Dwarkesh Podcast #79 - David Reich – How One Small Tribe Conquered the World 70,000 Years Ago

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Dwarkesh Patel
Today, I have the pleasure of speaking with David Reich, who is a geneticist of ancient DNA at Harvard. David's work, his lab's work and his field's work, has really transformed our understanding of human history and human evolution. It's fascinating stuff from many perspectives. In its own light it's very interesting. From the perspective of AI, which I plan on asking you about, it's interesting to understand human evolution and what that implies about the future of AI. Anyways, I'll stop doing the introduction.

David, we were just chatting before we started recording about new information you've been studying since the book came out: archaic humans and the relationship between modern humans and Neanderthals. Can you explain again what you're studying these days?

David Reich
What's very interesting is that what we have data from now are modern humans, the sequences of people living today. We also have data from Neanderthals who are archaic humans who lived in western Eurasia for the last couple of hundred thousand years. We have now sequences from many Neanderthals. We also have DNA from Denisovans. Denisovans are archaic humans who were discovered from the DNA from a finger bone that was found in a cave in Siberia. It was not anticipated to be a new group of humans but was sequenced.

So we have DNA from these different sources, plus bits of DNA from these sources mixed into modern populations. Based on this, in the last 10 to 14 years, we collectively have been piecing together an understanding of how modern humans are related to our closest relatives, who are now no longer with us in unmixed form: the Neanderthals, Denisovans and maybe others who are not yet sampled. The model that we have is really a model based on accretion. We start with the modern humans and then we add the Neanderthals once we obtain those sequences. We add the Denisovans and then the model doesn't quite fit and we add other mixture events to make the model fit.

At this point, there's a number of these mixture events that seem increasingly implausible. If you know the history of models of how the earth and the sun relate to each other in ancient Greek times, there's these epicycles that were attached by the Greek, Hellenistic astronomer Ptolemy to make it still possible to describe the movements of the planets and the stars, given a model where the sun revolved around the earth. We've added all of these epicycles to make things fit. One wonders whether there's some pretty fundamental differences that might explain the patterns that are observed.

Just to give you an example of this, the standard model is basically this: modern humans separated from a group ancestral to Denisovans and Neanderthals—these two groups for which we have sequences—somewhere 500,000-750,000 years ago. That's what the genetic papers, beginning in about 2012 and 2014. That's still used as the explanation for the vast

majority of the DNA lineages connecting them. Except for maybe 5% of the DNA, that's what we think is going on. Modern humans are one group and then there's a sister of modern humans, the Denisovan-Neanderthal group. They separated 500,000-750,000 years ago.

But what's become very clear in an important series of papers since that time is that there are exceptions to this. One exception is the mitochondrial sequence, what you get from your mother and what she gets from her mother and so on. The shared ancestor there between Neanderthals and modern humans is only maybe 300,000-400,000 years ago, which is after the split that's well-estimated from the whole genome. We've also learned this is true for the Y chromosome, inherited from father to father. It too is only maybe 300,000 or 400,000 years separated between Neanderthals and modern humans. Like with the mitochondrial DNA, the Denisovans are much more distant, maybe 700,000 years to a million years.

So the story told by these two parts of the genome is really different from the rest of the genome and incompatible with the main story. We know from these papers that maybe a few percent, 3-8%, of Neanderthal DNA comes from a gene flow event into the ancestors of Neanderthals from the modern human lineage a few hundred thousand years ago. It's tempting to think that both the Neanderthal mitochondrial DNA and Y chromosome come from that event. But the probability of that happening by chance is only 5% squared, which is very small.

People have invoked epicycles, like natural selection for the mitochondrial DNA coming from modern humans, or natural selection coming from the Y chromosome coming from modern humans, somehow being more advantageous and pushed up in frequency. But that would have to happen on both these parts of the genome to produce this pattern. It just seems surprising.

What's been put together is a complicated model and epicycle ideas like natural selection to make it work. It's not impossible. It may be the case. But one wonders whether profoundly different models might actually explain the data. That’s something we and others have been thinking about. Can there be other models?

One example we've been playing with is one where there’s much more DNA in Neanderthals from modern humans than the 3-5% estimated. We can get such models to fit but here it’s 30% or 50% or 70%. In that view, Neanderthals and Denisovans are not sisters. In fact, modern humans and Neanderthals are just as qualified to be sisters as Neanderthals and Denisovans. In that case, maybe it's not clear what's modern and what's archaic. Are modern humans archaic? Are modern humans modern? Are Neanderthals archaic? Neanderthals are modern.

What's also become clear in the last few years in a separate thread of research—not based on ancient DNA but based on using more powerful and sophisticated ways of pattern finding in modern data—is that modern humans are also highly substructured. We can see that even without ancient DNA yet. Of course, once one has ancient DNA it's so much clearer. But it's very clear that you can't explain modern African DNA without invoking very extreme substructure, as deep as the mixtures that contributed and mixed between Neanderthals and modern humans. In that mixture, which groups were archaic? Which were modern? Were they both archaic? Was one of them modern? Was one more closely related to Neanderthals and the possibly higher proportion of ancestry? It's not obviously wrong that the model's very different from the standard one we currently have.

Dwarkesh Patel
Interesting. From your book I remember that there are lineages of modern humans that are over 200,000 years separated from other groups, like the San hunter-gatherers from everybody descended from Eurasia. Then you're saying that 100,000 years before that is when we have a sister lineage with Neanderthals. On the new findings about how closely related Neanderthals are to us and how much mitochondrial and Y chromosome DNA they share, what model do you think is the most plausible to explain why there's so much shared ancestry?

David Reich
I'm very agnostic. I really don't know.

Dwarkesh Patel
The models you were just talking about, it sounded like you thought they were low probability. Is there one you think is higher?

David Reich
The models that are considered to be standard dogma are now low probability. There's a standard dogma that's developed over an accretion of papers where the history gets patched. Someone sequences a genome. Someone performs an analysis. Someone proves something that wasn't known before. We claim a mixture event we didn't know about before, an event that we didn't know about before. That gets patched onto the current model, which is now a series of patches.

Nobody has really rethought the whole thing very hard. The whole thing is not obviously very different. You can actually reassemble the whole model in a new way without doing it from the simple model up, but thinking about it again and seeing if it can be all related in new ways, In fact, it might be quite different in the way that I just described.

Dwarkesh Patel
Where did the most recent gene flow between Neanderthals and humans happen? I guess it's not the most recent, because the most recent was 60,000 or whatever years ago. But the one you're referring to here, where physically did that happen?

David Reich
Even that's not clear. Probably such a thing would have occurred somewhere in the Near East or in western Eurasia somehow. It's not even clear where the modern human lineage was residing at that time. The modern human lineage, leading to the great majority of the ancestors of people today, was probably in sub-Saharan Africa for the last 500,000 years at least. It might be much more. Certainly our main lineage was in Africa, probably 3-7 million years ago.

But in a period between about 2 million to 500,000 years ago, it's not at all clear where the main ancestors leading to modern humans were. There were humans throughout many parts of Eurasia and Africa with a parallel increase in brain size and not obviously closer ancestrality to modern humans in one place than in the other. It's not clear where the main lineages were. Maybe they were in both places and mixed to form the lineages that gave rise to people today.

There's been an assumption where Africa's been at the center of everything for many millions of years. Certainly it's been absolutely central at many periods in human history. But in this key period when a lot of important changes happen—when modern humans develop from Homo habilis and Homo erectus all the way to Homo heidelbergensis and the shared ancestor of Neanderthals, modern humans, and Denisovans— that time period which is when a lot of the important change happened, it's not clear, based on the archaeology and genetics, where that occurred as I understand it.

Dwarkesh Patel
We're humans and you would think one of the things history would have figured out is how humans came to be. That's probably one of the biggest questions you could imagine asking of history, of archaeology, of anthropology, of genetics. The conventional model is the thing you're taught in the third grade. This is one of the first things you're taught about the world. The fact that many parts of it could be wrong... We're learning in greater detail what those parts look like, at the very least. We're doing that right now because of new technology that's being used by labs like yours. That's really wild. The audience might not be aware of how much of a change this is in our understanding of the human past. I just really want to emphasize that.

The gene flow event you're talking about a few hundred thousand years ago happened between modern humans and Neanderthals. If it happened outside of Africa, then did that lineage go back to Africa and then come back out again? How should we think about that?

David Reich
The simplest version of this is that the main lineage leading to modern humans is in Africa at this point. As I understand it from talking with the archaeologists and the climatologists, Africa and the Near East are continuous ecological spaces at certain periods of time. So there's no difference between what's now the Near East and Africa. The fauna and the flora are pumped from Africa into the Near East or pumped from the Near East into Africa. The African range goes into that region. It's a place of overlap between Eurasian fauna and flora and African flora and fauna. That's a very natural place for interactions to occur, especially in periods of climate change. Animals, for example, from one region get pumped into the Near East. Then in another period of climate change, they get pumped into Eurasia or the rivers.

Dwarkesh Patel
Because there's a land bridge during different climatic events?

David Reich
There's always a land bridge, but the ecology with deserts and so on makes certain areas permeable or impermeable. In some periods of time, the Near East gets reclaimed by Eurasia somehow, ecologically. In other periods of time, it gets reclaimed by Africa. It's kind of a place of movement of flora and fauna out and in, again and again. I'm not an expert on this. The simplest model would be one in which an extension of the modern human substructure leading to us—the ones that some of those lineages coalesce to form people living today, the great majority of the ancestors—gets into the Near East several hundred thousand years ago and then mixes there with the ancestors of what we have now sequenced as Neanderthals. The skeletons that we have now are Neanderthals.

That gene flow event occurs there. It's modern humans from Africa—or the part of the African population that extends into the Near East—pushing into Neanderthals at that time. We have evidence of modern human incursions since that time into Neanderthal parts of western Eurasia and also in intermediate periods, from the skeletal record and maybe even recent claims in the DNA data. Certainly the genetic data attests to a very strong event a few hundred thousand years ago.

Dwarkesh Patel
How many humans are around at this time? To the extent that all modern humans are descendants of this group, how many different groups of humans are there—no genetically distinct necessarily, but just separate locations or so forth—such that there's enough gene flow between all of them and there's a shared common descent.

David Reich
I don't know. Here's one thing that is really interesting. A couple of years ago, we published a paper on relatively recent hunter-gatherer populations from mostly eastern and central

Africa in order to be able to discern these deep population exchanges that we would really like to know in order to understand human evolution. This included individuals going back up to about 15,000 years ago, which is the oldest DNA from sub-Saharan Africa, which is not very old. Really we would like to be able to probe 2 million years ago, but we can't. But with 15,000-year-old individuals, what you see is many groups at many places all with very reduced diversity. In other words, they look like they're living in tiny populations of hundreds of people and not exchanging DNA with each other very often at all over time. We see this again and again.

You take such a population and put it into a model. If it's this small, what will happen over time? It will lose its diversity over time, and it will become very non-diverse. Over time, Africa will have very little diversity. But of course, Africa today has great human diversity in it. What seems to be happening is that the whole continent of sub-Saharan Africa, and probably Eurasia at this time, is full of hundreds, thousands, tens of thousands of little groups that are communicating hardly at all with each other. They are in very small sizes and losing diversity. When we sample them, this is a group that leaves hardly any descendants at all, maybe none, amongst modern people.

What's actually happening is that occasionally these groups merge together and recharge their diversity. Diversity is maintained in the ensemble of rarely mixing groups. You can't really appreciate the diversity by studying any one group. You actually have to think about the whole ensemble of hundreds or thousands of tens of thousands of them as preserving the diversity. There's some question about the migration rate amongst these groups, an archipelago of little groups losing diversity and going extinct at some level. But together there is enough recontact to recharge the diversity and create the incredibly diverse populations you see today, for example, in southern Africa or western Africa or central Africa.

Dwarkesh Patel
I want to go back to what you were saying. For hundreds of thousands of years—not just with modern humans, but with even the so-called archaic humans, Neanderthals, and other species—there's been selective pressure for larger brains. This is despite the fact that they're in different parts of the world. If you're in Eurasia or if you're in sub-Saharan Africa, either way we finally got to a state where the niche we're in rewards marginal increases in intelligence and is willing to bear the cost of that and keep chugging on that variable.

Do we know why that was the case? What was happening in the world? What was happening with maybe primate brains such that the selective pressure was turning towards greater intelligence?

David Reich
That's a super interesting question. There's a lot of insight and ideas about this topic. It's an area to which genetics right now has contributed almost nothing. I wrote this book, "Who We Are and How We Got Here: Ancient DNA and the New Science of the Human Past". It's a bit of a misleading title or a kind of a bait-and-switch title. The way in which it's a bait-and-switch title is you might read it thinking you're going to learn something about how we became whatever we think is distinctive about us relative to other animals.

So I try very early in the book to say that unfortunately, with the genetic data available up to this point, we don't really have very meaningful insights about what makes us distinct, how we came to be distinct from other animals. What I'm going to tell you about is how we came to be, how we are from another perspective through mixture and migration. It's very surprising how we came to be and how we are through migrations and mixtures. A lot of people used to think that we were not mixed. In fact, it's been mixture again and again in the past in many populations we didn't anticipate.

Your question was about how humans evolved into a distinctive niche that includes having a strong reliance on a large brain, putting a large amount of metabolic energy into the brain, and having a brain relative to body size that is much bigger than is in the past. I have two things that are striking to me about that. One of them is that genomics actually has promise to learn about those things. We are potentially on the verge of learning a lot about those things. We just don't have important new qualitative insights about that topic right now.

The other one is that the large brain was already in place prior to the separation of Neanderthals and modern humans, and maybe Denisovans as well. The common ancestors of Neanderthals and modern humans probably had a brain as large as ours. It's not obvious that there's parallel evolution in multiple parts of the world. It may be that it's a sufficiently interconnected group that it's not a parallel evolution event but a single process.

Dwarkesh Patel
I have so many questions there. When you say that there's a single interconnected population, are you referring not only to basically all of Eurasia but also Africa?

David Reich
Possibly.

Dwarkesh Patel
Basically the whole world, even hundreds of thousands of years ago, can be thought of as having gene flow and being one global population?

David Reich
That's almost certainly true. We don't yet know the frequency of exchange between Africa and Eurasia, but this is 2 million years. It's a lot of time. Paul Salopek is walking around the planet in seven or eight years. People move incredibly quickly. Africa and Eurasia are not really separated by barriers that mean anything very important to a species like ours over periods of even dozens or hundreds or thousands of years. The idea that being in Eurasia or Africa is such a profound barrier that you would not expect people to move from one region to the other in periods of tens of thousands of years or hundreds of thousands of years, that's a strange idea.

Dwarkesh Patel
That's fascinating. By the way, it's so interesting that it's hard to think of the correct terminology when we say people. What kind of people are we talking about? Anyways, the ancestors of modern humans are at least in a position to have gene flow with other archaic humans in the Near East. But it doesn't seem like they expanded out hundreds of thousands of years ago.

If you're right that a lot of the brain size had already been accumulated before this with Neanderthals, then they should have been pretty smart hundreds of thousands of years ago. But they're not expanding out. Then something happened 60,000 years ago. Then this group that descended from the people in sub-Saharan Africa just explodes all across the world. Something seems like it changed. What do you reckon it was?

David Reich
This is outside my area of expertise. I'm being very much like a scientist right here. I'm very sympathetic to the idea that it's hardly genetic. I think that this is cultural innovation. It's very natural to think that this is cultural innovation. Humans sometimes develop a new technique of storing information, sharing information, and so on. For example, writing allows you to record collective knowledge in a library, computational knowledge, large storage devices, and so on and so forth. Language, conceptual language, allows you to create a cultural body of knowledge.

Dwarkesh Patel
You talk in the book about the FOXP2 gene, which modulates language ability not only in humans but in other animals. Obviously, all living humans have it. It's at least 200,000 years old when the human lineage starts to split off. Everybody has language, so what do we think it was?

David Reich
Well, I don't know what we had, what the language was. It's almost certainly the case that Neanderthals were using sounds and communicating in ways that are probably pretty complicated, complex, and amount to some kind of language. But some people think that

language in its modern form is not that old and might coincide with the later Stone Age, Upper Paleolithic revolution, 50,000 to 100,000 years ago, and might be specific to our lineage. There might be a qualitative shift in the type of language that's being used.

There's been one incredibly interesting and weird line of genetic evidence that was so weird that a lot of people I know dropped off the paper. They just didn't want to be associated with it because it was so weird. They just thought it might be wrong. It's stood up, as far as I can tell. It's just so weird. This is one of the surprises that genetics keeps delivering. That's probably going to come across in this conversation. I am pretty humbled by the type of data that I'm involved in collecting. It's very surprising, this type of data. Again and again, it's not what we expect. It just makes me think that things are going to be surprising the next time we look at something that's really not looked at before.

The line of evidence I'm talking about is one based on epigenetic modification of genomes. To explain what that means, the genome is not just a sequence of DNA letters, adenines, thymines, guanines, cytosines: ACTG. It also is decorated in anybody's cells by modifications that tell the genes when to be on and off, in what conditions. An example of such a modification is methylation in cytosine-guanine pairs. This turns down a gene and makes it not functional in certain tissues. This methylation is bestowed by cellular environments—and differs in different cells and also in different species—to identify which genes are more active or more passive. It's not directly encoded by the ACTGs locally. It's encoded by something else and sometimes even passed on by your parent directly. It's really very interesting.

This can be read off ancient genomes. The methylation pattern survives in Denisovan and Neanderthal genomes. We can actually learn which genes were turned down and turned up. Work by David Gokhman, Liran Carmel, and colleagues created these maps of where in the Neanderthal genome, where in the Denisovan genome, and where in modern human genomes, genes are turned on and off. There's a lot of technical complexity to this problem. They identified differentially methylated regions, several thousand parts of the sections of the genome that were consistently and very differently turned down or turned up in Neanderthals and modern humans.

They looked at the set of differentially methylated regions, roughly 1000 of them, that were systematically different on the modern human lineage. They asked what characterized them? Were there particular biological activities that were very unusual on the modern human specific lineage? There was a huge statistical signal that was very, very surprising and unexpected. It was the vocal tract. It was the laryngeal and pharyngeal tract. You can actually learn from little kids with congenital malformations, when a gene gets knocked out by an inborn error of genetic inheritance. For example, kids will have a face that looks different or vocal tract that looks different and so on. You know what the effect of knocking

out these genes is. We can actually imply directionality to how the modern human specific changes are.

The directionality is to change the shape of the vocal tract—which is soft tissue not preserved in the skeletal record—to be like the way ours is distinctive from chimpanzees. The shape that we know is very helpful for the articulation of the range of sounds we use that chimpanzees don't have in their laryngeal and pharyngeal tract. Even though we don't have surviving hard tissue like skeletons from this part of the body, we now have this methylation signature which suggests that these changes have occurred specifically on our lineage and are absent in both the Neanderthal and Denisovan lineages. If you think this change in the vocal tract is important in language, which seems reasonable, then maybe that's telling you that there are very important changes that have happened in the last half million or a few hundred thousand years, specifically on our lineage that were absent in Neanderthals and Denisovans.

Dwarkesh Patel
To the extent that humans have had it for hundreds of thousands of years, it's not clear then why humans weren't able to expand out of Africa and...

David Reich
We don't know that. We just know that today we have it. It could have been only a couple of hundred thousand years ago or 100,000 years ago that these changes happened.

Dwarkesh Patel
But then we know all modern humans have them, different groups of modern humans.

David Reich
Separate 200,000 years ago.

Dwarkesh Patel
So we know it's at least that old, right?

David Reich
Right. Although there is gene flow between all groups of modern humans, at least at low levels, going to 100,000 years. It's just that most of the separation between Khoisan and other groups happened 200,000 years ago.

Dwarkesh Patel
Let me motivate for the audience why this is so fascinating. First, it's obviously interesting. 70,000 years ago there are half a dozen different human species around the world that are pretty different. Fast forward to now, there's one. The fact that happened is wild. Another reason it's interesting for me is because I talk to people who discuss AI. Some have a strong

perspective that you just make the model bigger. It wants to learn so you make it bigger, give it more space, and it'll become intelligent.

One piece of evidence they use is that something happened with the human brain... the brains got bigger... we get humans dominating the entire earth. That's the perspective that if we make these AI models bigger we'll get something very powerful on the other end. To the extent that story is accurate or inaccurate, it might have interesting implications for AI. That's wild. Our anthropology or genetics about the ancient world maybe has some Bayesian update on how well we think these AI models will do in the future.

David Reich
One thing your comment makes me think about is that it doesn't map on in a simple way as an analogy. The human brain is maybe only three times larger than a chimpanzee's. That's not the kind of increase that computability has had since 40 years ago, which is many orders of magnitude. I'm aware of studies that have compared raw computability of chimpanzee babies to human babies. In fact, it's similar. For example, the ability to solve logic puzzles is pretty similar between chimpanzees and humans.

Some people argue that humans are not even more intelligent than chimpanzees at some fundamental ability to compute, and that what makes humans distinctive is social learning abilities. That's where a lot of our ability has gone: our ability to see other people, to empathize with them, to copy them, to incorporate bodies of information learned by other people. I'm not an expert in this topic, but it's a very appealing group of ideas. The adaptations humans have are ones that allow us to access a rich amount of shared knowledge and not just rely on figuring out each thing. That's not obviously the same as just adding more computability. Maybe it has some similarities.

Dwarkesh Patel
I still don't understand. Is the answer that we just don't know what happened 60,000 years ago? Before humans and other modern humans and other types of humans were interacting, but no one was in a dominant position at least in Eurasia. Now humans not only dominate, but in fact we drove them to extinction. Do we have any idea what changed between that time?

David Reich
This is really outside my expertise. There are ideas that have been floated, which I'll summarize possibly badly. In every group of human beings of hundreds of people—which is the size of a band—or sometimes a thousand people, they accumulate shared cultural knowledge about tools, life strategies, and build up shared knowledge more and more. But if you have a limited-sized group that's not interacting with a sufficiently large group of people, occasionally this group has an information loss. There's a natural disaster, key elders die, and knowledge gets lost. There's not a critical mass of shared knowledge. But

once it goes above some kind of critical mass, the group can get larger. The amount of shared knowledge becomes greater. You have a runaway process where an increasing body of shared knowledge of how to make particular tools and patterns of innovation, language, conceptual ideas, run amok.

An example I've heard talked about in this context is what happened with Indigenous Tasmanians. About 10,000 years ago, the ancestors of people in Tasmania—this large island south of Australia—were continuous with the aboriginal populations of Australia. They had fire, but they lost it because it got forgotten somehow. It's a cold place. They just forgot it. The cultural knowledge lost it.

What you actually have in the world 50,000 years ago is tens, or hundreds, or thousands, or tens of thousands, of different human groups. They each possess local knowledge and rarely exchange with each other. When we get lucky in ancient DNA and sample them, they're quite isolated from each other and have reduced diversity in the last tens of generations. The great majority of them go extinct, wiped out by natural disasters or other groups of humans or animals.

You have a vast experiment with an archipelago of these groups. What might be happening is that you just have a process of accumulation and loss of cultural knowledge. Since there are many of these experiments going on, maybe something takes off somewhere. Maybe that's what happened 50,000 to 100,000 years ago in people who all have the capacity to do these things.

Dwarkesh Patel
One thing I didn't realize until I read your book is how small the population that expanded out into Eurasia was, and how small even generally the human population was 50,000 to 100,000 years ago. I remember one of the papers you cited said that there might have been a population bottleneck around this time period. People talk about the Toba eruption. I don't know if that's the cause, but there's many potential causes. Anyways, I remember from somewhere that the ancestors of everybody in Eurasia was initially like 1000 to 10,000 people. How small was the human population that was the seed of this modern period?

David Reich
By bottleneck we mean founder event, a relatively small number of people giving rise to a large number of descendants today. The bottleneck occurred well before the mixture with Neanderthals, which is probably somewhere like 50,000 years ago, plus or minus 5000 years or something. We don't know where it occurred. Maybe it occurred somewhere in Arabia. Maybe it occurred somewhere in the Nile Valley. Maybe it occurred somewhere else. But it occurred maybe thousands, or even tens of thousands, of years before the encounter with Neanderthals that pushed some Neanderthal DNA into modern humans.

One way to see this is that in fact, this was not an unusual thing. This was not unusual to have a group with low diversity. The great majority of African groups would have had very low diversity. The one that started expanding into Eurasia also had low diversity, but it was so successful it didn't mix with very many other groups and recharge its diversity by remixing with other groups. Maybe it also expanded inside of Africa. There are lots of reasons to think that the expansion of the early modern human group outside of Africa would have been accompanied by a within Africa expansion of the same group, and that it would not have been unidirectional.

One way to look at the expansion of modern humans into different parts of Eurasia where we have data is almost as a kind of sort of forest fire. It throws sparks into different parts of Eurasia and interacts with the local people. Look at the first modern humans of African and Near Eastern origin who get to Europe, where we have the best data. We have a number in western Siberia, where we have the best data so far, of these very early ones from about 45,000 to 40,000 years ago which are called Initial Upper Paleolithic. A good fraction of them had Neanderthal ancestors in their last 2-8 generations. That's a kind of crazy result. We have only a couple of dozen or so of these very early humans. A very large fraction of them recently mixed with Neanderthals in their ancestry.

So a model that might explain the data is that you have sparks coming out of a kind of forest fire of humans expanding in the Middle East or Near East. They come in and they start going to places like western Siberia or parts of South Asia or parts of Europe. They mix with the Neanderthals. They produce these mixed populations, like these initial Upper Paleolithic groups we sample in the record, and they all go extinct including the modern human ones. There's just extinction after extinction of the Neanderthal groups, the Denisovan groups, and the modern human groups. But the last one standing is one of the modern human groups. That's what we happen to see, the interbreeding event that we see. The great majority of the ancestors of modern humans, for example in Eurasia, are not from the initial Upper Paleolithic ones. They're from a later wave from the core in the Near East after 39,000 years ago, that repeoples a place that's been affected by these sparks coming out of the same region. Those groups too disappear.

Dwarkesh Patel
That's so fascinating. The group that started 60,000 years ago and eventually makes it around, that one doesn't survive. The group that started 39,000 years ago is also replaced. We'll talk later about the Yamnaya. You can just keep going. The hunter-gatherers were replaced 8500 years ago by the farmers coming from the Near East, and then after that by the Yamnaya from the steppe. It is interesting that a group comes there and is replaced by the next group. That group stays there and is replaced by the next group.

David Reich
That's probably right at some important level. It's not a triumphal march of superiority and inferiority with the group that now comes in having advantages and somehow establishing itself permanently. What you have is a very complicated situation of many people coming together and natural disasters or encounters with animals or encounters with other human groups. It all results in an almost random process of who spreads or ends up on top and other groups coming in afterward. It may be that from a big picture perspective you end up having African lineages spreading into these different parts of groups, different parts of Eurasia. That's certainly what happened. At a local level, it would be very difficult to understand what's going on.

Dwarkesh Patel
The big picture is interesting in two ways. First, you're not thinking crudely in terms of the major species or the major subgroups of humanity, like Neanderthals, Denisovans, and modern humans. Even among these, there were so many subcategories of different groups in this archipelago. If you do a fine-grained analysis, that's even more fascinating than that. There's so much contingency and randomness in that process

David Reich
I think that's right. There are lots of analogies that you have later. There's European farmers encountering steppe migrations. There's Native Americans encountering Africans and Europeans as they come from the Old World. There's various other groups encountering other groups. You have people who cognitively or culturally have all the capacity to thrive in other contexts. But just because of the nature of the interaction that happens, one group declines demographically and one group doesn't. It's just complicated.

It's very tempting to think that at some level—I'm not trying to be politically correct—that it's something innate, some better biological hardware that makes it possible for these African lineages to spread into Eurasia. I have no good insight into that topic. I don't think there's very good genetic evidence or any other kind of evidence to say that that contributed in a very strong way. It's just complicated. We certainly have many modern examples where people with better or more competitive cultural complexes encounter each other and the ones that are more organized in a certain way sort of thrive more demographically somehow.

Dwarkesh Patel
Let's jump forward then, since you mentioned this. Agriculture was developed in the Middle East like 10,000-12,000 years ago. Later, the population of Native Americans declined because of disease. One of the hypotheses that you talk about in the book is that potentially this happened with respect to people in Europe by the Yamnaya with the bacteria that causes the bubonic plague, Yersinia pestis. The question I'm trying to ask is going back a bit. James Scott, who I think just died a couple of weeks ago, wrote his book, Against the

Grain. The whole book is like, “Agriculture sucked but we were forced to adopt it because it allowed some humans to organize nation states that were very abusive. But it did allow them to get the barbarians and co-opt them because they needed the labor to do this monotonous activity.”

One thing I didn't realize until I read that book is just how new most of the diseases that afflict humans today are, everything from cholera to typhus to tuberculosis if you just go down the list. It might have been because of agriculture: domestication of animals and the density that was created. The theory he talks about in the book is that potentially the reason the hunter-gatherers, the “barbarians,” couldn't fight back against these early nation-states was because they were getting killed off by the diseases. I don't know how much evidence there is for this. Basically, the question I'm trying to ask is about the way in which Europeans encountered Native Americans in the New World. Did that just happen again and again throughout history? If you go back to Europe 9000 to 5000 years ago, is that just what human history has been like? That wasn't a one-off event?

David Reich
There's an amazing book by Kyle Harper. It's called The Fate of Rome. He's a Roman historian. It's a history of three major plagues in the Roman period, two of which are really not even very well known. It argues that the decline of the Roman empire is due to just weakening as the result of plagues and other climatic, biological, climatological worsening events. There is a lot of reason to think that some of these events have been recurrent throughout history. It's not just a difference between farmers and hunter-gatherers, but it’s actually a lot of different types of interactions that are occurring.

The example that you mentioned is something that's been a big shock from the ancient DNA revolution. This is now maybe eight years, nine years old. The first large number of DNA sequences—from people who lived 6000 to 4000 years ago in the steppe north of the Black and Caspian Seas and in Europe—were being published around 2015. This group in Denmark, led by Eske Willerslev and Kristian Kristiansen and colleagues, looked at their DNA. They discovered in their sequence, from the 100 or so humans they sequenced, that there was also pathogen DNA. In 5-10% of the random people they sequence from around 4000-5000 years ago, there was Yersinia pestis, the agent of the black death, but actually without the plasmid that contributes to bubonic plague. That's required for flea-rat transmission. So it must have been pneumonic plague with an aerosolized transmission or something. 5-10% of random deaths means that the percent of people who were dying must have been even higher, because they weren't detecting everything that was there.

There’s a study by another group, Johannes Krause and colleagues, of people in plague pits in London from the 1300s epidemic. They found that when you apply this method to people we know died of black death, you only find a quarter of the people. So the rate was even

higher. If people are bacteremic when they die, if they have bacteria in their teeth, they almost certainly died of that agent.

A paper just came out a few weeks ago in Scandinavia. It was looking at these tombs from about 5000 years ago of farmers who were just on the verge of encountering people from the steppe. A huge fraction of them have Black Death when they die. They're buried in tombs and normal and they have rates that are even higher than 5-10%. It's this whole pedigree with many, many generations. It's not all at the same time. It's like the parents and generations and generations with a very large fraction. Well more than 10% have Black Death and have Yersinia infection.

So it looks like this particular agent has been killing people for 4000-5000 years in western Eurasia. In fact, it's killing a scarily large fraction of the population. As the quantitative person I am reading this literature, I think people are embarrassed by the implication. The implication is that a quarter to a half of deaths in this entire period are from this. It's so unbelievable and so ridiculous that such a high proportion of people over such a long period of time are dying from this one agent.

People don't even say it. They just publish one paper after the other, publishing more sequences. They just don't think about the implications of such a high rate of death. Yet it's really hard to imagine that people have bacteria in their blood and they're not dying of these things. It doesn't seem that people are selectively picking tombs. These are tombs that are buried properly. They're not grave pits.

The implication seems to be that this one agent we happen to be able to detect is killing a very large fraction of people in western Eurasia over this period. So what's the implication of that? One thing is that it seems to be coming from steppe rodents, probably. Maybe the people on the steppe—I mean, they are still dying of it—are somewhat more protected from it. Then it spreads into farming Europe, maybe 5000 years ago, which is when we start to see it. Maybe this results in disorganization of the population, giving such a high rate of death. Maybe it creates a type of situation that the Europeans encountered when they got to the Americas, where societies were disrupted.

In the last few years, we had Covid-19. It killed a half percent of the world population or something like that. It was so disruptive. This thing is killing a third of people or half of people randomly. It's randomly killing people with cultural knowledge, randomly ripping into structures. Was it Montezuma who died or one of his parents, resulting in civil wars? You have the Inca when the Europeans encountered them, just disrupting the cultures that were there. Maybe this would have created a situation where there was disruption in the old ways of life. Maybe combined with other things, or even just by itself, it could have created an opportunity for people to move in from elsewhere, even though they were not as densely spread.

There's a big observation we haven't talked about. It's something that we as an ancient DNA community have been looking into again and again now and keep making progress on. About 5000 to 4500 years ago in Europe, there's a radical transformation in the ancestry of Europeans. An example of this is what happens in Britain. About 4500 years ago, the farmers who are there arrived there 6000 years ago. They build Stonehenge. The last big stones of Stonehenge go up 4500 years ago. Within 100 years, 90% of them are gone.

They're replaced by migrants from the continent bearing prop majority ancestry from the steppe north of the Black and Caspian Seas. This is one place where we know what happened very well, but we see it all over Europe. We see it in Spain. We see it in Portugal. We see it in the Netherlands. We see it in Germany. We see it in Czechia. We see it in Italy. We see it in Switzerland. We see it everywhere. This wave of people from the east arrives. It displaces these successful, impressive, densely packed farmers with new people who have this ancestry from the east. They are not as focused on farming, although some of them are, as the people who came before.

Dwarkesh Patel
This is so crazy. Just for the audience if you're keeping tally, we have this one bacteria, Yersinia pestis, that's responsible. I mean we learned in grade school that it's responsible for killing a third of Europeans more recently, causing the Black Death. There's even theories that this helped with the Industrial Revolution because it drove wages up in Britain. Because of higher wages, they had to make machines... Robert Allen, the economist, has a theory about this. So it potentially causes the Industrial Revolution. That one's more tentative.

David Reich
It causes inflation. In the medieval one, it created a lot of inflation. The serfs, as I understand it, were sort of on fixed wages and so they had to be paid more. It basically inflated out their seigniorial responsibilities.

Dwarkesh Patel
So that's one of my things. The other is that during the Bronze Age, it allows the steppe people to basically replace the existing hunter-gatherer or farmer population in Europe. In literally all of Europe, people from the eastern steppes replace the existing people like the ones who built Stonehenge. Kyle Harper's book talks about this. The Plague of Justinian, the final one that killed off the empire, was also Yersinia pestis.

David Reich
Definitely. That's documented with genetics.

Dwarkesh Patel
We have the fall of the Roman Empire and at least once the replacement of the population in Europe. The second time basically, modernity happened afterwards. It's crazy for one disease. Potentially in the New World as well, I don't know what the percentage of deaths was.

David Reich
It's estimated to be not the primary pathogen, but who knows? In any case, there's others too. Some of the other plagues in the Roman empire are definitely not Yersinia.

Dwarkesh Patel
That's crazy. It's not only disease, but this one in particular has had this big a role in human history.

There are anthropologists and historians who have different theories about what the early history of humanity looked like. What kind of gods did they worship? How big were the communities? This informs their political philosophy today. James Scott obviously being the main example here.

Does genetics shed any light on this? Was agriculture in fact terrible for humans? Were the first nation-states abusive? Is this stuff that is just not available through ancient DNA?

David Reich
We have indirect information about some of these things. One thing that you might hope to learn about is whether our genomes reacted to the innovation of agriculture in a disrupted way. You might think that our genomes would have been in some kind of steady state. Natural selection had adapted us to the previous environments we were in. You might expect that in reaction to a change so economically, dietarily, cognitively transformative as agriculture, the genome might shift in terms of how it adapts. You might actually see that in terms of adaptation on the genome. You might expect to see a quickening of natural selection or a change. I don't think we know the answer yet to whether that's occurred, although they're beginning to be hints. We could learn that from the DNA data.

Dwarkesh Patel
Hints in which direction?

David Reich
There's an increasing view amongst geneticists that natural selection is a process where there's relatively little directional selection to adapt to new environments. One piece of evidence connected to this is the finding that there's very few genetic changes that are 100% different in frequency between, say, Europeans and East Asians, or West Africans and Europeans, or West Africans and East Asians. If there had been genetic variants that had

had modest selective advantages, they would have arisen 0.5-2% year by year, that's actually a lot. In a few hundred generations, they would have risen from very rare to very common, and in fact gone to 100%. There's thousands of generations separating Europeans and East Asians, and West Africans and Europeans, and so on. If that was a common process in evolution, we would expect many genetic changes to be 100% different in frequency between Europeans and East Asians, or West Africans and Europeans. We see almost none.

What that suggests at some level is that there's not strong adaptation over the last 50,000 years. If there were, we would have seen genetic variants driving to 100% frequency difference across different groups around the world, which have hardly been connected with each other genetically over the time frame that we're talking about. We don't see those variants. So maybe selection hasn't been important. But maybe over a shorter period of time, selection has quickened and variants have started rising in frequency in the last 100 generations or something like that. We might be able to appreciate that.

Maybe we could see whether there's been a quickening of natural selection over that time period. The view amongst common trait geneticists is that we've been at a kind of steady state where the natural selection that does occur is just there pushing down slightly bad variants. It's not adapting to new situations. We're at a kind of stable point. So it's not clear how that works, because over a scale of 2 million years we're clearly genetically quite different from our ancestors. Our brains are bigger. We do some things differently. Our proportions are different. Yet over the last 200,000 years, we are not profoundly different. There are not genetic changes that differ dramatically across populations.

There's a kind of disconnect. It's tempting to think evolution has stopped from one perspective, because there's so little fixed differences. On the other hand, if you look in the last 10,000 years in West Eurasian DNA, which we're doing now, it looks like a lot of change is happening. It's a very confusing situation. It feels like we don't really understand what's going on, but there's a lot to learn.

Dwarkesh Patel
Do you have a sense of what those changes might look like, or is it too early to tell? Obviously 10,000 years ago, we're talking about the beginning of agriculture.

David Reich
We're working right now on a study documenting changes over the last 10,000 years in Europe and western Eurasia based on tracing changes in about 8500 high-quality DNA sequences from people from this period. They've been collectively accumulated by us and others. We've been working very hard at this, led by Ali Akbari in my group. We think we have many hundreds of places where there's been very strong change in frequency over time,

where we're confident, We think there are many thousands where we can see traces, the whole genome is seething with these changes in this period.

Dwarkesh Patel
Can you give us a sneak peek? Do we know what phenotype any particular ones correspond to?

David Reich
It's very clear that there is extreme overrepresentation of change on variants that affect metabolism and immune traits. If you look at traits that we know today affect immune disease or metabolic disease, these traits are highly overrepresented by a factor of maybe four in the collection of variants that are changing rapidly over time. Whereas if you look at traits that are affecting cognition that we know in modern people modulate behavior, they're hardly affected at all. Selection in the last 10,000 years doesn't seem to be focusing, on average, on cognitive and behavioral traits. It seems to be focusing on immune and cardiometabolic traits, on average, with exceptions. On average, there's an extreme over representation of cardio metabolic traits.

Dwarkesh Patel
The immune thing makes sense. There are obviously more diseases. In what direction is the metabolic thing pointing?

David Reich
One example of this is that there's very clear downward selection against body fat, against predisposition to high body mass index, and predisposition to what today manifests itself as type 2 diabetes. That genetic combination in West Eurasia has been pushed down again and again over the last 10,000 years under the pressure of natural selection, without a doubt. Its action on many, many independent genetic variants is pushing in the same direction in an overwhelmingly statistically significant way.

One possible interpretation of this—and this is speculative—is that you're shifting from a mode of survival that's more feast and famine to one where food is more regular. It's not as advantageous to store fat. There's selection against fat storage.

Dwarkesh Patel
That story seems to point against the narrative that agriculture was terrible. If there had to be selection against storing fat, that seems to suggest that things must have been pretty good.

David Reich
At some level, it could be terrible on the individual level and good on the population level. I'm not doubting the evidence that you're maybe referring to, which is that there's a lot more

skeletally unwell people associated with the beginning of agriculture than there are in the hunter-gatherer period. On an individual level, life could have been experienced more harshly.

In terms of survival, different animals have strategies of investing less in their young but having many more young, or investing more in their young and having fewer young. The hunter-gatherer strategy might be the latter. The farmer strategy might be having more young. Some of them survive longer or something. More of them survive and, on average over a lifetime, there might be stable enough food such that if you don't rely on such adaptations, it might be better.

Dwarkesh Patel
One thing I'm very curious about is whether we have any sense of what it looked like when different populations came into contact with each other. In many of these cases, you're talking about 90-95% of the population being replaced, to the extent that sometimes you refer to them as ghost populations. Only in the aftermath, with this modern genetic technology, can we even tell that there was some other population here. We can see the trace of that. I know there's obviously many different cases and many different cases look different in terms of how violent it was or what the clashes look like.

If you focus on one example, the Yamnaya become a dominant group in so many different parts of Europe. It's not like Genghis Khan, where it's like one empire. There's the great Khan who everybody's pledging fealty to. They're not organized in that way, but they're still organized enough that they can go from place to place like, “We are the Yamnaya and we're taking over.” What did that concretely look like?

David Reich
That's super interesting. I'm going to back up a little bit. In my book, I have a section where I describe our initial findings and the conversations we had with archaeologists about them. Ancient DNA has been very disruptive to conventional understanding of the past.

We found evidence of massive disruption of the local population in Germany about 4500 to 4700 years ago, based on the arrival of people from the steppes north of the Black and Caspian Sea. Some of our archaeologist co-authors were very distressed by the implication. Because after the Second World War, there had been a reaction against the initial idea people had based on archaeology. In the beginning of the 20th century, when people would see new types of pots in a certain layer of the excavation, they would argue that this was the arrival of a new people, coming through invasion or through movement into a region. It was a very disruptive event like the arrival of the Corded Ware complex or the Bell Beaker complex. It was seen as a very disruptive event, mediated by invasion.

The Nazis used this idea to argue that these were spreads of Aryans moving across the landscape, being very disruptive and violent. The reaction after the Second World War was to say, "We don't know this." When you see the arrival of new types of material culture—pots, tools, or ways of organizing life—what you might be seeing is more so the spread of culture. You might be seeing something like people adopting the use of cell phones, which can be used by people of very different backgrounds. Or it could be a new religion spreading. It's not actually the movement of people.

In fact, how could there be a big movement of people? You're looking at densely settled Europe with well-developed agriculture? How could new people coming in from outside unseat these people, disrupt these people, especially once you have farmers who are densely settled. How could these be pastoralists coming from somewhere else? They're not as dense on the ground. In India, the British were in control, the Mughals were in control for hundreds of years but made hardly any demographic impact. How could people from outside with less density make much of a demographic impact?

But then you look at the genetic data and there's a 50-90% population disruption. You take the DNA from people after these events. Almost all their ancestors are from far Eastern Europe, right across most of Europe. The DNA proved that idea was wrong. It was very disruptive. The question you had is, what does it look like on the ground? The DNA results were extremely disruptive to people in archaeology who had made these arguments that large-scale migration, large-scale disruption probably didn't occur in the past. It was a real challenge to our understanding of prehistory.

It was a prime example that's been important for me in showing that we really don't know what the past was like until we actually look at it and have hard data telling us what it's like. Our guesses, our models, including many of mine, are likely to be wrong because when we have hard data, we're surprised. I'm sorry for that long preamble.

What's happened in the last few years is there's been something of a reconciliation after the book. Archaeology is trying to reconcile itself with the DNA data. It's arguing about the subtlety of these interaction events. People talk about what's happened in Britain, for example. Maybe the arrival of the Beaker phenomenon, which happened about 4,500 years ago, isn't an invasion. Maybe it's a kind of peaceful event. The reason we're seeing such a disruption might be that the previous people cremated their dead and the Beaker people buried their dead. So it looks like a much more abrupt change than it was.

In Iberia there's a 40% arrival of foreigners from the east and 60% local people, but the Y chromosomes are completely replaced. The local men don't contribute their DNA to later populations. It looks like that must be extremely disruptive to the local male population. People are saying, maybe this is a female mate choice. Maybe it's not what you think it is. Maybe it's not what happened 4,000 years later amongst the descendants of the Iberians in

the Americas. Today in Colombia, 95 percent of the Y chromosomes are European. 95 percent of the mitochondrial DNAs are Native American. We know what happened there. It wasn't friendly, peaceful, or nice. Maybe what happened in Iberia 4,000 years ago was much more peaceful, much calmer.

If you look at the details in Iberia, the period of this change is actually over 500 years. But if you look at a micro scale, now that we have better data, it's immediate in each place. In Southern Spain, it's very fast. In central Spain, it's a little later but still very fast. So actually there are these rapid changes occurring in one place or another.

People thought in Britain maybe this was a slow process, but we now have unpublished data from the Netherlands. It's clearly the same population of Beaker people that's spreading in Britain. There it's very disruptive. You actually have the whole series of people before and after. The earlier Corded Ware people are local, which is actually very unusual for Corded Ware. They're actually local people adopting the religion of the Corded Ware, but with mostly local ancestry. Then the Beaker arrival is incredibly disruptive. There's almost no continuity, very little continuity. Probably what's happening with the Beaker individuals is that one way or another, you have people who expand demographically and rapidly displace other people over a period of well less than a century.

Dwarkesh Patel
Do we know whether they were organized? In more modern versions of this, when Cortés goes to the New World, he's serving fealty to the emperor of Spain. Or you have the Mongols and Genghis Khan. In this case, I assume there wasn't enough hierarchical organization for something like that. But there was enough organization for a persistent invasion. We're going to keep going town to town, settlement to settlement, until we've reached the ends of Europe.

Were the Yamnaya just lots of different independent groups doing this at the same time? How organized was this?

David Reich
We don't know. There are debates even about that. One example I've heard archaeologists I work with think about is the Comanche in the US Southwest. They were another horse-based, expanding group. They expanded dramatically in parallel to the Spanish expansion and alongside the US expansion, before encountering the militarized United States at some point. It's local. There's local bands of people expanding. They go on campaigns. They expand to certain areas.

The Beaker people and the Corded Ware people were contemporary to ancient Sumer and a lot of the Egyptians we actually have written history from. It's not so ancient. They weren't

writing, but they were contemporaries of these people not so far to their south. So we really don't know what was going on.

We really don't know what was going on, but imagine if you were part of a community where there's a certain culture. We're getting this from reconstructions from Indo-European myth. That's probably the class of cultural shared knowledge these people were operating from because we think these people were the spreaders of Indo-European languages in this part of the world. At a certain age, males would band together and go on raiding parties and so on, and then maybe settle down later in life. You can imagine a process where, built into the culture, you have a process of expansion, exploitation.

One thing that's really interesting that has actually emerged in the last few years—and was not really strong at the time that I wrote my book—was an understanding of the relationship between the Yamnaya and groups like the Corded Ware and the Beakers.

The Yamnaya are these groups that thrived between about 5,300 and 4,600 years ago in the steppes north of the Black and Caspian Seas. They're probably the first people to domesticate the horse. That's arguable. They use the horse and the cart, which was newly invented, and the wheel to exploit the open steppe lands and be able to economically expand much more rapidly.

They're the world's first extreme mobile pastoralists, but they can't get further than the steppe. They expand into Europe. They expand into the little island of the steppe that's in the Great Hungarian Plain in the Carpathian Basin, and they stop. They can't expand their way of life to the forested parts of Europe, which is most of Europe. Somehow, the ancestry of the Yamnaya gets absorbed by the Corded Ware group, and then later the Beaker group.

That takes it further through Europe. But the Corded Ware group is quite different from the Yamnaya culturally. In fact, a lot of archaeologists think that they're so different, they can't be the same. They have some shared features, but the Corded Ware have many different traditions. One possibility is that the Yamnaya expanded and they encountered early Corded Ware. The Corded Ware learn some of the adaptations of the Yamnaya. Then they actually take Yamnaya women and absorb them into Corded Ware mostly male communities. They create a new community and that group expands.

One of the mysteries of the Yamnaya expansion was that everybody had this cognitive bias to think this is very male driven. People have these Indo-European notions of male-centered mythologies and so on. This must be an extremely male-centered migration. You look at the genetic data. You look at the Y chromosomes, which track male migration, and the mitochondrial sequences, which are more sensitive to female migration. It looks like the steppe expansion from the east to west involves both sexes. Both males and females expand. People have found this confusing. There's been a lot of incredulity about

this. Most people expect to see that it's an even movement of males and females, but it's quite clear that the bias is not so strong.

We think the most likely explanation for what's happening now is that it actually is a male-biased process, but it's one that's interrupted.So the Yamnaya expansion is very male-biased. It expands to the edge of the range. They encounter the Corded Ware complex people. Then what happens is the Corded Ware complex people interact with the Yamnaya people and in fact the Yamnaya people actually lose out in that interaction.

In fact, the Corded Ware males absorb and take Yamnaya females. They actually also take farmer females. You actually see these sites in early Corded Ware sites in Czechia, where both things are happening. Females from farmers and females from Yamnaya are being absorbed into the Corded Ware community. Then they expand further.

So what you actually have is a two-step process. You have a male Yamnaya expansion, and then that ancestry from the steppe is carried further through females being absorbed into the Corded Ware. Then you have another male-driven expansion under the Corded Ware and so on. That brings both female and male Yamnaya lineages West, but not always with the Yamnaya ancestry being associated with the intuition that you would think it's domination.

The same sort of parallel thing in another part of the world is what you see in remote Oceania in the Southwest Pacific. Look at Vanuatu, which are some of the first islands that people got to about 3,000 years ago in the Southwest Pacific. Moving to this other part of the world, if you look at New Guinea and Australia, people are there almost a little bit after 50,000 years ago. People are in the Solomon Islands and the Bismarck Archipelago to the east of New Guinea, maybe 35 to 40,000 years ago, and they stop.

The Pacific has all these fertile places that are good places for people to live. It's completely empty of people until 3,000 years ago. Suddenly, these people from Taiwan go through the Philippines. They skirt the edge of New Guinea and the Bismarck Archipelago. They get to Vanuatu and Fiji and Tonga and New Caledonia and Samoa about 3,000 years ago, super rapidly in the guise of something called the Lapita cultural complex.

If you look at the DNA of the people from this, they're almost entirely East Asian in ancestry. They look like early Taiwanese people. Today people in Vanuatu and Fiji and Tonga and New Caledonia have only 10 percent of this DNA. So something else happened afterward. The first people are almost entirely East Asian via Taiwan and the Philippines.

Then you look at later DNA from the same part and 2,500 years ago, 500 years after the initial arrival, there's mass movement of Papuans in a male-driven way from New Guinea and the Bismarck Archipelago into Vanuatu. You have people with overwhelmingly Papuan

ancestry from New Guinea coming into Vanuatu. That's the origin of the ancestry that's overwhelmingly there in Vanuatu, New Caledonia today.

So there's a two-step process. The initial step is East Asian ancestry and these people who invented outrigger canoe technology and long-distance sailing. Then the technology becomes adopted by Papuans, who are using this culture for the next few hundred years. We can see them trading back and forth between the Bismarck Archipelago and Vanuatu.

By the end, this culture is carried out by Papuan ancestry. Males from this group then spread into New Caledonia and take local females. But the ancestry is flipped from the way that people have this cognitive bias that it should be. People think, "Oh, it should be the East Asian males somehow dominating the local females or something." You see the reverse. This is what's going on.

It's very complicated and subtle. When you actually see evidence of males and females behaving differently, it proves that there's socially asymmetric behavior of two groups as they interact. What it means is confusing. It could be female mate choice. It could be violence. It could be genocide. It could be different patterns of male and female dispersal, with groups who travel being of one sex or the other. We can look for clues in the genetic data. Certainly in concert with the archaeology, we can maybe figure out more.

Dwarkesh Patel
That's really interesting.
Going back to archaic humans, we talked a lot about Neanderthals but obviously there were two different species of Denisovans. I don't know if species is the right word, but there were two different kinds of Denisovans and also the hobbits in Asia. I don't know if there are more, but we're talking about half a dozen different distinct groups and only one survives.

I understand if new cultural technologies are developed by this Near East early tribe, then they expand out through Eurasia. I get that might enable them to be so dominant. What I don't understand is how none of the other ones survived, not even one tribe of Denisovans or Neanderthals or hobbits. There was no niche in which they could just fend off. Everywhere this one tribe of African humans just dominated. How did none of them survive?

David Reich
I don't know. It may be a numerical issue. If you look at the part of the world where we have the best data in the Holocene, the last 10,000 years, there are places of long-term survival of hunter-gatherers for a few thousand more years than elsewhere. In the Netherlands, for example, hunter-gatherers survive for several thousand more years than in the surrounding areas, probably because they're exploiting the wetlands. But they're gone soon enough, once something happens. Mammoths go extinct mostly 14,000 years ago, but they survive

on Wrangel Island north of Siberia until 4000 years ago. At some point, each of these places is encountered by the spread of modern humans at high densities.

The other thing is that it's not even clear to me what expansion means. If you want to make a strong argument, you might argue that non-Africans today are Neanderthals who just have waves and waves of modern humans from Africa mixing with them. Who are the ancestors? That might sound like a silly kind of philosophical statement, but genealogically...

I don't know if this happened before or after my book. You probably don't know about this. There was a super interesting series of papers. They made many things clear but one of them was that actually the proportion of non-Africans ancestors who are Neanderthals is not 2%. That's the proportion of their DNA in our genomes today if you're a non-African person. It's more like 10-20% of your ancestors are Neanderthals.

What actually happened was that when Neanderthals and modern humans met and mixed, the Neanderthal DNA was not as biologically fit. The reason was that Neanderthals had lived in small populations for about half a million years since separating from modern humans—who had lived in larger populations—and had accumulated a large number, thousands of slightly bad mutations. In the mixed populations, there was selection to remove the Neanderthal ancestry.

That would have happened very, very rapidly after the mixture process. There's now overwhelming evidence that that must have happened. If you actually count your ancestors, if you're of non-African descent, how many of them were Neanderthals say, 70,000 years ago, it's not going to be 2%. It's going to be 10-20%, which is a lot.

Maybe the right way to think about this is that you have a population in the Near East, for example, that is just encountering waves and waves of modern humans mixing. There's so many of them that over time it stays Neanderthal. It stays local. But it just becomes, over time, more and more modern human. Eventually it gets taken over from the inside by modern human ancestry.

This is what happens to northern European hunter-gatherers. They become farmer over time, but they are intact on the male line. Culturally they stay on the male line intact. I'm not trying to be politically correct, I'm just saying that you can actually have scenarios where this happens, for example in elephants.

If you look at forest elephants, which are the smaller of the two species of elephants in Africa, they're very matrilocal. They have these female lines that are very intact over a long period of time. If you look at the savanna elephants, which are the bigger elephants in eastern and southern Africa, they have savanna elephant DNA overall. But their

mitochondrial sequences are forest elephant, which are the smaller West African elephants. The interpretation of this is that you just have waves and waves of dominant male bulls from the savanna coming into populations and eventually just replacing all of the genome in waves and waves of an intact forest population. So all that's left is the mitochondrial sequence, which is passed in the maternal line.

It's not even obvious that non-Africans today are modern humans. Maybe they're Neanderthals who became modernized by waves and waves of admixture.

Dwarkesh Patel
We were talking earlier about how small the initial population that populated all of Eurasia was, a couple thousand people. We were also talking about how random and contingent the whole history of humanity has been. Was there some chance, if a couple of variables were different, that "modern," civilization—greater population density, greater development, technology and so forth—would not have happened except for some really lucky chances? Or was it the case that even if that one tribe didn't do it, some other tribe of humans would have done it? Even if some other tribe of humans from Africa hadn't done it, then Neanderthals had enough cognitive sophistication that they would have done it? I know this is a very speculative question, but how random does "primate to civilization" feel? Does it feel like we had to go down the exact right path? Or was it the trend across many different branches of the family that leads to humans?

David Reich
I don't know. It's very speculative. I'm very tempted to think that there's so many of these groups that some of them would eventually have gone down this route. One example of this that's interesting to think about is the parallel development of agriculture in the Holocene in different parts of the world.

You have in the Americas what's almost certainly a completely independent development of agriculture 9000-8000 years ago from that in Eurasia. You can argue whether the East Asian and Near Eastern developments are different. They probably are, but maybe you could argue they knew about each other somehow. Or with the Papuan one, maybe you could argue they somehow knew about what was going on in other parts of the world. They probably didn't. Certainly the Americas one was isolated.

Suddenly for the first time, you have these independent evolutions of full-blown agriculture at the same time in many places in the world after the ice age. This makes you think that it's somehow deterministic. Somehow some kind of setup of characteristics at this time causes this to happen. Why doesn't it happen in the previous period of stable climate before the last ice age? Some people say, "Maybe it was actually not as good as the last 10,000 years."

I find that confusing as a statement. It's tempting to think that some sort of cultural or biological, more likely cultural, characteristics are in place and seeded already at the time of the last ice age, such that when the reemergence happens it happens in multiple places simultaneously.

Dwarkesh Patel
Because it happens so fast. It's not like you had to wait for tens of thousands of years after the ice age. It's literally 2000 years after the ice age.

David Reich
Agriculture is very old in the Americas.

Dwarkesh Patel
The ice age, was it 100,000 years or how old was it? Before that, at least some branches of the human tree split off 200,000 years ago. Neanderthals split off even before that. That's before the last ice age started, right? To the extent that your earlier statement that a lot of cognitive sophistication was already evident 200,000 or 300,000 years ago, doesn't that imply that we should have seen agriculture before the ice age?

David Reich
It's tempting to think that. I'm very confused about this personally. People say that the last 10,000 years are very unique on a scale of millions of years. If that's true, maybe we're in a very special time that is somehow a period of warmth and stability of climate that's unprecedented for 2 million years. Maybe that's true. But the other way people often say it is that we're in these cyclical periods of a few tens of thousands of years. The Holocene, the last 12,000 years or so, is a period of warming and then there's a period of a couple of tens of thousands of years, which is the last ice age. Then before that there's a few tens of thousands of years of warming. That's when we sample the late Neanderthals from. Then before that, there's another stage of cooling. Then before that, there's another stage of warming. So marine isotope stages 1,3,5,7,9 are the warm periods. We're in one now. Marine isotope stages 2,4,6,8 and so on are the ice ages. So the last glacial maximum was marine isotope stage 2.

Dwarkesh Patel
If there were "lost civilizations", maybe not as sophisticated as anywhere close to the last thousands of years. Maybe early Sumer, Comanche, Yamnaya level or something. But that happened before the ice age, or maybe in a part of the world during the ice age where climatic conditions were better, would we be able to tell based on modern techniques?

David Reich
I think we would.

Dwarkesh Patel
Okay, but there's just not any evidence of them?

David Reich
I mean, there are very sophisticated human burials in Eurasia, Africa, Australia, and so on in the marine isotope stage 3, in the last period of warming. There are burials full of beads, full of symbolic behavior. Maybe you interpret this as civilization, but extensive settled societies you don't see.

Dwarkesh Patel
We touched on this when we talked about population size. One thing I'm sort of confused about is that in one sense a lineage is very distributed. Obviously many different archaic humans contributed to the human gene line. In another sense, maybe the main one is a couple thousand people. I'm not even sure how to think about it. Can the entire human lineage just hang out in an area the size of Montana?

David Reich
The lesson from ancient DNA and the genome revolution has been that anyone in the world is the result of recurrent mixture again and again in the past. You might think that the last 500 years are unusual periods of history with the people of African and European and Native American ancestry coming together in the Americas. You might think this is unusual because of transatlantic travel. But almost every group in the world is the result of many mixture events as profound as these on many timescales.

South Asians are the result of mixture between groups very different from each other, as different as Europeans and East Asians, 4000-2000 years ago coming together and then crystallizing into a relative lack of mixture since that time. Europeans are the result of mixture of Yamnaya and farmers and hunter-gatherers. People in different Near Eastern groups are the mixture of early Iranians and early Levantine people and Anatolians who are super different from each other. There's huge differences amongst East Asians. There are huge differences amongst Papuans and East Asians. There are profound differences amongst different Native American groups that come together to form groups that we have data from later, in example after example we look for.

You think about any one lineage today, any one group of people, and you want to trace people's ancestors back into time and ask where our ancestors scatter in geography. At different time points, almost everybody's ancestors are scattered into different geographic distributions that are not all in the same place.

The evidence that our lineage was mostly in Africa is based on an assumption, a kind of inertial idea, that our lineage must have always been in Africa because Africa is the center of human history. But if you look at the archaeological evidence, it's not incredibly clear. If

you look at the genetic evidence, we have many early branches from Eurasia and only one from Africa. You have complexity and branching in Eurasia that's sampled in the DNA record, DNA from Denisovans, DNA from unknown archaic lineages that contributed to Denisovans, Neanderthals. All of those are represented in the Eurasian record, not in the African record. Part of that is the fact that ancient DNA is preserved in Eurasia. Maybe there's a period when our lineage resides in Eurasia. It's not obviously wrong. That hypothesis is out there as a possibility.

Dwarkesh Patel
One thing I would love to see—I assume this will change over time as more data comes up—is some sort of chart that is superimposed upon a world map and evolves over time. Maybe you can have blobs representing different population groups. You can start off with the archaic humans and go back like, 200,000 years ago, even before that because this is a global event. It's not just an African event. For hundreds of thousands of years, you can just see different populations splitting off, merging back together. If somebody could make that sort of animation, that would be very useful.

David Reich
I think you can. People have tried to make animations like this in some ways. But one way to think about it is that there's a huge danger in being too interested in yourself. This comes across in my book. It's very tempting to be interested in your own history and think it's important. It's obviously not important compared to other people's history.

However, if you think about one person's history and about where their ancestors lived two to eight generations back in the past, those are your great-grandparents and great-great-grandparents and you may even know where they live. Then you can actually just plot on a map a different number of generations back in the past where your ancestors lived. It's interesting to do within your family. My ancestors going back a few generations are in different parts of Europe, for example.

People do this and when you get a test back from one of these personal ancestry testing companies like 23andMe, they'll say, "Oh, you are 20% Irish and 30% Chinese" or whatever it is and so on. What they're referring to is if you roll back 20 or 30 generations, where your ancestors are scattered in proportions. But then if you roll back 3000 generations, there's some in East Africa and some Neanderthals, right?

For any one group of people or any one person, there's different time slices that matter. 30 generations ago, you get the 23andMe output. 3000 generations ago, you get the proportion of your ancestors who are Neanderthals or not Neanderthals or Denisovans or something like that. If you're from one of the many populations around the world that live in Denisovans. If you are any population going back further in time, presumably there's

something similar happening. Mostly in Africa, but possibly outside of Africa 300,000 years ago, people's ancestors will be coming from different places.

It's very plausible that people's ancestors are not all in Ethiopia 200,000 years ago. In fact some of them are maybe in North Africa. Some of them are maybe in West Africa. Some of them are in South Africa. Some of them are in Eurasia. Actually appreciable fractions are in each place. That braid and that trellis is coming together again and again over time. As you move further back, they'll collapse. Some will go extinct, some will reappear, some will re-merge. At any one point, there's never a singularity.

Dwarkesh Patel
I don't know if you're familiar with Nat Friedman's Vesuvius Challenge. I don't know if you saw that when it was going around. It's the scrolls in the library at Herculaneum. There's a volcano during the Roman empire, 79 AD. It buried the scrolls in that library. They all became literal ash, or at least very burnt. Nat Friedman found this professor who had done CT scans of these scrolls. There was really no way to decipher them. We just had the CT scans.

It felt like the kind of thing where somebody out there might be able to figure out a technique for how to do it. We know what the end results should look like. We just don't know what the intermediate steps look like. It feels plausible with modern technology. So they offered a million dollar prize and a 21 year old with a GPU coded up a CNN model to decipher these scrolls.

Is there something in your field which has this sort of feeling? There's something we need to figure out? We don't know the exact right technique. But if you could put it out and offer a million dollar bounty for it, maybe somebody will come up with a cool new technique to figure it out.

David Reich
There's many things in this area. I probably should give you a single answer. The basic answer is that we need DNA from Africa. We need old DNA from 50,000 years ago, 100,000 years ago, 200,000 years ago, from all over Africa. Because it's super clear that our lineage is complicated within Africa. There's archaic forms in the archaeological record. Modern human data is extremely substructured, with evidence of having come together from many different lineages, which must have been different archaic forms in Africa contributing to people living today. Having that would crack our understanding of how modern human lineages braided together and relate to the other archaic lineages we have data from. That's obviously extremely helpful.

Dwarkesh Patel
What is it you need to get those samples?

David Reich
We need to identify those skeletal remains, or the sediments in old caves that are well preserved or rock shelters that contain enough DNA to extract. We need extraction techniques that will allow us to get at that material. Maybe we even already have them. We just need to wait until that begins to happen. It would be revolutionary. The experience in Eurasia has been when we get DNA from old sites or new sites for which there's been nothing, we find Denisovans. We find people we completely didn't expect to see before, that breaks our understanding of the past.

The other area where I am super excited, and a thing to reward and incentivize, would be to try to crack this body of information, to try to understand how biological adaptation happened in the last hundreds of thousands of years. We simply don't know the answer to your question, from a genetic point of view. How did modern humanity, in cognitive and other types of propensities, develop? We don't know the biological underpinning of the differences that modern humans have from our closest living relatives. We just don't know how they evolved. It's not even clear how biological they were. We just don't know how to interpret the genome in terms of how these changes occurred.

I was at a talk a few years ago that was really shocking to me. There was a researcher at Caltech. She was talking about being able to directly read the brains of macaque monkeys. Monkey would be shown 2000 photographs. Her student would be recording from different neurons in its visual cortex and learning the neurons' response to different images.

What they would do is they would decompose the images of faces, human faces, into eigenvectors with the principal component analysis. Specific neurons were responding to particular eigenvectors. They learned the language of how the photographs and the decomposition of them computationally mapped on to the neurons. They actually learned a language for how that's the case.

What they did then is they showed a 2001st photograph to the monkey. They recorded from its neurons. Then they tried to use the neurons to reassemble a photograph. It was a perfect reassembly of the photograph. They had actually completely learned how this macaque's brain represents the photograph going through the brain representation.

In that case, they were able to completely figure out the language of appreciation of a photograph through the biological representation of it. If you look at the parallel problem of the genome, how does the genome code for development? How did we get to how we are today? How do we have our capacities and so on? At first principles, let's say you asked me, "What's a simpler problem, figuring out how to represent the natural world in our brain or figuring out how to code for development?" My cognitive bias would be to say that if you were presented with this problem ab initio, it's easier to code for development than to represent the outside world in a brain.

But this group and other groups are figuring out how to do this nearly perfectly with a readout from the brain. We really can't read a genome and tell you how a person looks or how a person develops. We can begin to say what terrible diseases they have, but not even predict that so well. It's very depressing that we can't actually read the genome enough to actually see how that occurs.

We actually don't even know how evolution happens. For example, does evolution happen by lots of little changes pushing in some direction? For example, if we want to move toward a different positive set point for height or for some cognitive capacity or propensity? Is this by infinitesimal change of polygenicity, many genetic variants pushing in the same direction? That's the mathematician's bias. Or is it like the example I told you about before with David Gokhman and Liran Carmel, with the voice box where everything pushes in the same direction and goes up to 100% and shifts all in the same direction in an incredibly simple and simplistic way.

If you talk to neuroscientists and molecular biologists, their brain tends toward the latter. These few examples suggest that maybe that's occurred. This polygenic paradigm of adaptation, when adaptation really matters, is that really what happens when important adaptation happens? Or is it instead something simple and simplistic and reliant on a small number of genes?

So what I would really like to know is if we can mine the genetic data we have from modern genomes and archaic genomes. We now have Neanderthals and Denisovans. We now have some early modern humans who are far enough back in time that appreciable change may have occurred. Can we actually learn the patterns of biological adaptation well enough to actually read the code of how we change and how we adapt to new pressures? That's something that's not impossible to imagine we learn how to do, but it takes a different way of thinking.

Dwarkesh Patel
There's one thing that would also be interesting. There's a big debate in trying to forecast AIs. How big is the information content that describes the human brain? With AI models, we can obviously tell very easily how many bits it takes to encode the parameters. If you want to go back to how many bits is it to encode the training paradigm itself, there's obviously the training code, then there's the hyperparameters. There's how many kilobytes that is.

We know that the human genome is three gigabytes, but we know only a small fraction is protein coding. Also how do you count the percentage that is responsible for regulation and so forth? But if you could only get the part that is responsible for the brain, how big would that be? Can we compare how big that is with respect to how big the training code for a model is? It would give interesting insights into how similar those two processes are.

David Reich
We're engaging with this in some way right now because we have incredible data from Europe in the last 10,000 years with huge numbers of samples. We can watch very small changes in frequency over 10,000 years. This period of time is not a particularly important time in human evolution. It's well after the important stuff happened, but it's an eventful time. The environments became very different. The lifestyles became very different. This is a period of time where we've done an experiment of nature. A push has happened against the human genome. There's agriculture. There's people living more densely. There's infectious disease happening in a different way, in a different type than before.

How does the genome respond to this traumatic set of conditions? You can actually watch all these little variables—all these little gene frequencies, tens of millions of them—shifting up and down in coordination. What can you learn from that? We now have all the measurements. We have a selection coefficient measured at 10 million positions across the genome. We know what the effect of those are on traits today because they've been measured in large numbers on the order of a million people today. What can you do with this data set? How relevant is this to important evolution?

That's the type of rich data that could potentially be mined to learn something sort of qualitatively interesting, beyond the storytelling that's characterized molecular biology. You could go beyond the FOXP2 where you say, "Oh, maybe it's this. Maybe this is the holy grail, or maybe that." Maybe you learned something about the process that's deep and profound. So my million dollars goes to someone who can actually come up with a way of thinking about the process that's really qualitatively profound.

Dwarkesh Patel
Interesting. All right, I guess we need to find the million dollars first. But somebody, if you've got a million dollars, and somebody else, if you got the idea, we can make a market here.

We were talking about the contingency of human history and human evolution. One of the really interesting things is that not only is it contingent, but it seems to be persistent at least across the last few thousand years. It's the way that genetics have changed, culture has changed.

The Indo-Europeans, the Yamnaya, disrupted the Indus Valley civilization 4000 years ago or something. Not only does that mean that many of the languages which are spoken in India today are descended from this group, but literally the actual core myths of Hinduism are descended from this initial group. How is it possible that for 4000 years things like caste, things like basic mythology, can be preserved with such high fidelity, especially in an era for half of which you don't have writing? Not half of that but for at least a couple thousand or 2000 years, you don't even have writing. How is that sort of persistent cultural heritability preserved?

David Reich
You're asking me a cultural question, not a genetic one. What you see in the genetic data from South Asia is an amazing process. Today in South Asia, almost everybody is on a gradient of ancestry with two poles, what we call the Ancestral North Indians and the Ancestral South Indians. That's true with very few exceptions. The exceptions are people with your last name, Patel. It's a minor exception but it's interesting that's your last name. There's also people from Munda who speak Austroasiatic languages or are admixed with them, or people who are Tibeto-Burman speakers.

But most people are on a mixture between two poles, Ancestral North Indians and Ancestral South Indians. When you look at genetic data from India, it looks like what you see today in African Americans. You have people with relatively higher or lower proportions of, say European and West African ancestry. It looks like a population in the process of mixture, like African Americans who are the result of mixture in the last ten or so generations between mostly two very different populations mixing in different proportions.

What happened in India is that it froze. The mixing started, and then it froze. The freezing happened 2000 to 3000 years ago. It froze because of cultural change. What happens in India is you have a three-part change. You have an arrival of three source populations, essentially parallel to what you see in Europe. There's a local hunter-gatherer population. There's what's probably a farming population, maybe also a hunter-gatherer population initially. Then there are these people descended at some level from steppe pastoralists. These are the three primary ancestral populations.

They come together at the end of the decline of the Harappan civilization, which ends about 3800 years ago. Groups from this Harappan group, which we actually have sampled, they're all on a different gradient. They mix with the steppe groups and with the local hunter-gatherer groups to coalesce to these two later groups, which we call the Ancestral North Indians and Ancestral South Indians. Then mixtures of these two mixed populations form in the Gangetic plain and form people all along this gradient. It's really a very simple mixture of two sources.

Then the cultural change happens, which locks in the caste system. People freeze and they stop mixing very much. Instead of people collapsing to a point—which is what you see in Europe after this type of mixing process of these three sources happening in any one region—you see this gradient forming and it's stable. Because of the enduringness of the caste system, you actually have a snapshot going back a couple of thousand years, without this continuation change.

It's genetically kind of an amazing system to look at because of people's reluctance to mix with people from very different groups in traditional communities. The three steps are the coming together of very different populations, then convulsive and profound mixing of

groups that had previously not mixed, and then locking into this static system as the caste system sets in. That's documented in the early texts, like the Rigveda. You can actually see the change in that discussion during the course of the Rigveda.

Dwarkesh Patel
I know you warned about being too interested in yourself, but what was it about the Patels? Why are they an exception?

David Reich
The first good genomic data from South Asians is, embarrassingly, from Houston, Texas. In the human haplotype map project, there was a sample from Houston, Texas of Gujaratis in Houston, Texas.

Dwarkesh Patel
Yeah, a lot of hotels in Houston, Texas.

David Reich
GIH. If you look at them, people are actually not on this gradient. They're in a few different places. They're clustered into groups. There's the main gradient and there's an off-gradient group. I forgot how we figured this out. Someone figured out that these people are all Patels. Patels have their own distinctive history with different relationships to people in Central Asia. It's probably some additional ancestry from Central Asia pushing them off the main gradient.

Dwarkesh Patel
Interesting. We've obviously talked about so many different types of fields. I'm not sure where exactly in what field you started your research. Obviously now your lab is doing stuff in genetics. You have to touch on how your research combines with the archaeological record? What are the inferences you can make from that? There's obviously different kinds of history. There's so many different disciplines here.

You start your field researching a certain topic. Do you just keep expanding? "Now I'm going to master archaeology. Now I'm going to master anthropology. Now I'm going to..." How does that process work through your career?

David Reich
It's a very unstable life. In some areas like in archaeology, for a lot of my colleagues whom I respect tremendously, the career trajectory is that you learn to become an archaeologist, you dig, and you have a set of digs that you're doing for dozens of years with similar or slowly evolving methods. My work has just changed so radically.

When I started doing this work, one could not sequence a whole genome. The genome was not yet sequenced. We had very little genetic variation accessible. The amount of data has increased by orders of magnitude every few years. What's changed is the types of data that we collect, the ability to collect ancient DNA beginning 14 years ago, the ability to generate the volumes of it we have. We had no ancient DNA in 2009. In 2014, we only had a few hundred individuals with genome-scale data. We have tens of thousands of individuals with genome-scale data now. We have data from places we didn't have data before.

It's such a destabilizing process. Someone like me wanders into areas that I'm not expert in. I'm not South Asian. I get to be part of trying to learn about the history of South Asia. I get to interact with archaeologists at the cutting edge of learning about ancient Southwest Pacific or ancient China or ancient Southern Europe. It's like an incredible privilege, but also I'm a kind of rank amateur in terms of a lot of the work I do.

One wanders from one area where one's an amateur into another area, where one is an amateur and tries to learn a lot. Maybe this is a little bit like what it's like in Silicon Valley right now. You're constantly doing new things and bringing some skills to bear that are useful. You're hopefully trying to be respectful of the people one works with and the tremendous knowledge people have. You're trying to learn as much as one can, and to work with other people to try to produce some joint research product that makes progress.

Dwarkesh Patel
Somebody's doing archaeology for their entire career on a certain group in some mountain somewhere, and then you come in. Here's the paper. We figured out the exact genetic combination that explains all your research. Is the reaction usually... I don't know how much of this you can say. Are people sometimes disappointed that you've been able to figure out the things in their field with a different technique?

David Reich
A lot of people we work with are incredibly excited about being able to do this. Prehistory is a period of time we know so little about. We have such poor clues. True archaeologists who are truly dedicated to understanding the past are super thirsty for knowledge about the time periods. If a new scientific technique becomes available that can probe these times, the true archaeologists who are truly interested in the past get incredibly excited. They embrace it as they've embraced previous scientific techniques, such as scientific archaeology, such as isotopic analysis, such as radiocarbon dating .

That's been my experience with people again and again in archaeology. People really want to know about the time periods before writing, when at some point one didn't even imagine one could learn anything. They're excited about this new type of information.

Sometimes people are dug in to particular views of the past that are challenged by the new findings that come from scientific research, such as ancient DNA. When the DNA is strictly in opposition to some of these models, that becomes an area of tension. I have found myself to be proven wrong in a number of cases, including by my own work or by other work amongst my colleagues. I hope to be someone who can welcome that.

One of my idols in this field is the archaeologist Colin Renfrew, who is a British archaeologist responsible for the Anatolian theory of Indo-European origins: the idea that farmers spread Indo-European languages. The language spoken in Armenia and in Iran and in northern India and in much of Europe today, spread with farming after 8500 years ago from Anatolia in all different directions. The demographic expansion and economic transformation associated with that spread farming. It's very plausible.

There was a debate with Marija Gimbutas and others who argued that these languages spread from the steppe, north of the Black and Caspian Seas. One of the main arguments for the Anatolian hypothesis was that steppe expansions could not have been demographically significant because they were much thinner on the ground than farming expansions. This is why the steppe could not explain it, even though other linguistic arguments made the steppe seem more plausible.

When the genetic revolution happened with regard to our understanding of Yamnaya expansions and Indo-European origins in 2015, Colin Renfrew at some point said, "I was wrong. I was wrong about this topic." In fact, the weight of evidence now suggests that demographic transformation did come from the steppe. It's kind of amazing it did. Maybe it's from disease, maybe it's from something else. Who knows what it is? That's a very interesting topic. But we adapt, we learn. So this is incredibly inspiring to be able to change one's opinion.

Dwarkesh Patel
Final question. You mentioned these different revolutions in our ability to understand the past, like radiocarbon dating and obviously now with ancient DNA and genomic sequencing. Is there something that feels like the next thing along the spectrum? One would hope in the future—like a thousand years from now when the future AIs are looking back on human history—hopefully there's no lost period. Hopefully, they literally know what kind of gods the tribe in the Near East that basically settled Eurasia worshiped. They would know everything. Along that spectrum, we're making progress. What is the next thing after advances in more genomic sequencing or more samples from different parts of the world?

David Reich
I don't know. The discovery of the ability to extract DNA from ancient human remains was such a shock that we could even do this. We just didn't think we could do this. There's a section in the introduction of my book which was sort of my impression of what it was like. I

had a conversation with my PhD supervisor about what it would be like if one somehow could open a cave or a room that was echoing still with languages that don't exist anymore, that are not yet spoken. You could hear the words still echoing somehow after thousands and thousands of years and record that down. That's what ancient DNA is like. It's an unexpected gift from the past that what we thought was an incredibly delicate biological molecule in fact is intact.

There must be other such things. It's just hard to imagine what they are. In ancient DNA, there is an extraordinary amount still to do. There is systematic sampling from many, many places in the world where yet there has not yet been sampling. There is systematic sampling in the ability to sample from deep, deep into the past, up to the point where we can begin to decouple these lineages from each other.

That will reveal incredible richness and that's something that we should all look forward to. There will be insights that come from that, both in terms of the understanding of individual places—places like many parts of Africa and South Asia and Australia and New Guinea and so on—where we have essentially no data currently in terms of ancient DNA. We'll also get insight in terms of deep time and the deep lineages that mix together to form us, where we really have no sampling except for the Denisovans and Neanderthals right now.

Dwarkesh Patel
That's a great place to close. David, thank you so much for coming on the podcast. I highly, highly recommend your book, "Who We Are and How We Got Here". It's just so wild. Basically, a lot of the stuff you learned in grade school at least needs a lot more clarification. Some of it is wrong. The fact that that's the case is crazy. I hope that, in five to ten years, there's a new edition of the book or a new future book you write. For all the questions that you talked about today, which we don't have the answers to, it seems like there's a bunch of progress happening here. I'm very eager to see what the future results look like.