 kilohertz, the auditory system can still use it, but it takes time. It has to adapt, not everybody can adapt. So there really is a value in finding what the physiological signal is. And injecting that when you're talking about a neuroprosthesis, I also believe in the neuromorphic concept. And you know, that's inspiring. Beyond that.

30:43 → 31:38

**Sunny Bains:** So there's a difference, though, between neuromorphic, which has to do with the engineering side, right and and neurocompatible, which is what I would argue. You're talking about physiologic which has to do with the output from whatever the device is, the engineered devices. And I just think it's important to separate the 2, and I would argue that if I could give you a device that was not analog. That would do exactly what you wanted, and was small enough and low power enough, which I don't believe is the case, which is why we talk about neuromorphic in the 1st place. But if I could give that to you, you wouldn't care. Whether it was neuromorphic or not. What you care about is, what is it that it's detecting? And what is it? So I'm just trying to be logical about where these definitions are. And the reason we think neuromorphic is promising is because it can progress it.

31:40→ 31:56

**Audience:** And if you said that neuromorphic device was able to reintroduce some aspects of the endogenous computation which are absent from the current algorithms. Then I would say, I don't care whether it's a digital process or an analog processor, I'd say we've made a fundamental gain, and we can hope for better patient performance.

31:57→ 31:58

**Sunny Bains:** Exactly. Exactly. Yes.

31:59 → 33:52

**Francisco Valero-Cuevas:** Hi on this side. Yeah, so Ralph Grace and as we were predicting that this would happen that we would get mired in definitions, right? So there could be bio-inspired or neuro-inspired bio on the log or neuro on the log or neuromorphic or physiomorphic right? So pick your place along this spectrum. But I think one other dimension of this is like Emo, Todorov and I would often discuss that. What's fascinating about biological systems is not that they work so well but that they work at all. If you look at what evolution gave biology by way of information, processing units, materials, actuators, sensors, right, and the fact that those things that no, no engineer in their right mind would pick right and that they work so well. So a very modest proposal is okay. Well, if nature could do it with every wrong ingredient and Lego block, any engineer would have thought of. Well, maybe there's something that could be learned, that's 1 thing, and then that's on the philosophical side on the practical side, I mean, I totally agree with the clinicians here at the end of the day. We don't need a chip, or a paper, or a device, or anything. We just want the patient to get better and again, there's a spectrum from the philosophy to the actually getting it done. So this is a wonderful discussion, because we have a group of people that actually span all of those dimensions. So it's just a lot of fun to watch. Thank you.

34:00 → 35:19

**Audience:** Perhaps everyone's just faster at me realizing this. But I haven't heard it said explicitly. I hear people kind of falling down on different sides of this issue, depending on a dividing line of the application that they primarily have in mind is one that is neuromimetic. It's prosthetic, like you're trying to replace a lost function. So quite literally, a prosthesis or a brain computer interface or a cochlear implant and for the people in the room that I hear that are more interested in applications where that's not the case. So epilepsy Dbs psychiatric neuromodulation. You're not trying to replace a lost function. You're trying to maybe disrupt something that's aberrant, or or in other ways modulate the system. You know, I'm in my application trying to repair white matter that may be damaged. I hear far less enthusiasm from those people for saying we need solutions that are neuromorphic either at the endpoints or in the middle. We just need something that meets spec right? We wish we could get more data, or we could get faster. And if the solution is neuromorphic or it's not. It doesn't really matter to us, whereas the folks that are, you know, replacing lost function sound much more enthusiasm. They sound much more enthusiastic for solutions that are neuromorphic in character.

35:20 → 35:36

**Sunny Bains:** Get, we have one other point, and then I'd like to get the value to expect to actually go ahead. No, it's not a microphone, it's not a perfect microphone.

35:46 → 37:07

**Duygu Kuzum:** So yeah, okay. So yeah, I totally agree with everything said. And considering the like vast landscape of different types of applications and needs for biomedicine. I think, like as engineers, we are used to determining metrics for things, right specs. So at the end of the day, whether something is neuromorphic or not, we would care about like size weight, power, functionality, and efficiency and functionality and efficiency, most latency throughput. So those type of metrics, as long as the system actually provides, satisfies all these metrics, so it will be actually translated into all different types of applications. So the main question should be, in which of these areas can neuromorphic contribute can be built like shorter real time, short latency closed loop systems can be built like really small chips, really lightweight and low power systems that could actually still provide the functionality needed and also do it in an efficient way, interfacing with the neural implant, or any type of implantable system, or prosthetic and matching the bandwidth of it. So it's more of like satisfying those metrics than deciding, should it be like brain or not, like brain? Or but but can we actually get inspired from brain? To satisfy those metrics? It it the main theme. In my opinion.

37:09 → 37:17

**Sunny Bains:** I so I think that neatly brings us on to another subject that might oh, I'm sorry

37:18 → 38:16

**Audience:** I just wanted to go back to the point about being on spec, and I would say, from my perspective as a clinician like, I don't care if it's neuromorphic, even when it's replacing function, right? I want to replace the function. And that's the priority. And, like, you know, so like, take people with paraplegia or wheelchair users right like anytime in the, you know, foreseeable future. I'm going to be recommending wheelchairs, because that restores the function of mobility really effectively, and current state exoskeletons are far from usable, even though they're more, you know, neuromorphic, far from usable for most participants for, like like assistance in Adls, I would bet a lot more money in the next 5 years on visually guided language. Robotics like these, foundation models for robotics having home robots that can help people way before Bci even comes close to being practical for most people and so I just I agree with you. But I would say, I agree with you even in the place of a function. And then, if neuromorphic adds something more like if it makes them walk better if it gets the power efficiency, if it pushes on that spec. I'm all for it, right, but never just for its own sake.

38:17 → 39:50

**Sunny Bains:** Well, let's explore that a little bit. So one of the things that came up during the discussion today, I felt, was the or one of the things I noticed was the alignment, finally, of the semiconductor industry, the computing industry because of AI with this area of implants and biomedical applications, because the AI people, as we all know, are coming up against ceilings in terms of the amount of energy that they're having to expend in order to do their computations. So they want to be sparser. They want to be smaller. They want to be more energy efficient. So they're actually looking at using neuromorphic in their systems or their systems are becoming more neuromorphic. So they're co-opting elements from neuromorphic. But actually, from your point of view, as people who would, for instance, want to implant things that have some intelligence to them. You're looking at. Well, we want to keep the size the same, because if it wants to go inside the body, we don't want it to get any bigger, but we'd like to be constantly increasing the amount of functionality that we can get on those devices. So I think that actually could represent a kind of alignment between the kind of big AI trajectory, and what I would see as the small AI. And I wondered whether that illuminated things at all, or was an interesting way to look at the problem of getting AI into devices.

39:54 → 40:44

**Audience:** So I think fundamentally, the question is about the difference between autonomy and interpretation. So if you are going with more autonomy. You like neuromorphic because it's in a closed loop control. The decision has to be made at the implant at the prosthetic level, but as a clinician. And this is we face that and wash you all the time. When we work with clinicians they want to interpret data. So they want to have actionable data on why something worked, not like magically, you put something in there. And then things started working. So I think this struggle will always be there. Whether you need a high fidelity data, whether you're constantly recording or monitoring how your prosthetics and implants are evolving over time versus whether decisions have to be made, you know, autonomously

40:45 → 41:50

**Sunny Bains:** Make that a bit more concrete. So let's think about something that everyone knows which would be a pacemaker, right, which is essentially, as I understand it, a relatively straightforward device with relatively low intelligence that I don't know whether it monitors or not. Normally. Now, I don't think they did at the beginning. But if you take something like that, so you've got 2 functionalities, you've got the operation of it's actually doing its job which is to keep your heart beating. But it also has the monitoring function and the data. But the thing is, how do you want to get that data out? Do you need to use that data in order to do the operation? And I would say that that is, that is a big question. So you can still be communicating data. Right? Does that make sense? You can still communicate data out while using a loop within the device itself. So I would have thought you still want to get the smallest most intelligent thing you can, as long as you can also do whatever monitoring you want to do at the same time. No?

41:50 → 42:41

**Audience:** So the reason I brought it up was because this was the first keynote, and I think somebody mentioned that stimulation takes 100 microwatts of power recording takes nanowatts. Even if it takes Nanowatt, it doesn't make any difference. So if you're logging and monitoring wireless. I would say, I would say, ledger keeping. If I take a lot of bandwidth and energy, all these other factors may not be that useful so again. So I am again a neuromorphic engineer. I want to be able to use neuromorphic computing. But I think we need to also look at where the key advantage is, where exactly do you need the autonomy? Where do you need to do computation on the prosthetics or on the implants? And that's where there's a key advantage.

42:42 → 42:51

**Sunny Bains:** So you talked about sensing and sensing, and stimulating it in that example, you didn't talk about the communication side, though.

42:53 → 42:59

**Audience:** Yes, because at least the clinicians that I talked to would want to see what's going on.

43:00 → 44:04

**Sunny Bains:** There isn't. There's a notion of just in terms of power. So where would the communication come in terms of the amount of power that it was orders of magnitude? Yeah. So that's the point. So maybe right now, clinicians want to get involved because everything is experimental. But what if we get to a point where these things are routinely being fitted. Do we need quite so much monitoring? Do we need quite so much communication? Maybe we can just send information about an event that happened, you know. Yes, there was an anomaly or something, and we want to send that to the doctor. But actually, they don't need to see the details at some point. So it's looking forward to that trajectory of going from science, as I mentioned, to to kind of understand what's going on with this patient, which is more of the personalization to the products you know, that are actually being used for years and years and hopefully can be left alone, but are slowly adapting over time. Maybe does anyone else? Yes. Sorry, Brad.

44:06 → 46:07

**Brad Aimone:** Yeah. I mean, this is, this is a great conversation. So maybe to get to this one of the things I'm thinking about. You know this, this idea that there's like this sort of power window that there is to operate in and I think it's. You know. I always think of the scene in Apollo 13, where they're counting amps as they're going up right. And I think when we think of computing. There's this certain budget we have. There's a certain amount of power that is available to do computation. What neuromorphic, neuromorphic hardware in principle does is it opens up a much bigger aperture of what computation you can fit in that power budget. Now then, the question, I think that goes to the clinical side. And I mean, I'm a neuromorphic algorithm person. You don't know me. But the question that I want to hear from the application side is power constraints and latency constraints and all that on conventional hardware wasn't an issue. What is your dream algorithm that you would want to stick in C 2 in a system because all of a sudden, now we've gone to something where, you know. Maybe we can move from a bang bang controller to something which is a very sophisticated predictive control system that that was just not. You wouldn't even think about building a custom circuit in the past, on doing well with the neuromorphic technologies, particularly new materials, may open some stuff up. But in some sense we need to hear you dream big. What is the ideal kind of task you want to solve? Now the math is going to look different when mapped to these architectures, but we can figure that out. But what is the dream? Because I think if you just take a standard like straight up, deep learning and stick it on a chip. You know, that's not always going to be the win. So anyway, that's, I think the we can do a lot with these neuromorphic systems. But you kind of have to know they have to be directed towards the right thing. So what is the dream? Is what I'm asking?

46:12 → 49:10

**Audience:** So I guess, as a clinician who puts these things in people all the time, you know, the dream, I would say, is really, look at the disease that we're trying to fix and fix that particular thing. So, for example, Parkinson's disease, we put in stn Dbs, but the Dbs system has a lot of problems. What are we really trying to fix? We're trying to fix substantia niger compactant neurons that have degenerated dopamine cells. In the case of when I look at my ophthalmology colleagues who are doing second sight. You know, these eyes kind of create new vision. I mean, those are incredible things that our colleagues are doing where they're giving vision to blind people. What are they doing? They're taking the retinal ganglion cells which there's 1 million in each eye and then giving sight, not by giving a million different or in cochlear implants. So the dream would be to design and come up with engineering materials and control algorithms. That's replacing those things right now to put in 4 Dbs leads and getting. The effect that we're getting is truly miraculous. But we know that what we're really trying to do is to control those specific neurons that are involved, so that as a neurosurgeon, I know that when I have to bump up my power, so, for example, if I have to tune my thing to a 5 volts and and jam the brain by 5 volts. I know my targeting probably was off. You know that I'm far from the thing that you know. I mean, I'm not gonna admit that that's my colleagues. So in that way, I think the engineering is off when we have to give a lot of power. And to me, what's you know? Why I was excited to come here was that neuromorphic means. Nature has figured it out. It's in us. And so if we can figure out those things, then we know that we're going to be, you know, getting closer to target just like. And when we think about neuromorphic, I would caution everybody. You know Tim Dennison, a long time ago. I don't know if he's still in the room, showed this video of how we got to human flight, you know. And what he told me in that video that it showed was that the Wright brothers were not the 1st to be in flight but they were the 1st man to have controlled flight. You know people had different kinds of flights before but the reason why we could get to control flight is because we understood the dynamics and aerodynamics, the engineering behind flight. And so he showed at that time what I thought were really funny videos where the engineers back then would actually make airplanes that look like birds. Well, those are not going to fly, because it's sort of morphic in the sense that it's bird morphic, but they got the wrong morphic. The morphic that you really need is the mechanics, the mechanism of action. How do those things work?

49:15 → 50:17

**Sunny Bains:** I think that's why I think the interdisciplinary teams that are sort of characteristic of the neuromorphic community are so important because what we need is people like you coming from the application side and kind of having a vague idea of what neuromorphic can potentially do and narrowing down the problem so that it can be so that some neuromorphic engineers on the other side, with with some help of some neuroscientists can. Can then break that into something that they can solve. Because you're the one who has the experience of all the different potential solutions. You're the one who needs to know who needs to say, you know what this is, where we really need to stick a chip and this is what that chip needs to do. And hey, neuromorphic guys, you know, if you think you can solve that great problem if you don't, then we'll ask somebody else to help us. So that's why I think it's so important to talk to you and to ask that question that Brad asked, which is, what is it that we can do for you?

50:21 → 50:53

**Audience:** So I actually, you said something really interesting that triggered it, which is, you know, in order to do a better job than maybe today is, we need to really understand the system we're trying to control. Right? So understand the dynamics. To me this is really a question to this community, like, do I need neuromorphic anything to understand dynamics? Maybe I need biophysical laws. Maybe I need data. Maybe I need both. And then the machinery to try to, you know, build a model and see if it identifies the dynamics in some way. So I guess.

50:54 → 51:27

**Sunny Bains:** No, so you might need it. You might need neuromorphic sensors in order to get the data. And then and then you might. Once you've got your dynamics and you figured out what you really want. Then you might need neuromorphic engineering to create the chips that are going to be actually implanted hopefully for a very long time and do their job. So that's what I'm saying. It's kind of understanding where the neuromorphic can fit in. That, I think, is one of the goals of this workshop. Right is understanding these affordances, if you like. Right?

51:28 → 51:48

**Audience:** And I would just say that the discovery process of understanding the system may, you know, maybe I don't think it's about neuromorphic. I think it's about having the laws and then you know the data and everything. Then once you have that, maybe AI, I guess, will be part of that. But then everything else I can see how neuromorphic can help you sense and actuate decisions.

51:50 → 52:52

**Audience:** So one of the things that I'm seeing that's happening as somebody who's implanting is we're putting brain computer interface but what's happening is the brain. We can't change the brain. But we can change the computer. So you know, one of the write-ups that I read about in preparation for this is the computer systems. You know, the Von Neumann computing. Well, that has to change. If we're truly going to go neuromorphic, because the way that our brain works is through spikes, we know that. So for us to implant things that's in the brain. That's more like a computer. It seems to me it makes a lot of sense to change the computational system. You know, for example, rather than Ann. Think about Spike sns. You know some of the write-ups that I read in preparation talks about that. Now then, the question I have for the engineers is, how are you going to make that? How are you going to make something that is parallel, processing, low energy, low power that also functions more like the human brain

52:53 → 55:24

**Audience:** Token engineer. Here, do I get okay? I'll be the token engineer. So one thing I want to step back, though, is, firstly, I'm also a son of a mother who has an implant. So her pacemaker is very important to her life. So thank you. 1st thing. The second thing is the thing that I worry about. It's not your clinician's point of view. It's the patient point of view. I worry about her having to go back to the hospital to change the battery. Okay, that is a significant thing. Right? That's general anesthetic. That's not a small event. Right. So battery life is really important, and the communication it seems like when they put the device to read it. It's NFC, so it powers it for the communication process. But when asked what the best way to get the data from it was, the doctor literally told her it's the apple watch that she had on her wrist. Right? Not the device because the device was only for 6 month visits. It was the apple watch that was actually most useful to her, okay the other thing. I wanna say, Brad's really brought up a really good point, which is, things are different. There's a lot going on. But engineers typically try to fill the middle gap between what the patient wants, what the clinician wants, what the application needs and understanding what technology is available. And then saying, Oh, yeah, it's got to be event based. Sensor. Oh, yeah, it's got to be a non-human parallel processor. Right? That's kind of their job right? If you try and understand the solution and dictate them, you know the specifics, and it starts to get a bit dangerous because spikes are something that were really created by nature to deal with noisy signals across ion channels, between membranes not across silicon. So if we say the solution has to be spiking, that puts engineers in a loop. It's like, Oh, you told us to be spiking. Therefore we can't think about quantum or Joseph S. Injunctions or anything else, you know, that's crazy and maybe more interesting. Okay. So I think the great thing that was said here was focus on the problem. Tell us what the problem is. Tell us what your limitations could be. Energy could be battery life. Whatever could be the patient needs to or shouldn't need to come apart in order to change the battery. Yeah, that would be, I think the best thing that you could tell an engineer would be. Here's our set of problems. Here's what we need to happen. Here's how we need to make it better.

55:26 → 55:26

**Sunny Bains:** Tim.

55:28 → 57:40

**Timothy Denison:** I'll build on that point. I think that's 1 thing we have to keep in mind is that nature evolved with a certain set of physical substrates for computation and it didn't have access to some of the physical computations. You know, structures that we have available to us. So we can't, as you know, also, living in England can't be too precious about, you know restricting our design set to nature when we actually have a larger superset of available technologies available to us. The one I'm going to come back to is I used to design cardiac pacemakers before I got into neuro. So a little bit about them. But it's actually a good point on being pragmatic. I actually liked how Ralph set us up this morning. I for me, I feel like there's been a bit of a digression back to the eighties. Very appealing for me. But in terms of hardware and thinking about neuromorphic as hardware as opposed to saying algorithms and how we've evolved into systems. And so I want to get the system's mindset and actually be cautious of any adjective. So I'm just going to say systems mindset. So cardiac pacemakers, the problems that came out and they were fixed rate. So you went up and down the stairs and didn't beat fast enough. You couldn't fall asleep at night because it was beating too fast. Medtronic went off and hired all the world's experts, and said, "How do we come up with a physiological adaptive rate response?" I'll be quick. We had all this list of just pages and pages of solutions, and then this guy came up with a very pragmatic motion crystal with the piezoelectric on the side of the can, and then the clinician would do a 1 for one mapping, so you'd have a lower limit for your cardiac pacing so you wouldn't pass out and an upper limit, so you wouldn't get heart failure. And then they did a slope based on the patient's motion. I would actually say, that's morphing how physiology works to 1st order, and it was also very practical, and it completely revolutionized the field. And so I think that's taking the systems mindset, maybe not being too overly concerned about the neuro at some level, but systematically, I think it comes down to. How do we start to learn from nature and how do we restore physiology?

57:41 → 57:56

**Sunny Bains:** I think that's a good point, but I think there's always a danger of saying yes. Well, that means you can create any device and call it neuromorphic, because there's a neuron connected to it somehow. And that I think this workshop is supposed to be a little bit more focused.

57:57 → 58:12

**Timothy Denison:** Well, so. But I think maybe we can pick it up either tonight or later, is that I think I'm going to the engineer who I haven't met before who was on the other side. I'm going to actually second. What he was saying is, I think we can come up with a better definition from neuromorphic than what we've had.

58:14 → 58:15

**Sunny Bains:** But it wouldn't be. You can always reinvent terms.

58:15 → 58:34

**Timothy Denison:** No, it's back to Ralph's point. It's not saying neuromorphic is actually the original carver-mead definition. It's actually a much more broad definition that's evolved. So I feel like we've devolved from how we started the conference, and we're getting a little too specific.

58:34 → 58:34

**Sunny Bains:** Okay.

58:35 → 58:52

**Ralph Etienne-Cummings:** I agree with that. Hold on. No, no, wait, wait. So so we don't have too much time. I think Robert can go next. But I agree entirely with Tim. We need to make the term much broader than the median.

58:53 → 59:24

**Sunny Bains:** I just am just someone who professionally deals with language. Right, that's my only job in life. I get very frustrated with words that don't mean anything anymore, because they've been broadened out so much that nobody and then and then everyone calls themselves neuromorphic because nobody can argue with them, because nobody knows what the heck it means. So I think there are bounds right. And we need to stay within those bounds. Sorry, Robert.

59:25 → 1:00:08

**Robert:** Yeah. So as a physician and a non engineer, I think I am one of the few in this room who is sort of new to this field. I can't help asking. You know, for trying to establish a hierarchy of priorities is the number one priority solving disease? Or is the number one priority achieving some kind of neuromorphic system? Right? And if we look at things, I mean, I completely understand the rationales, the wisdom of nature, the wisdom of biology, the wisdom of the body, etc. And that if we emulate it, maybe we can achieve great things. But I guess, maybe provocatively. Can we also ask the question, can we do better than neuromorphic? Right? So are there systems that we can design, but actually outperform neuromorphic is a question that I would ask.

1:00:12 → 1:00:46

**Audience:** Yeah, yeah. So this is a very good example. In the visual system. In the eye we have the optic nerd coming in and going out. So if I were the engineer designing the eye, I would not do that. I would have it at the back of the thing right? So mollusks apparently got it right. Human systems didn't get it right in the evolutionary process. So yeah, neuromorphic systems can be better than the human systems. And it's not necessary that we actually completely mimic my personal opinion. But we can go further. Perhaps.

1:00:47 → 1:01:14

**Ralph Etienne-Cummings:** So I disagree with that. Wait. What 1 point I disagree with is the notion that because the nerve comes from the front and goes back in the retina, it's a bad thing, you know where the power supply is for the retina. It's in the back of the eye. So they had to put. Nature had to put the you know, the processing element closer to the power supply. So it's like putting the data center close to the you know, to the nuclear station. That is why it is structured the way it is, it's actually a smart thing.

1:01:15 → 1:02:17

**Sunny Bains:** I'd also like to talk about this subject. I thought that was a really good point, but I think the reason you have a workshop like this is neuromorphic is one of the tools in the box. Right? We're not saying neuromorphic is going to solve all problems. But if you don't invest in neuromorphic, then you won't have that tool to reach, for when you have the right application for it. So the question is, what are the right applications for this particular way of creating chips and the algorithms, the associated system software that you're going to need to make that run. And, if we can find enough if we can say, Okay, yes, neuromorphic has a place neuromorphic, maybe not quite as it's defined at the moment, but something similar to that. Then it will be there when you need it. If we can't agree that that's a good way to move forward, at least with some of our resources, then it just simply won't be there. Yes.

1:02:18 → 1:03:11

**Audience:** I think that's a great point. But I think it's also like the thing where maybe it feels like we're floundering around right? And I love your point about like, okay, imagine this world where you have a massive power budget. And you challenge people like, what would you do with it? And I don't think I heard an answer. And I know in my field, right like we don't have the data or the biological insights to have an algorithm. We want to make it more efficient right? Like that. Wouldn't that be the barrier to producing better rehabilitation outcomes in general and in the priorities list I put up there for prosthesis users. I forgot to call it out, but, like the orange arrow was where they ranked power budget for their prosthesis, which was several orders of magnitude less commonly ranked than the other problems. Right? So I battery life up there. Yeah, it was like 10 people cared about battery life and 2,500 people cared about falls and stability.

1:03:12 → 1:03:21

**Sunny Bains:** Sorry, I'm just trying to remember. Didn't you say that you spent a huge amount of your time? Was it you who said you spent a huge amount of your time explaining how to recharge your batteries and all. Oh, that was, I'm sorry, Tim, that was.

1:03:21→ 1:03:27

**Audience:** And you know, for some of myself, with wearable sensors, it's a relevant factor, right? So I'm not saying it's never a problem. But I'm just saying.

1:03:28 → 1:03:37

**Sunny Bains:** Okay, so maybe that's part of the point is to eliminate. Sorry. Grace has been very patient with me. I don't understand why. Go ahead, Grace.

01:03:42 → 1:04:24

**Grace Hwang:** Well, we're running low on time. I do want to make a couple of points. Which is that? Yes, it is our goal to solve diseases, and it is our goal to identify technological solutions, and to identify the low hanging fruit and the longer term solutions. That's definitely the goal of this workshop and the other thing I want to say so this has been a great conversation. We've really been focused on humans, the human brain, human nervous system. And I'm glad that somebody brought up an alternative species. And I think neuromorphic shouldn't be constrained as just human species, we should be more flexible and open and think about other species. And the idea that we can learn from that aspect of evolution, and bring that into this conversation in the next day or 2.

1:04:24 → 1:04:45

**Sunny Bains:** Thank you for bringing us to a nice close there. So you're all going to have opinions about how I moderated this, feel free to come and share them with me quietly, quietly, in a corner, telling me what I can do better tomorrow. And are we done for the day, or what's what's next?