SCIENCE OF THE NOOSPHERE

Deborah Gordon

with

David Sloan Wilson

David Sloan Wilson: Okay, Deborah, thank you for talking with me.

Deborah Gordon: Thanks. It's great to be here.

DSW: And basically we're here to talk about the concept of organism as something which is more general than just you and me bounded by our skins and you're a great person to talk to about that because you study social insect colonies as a superorganism and so how would you define the concept of organism in a way that's sufficiently general, that it can encompass more than just what we obviously think of as organisms?

DG: I guess the more we learn about biology, the more fuzzy the idea of organism becomes because we are learning that everything that we think of as an individual organism is actually composed of many different organisms. So it's very hard to say what an organism is. For an ant colony, we think about what reproduces. So an ant colony consists of one or more reproductive females who lay the eggs and then all the ants that are walking around are sterile female workers, but the ants can't make more ants, it takes a whole colony to make more colonies. So in that sense, the colony is a reproductive individual and we can think of it as an organism in the sense that it makes more of its own kind.

DSW: Right. And of course, also it's a highly cooperative unit. Right?

DG: Well, they all work together to function as a colony and to make more colonies.

DSW: Right. Although there is a concept of cheating, right? There is a sense in which natural selection takes place within a colony. Is that right to a degree?

DG: Well, there've been a lot of different efforts to partition out the fitness or contributions of each component of a colony, but it's very difficult to do because we don't really know how to measure how much each individual contributes and how much each individual gets. So it's very hard to take it apart because it's very difficult to parse out what an ant gives to the colony by going out to get food, as opposed to what an ant gives to the colony by laying an egg.

DSW: Well now there's a mental component to the superorganism, which is something that you study a lot. Right? So the concept of a group mind comes along with the concept of a superorganism. So in what sense is mentality a group process in an ant colony?

DG: Well, we don't really see ant colonies writing books or doing differential calculus, but we can see that colonies function as a collection of different independent entities that work together. You could call that a mind. I mean, that's also how a brain works, but whether an ant colony performs intellectual operations, I guess that would only be true if you define it in the barest Turing sense that it can distinguish between states and make decisions, but don't really see an ant colony as doing intellectual work.

DSW: Well, foraging decisions, for example, the same kind of decisions that an individual organism makes with optimal foraging theory, for example, within an individual is made by a social insect colony, right? But that the individual ants are playing a role in a distributed process. Is that-

DG: That's right. So colony adjusts its effort to different tasks. So for example, it could change how much it's foraging in response to how much food is available, in response to what it costs to go out and get the food. For example, the desert ants that I study have to manage a trade-off with water loss because they have to spend water because they lose water to evaporation. So they have to spend water to go outside and look for food. So you could say that the colony is making decisions about whether it's worth it today to go out and forage given how much food there is out there and how dry it is. Now would you call that the act of a mind? I don't know.

DSW: I would.

DG: You would?

DSW: So, one of the great things about your work is that you talk about this and basically in relation to the environment of a colony and so a desert ant such as your harvester ants is confronted with one set of trade-offs, as opposed to a tropical ant, for example, in a human environment and lots of competition and so that requires... They're both distributed systems, but different kinds of distributed systems.

DG: Right.

DSW: Could you elaborate on that a little bit?

DG: Well, I think that, ants are a good way to understand how collective behavior evolves in relation to the kinds of changing conditions that the system has to deal with. And so, we can see by looking at ants that have evolved in the desert and ants that have evolved in the tropical forest, we can see the different kinds of collective behavior have evolved.

DSW: And then there's some sort of feed-forward systems as I think you put that in the case of the harvester ants, something good has to happen before they go out and in the case of the tropical ants, something bad has to happen for them to go in. Can you elaborate on that a little bit?

DG: Well, all ant colonies, all collective systems operate using very local interactions that in the aggregate create the behavior of the whole system. And for the desert ants, those interactions generate positive feedback.

That is, foragers don't go out to forage unless they have enough contact with returning foragers with food. So the more food there is out there, the faster they find it, the faster they come back and the more ants go out. So that's positive feedback. And the outcome of that for the system is that they don't go out unless it's worthwhile. So, it sets the default to not go out unless something good is happening.

In the tropical forest I study another kind of ant. Those are a turtle ants. They live in the canopy, they make these elaborate trail networks in the canopy. And they use a different kind of system that basically just keeps going unless something bad happens. So you could call that negative feedback. If a competing species shows up, if there's a rupture, if something happens to stop it, then they will slow down until they can repair it and fix it. But otherwise the default is just to keep going.

DSW: That's so great. And so, I know that you've written on ties with basically human technology, you call the ants, the Anternet. And so, what is the connection between the kind of distributed process in which each agent is responding to its local environment? Well, actually you've written quite broadly on this. So, cancer and the immune system and all of these are systems in which the agents are, well, the system as a whole is adaptive, but the agents are responding only to their given locality. So what's the application for the Internet? How does the Anternet inform the Internet?

DG: Well, the system that the harvester ants use is analogous to the system that's used in the internet. There's a protocol called TCP, which regulates how much data goes out in relation to the amount of the available bandwidth. So it also uses positive feedback. So when you press the button to send your email message, the data goes out in packets and each packet doesn't go out unless it's received an acknowledgement that the previous packet had the bandwidth to go on. So the more bandwidth there is, the more likely the system is to be reinforced to send out more. So it's positive feedback. So I worked on a model of the system and harvester ants with Balaji Prabhakar, who's a computer scientist who noticed this analogy between how that protocol in the Internet works and how these ants are regulating their foraging activity. So, that's the connection that we call the Anternet.

DSW: So you've actually studied a large number of ant colonies, even so that you could actually look at natural selection in action, during a drought of the many colonies that you're monitoring and you actually see some surviving, and so on. Can you elaborate on your studies at that scale?

DG: I've been tracking the same population of colonies since I was a grad student. So, there are about 300 colonies a year and just counted it all up. So I've tracked 1,057 colonies over this time, over 30 years and not all of the original ones are still with us. So by tracking the same colonies year after year, I found out how long they live. They live for 20 to 30 years. And-

DSW: You meant the average colony does?

DG: Yes.

DSW: Okay.

DG: A colony is founded by a single queen and she has one mating session in the first few weeks of her life. And she stores the sperm, digs a hole, starts a colony, and she goes on producing all of the ants and all of the reproductives year after year, until eventually when she dies, there's nobody to make more ants and in the colony dies.

DSW: There's no replacement queens or anything?

DG: That's right. They don't adopt another queen.

DSW: Wow.

DG: So during the time that we've been studying this population, things have changed. So from 1988 to about the year 2000 was a very wet period. And from 2003 on, there's been a drought. And in fact, there's another study looking at tree rings, suggesting that period, the two periods of this study, were first the wettest period in the Southwest, in the last thousand years or so, and then the driest. And it looks like the dry side is going to win out. I mean, it looks like it's just going to get hotter and drier.

And so we've seen very different relations among colonies and how they compete for foraging area, and how this foraging behavior regulated in response to humidity. The consequences for the colony are quite different when it's dry. So the ants don't go out unless they have a high enough rate of ants coming in with food. And they tend not to go out when it's really dry. But colonies are different. So some colonies are more likely to reduce foraging when it's dry. So they sacrifice getting food in order to conserve water.

And what we found is that in the midst of the drought, those colonies are the ones that are more likely to have offspring colonies. So apparently they can store food enough to survive, but losing water is worse and they do better if they actually give up getting food in order to save water. And so we will continue to see if that strategy, that particular way of regulating foraging is more effective as the drought continues.

DSW: Wow. And so, is there some plasticity in a single colony in terms of capable of changing their strategies? What you would call some colony level of learning?

DG: I don't see any evidence that ants learn there's plasticity in the sense that the process itself is stochastic. So no ant is deciding, okay, this is a day when we're going to save water, but in the aggregate, all those ant-by-ant decisions about how much stimulation they need in order to be willing to go out. Those add up to the activity of the colony. And we've been looking actually at differences among individual ants. So we marked ants with colored paint, so we could tell one ant from another. And we looked to see whether within a colony, there were some ants who were just more reluctant to go out when it was dry. And if that were true, then you could see how the differences among colonies would be a result of the distribution of certain types of ants. So one colony that had more wimpy ants who just refuse to go out when it's dry, would end up foraging less, whereas a colony that had fewer of those, would end up foraging more.

But in fact, we didn't find that. We didn't find differences among ants within a colony. So everybody in one colony is equally likely to reduce foraging at a certain humidity level, whereas everybody in another colony seems to be different. So the differences among colonies, aren't due to the components, to the distribution of certain types. And actually, there's a long history in how we think about social insects of imagining that the behavior of the colony is a consequence of the distribution of certain types that you have, so many ants who are like this, and so many ants who were like that. And that, what evolution would be shaping would be that distribution.

DSW: Right. But that's part of the difference between your view of ant colonies and Ed Wilson and Bert Hölldobler.

DG: Yes. So, with respect to this particular decision about how they manage foraging and response to humidity, we don't find that colonies differ in the distribution of certain types, but that everybody in one colony is different from everybody in another. And we're learning that it has something to do with the neurophysiology of dopamine. So we have found that when we give ants dopamine, they're more likely to forage, but the ones in the colonies that reduce foraging more, respond more to dopamine.

And there's another component that we find the colonies differ in just how much they lose water. So maybe differences in the particular configuration of their exoskeleton or something about their anatomy or something makes some colonies a little bit more likely to lose water. So those are the ones that reduce foraging when it's dry. So they feel a little thirstier or something when they come back from a foraging trip and it's been really hot outside, they're just a little bit more reluctant to go out, but those are more responsive to dopamine. So it seems that dopamine overrides the ants' reluctance to go out when it's dry.

DSW: Okay.

DG: So the differences among colonies may be due to differences among colonies in some small modulation of the dopamine system that leads to these differences in how individuals make decisions.

DSW: That leads to my next question, which is a little bit hard to articulate, but so often, especially inclusive fitness theory explains variation among colonies as due to genetic relatedness.

DG: Yes.

DSW: But when you think of a colony as a complex system, as you do, then it's quite possible that a very small change in a complex system can create a large systemic level effect. Which basically leads to a whole new view of variation in which genetic relatedness, high genetic relatedness, is not perhaps necessary. And so, if you could just elaborate on that, I'd love to hear your views on that.

DG: Nothing about what we understand about the system implicates any role for genetic relatedness in how it works.

DSW: Okay, there's a bold statement.

DG: Yeah. I mean, it's not as though the ants are calculating how much they ought to forage given how much food, one of their true sisters is going to get, rather than one of their half sisters. So I think that that idea...Well, as you know, it all began with Hamilton's beautiful insight about the consequences of relatedness for how a worker would be more related to her sisters than she would be to her own daughters. But in that very beautiful story, the queen mated only once. And we find that in fact, in particular in this system, we know that the queen has to mate many times because there are too different lineages that have to mix. So there don't seem to be many ant colonies out there that follow Hamilton's idea.

DSW: And also, there're some colonies of multiple queens. Right?

DG: Yes. There's some kinds with multiple queens and it seems to be quite common that ant queens mate many times. So the workers are not more related to their sisters than they would be to their own offspring.

DSW: Right.

DG: So that was the origin of this notion that tuning genetic relatedness would somehow tune the relations among ants and drive how the colony works. And I think it's a great idea, it just doesn't seem to apply to ants.

DSW: Right. Well, one of Teilhard's concepts was that a superorganism might consist of a brain of brains that the lower level unit in some respects has this neuron-like status, but in other respects might be quite a sophisticated decision-making unit in its own right. And I know from honeybees that that's certainly the case. That the scout bees, for example, when they were evaluating a cavity, based on Tom Seeley's work, they're making, as individuals, quite nuanced decisions about the quality, multi-dimensional decisions, about the quality of the cavity. And then they go back and they vote in a social process. Is it also the case that an individual ant is in some ways just has a neuron-like status, but in other ways, could be a brain in its own right?

DG: Well, ants do have brains in their own right.

DSW: I mean function in as some kind of autonomous unit?

DG: Yeah. The ants do function as autonomous decision-making units and in the aggregate that creates the decisions of the colony. And I have found over time that it seems to me to be less and less useful to try to take those apart, because you can't really explain anything that the ant is doing except in the context of the colony. But the colony is no more than a bunch of ants. And so, I think that we can go around in circles trying to parse out which part is the individual, and which part is the colony. When those abstractions don't really apply to what's happening. Because what's happening is, ants are doing things and they interact with each other and we call the whole thing a colony.

DSW: Right. So the colony is truly the unit of selection in most respects.

DG: Yes.

DSW: Right, the final question, Deborah, is, I'm sure you're asked all the time, what's the relevance of this great ant work for human complex systems? And how do you answer that question? You already have to a degree, but so what's the relevance of studying this kind of superorganism, the ant superorganism for human social cooperation and so on?

DG: Well, I'll go back to where we started that because of the incredible diversity of ants and what we can learn from them about how collective behavior evolves in very different conditions. Maybe we can see general patterns that we could see also in human systems and in other systems like cellular systems, smaller…and I don't know if humans are bigger, but more towards human and more towards things we think of as more like cells, like bacteria and even cellular systems. So I don't think that people behave like ants or that people ought to try to emulate the ants, or anything like that. But I think that maybe we can learn from looking at the diversity of collective behavior about different possibilities for how collectives can operate and respond to changing conditions.

DSW: Awesome.