Jess: Hi everyone, I'm Jess.

Catherine: And I'm Catherine, and welcome to Across the Cline, the podcast where we explore the unusual ways we can meet in the middle.

Catherine: Hi everyone, today we're joined by Andrea Stein, who's part of the Department of Mathematics at UCR, and Brian Whyte, who was formerly part of UC Berkeley's Department of Environmental Sciences. Would you like to introduce yourself, Andrea?

Andrea: Hi, yeah. My name is Andrea, Andrea, however else you want to pronounce it. All pronunciations. I do research kind of at the intersection of category theory and analysis in particular. Like I'd say my current work is looking at kind of compositional structures of, like, physical systems. If you look at, like, a system of classical mechanics, how do you compose those together, into bigger systems, is kind of what I'm thinking about. I'd say I have an interest in probability. And I would hope that the research I do in the future is looking at similar kinds of notions of composition, but in a framework of probability and composing smaller, like, random processes into larger ones. And thinking about that.

Jess: Cool. We'll definitely get more into the details on that because I'm sure a couple of us don't know what you mean by composition. But first let's introduce Brian also and we'll get right in.

Brian: Hello, I'm Brian. I'm a biologist that studies animal behavior. I was at UC Berkeley, but I come from New York. My dissertation research was on social recognition in ants and trematodes. By social recognition, animals form societies and they decide who gets to be members in those societies. Ants do this by smelling each other. Trematodes, which are parasitic flatworms, arguably do this, but my work was just behavioral work trying to show that they do this and was comparing them to other social organisms. The work that I'm interested in doing in my future is moving towards like the realms of collective biology or emergent properties. So by studying animal behavior in social context, I'm usually talking about individual animals. But biology has started to, thanks to the help of other disciplines too, started to expand its scope to noticing like the abstract complex networks above the scale of individual organisms, things that you can only see at the scale of societies and collectives.

Jess: So yeah, that's- I already see maybe some overlap. Andrea, do you feel like those emergent properties are pertinent to what you do and how so, how does math, how do you go about studying those and knowing when that's an appropriate way to go about studying a system?

Andrea: Right, yeah. That's a really good question. I would say that there's a lot of mathematical tools that exist that can be applied toward looking at emergent properties. I know nothing about, but fractality was very concerned with, with this idea. Um.

Jess: Actually, to interrupt you really quickly. Can we define emergent properties for our listeners?

Andrea: Yeah, sure. Uh, do you want me to give a definition of that or? Okay.

Jess: Or, we'll think of it if it's different between you two, but you can go ahead.

Andrea: Yeah, I guess. So I would say the way I think about emergence would be if you take some systems, what is a system? a system of, of, uh, of like, uh, a physical system where we have like, particles moving around in space, or maybe this is an electronic system, maybe this is a network of some kind. But if we take smaller systems and piece them together into bigger ones, and our bigger system exhibits some new property that our smaller ones did not, uh, this might be known as an emergent property than the sum of its parts.

Jess: Yeah, so Brian, do you want to just, uh, explicate your example in biology? Just to reinforce it?

Brian: Yeah, uh, definitely it's the essence is that like something that is more than just the sum of its parts. Um, in biology there's specific phenomenon that are, I think, classical examples of like emergence. So you've got like, uh, synchronous fireflies, you know, uh, that fireflies make uh, their flashes and if they do this as a group, they start to all synchronize on the same pattern in an interesting way. You've got things like the structures that ants and termites can make as a collective. But I do think that emergent properties are actually very, it's almost like they're too abundant. It's just a matter of scale. If you look at anything too closely, you realize you can't really explain it unless you step back a bit. So, you know, biology, all of it is rooted in chemistry in the physical world, but you can't chemicals to explain all living things. So emergent properties in the broad sense, I think are just like a very huge thing that all scientists have to deal within their methods of explanations. But in biology, and what I'm interested in, it's mainly about, like, how a collective of organisms can do something as a group that none of the individuals are really controlling. But collectively, they all can perform it together.

Catherine: I feel like this kind of ties sort of emergent properties, like is our perception of reality kind of an emergent property of everything we've experienced either like, I'm not saying it's actually, you know, technical definition of emergent property, but it feels like how we understand the world comes from, you know, the, our genetics, our culture, our experiences, and life. And I'm just wondering like, what are your thoughts? Just emergent properties of themselves, like as math, the entire field of math, and emergence of every little different subfield. And same thing for biology, is that an emergence of all other sciences?

Andrea: Math feels like it is very decidedly not emergent. There's definitely things that are kind of on the border of like what is or isn't math, but it does seem like math as a field is kind of just, here's all these subjects in math. Here's how they fit together. Um, there can definitely be results that like are kind of emergent in this way of, of two subjects that like don't have very much connection to, uh, to, to one another. Someone realizes that there's actually this really deep connection between the two, that, that no one had noticed before. Um, so there's definitely like a degree to which like things mix with each other and there is complexity and interaction and new areas of math can kind of spring about nowhere because of unexpected things that already exist. But it is also very like, and I mean- I also don't know that it is, math as a field kind of does just feel like it's the sum of all of the subfields that, that, that it consists of to me.

Jess: Yay, we found an example of non-emergent property. Yeah. Well, I mean, you were saying, from my understanding of category theory, which we haven't gotten into a lot in this conversation, and might not because of time, but is category theory a way of being able to unify the various fields of math and have them be able to speak to each other? Is it like a common language between fields? And can we think about this common language? worth like trying to pursue this common language that unifies all these sums to understand their emergent property? You know?

Andrea: Yeah. Yeah. I mean, that's definitely what, what, uh, I would say proponents of category theory would certainly like to, to say that yeah, category theory is like a unifying language to all math. I think something that is true about category theory is that pretty much all today is built off of set theory and category theory can model set theory. And so you can create any mathematical results that exists based on set theory in the context of category theory, and you can construct category theory itself without the notion of sets per se. Um. I don't think that's necessarily effective to spend your time taking mathematical results that- I mean, uh, the- this is a thing that people do. People take mathematical results that already exist,

turn them into a categorical version, and then use that to prove new stuff about it. This is categorification as a subject, which I would say, like, my work is- probably best understood as being within that like broader domain. I don't think, and I mean, so useful stuff does come out of doing this. I'm also highly skeptical of trying to just turn all of math into being in terms of category theory and then saying, look, we did new things. We turned math into being in category theory. Yay. Uh, it feels a little silly to me. Um, but I mean, I, I do think that category theory like very much excels at, at, at, mathematically examining what the relationship between mathematical structures is. That is category theory's bread and butter. And so it is very good for- You could say it's very good for unifying all of math under one umbrella. I would, I wouldn't necessarily disagree with that, but I don't think that's interesting to unify all of math under one umbrella. I do think that it is very good at translating between different areas of mathematics and making precise how different areas of math relate to each other and, and what those connections are.

Catherine: Brian, I want you to jump in as well, but before we continue, I just want to clarify for our audience and for myself what category theory is. And my understanding is that like, so you have sets or we'll just call them groups. And these groups have different components in them, right? And they relate to another group that has other different components. And category theory examines not the objects themselves, but rather the relationship between group A and group B, and then you can kind of, I guess, fractal this where you can make bigger groups that have these two smaller groups and then look at another giant group and that relationship and so on and so forth. Is that a correct sort of, I don't know, basic rudimentary understanding of category theory?

Andrea: I would say so. I want to push back on your language choice because a group is a different mathematical object, which is not what we're referring to here. Yes, I think that what you are saying is, is, is, I would agree with that. Um, I, yeah, you will hear me be very precise about my language because, like, mathematics is full of lots of definitions where we define the certain words to mean the certain mathematical concept and lots of existing words that we might use casually to refer to things, um, like have different mathematical definitions. And so like they're kind of like reserved words for that particular thing kind of so like that wait, that's not a group You're not talking about groups here talking. Yeah. Yeah. Yeah, that's that that's roughly the idea.

Brian: Yeah, um I'm wondering uh so I know I've heard that like mathematicians like blackboards and early you uh reference that you said that blackboards are better than whiteboards. Um, uh-huh. I'm

imagining if I came across a blackboard that mathematicians were writing on If, if I would think that it's a category theorist involved, if instead of like formulas where like this plus this equals that, you just have a bunch of arrows pointing to different things.

Andrea: Yes. That is, that is exactly what it looks like. I, I was literally just yesterday, I was in my office on a whiteboard, unfortunately, not a blackboard.

Brian: Oh no.

Andrea: But making a big, so, so, so what you are describing in the category theory parlance is a cumulative diagram, basically, where you draw your mathematical objects and then you draw little arrows denoting a relationship between one object and the next. And then you look at how you take a whole bunch of these different objects and put a whole bunch of arrows between them. And if I look at this big picture, and that's called a cumulative diagram. And yeah, you are absolutely right. I would say... This is going to make me sound horribly, uh, like, uh, self, um, uh, complimentary or whatever, but I, I would think that a good category theorist would also, um, accompany such a cumulative diagram by also having a lot of formulas and whatnot in the more classical way as well and equations and whatever. That is not to insult people who don't have that, but I'd say as far as like what my own work is concerned with, there needs to be a balance of those two things. But in terms of what the category theory part itself looks like, you are dead on. It is a bunch of little like symbols. So it's like here's A, here's B, here's C, here's D, here's an arrow from A to B, here's an arrow from A to C, et cetera, et cetera.

Brian: My chalkboard would just be a bunch of like circles of like either filled in or not filled in at drawn in ways where it looks like they're fighting each other. And just basically like a step by step like you have them in this scenario, then you have them in this scenario. And maybe this is the explanation. Like, that would be what my drawings look like.

Catherine: So like it seems to me that like both you kind of in a sense study relationships either through category theory or through social insects right, Brian? So like guess I kind of want to hear how I guess studying that like what are the relationships that you see in social evolution?

Brian: Well, uh I'm pausing because there's specific interactions that are cool that I could talk about of just like what individual animals do and those are their relationships. But I feel like the far

out philosophical extension of this is that in social evolutionary biology, we had to realize that when we talk about relationships between a bunch of separate already making these huge assumptions about the biological world. I know that it's obvious to just say, I am a human, my name's Brian, I am one thing, but I am also made up of trillions of cells and the thing that I perceive as one thing, one unbreakable unit is actually a breakable unit made up of many different parts. And so this is relevant to social evolutionary because the reason we can understand selfish survival of the fittest framework, how, what you would expect to be selfish organisms doing things. Why we would, why we can still explain why they are selfless sometimes is because we've kind of changed what the self is. Selfish versus selflessness, you, is not a problem when you start to change what your definition of self is. And so an ant colony is called your super organism because it has similarities to your multicellular body and so in the same way that it's not weird to question like, oh why is this cell in your body doing this? You just explain it as like, well it benefits the whole body. You can do that with groups of animals in certain situations. I don't know if that answers what you're talking about.

Jess: It's interesting because it seems like when you feel like you're unlocking an emergent level, like say a superorganism, that seeing it as that, it seems like it's always because we notice some resemblance to a different lower level structure, right? We're like, oh, it's metaphorical thinking, I feel like, in a way where it's like, oh, wow, a colony is kind of like an individual. And now we think about the colony as an individual and see what happens when we do so. How often do you feel like identifying these emergent properties as seeing it is just like drawing a metaphor to like a different one. Like, where do you think it's not?

Brian: Um, well, it definitely is, or like, you know, analogies are what drives this to just realize that like, you know, I'm pretty sure the reason why, uh, ants have been studied so well and are like such a well-known topic and model for social evolution is because humans throughout time, throughout history, around the just look at these tiny insects walking single file in a line, carrying these together and just being like, huh, that's, that's kind of like what we do. That's weird. Like we, we are organized groups too. Like it's just, you know, you see, you see small creatures doing things that are like similar to what your own society does. And so that analogy fuels you to like, try to understand or, you know, in the end, there are plenty of differences, but the, the analogies make you find patterns. I mean, I think the, so like saying, oh, look, we have this new framework of an organism and basing it off of, like you're saying, like a metaphor of just another level of organization we've noticed. I, uh, there, I think the difficult thing is to understand, like, is

there basically like five levels that have happened or is it more of a spectrum on how you define things. But you know, that's just like all things. It can be changed based on changing your theories about the relationships between all the units in these systems. Do you want to ask a follow-up question to clarify what you were wondering or?

Jess: No, no, no. I think that's getting at it. I'm thinking about these emergent properties as we've discussed them kind of in the beginning too, and just thinking when do we actually draw this line where we're like, okay, now this is a higher level thing that we're looking at that is its own thing that's not the sum of its parts. I think about, for my example of an emergent property might be like these bacteria that like get together and help this squid to bioluminescent at night. The bacteria individually can't glow or they don't glow, but when they all come together in the light organs of the squid, they have this density-dependent relationship where now they are more than the sum of their parts because they can glow as a unit. Now they're like a glowing unit. So I'm like, okay, this feels like now a level that now natural selection can act on, right? That's how we define it, it seems like in biology, right? It's like, what does selection see? Like, what is a phenotype or a trait now that we can like favor through time? So I guess like I'm just trying to like have more like concrete examples of just like when that like takes place, like, what is the new unit?

Brian: Yes, cause like those things like that bioluminescence example. They certainly, like visually, they look like a unit because as, if you only saw one of them, you wouldn't be able to see one of them. They wouldn't have a glowing effect that you could notice. But if all of them are together in that environment in those conditions, then you get this phenomenon of glowing. So like once it reaches the point where you can visually see a glowing thing, then it's like, look at that thing, that singular thing. And yeah. But for when talking about like individuals in biology and I've been talking about how like, you know, a cell is an individual, but I made up of cells is also an individual. I really feel like the, my preferred trait to focus on is units of reproduction. So I think that's why it makes sense to consider a multicellular body as one body separate from another one, not just because it's physically separated from other ones, but because that entire body can replicate itself. Um, and the same with like ants, basically you can view the colony reproduces because all of the workers don't do the reproduction, they just have their queen or a few queens do it. So I feel like the most important trait to focus on to explain these levels of unity is to look at what is unified during reproduction and what can reproduce itself. So you can talk about the unity found within a forest and all of the species there, but the idea of a forest replicating itself is really odd, you know, they can spread, they can grow, they can, an island can come up

and then now it has a forest on it, but to view that forest as just like the offspring of a forest from mainland feels like not a good model or explanation. It doesn't really cover things and there's certainly a lot of variation that is not accounted for by saying like this thing birthed this other thing. So yeah, I like, yeah, I'll just say that.

Catherine: Though wouldn't that break down when you start thinking about mules, Brian?

Brian: Mules?

Catherine: Yes. That can't reproduce.

Brian: Oh yeah, no, definitely. And that's, it goes back to the species concept too. Yeah. And also, well, there's other examples. There's a, well, viruses are considered maybe not alive because they require to be inside of living cells to function. So there's some species, I think it's a famous species. Is it cichlids? It's a kind of fish. No, it's Amazon mollies. I think it is. That they actually require mating with other populations in order to reproduce. Without getting into the details of it, it's like some would argue whether they are a species because they need to have another species in order to keep reproducing. Mules being something that on its own, it's a product of hybridization if I'm correct, itself, but it can't propagate itself. So it seems like not its own separate thing if it can't propagate. But then we can make this even more complicated by just saying like, well, every living thing needs its environment, so it needs other things around in order for it to function. So you could say, I think that's why some people like Lovelock and Margulis and the Gaia hypothesis have extended like individuality to the point of entire systems or planets as if all those parts need each other in order for any of that part to make sense or exist. But I do think that, you know, to go back to why I feel like Division of Labor or just following a reproducing unit makes sense is that that seems to be the essential - I think that's the most important quality out of all the qualities that Living Things have is the way they replicate themselves. I'll just leave it at that. We could argue that too, but yeah. Yeah.

Catherine: So Andrea, I'm wondering, do you have like a similar sort of, not like reproduction, but like a similar trait or something that you use kind of as a definer cutoff for what you consider to be a unit of interest for you and your work?

Andrea: Oh, okay. Um... I mean... I mean, I guess, I guess it's very easy for me because so, so we've talked about what category theory does, but we haven't said what a category is. So, so mathematically,

a category is just something that consists of objects and relationships between objects. And typically when we use categories, we specify that all of the objects in that that type of object and all of the relationships between objects are those kinds of relationships. I'm not saying what that and those are, it's just something. So this makes it really easy to say, here is exactly what we're looking at, we're only looking at things that satisfy these properties. Yeah, I mean, you can get into weirdness there in terms of like, there's definitely lots of edge cases with whatever you're looking at of things that they do satisfy all the properties, but like only barely. And it's like, what does only barely mean in the sense, eh, I don't know, who knows. But yeah, I, I think math tends to be fairly clear cut in terms of like, everything is very precisely defined and so it is very easy to This thing is either like something else or is not like something else. It goes into this category or it doesn't go into this category.

Jess: Cool. We are kind of going over, but is everyone still okay to be here?

Andrea: I'm good until three, I will say.

Jess: Okay. Yeah, I mean, yeah, we don't have to push this idea any further, but I think it is interesting to think about what is the similarity, I guess, then, between all these emergent properties and how you know when it's relevant to study at that level. Um, do we feel like there's anything else to say about that? Like determining the level of relevancy for your question, I guess.

Brian: I can at least add that I, I think it's in biology, it's, I think it's fine to have like intuition and non-explained logic, scientifically proved or whatever, like reasons to believe something as an individual or not. I mean, it's, it's a starting point. And I think. You know, of course we have viewed things that, creatures that are similar to us around our same size behave like individuals are, are, are like perception of what an individual organism is. And yet there is all these cases out there where it stretches what an organism is or isn't. It also stretches what like is considered alive or isn't. But, um, I don't view it as too much of a problem because I just feel like we understand there's just an intuition about it that we're fine with that being the baseline that you can then argue from. While, you know, I'll say that you could argue about whether a squirrel is an individual or not, but I feel like regardless of science and perhaps across cultures, the perception of that squirrel, there's at least enough similarities there, even if we can't really talk about it and agree on a set of, like, seven rules that define what a squirrel is or isn't. Um, you know what I mean?

Jess: I think it is like, yeah, worth highlighting just like the role that intuition plays and how there are just these similarities across time. I wonder, are there similarities in terms of the different systems of logic, Andrea? Because you had mentioned that there were different systems of logic. Do you have any examples of those and how they're-

Andrea: Yeah, that has been fleshed out well mathematically is called intuitionist logic. Um, it is nearly identical to classical logic, except for one rule. Um, if you look at the, like, uh, there's, there's something like or . I forget how many there are sub- I think it's is the number of like primitive axioms from which all of logic is built under classical logic. Logic doesn't like one of those axioms. It is an axiom called the law of the excluded middle, which says that for any proposition or any statement about the world any mathematical statement, et cetera, that statement, or either that statement is true or that statement is false, one of those two has to be the state of reality. So, so, intuitionist logic rejects that. And as a result, you get kind of an intermediate truth value that is neither true or false. And that truth value is not not true. Not not true, under Intuitionist logic, is not the same as true, but still there. So, so. Um, so there's, there's one instance, um, I'd say the other like notion of logic, there's a few other systems of logic that reject other axioms. That's the main one I know of. Um, I should note there's other things to intuitionism besides this. This is like the, the main thing, but, but, um, there's, there's other mathematical axioms, uh, I mentioned before that most of math is built on ZFCs or Zermelo-Fraenkel set theory with choice. Intuitionists typically reject the axiom of choice as well. Um, uh, so there's one example, another one, uh, that like I'm aware of historically, but I don't know how much it's been fleshed out mathematically, um, uh, is the, um, I don't know what like the appropriate term is for like the system of logic that it encapsulates, But I know in Buddhism and Indian philosophy, there's this thing called the Tetralemma that is giving four truth values of something can either be true or false, or neither true nor false, or both true and false. I think it would be very interesting to investigate this mathematically, but I don't know how much has been done in that respect. But yeah, so those are the two systems of logic that I can name off the top of my head that are not classical logic or Boolean logic.

Jess: Yeah, oh, Brian, were you gonna?

Brian: Well, first I was gonna say Axiom of Choice just sounds so like
cool and dramatic and biblical. It's like Prometheus stealing the light of knowledge from the gods. You have like the axiom of choice

was provided and these mathematicians said, no, I don't want it.

Andrea: Like yeah. I mean, I can, axiom of choice is one of those things I can say simply what it is. So, so everyone accepts the axiom of finite choice, which says, if you have a set of finitely many things, you can choose something from that set. Um. And I mean, this is usually uncontroversial. It's fairly uncontroversial to say, I want to choose one thing from this set, even if the set is infinitely big. It is a little more controversial when you say, I have infinitely many sets, and I want to choose one thing from each of those infinitely many sets. You get weird stuff when you do this, if you allow one to choose one thing from infinitely many sets if you have a large enough infinity as your number of sets that you're choosing things from. One mathematical consequence of this is that you can do some mathematical wizardry to take a ball, a like solid ball, maybe it's made of iron or whatever, the hypothetical mathematical ball though, and cut it up into infinitely many slices and rotate those slices around and then put those back together once and then put them back together twice and get two balls, each of which have the same volume as the original one. You just copied it by cutting up into infinitely many pieces and rotating it a bunch. This is known as the Bonack-Tarski paradox. This comes directly out of accepting axiom of choice as true. And for that reason, some people say we should reject axiom of choice in its full generality. We should only allow axiom of choice for a certain small enough infinity, uh, that you're, you're choosing one element from each, each set of, or, or we should only accept finite axiom of choice, uh, et cetera. Um, so that is, that, that is what axiom of choice says and what it does. Yeah.

Brian: Um, I was, I was trying to read some like articles about category theory so that I could understand it more. Um, and there were like some sentences I saw that I wondered, this is from like a quanta magazine article I was reading. So I think, I think they're pretty good source, but I wanted to know if you feel like yes or no, these sentences, uh, like do explain category theory or like, no, that's, that's something else. Um, so one of the sentences was. To say that plus equals and leave it at that is to overlook all the different ways in which they're equal.

Andrea: Um, I don't know that describes category theory as a subject, but it does definitely get at something that category theory has, which is multiple different notions of sameness. So, something my advisor likes to say is, what the hell do you mean A equals B? A doesn't equal B, they're different letters, you know? Uh, and, and, uh, I, I think the notion of equality is something that many mathematicians take for granted, but is not a very precise thing. There are multiple senses in which things could be equal to each

other. And so category theory gives a language for expressing a bunch of these different notions of equality. Like roughly speaking, there's kind of four tiers that are generally accepted. There's strict equality which only applies if the two things are the same thing. They're exactly the same. Um, and there is still a little wiggliness about what does it actually mean for them to be the same thing, but sure, we'll, we'll take that. Then there is isomorphism, which is two things have all of the same properties as each other and are essentially indistinguishable from each other. They might not be the same, but you could, they're, they're like perfect identical twins of, oh, one is sick. the other is gonna sub in for the first one at school, uh, no one, no one knows the difference, maybe that's a silly example or something, but, um, but so, so, so there's that. And then a little weaker than that, you have the notion of equivalence, um, where, where they don't need to be quite so indistinguishable, but they need to have, uh, like most of their things, most of their things need to be in common with each other. And then weaker than that, you have a junction, which also There's a nice particular relationship between these two things that makes them special and lets you translate facts about one into facts about the other and vice versa, but it might not be that they have all the same properties.

Brian: Yeah, I think that helps a lot because the idea of being able to just question a little bit further what you mean by these two things are the same, it makes a lot of sense. could say, you know, you've got humans that are twins and people can imply, oh, they're the same person, but it's like, they look the same, but there's so many other differences about them. And there's a lot of things where like, if you say two things are alike, you can at least realize that they're not alike in every single possible quality you can measure and perceive. Right. Yeah.

Catherine: So, Brian, what is that? Do you think like comes into play with like ants and, you know, recognizing each other, whether or not they're from the same colony or not, how like precise are we going here? I mean, obviously, I assume ants aren't doing, you know, genetic analyses on every single ant they're going to come across, but like, how deep is it? I know there's some levels like pheromones and stuff, but are there other like factors like location or I don't know?

Brian: Yeah, so about like, you know, because it's like ants in a colony and the all have similar enough smells on their surface, so they will other, when they interact with each other, they certainly interact in a different way than if they encountered an ant from a different colony who smells different. In the species I worked with, they're called Argentine ants, but they're just a specific species

from Argentina that invaded California. They're super aggressive. If anything starts to smell slightly different from them, they will, well, any ant that starts to smell different from them, they will act pretty aggressive towards it. I think it's easy to view this as they use a material thing, they use a chemical cue, they simply like notice if that cue is their own or not. You know, it's as simple as like, you know, there's group A, there's group B, group A notices that B is different. But I think, of course, you know, when you look into this you realize you don't know what's going on in the animal's head and it's not as simple as just like exactly one chemical component that's found anywhere on the surface and that leads to rejection. It's way more...Aggression is expressed in a much more varied way. It is not this like on or off you either have the cue or you don't. So it's kind of like, certainly these ants don't have passports where they just simply show like, look, I have the passport, therefore, no more question about it. It's more of like they're just noticing some general qualities that seem indicate sameness I think this is like, it's what I wish I could just study forever. I just feel like we, we assume that just like we assumed that like a species has an essence that makes it different from other species and that there's just like a real fine line here. There isn't a fine line in that like objectively defines one society as, as separate and different from another. You know, I, I could go to the example of the immune system of our own bodies. So just like how I've talked about how ants are similar to multicellular bodies before, our own multicellular bodies have immune systems that decide what living things get to be in here and grow in here or not. They try to reject things that seem to be bad. But that process is incredibly complicated. And even though we've studied it for so long and we know about it well enough to make things like vaccines and medicines and understand immunity, the idea that there's just like a list of bad things and a list of good things and your body just like checks those off it doesn't make sense like e-coli can be accepted in some situations and rejected in others so it's to get to your point it's just that I think there's so much we don't know and what's fascinating is that even though in the same way that we try to puta category on things to say like this is one ant group and this is another ant group but it's not really that objective the ants themselves are trying to do that but they also achieve that same objectivity. So it's really cool to study that for that reason. Like I'm just amazed with how like they just experience smells and for some reason that smell means like I need to fight you. And I just don't know why.

Jess: Yeah, I feel like that's what convinces me too of like, sorry if my service is a little choppy, I don't know if I cut anyone off, but yeah, like that's what convinces me too that like there maybe are like so much real categories or maybe real is the wrong word, but

just that like species themselves are using them, right? Like when we're trying to define like what is a species, what isn't, like the actual species are like mating with ones that they see as same and not Or maybe we just never see the results of like the pairs that are not correct But it is really like nice to see that's not just a category we're imposing. It's like ones that these animals are seeking themselves

Catherine: Yeah, and I feel like this ties back to what Andrea was saying with like how she's describing how different mathematicians Like figure out like what is this equal to that? I see that like reflected in other parts of the world as well just like what you said like this species is going to hybridize with this one, we know they aren't the same. But to that animal, it's like, well, you're close enough to whatever. Like, and that's how you get hybrids that are somewhat viable, like, you know, um, between flowers or animals or with Brian's example with ants. I guess if you like to spray a bunch of chemicals enough on this one ant this part, yeah, it's same enough for the little worker that comes across it, right?

Brian: Well, yeah. And, um, I mean, like to see how ants use this to kind of like program sameness is really cool. Like when they're, when they're born, they don't have these smells because the smells are in their exoskeletons and they don't have those until they're an adult. But in order to, if you grow up in a colony where you are getting groomed on by other ants, you're, you're having that identity put on you. And so you're, yeah ,it's, it's just like, you're, you're able to actually just have something put on you. are now, same enough. I think what's so cool is, is, is not like how fascinating it is to think that, like, what if we could just ask those ants, who do they think like it's part of their society or not? But what I think is so cool is that even if you could ask them that, you'd ask one and like, who, like who is, what defines your colony and they'd be like, oh, you know, compounds A, B and C. And then the ant next to them would be like, oh, I thought it was C, D and E. Like, I don't think they all have the same like, homogenous perception of membership. They just have all of these... there's an emergent... I view colony membership as this kind of emergent thing where no individual holds the true identity and there's no true identity that others are being compared to. But there's something way more loose than that and yet it still functions enough so that you have these very strictly aggressively maintained boundaries.

Jess: So are these boundaries maintained through like policing of like what like or like how are these boundaries like maintained?

Brian: Yeah policing is a word that has been used in research of like social insights because especially with like bees they you know you

can use the word guard too because they they have like an entrance and bees at that entrance are usually doing the role of noticing whether a bee smells different or not but I bring up the bees as an interesting like when talking about how these boundaries are enforced because honeybees are notorious for like, they kind of don't care unless the going gets tough. So there's certain seasons of the year when nectars are harder to get to. That's when they'll actually like start to try to raid each other's hives for honey. And that's when guards will notice that, wait a minute, you don't smell the same and start fighting each other. But other times of the year, you can easily like mix individuals and it's very likely that, actually, I mean, I don't know how likely this is, but I've heard it proposed before that when colony collapse happens, like when a bee hive has suffered enough that it reaches a point where now it just scatters and everyone's gone because they don't just all drop dead in the same pile. They just kind of scatter and you don't see them again once they reach a small enough size. It's very possible that those bees are just going to join other hives, that they're capable of joining other hives. that it's not like this perfect like, oh, you smell different, therefore you will be rejected.

Catherine: You know, kind of going back to what I was saying a while ago, this like overarching theme that I kind of see throughout our conversation today is that of like relationships and like studying relationships. So for the two of you, do you think that is kind of like the, I don't know, like how, do you think that's kind of ultimately how discovery works?

Brian: just seeing how things relate to each other, because I can see in my own dissertation work that how I came up with my thesis was like, well, we looked at this thing in one organism, and it's similar to my current study species, so there's a relationship there. So let's see if this phenomenon also occurs in my study species. So yeah, I guess the question I am posing to the two of you is, do you think, yeah, is how studying relationships is how we uncover new information. I'll say for biology, I'm pretty sure that relationships between the things that we're studying is so fundamental to the science of biology because we kind of have this, what was the term I was going to say? We kind of have an axiom of relationships, this assumption that all living things come from the same original living thing. We don't have any good reason to believe that the living things on earth come from separate origins of life from non-life. Um, and so, you know, in, in the same way that we were talking about before, like a chalkboard with a bunch of arrows being category theory, biology is a chalkboard with a bunch of arrows radiating from a common source.

Andrea: I'd say in math, category theory wouldn't exist if everyone was already studying the relationships as being a way to, to, to discover or invent new mathematical and constructions and theorems and whatnot. Looking at relationships is not the only way that you can do math. Um, and category theory did not exist as a subject until the s, which was after a lot of other mathematical subjects had already existed for a while. It did not become clear, I would say, until like the past century that studying relationships were a very important thing to studying mathematics as a whole. Um, it is important. It's not the only thing, But it is very important, I would say.

Brian: I was wondering, kind of relating back to before when we were talking about like cultural influence on these theories. Category theory was very recent, you just said, but where did it start? Was it in the US? Where was it?

Andrea: Well, okay. So it's the two people that are kind of credited as having pioneered the subject are Saunders Mac Lane Um, fuck what's Eilenberg's first name? I forgot Eilenberg's first name. Um, Eilenberg. Yeah. First name unknown. Um, I, I want to say that was in the U S I'm not sure though.

Brian: Uh, do you, do you just like, what is your perception of like how, how it's the world participate in this or is it mainly like from certain universities that you know of or?

Andrea: Right. So that one's a very interesting question. I would say category theory is most contentious in the US, I would say out of anywhere. I would say it's generally a somewhat contentious subject in math because there are some very strong advocates for it who think it is going to revolutionize all of mathematics, and there are some old school people who think that it is absolutely useless and just a bunch of abstract nonsense. I don't necessarily agree with either of those perspectives, I'd say I'm more in the middle. But my perception is that category theory is more popular in English speaking countries than other countries, but also not as popular in the US as it is in Canada and England and Australia. Um, it seems like a lot of Europe uses category theory and is more willing to teach it and, and is, is like more of an expectation that people know about it. But I don't think as many people in other parts of Europe, besides the UK, are actively researching like heavy ca- like category theory for category theory's sake, category theory itself stuff. I'd say my, my guess is that probably the reason why it might be taught more in Europe is because my understanding is that pure math in general is a little more popular in Europe than it is elsewhere in the world and category theory is very good for solving certain kinds of problems in pure math. Um, but, but in that context, it would explicitly be like as a

tool for other problems rather than like as a subject that one would do research on in its own right. Yeah, I guess I would say by contrast though, like even if I would say category theory is a little less popular in the US overall, it is also where we see the most, like the US is also where we see the most like category theory being applied to another subject outside of math the most I would say. And this is like, I think this is largely just because we are now getting into a very particular field of not just category theory, which is already a niche field, but category theory applied to other things. And so at that like fine of a grain, it's really more just about like who are these specific faculty and researchers who are investigating this stuff? And a lot of them are centered in the US. English-speaking countries, Canada and Australia.

Jess: Cool. Okay, well, I do feel like we should probably wrap it up. It's getting to be a long episode, but we usually end by just asking what each of you have sort of learned from each other or have inspired in each other. So if anyone, whoever has an idea. Yeah, Brian, you want to go first?

Brian: The time I'm going to retain from our conversations is the tetralemma. I'm going to just keep trying to frame things as not only true or false, but also both false and true or neither false nor true if I'm getting it correct. So that's it. I've never bothered thinking about things that way. I've always just bothered like, is it right or is it not? So I wonder.

Andrea: Yeah. Yeah. I mean, I feel like I've learned a lot about ant behavior that I did not know before. Um, I'm definitely going to be thinking about that. Um, I'll probably be thinking about like, oh, what mathematical tools would we use to model these kinds of like larger ant phenomena from smaller ant phenomena? You know, how do you, how do you get an ant colony as a structure of these individual interactions? It's a very puzzling question.

Jess: Awesome, those would have been my two also. The Tetra Lemma is so interesting, like how you can deal with contradiction better like that. And I don't know, I think that's important in a complex system, right?

Catherine: Yeah, I feel like that could help so much with science because it's like, oh, p-value is greater than .. Toss it away, but like, that doesn't mean that all right, it bad, you know. Yeah. But anyway, we'll thank the both of you, Brian and Andrea, for having a very long chat with us, but it's been such a fun couple of hours.

Brian: Yeah, it's great. Thanks for having me.

Andrea: Yeah, I agree. Thank you for inviting us. I've enjoyed the talk.

Jess: Wow, okay, that was such a cool episode, but so complex. So yeah, let's just start talking about, to me, I'm also taking away what Brian took away, which is this idea of the Tetralemma. And I think what was so cool about that to me is that it's another form of logic that can seemingly allow for contradictions better. Because when we were talking about all the other forms of like either A or B is true and then the intuitive logic got to say that neither of them, right, that the thing it added, if I'm remembering correctly, was that like it could be possible that neither are true but then the tetralemma included that both could also be true and the fact that that one is not as explored of a type of logic system I think reflects a lot about contradictions and how we don't like them. And so I thought it was really interesting in that sense.

Catherine: Yeah. I guess that's a lot of it, at least for us, like our training as scientists, how we're taught to approach our predictions, our hypotheses is to have two sides that should be mutually exclusive, like A makes B bigger or A makes B smaller. You can't have both. Or can you have both? Who knows? And I think it just plays into a lot of what our conversations have been about. Just like in science, we're trying to explore and explain phenomena. That often means having to simplify it when the world is so complex. So maybe sometimes A does make B bigger. It depends on other variables that we haven't measured. And similarly, in other situations, A makes B smaller.

Jess: Yeah, well that's interesting too, this idea of the simplifying, how we have to simplify. Because I was thinking about Brian's example of the map and the map of the kingdom, right? We want to simplify with our models to have a map that represents the territory and reality, right? Our model being the map, the territory being reality. And we want our models to approximate reality as much as they can. even possible unless we literally put a map over it and have everything one-to-one, like the size, is it everything like that? Because otherwise we are taking out details, right? Weare selecting what we think is important to:, ::, include in the model and not, and we don't always know what details are important or not. And so there's definitely some assumptions that go into that. But then the other side of that is that if we don't simplify, if we do just have a model or a map that is directly on the territory, we actually can't make projections either, right? And that's what we want to do.

Catherine: There's no use in a life scale map. You can't carry it around. You can't put it at... copy of your city which what's the point then?

Jess: Yeah it's like all you know it's the overfitting concept it's like all you know then is your kingdom really well and you can't know anything else.

Catherine: Yeah you can't generalize it for sure. And I guess this kind of reminds me of something that Andrea said, and it stuck with me for a while, was when she was talking about her advisor saying, you know, what do you mean equals B? They're different. And like, I guess it's because a lot of times when we're doing, I don't know, science, I guess, again, we're saying this sample here is a representative of the population. So in a way, I feel like we're saying, you know, A is B, but they are different, even if they're similar in certain ways.

Jess: Yeah, that's something like really interesting to me is when we say A is equal to B, it's like we know it's not exactly, but we're saying that it's equal in the properties that we care about. And so, and then like kind of eliminating like the other things that differ between them, but that like aren't of interest, it seems like, right?

Catherine: Yeah, I guess so, because like I'm thinking just, you know, a math equation. If A is equal to B plus C minus D or something, we're saying that A is only the product of three things, B, C, and D. But we're focused on BCD.

Jess: Yeah. Yeah. It becomes like kind of a placeholder. Um, heathland, and it's just like, it really makes me think about what, um, how we define sameness and difference, like, right? Cause it's like, we can focus on, uh, the properties A and B share in one context. But then we could take A and say it's equal to C over here, if we are like different characteristics. And so I guess that's why like it's important, you know, this idea of isomorphism that they bring up, right? Like I think isomorphism is supposed to be that the two things you're comparing map to each other one to one. But I worry that sometimes we only see isomorphism because we're only looking at like certain properties. I guess it comes down to pragmatism, right? Are these things same? Should we see these as same for the purpose that we're trying to fulfill? Like a species, right? Yeah, members of this species are going to be different, but for the purpose of reproducing and having a viable offspring, they're same enough in certain ways. You know what I'm saying?

Catherine: Yeah, this kind of what Brian brought up with how ants recognize each other and how sometimes, or maybe it wasn't ants, I

think it was bees, where sometimes bees don't mind, stranger bees, and sometimes they do mind. So it's kind of like, are you same enough in this context that will make me want to attack you or not attack you?

Jess: Yeah, yeah. I was thinking of that same example because I feel like that is cool in the sense that it's very contextual, right? And I'm not sure math is always able to be that contextual when thinking about sameness. I don't know enough about math, but I think that, you know, that's really, really useful for us to think about is like, how sometimes the boundaries of self are very strict, and then how sometimes they're not, and it's not anything inherent about the organisms themselves all the time. Even with the ants, Brian was saying they use the cuticular hydrocarbons on their surface to sense self versus other, but they also were given those through their social context, right? They're groomed by their society members. They have like these traces of the environment that are these kind of physical manifestations of context. And so yeah, it's kind of cool in the biological world how context is brought in and how it matters in strictly patrolling same versus different. You know?

Catherine: Yeah, definitely. I'm going to say, I think this is the first episode where I went in absolutely knowing nothing about at least one of the fields, which was in this case, math, at least math beyond calculus and all the greater higher levels of math that really does become philosophical. So for me, I mean, this conversation was just so fascinating to hear about what math is and like that you can explore different fields in math and you can have theories about math. And I just thought that was so cool. But also like this episode was one that required me to actually sit down and like, you know, think and process this new information. And it's so interesting to hear like what Andrea was saying about what even mathematicians think about the usefulness of math, like whether or not math is real or not. But like there's one camp that's like math is real and like it's like the only thing that's real versus math is useful, but that's it.

Jess: Yeah, I think that's something we have to think about a lot. Not just in math, but in science more broadly is just like, are our representations and understanding of the world really reality? Or is it pragmatic? Is it useful for sending people to space or doing all these various things that really give us a lot of faith in science being a really good description of reality. But I guess, and I think of course, it's probably one of the best things we have, but it begs the question of should, or is, this pragmatism, is this ability of science to produce results and be predictable. That feels like we understand reality, right? like when we can predict when something's going to happen and it does, like that feels like our map is really like getting close to the territory, you know, but then in biological

sciences it's like, and when you started adding in interactions in general, you know, even in physics, right, like things become really hard to predict because the more interactions you have, the more possible outcomes there can be. And so then, you know, this kind of gets into the emergent property thing, you know, the outcome, the emergent outcome of all these interactions can be so different from just like one little change, you know, and we aren't even aware of all the interactions going on, you know.

Catherine: Yeah, and it just blows my mind to think how scaling works and like how at a small scale, it's like you have different rules compared to at a large scale. You have, let's say, ants, because that's what we've been talking about ants. So an ant doing one thing, it doesn't scale up as you would scale up a picture for the colony. The colony doesn't behave like one big ant. It has different behaviors. It's so interesting, but it's also cool what Brian said is that we'll just think of the colony as an organism, which got me thinking like, yeah, our cells have rules for themselves and our entire bodies though, we don't always see those rules play out. I mean, I can't do, I can't replicate myself. I can't bud off and clone myself, but my cells can.

Jess: There's rules, and there's behaviors, and there's traits that emerge that aren't the same at the next scale. So it's like, yeah, a colony now can do a new thing that an ant could never do. And so it's playing by different rules now because it has new capabilities. Right? And so, yeah, that's something so interesting to me about emergent properties is literally it is this source of novelty that can now have an influence in the world. It's now a thing. But it's like you can't make sense of it by the sum of its parts per se, because the sum of its parts don't do the thing. And also like it's so complicated what led up to that, that it's hard to reproduce, you know? So that's an hell.

Catherine: And similarly with category theory, as Andrea was saying, how you have sets that become part of sets, that become part of sets, and so on and so on and so forth. all these paradoxes that come, like if you have unlimited amounts of sets, can you make an unlimited amount of sets from an unlimited amount of set? And I think that dives into just this hierarchical, like, complexity of life. Like, how far can we keep going down or keep going up in terms of scale 'til it just stops making sense?

Jess: Yeah, right. I was thinking about that too, because it's like you could kind of go into infinity, like in both directions, small and large. But there is this intuitive aspect that they both talked about, right? Where we intuitively recognize something as a unit all of a sudden, right? We recognize, even though we area bunch of cells,

we recognize our body as a unit. We recognize our society as a unit, you know? And so I was starting to think maybe the reason that we - and that we...And I brought this up in the episode, it's just like, I think that sometimes we rely on these kind of self-referential analogies or metaphors between the levels of description, right? Where it's like, okay, this ant's body has this division of labor of the cells, and then the ant society has the division of labor of the ants, so where some ants kind of serve as the gonads that reproduce, the queen, right. And some ants are like the skin cells that defend the body but don't reproduce but are important. And it's like it's only through having that like one-to-one metaphorical mapping that we recognize this emergent level as its own unit, right? So it's kind of an interesting because it's definitely a property of relevancy for us like rather than necessarily like it being anymore real of a unit. I guess with evolution though, we're trying to figure out what is natural selection seeing? And I mean, that's a metaphor too, right? Like selection doesn't see. But like, is natural selection seeing these same units that we see? Like, is natural selection acting on a colony or the acting on individuals or genes, right?

Catherine: Well, that's a whole can of worms I don't want to open because, well, biologists don't agree on that. We don't agree on many things. and what is life? Biology, like I said, whenever I teach, life is complicated in many ways, and biology is complicated because of that.

Jess: Well, yeah, and then what I didn't think about too, when you just were talking about the sets, being nested in sets though, is it was something that Brian said about how it's like, yeah, you can think about a cell, like, or the DNA, right? as it's something, but it actually doesn't make sense if it's not in a cell and if it's not in a body. So all of these things that it's within really do define it in some way? Or you can't take it out of that nested weird context that it is in, because then it just isn't the same. So I guess context again and interactions are seen.

Catherine: Yeah, and what set theory and like category theory focuses on as we learned it's those arrows between your different sets that's what it looks at, not the sets Themselves, but how they relate to each other which reminds me of figuring out how do ants relate to each other, how colonies relate to the environment, so it's like I guess it's ecology but the study the relationship between you know organisms and their other organisms or the non-living components of their environment.

Jess: Yeah, that was something that was a big takeaway for me is just like, I'm trying to go into the world now as a scientist thinking about relationships rather than static properties, right? Because we

define stuff all the time by like, okay, we see this as a unit now, we got it. And we want to look at it, we want to break it open and look at what's inside that unit and define it by its like inherent properties in this sort of static way. But like, you know, everything is created by these interactions and relationships and those relationships are always changing, which then also changes the object, right? And so really like these units like are not so static, I think. Not in the sense we need to treat them as these static things we can grab on to and count and quantify. But then it's like by thinking about their connections to each other that really makes it destabilized because things are always in the process of changing through the new types of relationships they can have.

Catherine: Yeah, that reminds me of a joke that one of my lab mates and good friends in my lab always says. She's in the neuroscience program and kind of a joke that she says to like jokingly tease on some of the other students in her program is that how they're so focused on like what this neuron or this brain cell does in a petri dish, but not in the broader context of this organism as a whole. Its behavior because how a cell responds to a stimulus, you know, when it's not giving or receiving input from any other parts of the body. It could be so different to how an actual live organism works. And again, broadening that out to, okay, you have the whole organism. It's not living in a black box alone. It's living probably in some environment that has food, that has predators, that has other conspecifics. Again, we have if you look at everything and if we study things globally, it's the math versus the entire town problem.

Jess: Yeah, it's true. I think it's really just a limitation of our computational power and our own. We have to define our systems narrowly so that we can make sense of them. That's the thing is we're trying to look for causality a lot of the times, and so we take actors, right? Like we bring the things into a lab and we control everything except the variable we're interested in, but in the process that disembodies the object of interest from its context, which its context is also a part of creating what it is. So, you know, I guess this gets again at like, what we're doing is useful and it definitely has like beneficial impacts for us. But is it getting close to reality? Or, you know, like, I don't know, because it feels like it is, like, it feels like we're getting close to reality, we can predict things, but then all these studies, like, are done in this context that disembodies the objects of interest from their context.

Catherine: Yamahtta's true, but, you know, not to take away from, you know, the work that someone in cell biology does, it's super cool work and super exciting. Um, but I think that's why we just need more collaborations and more crosstalk. Because yeah, like you said, it's

a matter of our limits. One person cannot study everything. So that's why we should consider other fields more and like, okay, fine, let's, okay, we figured out that the brain does this really cool thing. Let's see what happens in a live animal and so on and so forth, or going down in scale, stuff like that. The relationships that fields have with each other, ha ha this podcast, but also the relationship that we have with each other too.

Jess: Yeah, no, I mean, it's so true. We can't, and I think that's why we divide. The field of science is divided into so many sub-disciplines because in a way, these emergent levels now, they... How do I want to phrase this? We have this complex network of genes, but then that does create this more simple unit of a body. And now it is a little bit more simple at this one level, and we can see how at this one level where it's simple, it interacts with other things at that level that are simplified through becoming an emergent property. So I guess it is good just to have people looking at these different scales. is going to be like the common language between the different scales, right? And I don't know, I don't know the solution to that, but it's cool.

Catherine: Yeah. And not just the sciences, but other areas of research, history, the arts, the humanities, social sciences. I mean, there's, you know, a little utopian, but like, I feel like there's so much that all of our fields can and take away from each other.

Jess: We can all be interesting new emergent properties through collaborations, you know? Like every one of these episodes, there's an emergence of ideas that never existed before because we put together things that had never been in connection. Well, not never, but really, these two people have never talked in this context ever before and so they can create stuff. new and that's the benefit right of connections and relationships is like new emergent properties is how we get novelty in the building blocks for us to play with.

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