Animal Algorithms and Artificial Intelligence

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Announcer:

Greetings and welcome to Mind Matters News. Animals are capable of incredibly impressive and clever feats, from birds migrating across the world to insects building massive complex homes. To talk about these and many other examples, today we're joined by Eric Cassell, author of the book Animal Algorithms. Now, here's your host, Robert J. Marks.

Robert J. Marks:

Greetings. I am your bearded host for this episode, Robert J. Marks. Today, we talk about algorithms and specifically algorithms embedded in animals. An algorithm is a step-by-step procedure to do some task. I have a recipe for my grandfather on making what he called swankem, and all recipes are examples of algorithms. Swankem was a dessert made from old, hard, cold biscuits that they used during the depression. Here's the recipe. First, you break the biscuit in a bowl. You cover the biscuit with two dollops of apple sauce and three teaspoons of sugar. You pour in some fresh cold milk, add a dash of vanilla abstract, and you have the equivalent of a poor man's apple pie. So this recipe for Swankem is an algorithm. It follows a preset list of instructions.

Robert J. Marks:

Algorithms are also in Google Maps. If you go to Google Maps, it gives you directions. Those directions form an algorithm. You're given a sequence of instructions like go six miles south on I35. Take exit 32 A. Turn right, etc., etc. These directions are themselves an algorithm. And very importantly, very significantly, every computer program ever written follows an algorithm. Well, here's what we're going to talk about today. Astonishingly, animals are born knowing remarkable algorithms. What are some of these algorithms, and more interestingly, where do they come from?

Robert J. Marks:

Our guest today, Eric Cassell, has written a book entitled Animal Algorithms. It's a fun read. I endorse the book. It's easily understood. And I tell you, I learned tons about animal behavior from the book. It was really fascinating. The author, Eric Cassell, has a degree in biology from George Mason University, a degree in electrical engineering from Villanova, and a degree in science and religion from Biola University. Maybe he's trying to get more degrees than a compass, but these are very, very important prestigious degrees.

Robert J. Marks:

He has been an engineering consultant for the Federal Aviation Administration, the FAA, and also for NASA. And he has over 40 years of experience in various aspects of systems engineering related to aircraft navigation, air traffic control surveillance, and safety systems. And you notice the first thing I mentioned on here was aircraft navigation. And some of his expertise in navigation proves useful in this book. How do animals navigate? Eric is a technical expert in various aspects of global positioning systems, GPS, which I use every other day. And his interest in animals resulted in the book that we're going to talk about, Animal Algorithms, published by Discovery Press, and that's what we're going to talk about today. Eric, welcome.

Eric Cassell:

Thanks, Bob. I appreciate that very much, and I'm really happy to be here and honored to be interviewed by you.

Robert J. Marks:

Wow! Okay. Well, I'm honored to interview you, so we have a mutual admiration society going on here. Let's go back to the fossil record, Eric. How did you, with your background in engineering, I guess you do have a background in biology, but how did you become interesting in this topic of animal algorithms?

Eric Cassell:

Well, it first started actually before I became more involved with biology. My career, I started out in engineering, and early in my career, I started working on aircraft navigation systems. That was my primary field and actually has continued for all this time, for the most part. After I'd been working in that field for a number of years, just happened to read some articles about bird navigation. And what fascinated me was several things related to that that really impressed me about the way that birds navigate so accurately because some of the birds do some amazing long-distance navigation. For example, Arctic terns migrate between basically the North Pole to the South Pole annually, and there's a number of other birds that do similar types of long-range navigation.

Eric Cassell:

And so, after reading about that, I started to think, "Well, how do they do that? How are they able to navigate so accurately?" In many cases, birds are able to navigate back very precisely to the same local area each year in their annual migration. And then, as I started to read a little bit more about it, it turns out that not just those kinds of birds, but other birds that are able to navigate to other areas where they will nest in a specific region every year. And so the question that occurred to me was, how are they doing that? What's the mechanism? And at that time, this was, again, quite some time ago, although there was a lot of information in the research about the navigation and migration that these birds do, very little was known about exactly how they do it. And so that's what initially piqued my interest in this. And then, as time went on, I became more interested and started to try to learn a lot more about it.

Robert J. Marks:

Okay. You mentioned the idea of a magnetic compass. What's going on here? I read somewhere, Eric, that if you take a homing pigeon, which they used for communications, I think, in World War I and World War II, and you tied a small magnet around their necks that they couldn't go home. It confused them. So what's going on with this magnetic compass?

Eric Cassell:

Right. So in the case of the magnetic compass, that was actually the first navigation sensor, if you will, that scientists had determined that a number of animals were using, including pigeons. And that was the kind of experiment you're talking about. That was one way that they determined that they were actually using the Earth's magnetic field as a source of a navigation sensor. And it turns out that actually pigeons use more than that, but that's one of the methods that they use. And so, in the early days of scientists doing research into this, that was the primary focus. And as they did more research, they found out, well, in fact, it's way more complicated than that. And as time has gone on, they've determined that there's a number of other navigation sensors and navigation sensor information that various animals use.

Eric Cassell:

And to make it more complicated than just the sensor type, one of the things that I think is underappreciated even with the magnetic compass is that it's not just a matter of determining north and south. So, in other words, the magnetic compass does give you fairly accurate direction in terms of north and south, although it's not perfect. The magnetic north actually moves around over time, so it does drift, and so that does affect the accuracy of it. But the other aspect that I think gets overlooked quite a bit is these animals don't just simply move north and south. So, in other words, yeah, we tend to think of, for example, migrating birds. In many instances, they'll migrate between north and south like a lot of the birds. The migratory birds of North America will migrate between North America and South America. So, in general, it is kind of a north and south movement, but that is not always the case.

Eric Cassell:

There are a number of birds that migrate in different directions and, in fact, follow multiple complex routes on their migration paths. So, again, it's more complicated than just knowing north and south. The question then is, okay, if the goal is to migrate, let's just use an example. They need to fly to the Southwest. Well, how do they do that? If you know north and south, that's one thing. How do they know how to fly in the southwesterly direction? That involves two things. The first thing is knowing what is the goal. Where are you trying to fly to?

Robert J. Marks:

Now, Eric, would they travel in the Southwestern ... oh, because that's their destination, I guess. Right?

Eric Cassell:

Well, yeah. For example, there's some birds, and then actually Monarch butterflies are a good example of this, where one population of monarchs migrate between Eastern Canada and a certain region in Mexico. So that's basically migrating from Southwest and then back to Northeast. Right? So then the other problem then is how are they computing that? Okay, you might know you want to fly Southwest. They have to have a mechanism or an algorithm to actually compute that southwesterly direction and follow that path. Even what you tend to think of as a fairly simple migratory path is actually a little bit complicated, and it does involve some mathematics.

Robert J. Marks:

Yeah. You mentioned in your book that they literally use spherical trigonometry, essentially. That was astonishing to me.

Eric Cassell:

Yeah. Well, that's getting into much more sophisticated mathematics and the algorithms that some of these animals use. So this is a little hard to talk about in an audio presentation. If we had a visual, it would be easier to illustrate. But one way to think about it ... and the term that I'm talking about is when animals fly, what we call great circle routes. These are the routes ... that's a term actually that came out of aircraft navigation when aircraft started flying long-distance flights between different continents. And so an easy way to think about it is if an aircraft was flying from, let's say, New York to Tokyo, they're on generally about the same latitude. And if you looked at locations of those two cities on a map, on a flat map, you would think the shortest route would be flying directly west from New York to Tokyo. But in fact, that's not the case.

Eric Cassell:

When you look at it on a globe, it turns out the shortest route is flying almost over the north pole. Those routes go well Northern into Canada. So that's what we call a great circle route. And it turns out there's a number of these birds that do these long-distance migrations that actually do follow great circle routes. And the way that you have to compute that, at least the way we do it in our aircraft navigation systems, there's spherical geometry involved. So that's a complex mathematical calculation to be able to compute and follow such a route. Now, we don't know how animals do this. It's likely that they're using some sort of a shortcut rather than some sophisticated mathematics, but we really have no clue as to how they do that.

Robert J. Marks:

You also mentioned in your book about other cues that birds, and you talked about the Monarch butterfly, that insects use for navigation. I thought this was very interesting that not only the magnetic sensor was used, but other things were used. Could you talk to that?

Eric Cassell:

Yeah, exactly. As the research has continued over the years, and there's been quite a bit of research into this probably over the last 30 to 40 years, they're finding more and more about a number of different navigation cues that animals use in addition to the magnetism. One is a sun compass where they can navigate using the position of the sun. One that's really interesting is where they use not just the sun directly, but the polarization of the sun's rays, which comes in very handy on, for example, cloudy days where you can't see the sun directly. But there is a way of using the way sun refracts through the atmosphere and determining the polarization, and then thereby determining the location of the sun. That is also a really sophisticated, complex mechanism to think about that.

Eric Cassell:

Again, this is something hard to picture on an audio presentation. There's actually a diagram in the book that tries to explain it, but it took me a while just looking at how that was done and trying to understand it. So again, that's another thing that's a mystery as to how animals actually do that. There is other types of sensors. Some animals, particularly some birds, use celestial navigation where they can actually use the stars. So, for example, in the case of the pole star, that's approximate indication of north. Some birds use that to navigate.

Eric Cassell:

Another one that's really interesting is determination of distance. Some animals are actually able to integrate a mechanism that would be the equivalent of an odometer, where they're able to determine the distance that they've traveled. I'll get a little bit more into that one a little later as well. The other method that is really fascinating is one that's not just using the sensor information directly, but there are other methods that animals use where they integrate this information. There's a technique that the animal behaviorists call path integration, which is ... for those familiar with the early days of ship navigation, there's a method called dead reckoning where the ancient mariners would use a technique to determine the distance that the ship has traveled as well as trying to estimate the angular path. In other words, was it traveling east, west, north, etc.?

Eric Cassell:

That was the earliest method of longer distance navigation, primarily with ships. And there's a version of that some animals use, again, that they call path integration, where they're actually able to keep track of the distance that they've traveled as well as the angular path. In other words, again, traveling east or north, etc. And then, what they are able to do with that information is, if they're traveling outbound, for example, they're out foraging or traveling to a location for a new nest or something like that, and then they need to be able to return to their home nest, they use this information during the outbound part of the journey. And even if it's a complex path, in other words, they keep turning, traveling different distances and directions, at the end of the journey and before they return home, this mechanism is able to actually give them the shortest distance route back to their home nest, which is amazing. And again, that involves some complex mathematical calculations in order to do that.

Robert J. Marks:

All of these results are just astonishing. And the thing that's astonishing, and we'll talk about this later, is that these animals are born with these algorithms already embedded inside their brains or whatever they use to perform these operations. It also strikes me that my grandfather, the one that invented swankem and had a third-grade education, said that there's very little that man or nothing ... he said nothing ... that man ever creates that wasn't done first by God in creation. And I was going down the list that you have here, the sun compass, the magnetic compass, celestial, the path integration that you talked about. All of these have been discovered and used by navigators, human navigators. And so we've discovered these things that were already embedded in nature. The one I don't think we've ever used is sun polarization, which is fascinating. I wonder how useful that would be.

Eric Cassell:

Well, actually, if I could interrupt you there for a second, it turns out there's a theory that that has been used.

Robert J. Marks:

Really?

Eric Cassell:

Yeah. The Vikings used a device called a sunstone that's documented in the Viking literature. There's an indication that was used for navigation. The theory is, and there's not a lot of really good direct evidence for it, but there's a lot of information that indicates what the Vikings were doing was using certain types of stone that have specific kinds of crystals in them. And we do know now that these crystals can be used to mimic the indication of the polarized light from the sun, in other words, what we think animals use. On a cloudy day, you can hold these stone crystals up, and when you look at it, you're able to actually determine the polarization of the sun and therefore infer the direction of the sun, so that's been proven. And the speculation is that the Vikings, when they went on these long-distance routes from Scandinavia to Iceland and North America, that they were actually using the sunstone as part of their navigation tool.

Robert J. Marks:

That is just fascinating. I know that we use polarization when we go to the theater and we get these dark glasses. They do the polarization. You can get anti-polarization lenses in your glass glasses so you don't see the glares off of it.

Eric Cassell:

Right. In sunglasses, yeah, etc. Yeah.

Robert J. Marks:

Yeah, exactly. But the fact that polarization was used for navigation, wow, that's really interesting, both in insects and by the Vikings. In the book, you talk about these animal navigation systems, and you talk about how they're engineered. Both you and I have backgrounds in engineering, so I think it'll be fun to talk about some of these examples of engineering of these navigation systems. Could you talk to that?

Eric Cassell:

Sure. And I'll use an example, what I think is a really interesting and fascinating example of it. There's a species of ant called the desert ant. As the name applies, they reside in the desert areas, and the particular species that's been investigated quite a bit is a certain species that resides in Africa. This particular desert ant actually has multiple navigation sensors, and it employs many of the ones we just talked about. It uses the polarized light from the sun, the sun compass. It does use landmark navigation as well. It uses an odometer that I mentioned. And I'll describe that a little bit more in a second. And it also uses chemotaxis. In other words, it uses sensing of chemicals to search for food or its home nest, things like that.

Eric Cassell:

One part of this that's really interesting is the odometer. And there was an interesting experiment done to prove this where the scientists doing the research, they were able to modify the legs on these ants, and they called them stilts and stumps. What they did was they either added stilt, or added to the length of their legs, or in the other part of the experiment, they actually cut down the length of their legs. And the outcome of the experiment was that they were actually able to prove that what the ants are doing is they're actually counting their steps when they travel away from the nest. And they use that as an odometer. And it's just unbelievable that an ant is able to do that. It's actually counting its steps. And then that becomes part of this path integration method where, when you combine the odometer with the angle or the path that's being traveled, again, north or east, etc., using these other compasses-

Robert J. Marks:

So that's an example of path integration that we use. I've seen a lot of people, for example, people that do construction, marking off distances by taking a step and saying each step is equal to three feet or something like that. And they take a number of steps, and they add them up, and that's how long they've gone. So these ants use a similar thing. That's path integration, right?

Eric Cassell:

Yeah. When you combine it with the angular path, right? So you have to know, okay, what direction am I traveling? And then what the ants are doing again is, at the end of their journey, if they've been out foraging, for example, and they need to return to their home nest, they use that. All that information has been stored and integrated. And then they compute the direct path back to the nest. To me, it's just unbelievable that an ant is able to do such a thing. So this, to me ... oh, by the way, one other aspect of this that indicates engineering is it's not just the fact that they have multiple sensors and integrate this information. Part of the control process is that they're able to select the optimal navigation source during that particular journey. In other words, if it's cloudy, they'll use the polarized light compass. If it's sunny, they just use a normal sun compass. In other conditions, they'll use landmarks. And this is all programmed into the ant to select the best method.

Robert J. Marks:

That is astonishing. I'm working on a project now where a system has a number of different potential ways of doing things. And then there is a system that analyzes all these systems and says which is the best one. It sounds exactly ... that's exactly what these are doing. That's really, frankly, astonishing. You have a background in aircraft navigation, and I'm wondering what your opinion is about the comparison of these algorithms to the way that animals navigate.

Eric Cassell:

Yeah. I think there's a direct analogy and comparison with, for example, with what these desert ants do with modern aircraft navigation systems. Modern aircraft use a number of different sensors for navigation. Initially, the first ones were based on ground-based radio systems, where there was transmitters on the ground, and aircraft used the information from these transmitters to estimate their position. When aircraft started doing more long-range navigation, particularly across the oceans, they obviously could not use these ground-based radio systems because they don't have over the horizon capability. So then they figured out, "Okay, what's the best way for an aircraft to determine its position when it's out in the middle of the Atlantic Ocean," for example?

Eric Cassell:

Well, they developed what's called an inertial system where these devices actually measure the aircraft's movement during its flight. In other words, it's able to determine when it turns or banks, accelerates, decelerates, etc. Any movement of the aircraft is captured by these inertial systems, and they use that to actually determine how far and in what direction the aircraft has traveled. And so that's actually very similar to these path integration systems that are used by some animals like the desert ant. And then, more recently, of course, GPS has really revolutionized aircraft navigation because-

Robert J. Marks:

Oh, yeah.

Eric Cassell:

... it's by far the most accurate system that's ever been developed and has become nearly universally used by aircraft. And, of course, like you mentioned, we use it in our cars. We have it in most cell phones now, so you're able to determine where you are pretty accurately. The analogy between the manmade systems and some of the animals is the fact that aircraft systems, again, use multiple sensors and integrate that information and are able to actually ... the way they're programmed today is they're actually able to select the optimum source for the navigation information, again, depending upon certain conditions, so that's all automatically done.

Eric Cassell:

And then the other part of it that is, again, analogous is these are actually backup sensors. So, in other words, in the aircraft design, if one sensor fails for some reason, there's always a backup to switch to.

And the same applies again to animals like the desert ant because they have multiple navigation centers. If one of them is not usable, it simply switches to another one, again, directly analogous to aircraft systems.

Eric Cassell:

Another aspect is the fact that when you build a complex system like that, and these aircraft navigation systems today are highly complex with basically millions of lines of code are required to program these systems, and all that information has to be integrated, and it has to be coherent for the optimum performance. You have to design ... engineering the system to work that way. The same is true for these systems in, for example, and ant. These systems are actually integrated and optimized in a complex manner, so that's a pretty good indication of the engineering involved in an animal system.

Robert J. Marks:

That is astonishing. One of the astonishing things about everything that you're talking about is that these animals are born with all of these algorithms already embedded. It occurred to me that humans have some algorithms embedded in them also. I know when a baby is born, they have a predisposition to recognize faces, for example, and they know that they should go for the breast. So they have rudimentary algorithms also. A question concerning the algorithms for animals is, where do they come from, and how do these algorithms present a problem for what I will call fundamentalist Darwinian evolutionists?

Eric Cassell:

Yeah, and that's the great question, and that's one of the themes I talk about in the book because it does present a problem. It's a conundrum about where does the information come from. There's a number of different aspects of these algorithms. One is, in some cases, for example, the navigation and migration information is, as you indicate, is basically pre-programmed. So, for example, a number of animals are born actually knowing what direction to migrate and the destination where they're trying to migrate to. That information is somehow embedded either within the genome or, in some way, in the animal when they're born. So that's one aspect of these algorithms and the information.

Eric Cassell:

The other aspect is, again, in many cases, these are complex systems, and the navigation information involves, in some cases, sophisticated mathematics, again, your computing, geometric paths that have to be computed through trigonometry and other mathematical techniques. So again, these are algorithms that are somehow embedded in these animals. And at least to date, we really don't have very good indication of how they do that. There has been some research. People are trying to understand this better. There's some indication about some techniques that are embedded into the brains of some animals. But so far, the research really hasn't nailed this down is about how animals are actually performing all of these algorithms.

Robert J. Marks:

One of the examples that you talked about, which is the migration of the Monarch butterfly, how it takes numerous generations, I forget how many, in order for them to get from point A to point B. So they-

Eric Cassell:

Yeah, it takes three generations.

Robert J. Marks:

Three generations! So they fly to some places. The butterflies have babies that grow up that fly the second route, and those butterflies die. They have kids, and they complete the route. And that is just astonishing to me that they can have this predisposition to seek the same goal.

Eric Cassell:

Yeah, right. And that is one of the things that's a big mystery about it. The other mystery that some people recognize, again, I think is maybe a little bit underappreciated, is the fact, like the Monarch butterfly, honeybees, ants, in many cases, these insects, they have really tiny brains. For example, honeybees' brains have less than one million neurons compared to humans and other primates that have billions and billions of neurons. These algorithms are programmed into these extremely tiny brains, which is a good indication that ... the term that's used for a lot of these kinds of behaviors in terms of neuroscience is called a neural network. So, in other words, how the neurons are actually arranged in the brain. Again, it's an indication that there's a lot of sophistication about how these neural networks in such tiny brains are designed, and they must be really efficiently designed to be programmed into such small brains.

Robert J. Marks:

And the question is whether this can be explained by fundamentalist Darwinian evolution, which I think you question.

Eric Cassell:

Yeah, exactly. I think there's a good indication that these are engineering and designed. And the fact that it's very difficult to explain how such complex mechanisms and algorithms come about through basically a random process of trial on error. How can such a complex integrated system evolve through basically a trial and error process?

Robert J. Marks:

How do ants find the closest distance from the Milky Way bar you dropped on the sidewalk back to their anthill? How do bees know how to build their hives or termites, how to build their homes that control temperature? The answer is algorithms, algorithms that these insects are born with, algorithms that are step-by-step procedures for doing something. And remarkably, insects again are born pre-programmed to follow these algorithms. Okay. What is the primary aspect of insect social behavior that makes it so complex?

Eric Cassell:

Well, the thing that's interesting about insects is that many of them have social behavior that involves significant numbers of the animals living in colonies. And these colonies are not just a case of just simply a number of animals just simply living together, sharing a nest, etc. The colonies themselves are actually quite complex. And as time has gone on and scientists investigate these in more detail, they're finding more and more information about just how complex these colonies are. Some of them, the ones that are the largest colonies, scientists define these as being eusocial. And that involves a number of things where, for example, there's a division of labor. You have-

Robert J. Marks:

Okay, eusocial, you're about to define that. It means this division of labor.

Eric Cassell:

Right, right. That's one of the primary indications of what represents a colony of insects that would be eusocial. So there's a division of labor where some of the ants might be responsible for foraging, some of them, for maintenance of the nest, some of them for tending to the queen, some of them for tending to or feeding the young, etc. So there's that aspect. The other aspect of these types of social constructs is the reproduction and how reproduction occurs. In a number of them, in most cases, there's a single queen only that reproduces. Sometimes they have multiple queens.

Eric Cassell:

Basically, what is going on with this division of labor is there's actually different castes. That's a term that's C-A-S-T-E-S, where you're dividing up the group amongst specific subgroups of animals. And these are the subgroups then are the responsibility of doing these different tasks in the colony. And again, when it comes to reproduction, the queen would be the one primarily responsible for producing the offspring. But then there's another caste of males that's responsible for inseminating the queen for reproduction. So there's a lot of division of responsibilities, and that whole aspect of it becomes quite complex in these larger groups that we call eusocial.

Robert J. Marks:

In eusocial swarms, not all insects are created equal. Are they? They can never obtain equality in any way.

Eric Cassell:

Right. That's right. Yeah. And there's some, and we'll talk about this a little bit later as well, but one of the castes, for example, typically does not even reproduce at all in these social colonies.

Robert J. Marks:

In your book, you talk about a superorganism. What is a superorganism?

Eric Cassell:

So that's a term that some of the scientists came up with to talk about these most advanced eusocial organizations. In other words, these are the largest ones. And the reason they call them a superorganism is because the attributes of the colony has a lot of analogy with an organism. So, in other words, what they're saying is, if you think of an organism, we have a number of different organs within our body, the heart, the lungs, brain, skin, etc., doing different functions within the body. And so what they're saying is, in these superorganism's colonies, again, they're made up of thousands, or even some cases, millions of individuals, different groups of animals within that colony are doing different functions.

Eric Cassell:

So what they're saying is you can tend to think of that as the equivalent of an organism. It's just that it's made up of a bunch of different individual animals. And again, some of these superorganisms, particularly ants, termites, they can be comprised of millions of individuals. And some of the research into these ... as an example, in the Amazon rainforest, these types of colonies actually make up a huge portion of the biomass, which is incredible when you think about it, the fact that these animals, the types of animals and the colonies have really become of a dominant form of life in these regions.

Robert J. Marks:

It occurred to me that, in a way, our functioning part of our bodies are kind of like swarms that don't move. We have a bunch of cells, for example, in our lung. Everything, as I understand, from biology starts out as stem cells, and then they become different types of cells. But it seems that in our lung, for example, we have a bunch of cells, and they're not insects, but they're little individual agents that act together towards a greater good. So I guess we're an organism, and the idea insect swarms are a superorganism where these individual agents are crawling around and not directly connected to each other. You mentioned different castes, for example, in the swarm colony. Other than that, what role do algorithms play in insect social colonies?

Eric Cassell:

Well, and you just touched on that. The problem here is the fact that these are separate individuals. When we think of a single organism, there is overall control and coordination amongst the different organs, if you will, within an animal. So, that's all embedded within the animal, controlled within the animal. In the case of these colonies, these are actually separate animals. They are all individual, completely separate, autonomous animals. Then the question arises, okay, how is the behavior of all these individuals controlled?

Eric Cassell:

And the first answer is, there is no overarching overall control. In other words, there's not some higher-level mechanism that controls the behavior of the individuals within the colony that we know of. So that means that the behaviors of the individuals somehow is programmed into each individual such that these algorithms that must reside within the individual and or termite, for example, must be programmed such that they know what task they're supposed to be doing at any given time. That in and of itself must be extremely complex.

Eric Cassell:

And we know that there's a lot of information that actually is being used and exchanged for these animals to make these decisions. So one of the ways that they do this is that they use pheromones, basic chemicals that are exchanged between the individual animals. And these chemicals or pheromones are actually used as an indication. Okay, something is going on in the environment, or something is going on amongst this other group of individuals in the colony, therefore, I must be doing this task, for example, foraging, tending to the queen, etc.

Eric Cassell:

And one of the things that's been found is that there are some ant species that use as many as 30 or 40 different pheromone or chemical compounds that are exchanged amongst the colony. And that also is just, in and of itself, is a highly complex mechanism because you have to have the mechanism within the animal to actually just simply detect the presence of this chemical compound. And then, once you detect it, that information is then used to govern the behavior. So there's a lot going on in these colonies that's controlling their overall behavior as a group because, again, there's a goal here that the behavior of the entire group must be governed to benefit the overall life of the colony.

Robert J. Marks:

I found this fascinating in your book, all of these different pheromones. So you have one pheromone, for example, that tells the ant how to get home. You have another ... I mentioned in the beginning about the shortest distance between the Milky Way bar and the anthill. And the way that's accomplished, as I understand, is that the ans lay down pheromone and that the ants are marching back and forth with little pieces of your Milky Way bar to the anthill, and they follow a pheromone path.

Robert J. Marks:

In fact, I have had fun. If you ever see one of these ant trails, there's a little line of ants going back and forth. If you dampen your fingers and you break that trail, the ants go up to where you've broken the trail, and they get confused. They don't know what to do. They don't know what path to follow. Now, eventually, they break on through to the other side, and they rediscover the path, going back and forth. But just by interrupting that with wetting your fingers and interrupting that path, you have ruined their day. They don't know how to get back and forth. And, of course, I would advise if anybody did this, wash your hands after you're done because you've got ant pheromone on them.

Eric Cassell:

Yeah, and that's exactly right, but that's also an illustration of, in this case, ants. There is a lot of programming going on. In other words, these algorithms are programmed. But the other interesting part of that is that they are actually able to adapt in real-time. In other words, in the example you cited, you broke the path, they still figure out a way to adapt. And the same thing is true-

Robert J. Marks:

They do.

Eric Cassell:

... for other parts of their behaviors, where, if something is going on in the environment, like part of the nest, for example, gets destroyed, you'll see the ants immediately stop what they're doing and go repair the nest. So there's a lot of adaptability in the way they behave, which, again, means these algorithms are highly adaptive and programmed to account for these different contingencies.

Robert J. Marks:

There's lots of engineering applications where we have learned from swarm. One is called the Ant Colony Optimization. It is literally an optimization algorithm that's based on swarm. I have a friend, Russ Everhart, who, with a colleague named Kennedy, had Particle Swarm, which was based on social insect swarms that also performed optimization. And I tell you, one of the most chilling things I think that we have to face today is swarms of drones, where these drones come along in a swarm, and it's just like the anthill you mentioned. You kick it over, and you come back in a week, and it's rebuilt. It's the same thing with these drone swarms of, say, thousands of different drones. And they attack. If you get through, they can accomplish their mission. And this has been chilling. I think that there's ways to counteract those military swarms. But again, these are things that we are learning from swarm technology and the techniques that you're talking about that we can apply to everyday applications in engineering. We're learning from the swarms.

Eric Cassell:

Yeah. And a related aspect of that is artificial intelligence because obviously, drones and a lot of other devices that are being developed today involve artificial intelligence. Right? Well, one of the things that they're learning about it is the fact that it's much more complex to program these drones, even to just mimic what animals do, because the behaviors are actually way more complex than people thought. But then the implication of that is the artificial intelligence, the computer programs, do end up having to be really complex and sophisticated, which again is a further indication of how sophisticated the algorithms are in these animals.

Robert J. Marks:

Yes, yes. And there is a field of artificial intelligence called swarm intelligence that specifically investigates the application of social insect swarms to engineering. What can we learn out of insect social behavior? And it's really a fascinating field. We still get back to where does this come from. What are some of the challenges for naturalism in explaining this behavior, this complex behavior we see in social insect colonies?

Eric Cassell:

So, yeah, there's a number of challenges I believe for Darwinian evolution in explaining this. The complex algorithms is one part of it. Again, as we've mentioned before, if you have a complex algorithm, and if we think of it in terms of, for example, a computer program that is large, has a number of lines of code that we would program, it's again, trying to develop such a system that works properly through a simple trial and error process. In other words, random mutations and natural selection. It's very difficult to see how that kind of a process could result in such a highly complex functional system.

Eric Cassell:

The other aspect of this that's a little bit of a side issue in terms of what I've examined in terms of the book and the social behaviors is the notion of altruism, where, as I mentioned before, there are some castes in these large social colonies of particularly insects that don't reproduce. Okay, you would say, "Well, okay. So what?" But the problem that presents for regular Darwinian evolution is that, for example, under Richard Dawkins' theory of the selfish gene, if an animal doesn't reproduce at all, how does it advance the progeny and contribute to the next generation? Why would such an animal even exist?

Eric Cassell:

But they do exist in these large social colonies, so that has presented a problem. And actually, Darwin even recognized this in his time. He wrote about it where this kind of phenomena, with particularly the social insects, presented a problem for his theory, the fact that these types of ... these castes actually exist in these colonies where they don't even reproduce at all. He wrestled with that. He did not have an explanation. More recently, evolutionary biologists have come up with a theory. They call it inclusive fitness, which basically means that when you examine the group as a whole, the group or species, or population in this case, in a colony benefits from the fact that some subgroups do not reproduce, but they're contributing to the overall existence of the colony and propagating the colony over time by doing certain roles and tasks within the colony, but actually not reproducing.

Eric Cassell:

And they go through ... really, it's a complex mathematical calculation to show that, okay, you're sharing your genes, or at least a portion of your genome, with the other animals in the colony, therefore in a indirect way, you are benefiting, even though that group of animals is not actually reproducing. It's a controversial theory. Many evolution advocates believe that that's a reasonable explanation. Others have contested that, and there's a lot of discussion in the literature that's gone back and forth about this, about whether that theory is actually adequate or not. That issue doesn't really impinge directly on what my assertions are about these issues in terms of social insect colonies and the origin of these behaviors. That is a related issue, but a more fundamental issue, again, is where does the information come from that programs these complex algorithms and controls the behaviors of all these individuals in a colony?

Eric Cassell:

And again, another aspect of this, there actually has been quite a bit of research done that's in the literature, is examining the genomes of a number of these insects, and bees, ants, termites, etc. And what they have found is that the species that engage in these larger social colonies, again, the superorganism type of colonies, the genomes indicate that there's actually a large number of either novel or genes that have been modified in these animals and that they range from hundreds, in some cases, thousands of genes, again, that are either completely novel genes that have no common ancestry in the related animals previous, or they're modified in some way.

Robert J. Marks:

I think I've heard those called orphan genes. Is that right?

Eric Cassell:

Yeah, that's the term they use. They're called orphan genes.

Robert J. Marks:

They have no ancestry.

Eric Cassell:

Right. So again, the question is, does regular Darwinian evolution provide a good explanation for that? And the answer really is no. That's one of the problems that's been a challenge for Darwinian evolution is that really is, again, random mutation, natural selection. How do you explain, for example, hundreds of these novel genes all of a sudden appearing in a population or species? Darwinian evolution really can't explain that. Whereas from more of a design perspective, that's a little bit better, I think, much better explanation that this could be a result of design.

Robert J. Marks:

Naturalism has a rough time explaining some of the incredible properties of the world in which we live. In biology, irreducible complexity is an example. How do we explain complexity that fails when a single component of a complex biological system is removed? It's like the game of Jenga, where removal of any single block in the stack sends the whole stack of blocks just crashing down. Similarly, how do these interdependent components of biology that we see and observe every day combine themselves into a single complex system, an irreducible complex system? There are other biological features that naturalists have a difficult time with. They have a difficult time explaining them. Look, to write an algorithm. There has to be a foundation of information on which to build. What is the source of that information in animal algorithms?

Eric Cassell:

So that's the fundamental question about this particular topic. There's a general problem with evolutionary theory in trying to explain the origin of information. As we know, there's a lot of information that goes into, for example, building and developing an individual animal or other type of organism. So the information, for example, includes how do you build the body? How do you construct the brain of an animal? Things like that, so there's a lot of information involved in all of that. And there's been a lot of research that's gone into those kinds of aspects of animal development.

Eric Cassell:

The aspect that I'm addressing more specifically has to do with these ... the behaviors are the subject of the book. And this particular aspect actually has, I believe, a little bit more of a challenge than maybe the physical development of an organism because, as you indicate, what we're talking about here are actually algorithms that control the behavior. And as we talked about in the previous podcast, many of these algorithms are quite sophisticated and obviously, involve a lot of information that is embedded within the animal in some way and actually is used by the animal in controlling these behaviors.

Eric Cassell:

So again, the question is, where does this information come from? The process of standard Darwinian evolution, again, is one of random variation, mutations, and natural selection. But there's been a lot of work done that show that, in fact, is a inadequate explanation for the origin of this kind of information. There's a concept called as no free lunch theorem that William Dembski has talked about and written about quite a bit. And his research and analysis has shown how it's really difficult or near impossible to generate new information through these purely random kinds of processes. A lot of good information and analysis of that topic is contained in a book called Evolutionary Informatics.

Robert J. Marks:

Yeah, which is a great book. Yes.

Eric Cassell:

I agree. And since you were one of the co-authors of that book, I'd ask you to maybe explain that a little bit more.

Robert J. Marks:

Well, let me talk about no free lunch. There was an astonishing paper published in 1997 by Wolpert and Macready. And it was published in the IEEE Transactions on Evolutionary Programming. And Wolpert and Macready, they toppled a big area in design. It used to be ... well, if you think about it, design itself is an iterative process. I like to use things like WD-40. Why do they call it WD-40? It's called WD-40 because it took 40 tries for the industrial chemist to come up with the final solution. Same thing with formula 409. Formula 409 took 409 experiments before they got it right. Design is search, and you have to bring expertise into the search process, into the design process. If the people doing WD-40 ... I think the guy's name was Larson. If he hadn't been an industrial chemist and they had given this problem to somebody with no domain expertise, like, I don't know, a high school chemistry student, we would be using not WD-40, but WD-one million, 263,000. It's just that domain expertise is incredibly important in design.

Robert J. Marks:

Anyway, getting back to Wolpert and Macready's original paper in 1997, they called it the no free lunch. They weren't the inventors of it, but they were certainly the popularizer of it. But they came up with this idea that if you have no domain expertise, if you don't know what you're talking about, that one technique of searching, of doing the design, is as good as any other. This is just astonishing. And this means that if you do just random search ... random search is blind search where you know nothing ... ah, that's as good as any other search on average.

Robert J. Marks:

There's a movie called UHF that starred Weird Al Yankovic. He was the only star of it. And there's this one short scene where a blind man ... we know he is blind because he's sitting on a park bench with glasses, dark glasses, and a cane. And he has a Rubik's cube, and there's a sighted guy next to him. And the blind guy gives a little twist to the Rubik's cube and shows it to the other guy. And he says, "Is this it?" And the cited guy looks at it, and he says, "Nope." And then the blind guy gives it another twist, and the sighted guy looks at it, and he says, "Is this it?" And the guy says, "Nope." That is an example of blind search. And the fact that they used a blind man to do it is very appropriate.

Robert J. Marks:

And in order to get a result, in order to get a design, you can't use blind search. It just takes too long. That's the reason that the blind guy is never, ever going to solve that Rubik's cube by just saying, "Is this it?" "No." "Is this it?" "No." He has to have some sort of domain expertise to figure out what that Rubik's cube is going to do.

Robert J. Marks:

And so, in every design that we see, and that includes insect algorithms and other things, there has to be an infusion of a designer with domain expertise in order to guide the process, even in the Darwinian example where you have the repeated steps of survival of the fittest, repopulation, and mutation over and over and over again. Think of the survival of the fittest. What determines who is fit and who is not? And that has to come, even in an evolutionary way, that has to come from an expert.

Robert J. Marks:

There is a field in electrical engineering called evolutionary programming, and people use evolutionary algorithms to do this. But the way they do it is they put a lot of domain expertise into figuring out what the fitness is in order to guide the solution teleologically to the final result. And so, when we see incredible designs that Eric Cassell is talking about in insect swarms, and just in general, in animal algorithms, we have to address the question where did it come from. It can't have just originated by random chance. You can't have, is this it, no, is this it, no. Is this a good social algorithm, social swarm algorithm? No, you can't do that. You have to have domain expertise. And this is the evidence for design. Both Eric and I have degrees in electrical engineering. We have design stuff, and we know design when we see it. And you have to have that domain expertise in order to have sophisticated design. So Eric, how'd I do?

Eric Cassell:

That was a great explanation. I appreciate that. I really like your analogy of the Rubik's cube. That's a really good analogy.

Robert J. Marks:

I do use that little clip in some of the talks that I get. The guy is saying, "Is this it?" "No." "Is this it?" "No." And the guy's going to be there forever. You mentioned that many of these algorithms that you're talking about in terms of social insects and animals, in general, they're pretty complex. And they're analogous to computer software programs. Imagine writing a computer software program to do something. You type something randomly on the keyboard. You hit run. And when you hit run, you ask, "Is this it?" "No, this isn't the algorithm." So you type something else, which is random. And then you hit the key, and you say, "Is this it?" "No, it isn't." It'll take you one heck of a long time to come up with the algorithm to do anything using that process, using no domain expertise. You have to know what you're doing. You have to figure out your expertise, and you have to incorporate that expertise, that information, into the algorithm. So what do you think about all this, Eric, in terms of animal algorithms? I guess you're saying it applies there too.

Eric Cassell:

Yeah, exactly. And I think it's directly analogous. I think there's actually two problems. One is the development of the algorithm, as you indicate, just trying to develop an algorithm or a similar computer software program in such a manner. For those of us that have written computer programs, I mean, it seems almost impossible you could ever even do that, particularly for something that's highly complex. But the other aspect of it that I think gets overlooked is the fact that even if you actually are able and somehow to start off with a functioning algorithm or program, if you have all of these random variations or mutations going on in the genome, well, almost always, whenever you have a mutation, it's going to degrade the algorithm. It's not going to provide improved functionality or some new functionality. It's almost inevitable that it actually degrades the algorithm.

Eric Cassell:

And that's actually what has been found when scientists research mutations in genetics is that, for the most part, these mutations actually degrade. In some cases, it's proteins or whatever the gene functionality might be. It's more degratory than helping. And so, that is really a major problem for things like these algorithms that control behaviors because ... let's just take an example. In the case of, again, these large social colonies of insects that involve a number of algorithms and a number of different aspects of behavior, if you have some random mutations going on, and the algorithm gets changed and, in other words, the behaviors get changed, well, it's much more likely than not that such a change is going to be degratory to the organism, to the colony because the animals would be engaging in behaviors that are either the wrong behaviors or the behaviors at the wrong time.

Eric Cassell:

In other words, let's just take one case. Something changed about when the animals, let's say, honeybees, go out to forage for food. Well, if something changes in that algorithm and the honeybees fail to go forwards for the food, the colony is going to die. And so, that's why I'm saying, and more often than not, some kind of a process where you're having these random mutations and the algorithm ends up changing in some way, much more often than not, that's going to be detrimental to the colony. Again, that's something that's hard to square with a process that involves some random process and selection, and presuming that's going to result in optimization. Well, in some cases, maybe there's certain aspects of it that might do that where, if there's some kind of a change in the algorithm of the behavior that's detrimental, maybe in some cases that gets selected out. But for the most part, they're not beneficial, and it's hard to see how such a process can actually result in an optimization of these behaviors or algorithms.

Robert J. Marks:

We see, for example, the lofting of the importance of mutation in the process of Darwinian evolution, but you do not see pregnant mothers lining up at the doctors and saying, "Will you please mutate my baby?" That is not something which is going to happen. So you have to bring it down to practical application. Also, what you're talking about is a topic which is covered, I believe, in Michael Behe's new book, which is Darwin Devolves, which is that we're not getting better and better. We're getting worse. And this was a premise which was put forward by John Sanford earlier in his book, Genetic Entropy, which says that the genome is getting more and more random. And we see more inheritable diseases today and inheritable conditions today than we ever have because we're keeping on mutating, and we're devolving just exactly like you're saying, Eric.

Eric Cassell:

Yeah, and that's right. That's, to me, one major takeaway from bee's research where it's showing that even in some cases where there are genetic changes going on or mutations, and in some cases, they might be beneficial to an organism in the short term, in fact, the benefit comes from a gene that's broken. It actually is a broken gene that, in some ways, they may be beneficial, result in something beneficial to the animal, but really, it's because the gene broke, not because it actually improved the gene or improved the overall genome in some way, or developed some new characteristic. That's not what goes on for the most part.

Robert J. Marks:

Okay. Let's talk about another aspect of animal algorithms, and that's a concept named convergence. I'm familiar with Simon Conway Morris's pioneering work in the concept of convergence in the history of animal development. Talk about convergence as it applies to animal algorithms.

Eric Cassell:

Yeah, convergence is this term that evolutionary theorists apply to characteristics that appear in animals that are actually unrelated. In other words, there's no common ancestry. So it could be some physical characteristic, or in cases what I'm talking about are largely behaviors that appear in animals that have no direct ancestry relationship. And so, that does present a problem for Darwinian evolution, being that how does such a characteristic appear in these different groups of species that are not related in any way. So there's a problem of, okay, if it's a low probability event of these genetic changes occurring in the first place, what's the likelihood of them happening in completely unrelated populations or species? So that's been a problem for evolutionary theory.

Eric Cassell:

And one of the explanations that's been used in some cases, and it does make some sense, is, in this part of evolutionary theory called evo-devo, where a good example might be certain physical characteristics, for example, bird wing design. We know that there is, based on research that was done in developing airplanes, we know there's a lot of constraints in how you construct a wing. So that actually constrains how those wings could be designed in birds. So the idea then is that in the process of evolution, because of these constraints when you have birds developing wings with certain characteristics, and these bird populations or species are completely unrelated, well, it may be because there's these constraints, these physical constraints in how design can even occur in the first place or be functional.

Eric Cassell:

So that's somewhat of a plausible explanation that you could apply to things like that. The same idea would apply to, for example, fish fins. That does actually not work for many of the things that I've addressed in the book. For example, these navigation systems or sensors that animals employ, the different kinds of compass compasses, for example, and other kinds of navigation sensors, there really aren't the same kind of physical design constraints or reasons why an animal would develop a certain kind of navigation center. That analogy just doesn't work, for example, with bird wings. That means that these designs that are used for navigation, for example, are really kind of contingent. They're not deterministic. There's nothing driving a certain kind of design or even the use of a certain sensor.

Eric Cassell:

And as we've seen, animals employ a number of different kinds of sensors in different ways. And some animals use one sensor, two sensors, three sensors, and other animals use others, but there's a lot of commonality that appear in animals, again, that are completely unrelated, no common ancestry. But they're using similar kinds of navigation sensors and systems. Again, that begs the question, where does that come from? Why would that even be the case? My thesis is it's a more plausible explanation that there's common design going on rather than some sort of evolutionary explanation based on this notion of convergence. The same thing applies to, for example, the social behavior, where the biggest groups of animals and insects that engage in these social colonies or ants, bees, and termites. In many cases, the behaviors of these animals in these colonies are very similar. They're not identical, but there's a lot of commonality in these behaviors. And again, they appear in groups of animals that are completely unrelated, no common ancestry. So how does that occur through an evolutionary process? That's difficult to explain. Much easier to explain through a common design.

Robert J. Marks:

Well, this is a problem which is amplified by Simon Conway Morris's work. Now, you're talking about the existence of similar behavior in different species like ants, bees, and termites. Simon Conway Morris was looking at the similarity that happens when you have these geographically separated animals. I don't remember the specifics, but there might be an animal in South America and another one in Japan who have never had the chance of biologically interacting, and they have the same sort of DNA, same sort of attributes, even though they're geographically separated and couldn't have been in the same evolutionary chain if you will. So yeah, this enforces that. This is very interesting.

Eric Cassell:

Yeah, exactly.

Robert J. Marks:

Something interesting in this, naturalists, they contend that evolution has no goal, that evolution ... you're always looking at your toes. Evolution is always looking at your toes. Wherein I think it's more reasonable to assume that there is teleology, that there's a goal which is being pursued. Now you address this in your book, so let's talk about teleology as related to animal algorithms.

Eric Cassell:

Yeah. This is more of a philosophical issue and maybe a higher-level issue that arises, particularly with many of the aspects of behaviors that I've been addressing. If you go back into the history of scientists looking at the world as we see it, particularly organisms and animals, Aristotle had a concept that involved a certain version of teleology. So that was actually a dominant view for quite a long time, until closer to the period of Darwin and the development of evolutionary theory. And subsequent to that, many of the defenders of the evolutionary view basically assert that the concept of teleology or purpose really shouldn't be part of science and doesn't play a role in explaining this. I'm thinking of Richard Dawkins, Michael Ruse, Jerry Cohen, people like that. That's the strong point of view that they have that basically, you can't infer purpose or teleology in aspects of, in this case, animal behavior.

Eric Cassell:

I use a term in the book. I refer to the people that take that point of view, they have a teleophobia, meaning that they have an aversion to admitting that there's an existence of design or a final cause in nature, which again, gets back to Aristotle's original theory. But I think when you examine the behaviors that are described in the book, in almost every case, you can find that there's a lot of evidence for purpose or goals. So just to take one aspect of this as an example, again, in these social colonies, when you look at particularly the ones that are considered superorganisms, you have a higher level functionality of the colony. There's something that's determining some higher level functionality that then drives all of the individual behaviors that the, in this case, insects engage in. So something is setting some higher-level goal or purpose, and all of the functions that go on within the colony are supporting that higher-level goal or purpose.

Eric Cassell:

And there's plenty of evidence to say that's the case, and the same thing could be said about many of the other kinds of behaviors that I talk about. That kind of higher-level goal or purpose fits more within a design point of view than it does, again, with the Darwinian view now where the Darwinian evolutionists are saying, "You can't even admit that's a case. You can't even account try to account for the fact that there might be some higher level purpose to these behaviors because it's just totally contrary to Darwinian evolution." So that's the fundamental problem that's being dealt with.

Robert J. Marks:

In terms of teleology, when I was learning to drive, the first thing my dad told me, he says, "Don't look where you're at. Don't look over the hood. Look at where you're going." And that's the only way to drive. I think that most new drivers are told that I. Yogi Berra has a great saying. He says, "If you don't know where you are going, you will never get there." This is the problem with teleology and having a goal being defined as opposed to just looking at your toes all the time.

Eric Cassell:

And the other thing, just to pick up on that, that is interesting to me as an engineer, from an engineering perspective, when you look again at many of the behaviors and systems that we've talked about, there's significant evidence of engineering. And when you do engineering, you definitely have goals and purposes for how you're designing something.

Robert J. Marks:

Yes.

Eric Cassell:

Whether it be some physical mechanism or behavior, there's a construct there that the engineer has in mind. Okay, this is the purpose. This is the function that I want to design this thing to do. So that's, again, evidence that there is some higher level purpose involved in how these systems or behaviors are designed.

Robert J. Marks:

Thanks, Eric. This has been a great and wonderful chat. I've really enjoyed this time with you. Let me summarize the points, I think, as you have made them. The source of the algorithms in animals requires an explanation. Where does this come from? It can't be from a blind search. Is this it? No. Is this it? No. It can't come from that. Where do the information for all of these algorithms come from, and why is there convergence? Why do we see similar aspects among different species and among geographically separated species? Why do we see such commonality there if there is no teleological aspect of their design? These and other things, and fascinating things, are addressed in Eric Cassell's new book, Animal Algorithms, published by Discovery Press. I have read it. I endorse it, and it's fun and an informative read. So please get a copy if this sort of stuff interests you. So until next time, be of good cheer.

Announcer:

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