NUMENTA
ON INTELLIGENCE

Episode 9: Interview with a Neuroscientist – Konrad Kording Part 2

Matt:	00:06	Welcome back to the Numenta on intelligence podcast. This is Numenta community manager, Matt Taylor. Last month, we released part one of an interview with Dr. Konrad Kording who runs the K-lab and UPenn, where we talked about uncertainty in the brain. Coming up is a continuation of that conversation, which will also be available as a video on the HTM School Youtube channel.
Matt:	00:31	So you mentioned motor output, motor representation in the visual cortex. So let me talk– let's talk about that a little bit. Why do you think motor output is produced across the entire neocortex? Why is there motor everywhere?
Konrad:	00:45	So I mean like this, of course, the motor serve in this argument. Why do you have the brain? To move better. That's the only reason why you have a brain.
Matt:	00:54	What about the visual areas?
Konrad:	00:55	Visual areas– so that you can move better.
Matt:	00:55	It's everywhere, everywhere. So does it feel like your whole brain is like basically modeling your whole body constantly, all at the same time and the space around it? I mean, it has to be, right?
Konrad:	01:15	Well, yeah, I don't know but like you can make a pretty clean argument that movement is what things are about. The only way how you affect your evolutionary success is to somehow sending the right commands to the right muscles at the right

time. Even speech is ultimately a movement act, and suddenly a lot of the way of the way people think is built on circuits that were more simple movement circuits.

Matt:	01:46	Have you seen, I saw, so I saw this x-ray recently of a mouth, like with an MRI or something while it was talking and the complicated movements inside your mouth is ridiculous. It's like a gymnastic feat. It's amazing.
Konrad:	02:02	It's off the charts. But then if you think about it, if you do sports, you might spend an hour every day. Or if you're a world-class athlete, you might spend several hours everyday training. In that sense, all of us are world-class athletes at speaking. You spend hours everyday talking to your friends.
Matt:	02:23	We started learning as soon as we started making noise, you know?
Konrad:	02:27	That's right. So we have tens of thousands of hours of experience moving our tongue or mouth, and the way we speak makes a huge difference on how people perceive us. It truly is important.
Matt:	02:47	When you think about it from that way, we're much further from real language understanding than we think, you know? Because I feel like I'm on the same page with you. Motor, I think, is essential. The motor aspect that the integration with reality, with your motor commands, and that's so crucial to language as we've learned it. I mean, because that's the only way we know how language exists is through movement and feedback with other people we're communicating with.
Konrad:	03:14	That's right, yeah, and how they perceive us and how we share ideas. Like some of the most amazing things that people do is they have shared intentionality. Like you want to understand intelligence, I want to understand intelligence. Like at some level, what makes life as scientists so enjoyable is that we share that.
Matt:	03:40	Right. It's the social interaction. It's brains and brains, the collection of brains, you know, that really make us human. I think.
Konrad:	03:47	Yeah, it's a crucial aspect of what makes us, us.
Matt:	03:52	That's great. Okay, so I got another topic. It's a technical topic. It's from one of your papers about, well you call it, I like to use

		it, the phrase "time-warping", but maybe you can explain the phenomenon I'm talking about in the brain. You know, when a monkey for example, reaches or does something or does a task and how the neurons involved in that task, at least observed in that task, don't necessarily happen when the reach happens. Why is that?
Konrad:	04:23	It's really interesting if we start at the other end.
Matt:	04:29	Great.
Konrad:	04:29	Let's say you see something, I show you a flash of light and I ask you to push the button as soon as you see the flash of light. Okay, so it takes a little bit for the information to make it from your eye to your higher order brain areas. What is interesting is how long it takes for it to make it cross your eyes depends on how bright it is. If I give you a super bright flash, it's kind of going to make it to your retina faster than if it's a dim light.
Matt:	05:03	I can see that, yeah.
Konrad:	05:04	So what that means is that the processing that's going to happen in your visual cortex will be faster for the bright things and slower for the not-so-bright things. Now, that introduces that basically that you aren't time-locked to the outside world. Sometimes you're faster, sometimes you're slower and it depends on things like brightness. Now we can make it more complicated. There's like this famous drawing, where you have an elephant but the legs aren't right, so it's clearly not an elephant. So if you're in that situation, it takes you a while to parse that image. And sometimes some people have that Eureka– "oh my god, that doesn't even work, those legs" element like very quickly and some of them haven't very slowly. And how fast or slow you have it depends on the situation. So what that means is that the inside of your brain isn't locked in time to the outside. There's like random time delays happening. Sometimes things go faster, sometimes things go slower. This is a huge problem for the way we analyze brains because what we do, typically, is we give a stimulus and we measure the neural activity that happens after the stimulus. But what if sometimes the neural activity is early, and sometimes it's late? Well, it means that it's all going to be washed out in a way.
Matt:	06:35	You mean later than normal or just like it's not always perfectly happening–

Konrad:	06:40	Let's say that let's take the easiest case. Let's say we have a brain cell. It shows me after some delay, a little spike when it sees something. Now it means that if sometimes let's take it only the brightness. Sometimes it's 20 milliseconds earlier, sometimes it's 20 milliseconds later. So at that point of time, if I ask what the average activities of the neuron, it will be totally washed out. The spike will sometimes be early, sometimes it will be late. So it will look like this is a very boring, very sluggish, very smooth cell where maybe what it does is something like it says like yes, no, I just saw it. It's actually very precisely timed.
Konrad:	07:24	It could be incredibly precisely timed relative to when you actually see it.
Matt:	07:30	But specifically to the context or something, you know?
Konrad:	07:34	That's right, exactly. It could be really complicated, and what that means is if we analyze that data as we do at the moment, it would look like the whole brain is boring, everything's kind of lowpass, nothing much happens there. Well it turns out that in one trial where you see it early and then another trial you see it late, and then you can't even say which cell is earlier or later because well they will, maybe you'll recognize both of them sometimes early, both of them late at a later point of time, so the interpretation then gets to be difficult. Now I think this is much more problematic even on the movement side. When I ask you to say, plan to touch the tip of your nose with your hand. Well sometimes you might do it like just in time for the movement, or sometimes you might do it now and like keep talking with Konrad, and then you execute it. And what that means is that there's no alignment of the outside world with what's in the brain. But everything we do in neural data analysis, or most things that we do, is based on the assumption that it's locked to the outside world.
Matt:	08:41	Right, right.
Konrad:	08:43	Okay, so now time-warping is like a technical set of algorithms to kind of undo those kinds of problems.
Matt:	08:49	It's a data-processing function, right? To help identify.
Konrad:	08:54	Exactly. It's like the way we use it is if you give me lots of neurons and I want to ask the question, well, how fast are they like jointly stepping through that process that they normally do? And it allowed, it basically allows that on some– that sometimes it might be earlier, sometimes it might be later, but this is a

universal thing. Like your brain is not time-locked to the outside world, and once you realize that anything you analyze in neural responses is getting much more complicated.

Matt:	09:32	Yeah, that makes sense. I mean there's certain experiences you have that seem very slow and others that seem very fast, and there's some evidence that has to do with, you know, the balances of chemicals in your brain and stuff like that. I mean, in the context for computation in your brain.
Konrad:	09:48	Right, and the temperature. If I heat up your brain a little bit, the wave–
Matt:	09:53	No thanks.
Konrad:	09:53	The valley of spikes might go out and get, go through it a little faster, like a little bit like you can just do it, get warmly dressed, run really hot in the sunshine.
Matt:	10:07	Alright, well next time I take an exam, I'll dress very warm.
Konrad:	10:12	Nice.
Matt:	10:14	Ok. Dr. Kording, a couple more questions from our forum. We have a couple, almost a couple thousand people at our HTM Forum and I sort of let them know sometimes who I'm going to talk to and a couple of questions I'll give you from the forum. Somebody read your research page and said that they quoted the page saying that you sort of have these two angles and one is, and this is for addressing information processing in the nervous system. One angle is analyzing and explaining electrophysical data and you study what neurons do, and the other being analyzing and explaining human behavior, which is setting with all those neurons do together. And I thought this was interesting, his question is, "How do you begin to model that huge gap?" You know, those seem like they're going in two different directions, so he'd like to hear you talk about that.
Konrad:	11:04	Yeah, so this is a huge problem, that there is this huge gap between basically behavior, which is complicated. It includes billions of neurons, and what an individual neuron does. And I'm not sure how to cross that gulf. In fact, like I've written a couple of papers where it kind of like, voiced the worries that I have about that. So when we make that bridge in neuroscience, we are often very imprecise. Say we take some brain area, we find that there's some neurons that do something. And then we say, oh yeah, therefore that part of the brain solves the face

recognition problem. And that logic doesn't work like that. It's basically finding that there's a difference if I show a different face doesn't mean that these cells don't do other things, and the correlation with faces doesn't mean which role it has in communication. Like for all that I know, if I give you a task where you press your right finger when you see a face, that like muscle has a really strong correlation with there being a face, and yet arguing that your muscle processes faces is perfectly pointless. And so yes, there's that huge gulf between those two views and it's a little unclear how to bridge it. And you might argue that it could be impossible to naively bridge the gap. And let me kind of make the point on how it could be impossible. So it could be that the way how all the neurons interact. Let's say, I look at you and I like phrase a sentence that that way is of such a complicated nature that people could never learn it. And the analogy that I want to use here is like deep learning systems. Let's say you take ImageNet, a big data set of images that are labeled and we have like since AlexNet, we have like good deep learning systems that can solve that. They aren't very good because I have Amazon Alexa here here who just decided to turn itself on when I used it, when I used its name.

Matt:	13:24	That happens to me all the time.
Konrad:	13:27	So basically if the brain is something like a neural network– which means that it optimizes its properties, it has plasticity, it adapts to the outside world– then at some level, the way how your brain operates is as complicated as the world in which it is. So you can't properly describe my brain, unless you also describe how dinosaurs work.
Matt:	13:57	This is, yeah. This is the relation to your dinosaur mascot.
Konrad:	13:57	That's right. I try to bring in an example of a dinosaur on anything that I say. So basically any reflection of the thing– Anything that I know, it must be reflected in a satisfactory model of Konrad, which means that cannot be a compact model of Konrad because Konrad knows stuff about dinosaurs. So if you cannot compress a model of Konrad, then in a way, we can't produce something that is both a workable model of Konrad and can be understood.
Matt:	14:30	Perhaps. However, my counter would be– I mean a model that has learned how to be Konrad, I would say absolutely, you're right. But there's also the substrate in which that model learned reality.

Konrad:	[14:48]	That's right, and I agree with you, that at some level maybe the reason why the gulf is so big is because behavior, as people exhibit, kind of contains all those things that we learned from the world, and rightfully so.
Matt:	[15:06]	That's absolutely right. Yeah.
Konrad:	[15:07]	And if it contains all those things, then maybe we are barking up the wrong tree. Maybe what we should rather say is, okay, what is the substrate? What is the learning algorithm? What other cost functions that the brain may be optimizing? Is it using an optimization algorithm? Those questions then become very central, whereas the question of kind of like how does it work at the low level, like, okay, "how do neurons contribute to behavior?" might be the wrong question. Like the fact that like somewhere in Konrad's early visual cortex, neurons have GABA wavelength. That might not be meaningfully part of a description of how Konrad works.
Matt:	[15:50]	Right. It's so hard to decide what to study and what is contributing to the overall model.
Konrad:	[15:57]	Yeah, so in that sense, my answer to that gulf is the gulf might be of the nature that we need to rethink what we want to study on both sides. Maybe the way we study behavior isn't quite right, maybe the way we study neurons isn't quite right. But how are those two can come together, that is something that people tend to expect that someone else will solve it.
Matt:	[16:21]	Right. Well, I'm hopeful in neuroscience right now because I dunno how much you know about what we're doing at Numenta, but we're really excited about grid cells. We've incorporated into our neocortical theory, you know, knowing that I've talked about grid cells a lot in other interviews. So I don't think I need to like give a basic description of what grid cells are, and I'm sure you know what they are.
Konrad:	[16:47]	Okay, but look, here's the problem. So grid cells, you refer to the tuning of cells. We thought tuning cells that basically as you keep walking in some direction, like periodically like go up and down in the activity. Is this really something about the brain [inaudible]. Maybe this is rather something that characterizes the specific environment in which rodents are raised with like that kind of representation is useful. If you had different mice, it might be totally different, or different humans. So the question is to which level are tuning of neurons really the right level to reason about intelligence? Because the problem with tuning, like grid cells, is that it reflects the experience in the whole

world. And therefore, that it might be usually dependent on the world in which you grow up.

Matt:	17:43	And that makes total sense even in the grid cell community right now because there's still questions about, do rats create a two dimensional representation of space? Is the grid cells they're creating only two dimensional versus other animals that move through 3D space? Are they fundamentally different in the way that they represent space?
Konrad:	18:01	Right. And what if you gave mice like little flying things, which they can move in the 3D space?
Matt:	18:06	Well we know the brain is so plastic and malleable, who knows? I mean you just don't know. But I definitely agree with you, like my grid cells that work in my brain were built off of my experience with the world, and I don't think that they would work with it for anybody else. You know, or maybe any other species for sure. I mean, there could be some things that are the same within species. I don't know. I'm getting way out of my league here, but the way everyone interacts with reality has a specific, what I like to call– I always go to a Max Tegmark because he describes these different layers of reality. There's an internal reality that everyone has that is unable to be shared. I cannot share what red is to me with you, except through a consensus reality, which is language to where we both labeled these things and we have symbols to represent them and we can understand them. And then there's actual reality, which we all try and understand as best we can and communicate about with consensus reality. And this whole idea is that my internal reality or the grid cells that I have are a part of that. The grid cells a mouse has are a part of its internal reality. So it's really hard to differentiate what those mean to them versus us versus that.
Konrad:	19:17	Right, exactly. So that's just why I'm like worried a bit, like which role findings like grid cells should have in the way we conceptualize intelligence?
Matt:	19:30	Right. And that's an open question.
Konrad:	19:34	So but in that sense, to come back to the question that was asked, it's like how to bridge that gap? I don't know. And I'm pretty convinced that right at this moment, very, very few people have thought hard about it. It's a huge gap, and it's a gap that we need to acknowledge that we don't know the solutions. If we pretend that we do [know] them, we will misguide people.

Matt: 20:01 The dangers of this gap is that there's, it's so big. I think there's so many crazy ideas between one and the other, that it's really hard to differentiate between whose idea is crazy versus whose is brilliant. I mean, in this space, it's hard to say sometimes.

Konrad: 20:18 No one knows, exactly.

Matt: 20:21 I know. So anyway, Dr. Kording, it's been a pleasure talking to you. Thanks a lot for taking your time and giving it to us in our community. It's been really great. So is there anything that you have a soapbox on that you want to talk about, while you have this opportunity?

Konrad: 20:37 Absolutely. I want to talk about causality.

Matt: 20:39 Okay, great.

Konrad: 20:41 So I think a lot of the language that we want to use when we talk about brains is causal language. We want to ask how neurons make things happen, how brain areas to make things have, or how neuromodulators might make learning happen. Those are all causal questions. We know how, like we want to know how one thing makes another thing happen. When you look at the bulk of the approaches in neuroscience, the correlational findings– I show you a face and I see what the activity in your brain is. And those two are very different statements, so correlations are not really indicative but underlying causality. And I want to encourage everyone who wants to think about intelligence to start thinking about causality. The problem we solve in the world is to understand the causal chains in the world. We don't care what's correlated. We care about which things we could do to the world to make the world more pleasant for us. And we– Same thing as scientists, we fundamentally care about causality– which things make which other things happen, and it's just so easy to measure correlations. And I believe that a large part of the community therefore effectively start equating the two of them, and that's something that we should avoid.

Matt: 22:05 That's a good point. What do you think companies like us that are trying to work in this space can do, can benefit from that type of a perspective?

Konrad: 22:16 I think for a company like Numenta, if you want to, I mean like ultimately what do you build into your models? Is it causal chain? You say this is what this neuron does to that other neuron. So in that sense, when interpreting the existing literature, you could benefit from thinking about it in terms of causality. What does, what do the experiments actually say and what do they not say about causality? But also then when it comes to say, if you're implicitly building objectives that the system has, the thing– the question is, what are the meaningful objectives? What's their causal role? How do they cause behavior in the end? And so in that sense, I think it came, the concept can be usefully implemented in any model of neural activity.

Matt: [23:10] Right. Yeah. It's just so difficult to put lots of the models together, you know, in a way that makes sense for everybody involved.

Konrad: [23:19] That's right, but the concept of causality, that is something, if you asked yourself how you think about intelligence, the concept of causality is what makes it intelligence.

Matt: [23:32] But I mean, at any point in time, I've got neurons that are predicting what's, what's going to be happening in my environment right now. You know, that's sort of the brand as a "prediction engine" sort of idea, right?

Konrad: [23:45] That's right.

Matt: [23:46] And the causality of those predictions being made involve vast amounts of past experience, not just the past second or the past minute, but years, years.

Konrad: [23:58] That's right. And you could, but you could for example view the prediction– If you view the prediction engine like that, you can say that the wanting to predict things is the thing that causes the tuning curves in the end.

Matt: [24:16] Oh yeah. I can see that, wanting to predict things.

Konrad: [24:20] Yeah. The goal of trying to predict things is what gives rise to how they compute.

Matt: [24:28] I see. I'm under the impression that the prediction's not a goal, it's just something that happens as a part of the mechanism of the neural network. At least in HTM, you know, we have a sequence memory theory/algorithm, and the predictions just occur if you connect them to the input the right way.

Konrad:	24:48	That's right, but the way how you set up the connecting them to the input in the right way is such that they change themselves so that they get better at predicting.
Speaker 2:	24:59	Yeah, absolutely. Yeah. And it's super complicated, it's like the world is topological, so you've got to have all these localized computations that, I mean, it's super complicated. But I mean I think I agree with you. I mean, causality is super important and we can't make any assumptions about why we're seeing what we're seeing if we're monitoring neural populations necessarily, unless we know the– and we can never look at the internal reality of the system to verify it anyway, so we have to be very careful about the assumptions that we're making, right?
Konrad:	25:30	That's right. And I want to add one more thing. The back propagation of error algorithm is also just a causal inference algorithm. It tries to figure out which changes in neural properties would make performance be better. So local prediction versus global optimization leads to very similar logical structure, where you have an objective in learning that gives rise to computation.
Matt:	25:58	Right. Right. Well, that sounds right to me. Alright, well Dr. Kording, thanks again for joining us.
Konrad:	26:07	Thanks for having me on.
Matt:	26:08	No problem.
Matt:	26:10	Again, this is Matt Taylor. Thanks for listening to this episode of Interview with a Neuroscientist on the Numenta On Intelligence podcast.