The Astonishing Algorithms That Allow Animals to Navigate & Migrate

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Robert 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. 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 extract, 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 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.

Robert Marks:

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? Our guest today, Eric Cassell, has written a book entitled Animal Algorithms. It's a fun read. I endorsed the book. It's easily understood. And I tell you, I learned tons about animal behavior from the book. It was really fascinating.

Robert Marks:

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 important prestigious degrees. 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, it 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 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 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 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?

Eric Cassell:

And at that time, this was, again, quite some a 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 the 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 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 sort of 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 used 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 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. A lot of the birds, the migratory birds in 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. There are a number of birds that migrate in different directions and in fact follow multiple complex routes on their migration paths.

Eric Cassell:

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? So that involves two things. First thing is knowing what is the goal. Where are you trying to fly to.

Robert Marks:

Now, Eric, why 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 actually Monarch butterflies are a good example of this, where one population of Monarchs migrate between sort of Eastern Canada and a certain region in Mexico. So that's basically migrating from southwest and then back to northeast. 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. So 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 Marks:

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

Eric Cassell:

Well, that's where we're 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. 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. When you look at it on a globe, 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.

Eric Cassell:

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 some 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 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 the sun compass where they can navigate using the position of the sun. The 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 the 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. 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. It's a mystery as to how animals actually do that.

Eric Cassell:

There's other types of sensors. Some animals, some birds use celestial navigation, where they can actually use the stars. So, for example, in the case of the pole star, that's a approximate indication of north. Some birds use that to navigate. 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.

Eric Cassell:

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 called path integration, which is, for those familiar with the early days of ship navigation, there was a method called dead reckoning where the ancient mariners would use a technique to determine the distance that the ship has traveled and as well as trying to estimate the angular path. In other words, was it traveling east, west, north, etc. That was the earliest method of longer distance navigation, primarily with ships. And there's sort of a version of that, that some animals use, again, they call it 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.

Eric Cassell:

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 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 fed us 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 that would be.

Eric Cassell:

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

Robert 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 a certain types of stone that have specific kinds of crystals in them. And we do know now that these crystals can be used to sort of mimic the indication of the polarized light from the sun, in other words, what we think animals use. So if you hold... 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 route from Scandinavia to Iceland and North America, that they were actually using the sunstone as part of their navigation tool.

Robert 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 glasses so you don't see the glares off of it.

Eric Cassell:

Right, in sunglasses, yeah, etc.

Robert 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 example 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 implies, 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 then 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 in a little bit more in a second. And it also uses chemotaxis. In other words, it uses sensing 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. Where 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 lengths of their legs. And the outcome of the experiment was that they were actually 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 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 that number of steps and they add them up and that's how long they've gone. So these answers use a similar thing. That's path integration, right?

Eric Cassell:

Yeah. When you combine it with the angular path. 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, 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 then... 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 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. That's exactly what these ants are doing. That's really frankly astonishing. You know, 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, 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's 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 figure 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?" 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 ants.

Eric Cassell:

And then more recently, of course GPS has really revolutionized aircraft navigation, because 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 just 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 programed 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 sensors, if one of them is not usable, it simply switches to another one. Again, directly analogous to aircraft systems. 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. So for the optimal performance, you have to design... Engineering, the system to work that way. The same is true for these systems in, for example, an ant. That 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 Marks:

That is astonishing. You know, 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. You know, 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 that 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, 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 are they trying 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. The other aspect is, again, in many cases, these are complex systems and the navigation information involves, in some cases, sophisticated mathematics. Again, you're 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 sort of techniques that are embedded into the brains of some animals. But so far, the research really hasn't nailed this down about how animals are actually performing all these algorithms.

Robert Marks:

You know, one of the examples that you 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.

Eric Cassell:

Yeah, it takes three generations.

Robert 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 that is just astonishing to me that they can have this predisposition to seek the same goal.

Eric Cassell:

Yeah. 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, 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 brain are designed. And they must be really efficiently designed to be programmed into such small brains.

Robert Marks:

Yeah. And the question is, 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 design. And the fact that it's very difficult to explain how such complex mechanisms and algorithms come about through basically a random process of sort of trial and error. How can such a complex integrated system evolve through basically a trial and error process?

Robert Marks:

This is all so fascinating. Thank you, Eric. We've been talking to Eric Cassell about his new book entitled Animal Algorithms. Next time we'll chat about the algorithms that make insect swarms thrive. What about bees? What about ant hills? What about termites building their incredible nests? So until next time, be of good cheer.

Announcer:

This has been Mind Matters News, with your host, Robert J. Marks. Explore more at mindmatters.ai. That's mindmatters.ai. Mind Matters News is directed and edited by Austin Egbert. The opinions expressed on this program are solely those of the speakers.