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00:00 Sarah: Welcome to the Science Podcast for September 6th, 2019. I'm Sarah Crespi. On this week's show, we start with contributing correspondent Lizzie Wade. She spent 12 days with archeologists searching for a lost city. We talk about how you lose a city, and how you may go about finding one. And I talk with Christophe Coupé about the data density of different languages, and the relationship of that density to how fast we talk and how fast we can process language. And now we have contributing correspondent Lizzie Wade, and she went on a hunt for a lost city. Hi, Lizzie.

00:45 Lizzie: Hi, Sarah.

00:47 Sarah: Can you talk a little bit about your journey?

00:49 Lizzie: Of course. So, we met up in a city called Comitán in Chiapas, and then we drove about seven hours to part of the Mexican-Guatemalan border. That's a little corner that we were staying at this eco-lodge. We had guides from that eco-lodge who took us into the reserve, Montes Azules. So we went up first in a motor boat for a few hours, and we set up a base camp, but basically from there, we were kayaking and hiking in the jungle. And it was extraordinarily difficult but... [laughter] If there was no trails carved, the guides would machete through the jungle, but everything has spines. Everything is so different from each other, there's so much information and all the plants are so heterogeneous, and there's just so much stuff around you that it's hard to even interpret individual things. So it was very easy to grab onto a tree that was covered in spines and not really even realize it [laughter] until your hand was also covered in spines.

01:51 Sarah: They had to cut every step of the way.

01:53 Lizzie: Yeah. Every step. I've been in some pretty remote places before, but never a place where humans really hadn't been for decades or potentially centuries, and that was very, very hard. And, it felt like the environment was just pushing us out and making it impossible. And the rivers were also completely covered in brush and had to be... We had to machete from the kayaks, and it was really intense.

02:20 Sarah: Okay, should I spoil it? Should I say whether or not you found a missing city?

02:25 Lizzie: Yeah. I think... It's hard to talk about it if we don't say what happened.

[laughter]

02:31 Sarah: Yeah. So, spoilers, you did not find a long lost city. What were you looking for?

02:37 Lizzie: I went to Chiapas, Mexico with some archeologists who were looking for a city

called Sac Balam which was the capital of the Lacandon, Maya. There's sort of two groups named the Lacandon: One exists today, and one is a pre-Columbian Maya group, and we were looking for this previous Maya group's last capital. Sac Balam means the white Jaguar, and the Lacandon built it basically to hide from Spanish invaders which they successfully did for over 200 years.

03:11 Sarah: Wow. What's the timeline here? And, I guess I should ask, what century are we in?

03:17 Lizzie: Yeah. So, the Spanish first come to Central Mexico in the early 1520s. So Tenochtitlan, which is now Mexico City, the Aztec capital, falls in 1521. And that's a pretty straightforward conquest story. The Aztecs were an empire, the Spanish were also an empire or wanted to be, so they took over all that land. But when you get to the Maya world, it's really really different because there's not really a centralized control. Every city is independent of each other, and they're oft in this elaborate web of allies and enemies. The Spanish can't come in and conquer one city like Chichen Itza, or whatever, and then everything passes to them. They have to do it one at a time.

04:02 Sarah: Getting back to this missing city, Sac Balam, the Lacandon live there, but they didn't always live there. They actually move their city to this harder to find location.

04:13 Lizzie: Yeah. The Lacandon lived in this island in Lake Miramar which is in Chiapas also. They were attacked by the Spanish at least once, maybe a couple of times, I can't quite remember. And they had held out but they knew they weren't gonna be able to do that forever. So, preemptively, in the late 1500s, they pack up, move really deep into the jungle, and built this other city called Sac Balam.

04:37 Sarah: But eventually Sac Balam was taken by the Spanish. Can you talk about how that happened?

04:43 Lizzie: By this point, it's the 1690s. The English colonies in the US are firmly established at this point. I think Harvard University has been founded. This is very much the world we live in now. Most of the "conquests" that are going on right now are not huge military invasions. It's more of proselytizing. So these two priests are like, "We have to convert the people of Sac Balam." They're devoted to this idea. They hire these local Maya guides who lead them around in circles for five months without them realizing it because the local Maya are so scared of Sac Balam. The people in Sac Balam have been raiding other Maya.

05:22 Lizzie: Months and months go by of them just walking around in circles, and then finally they realize something's going on, and they hire the leader of another local Maya group. And we don't really know what his motivation was, but if you think of the Lacandon being scary and potentially having attacked this town, this guy may have been like, "Whatever. Enough with this." He takes the Spanish there.

05:43 Lizzie: It's mostly diplomatic. They're not immediately killed as previous Spanish visitors were. They convince a retinue of the Lacandon leaders to come with them to a city in Guatemala, for more diplomacy basically. But, on the way there or on the way back, almost all of the Lacandon

leaders die. They get sick and die, and it sort of collapses.

06:06 Lizzie: And there's not like a big battle. The Spanish descend on this town of a couple of a hundred Lacandon with 1,000 of their soldiers and their ally Mayan soldiers. Sac Balam gives in really easily at that point. And then, it is a Spanish town for another 15-20 years, and then everyone is relocated closer to this Pacific Coast of Guatemala which was part of the Spanish colonial policy of... It's called "Reducing Maya Community." So they move people out of where they've always lived, and make them live in these new communities where they get easier to control.

06:41 Sarah: What surprises me then, after all of those events, is that the location of Sac Balam is not known.

06:47 Lizzie: Yeah. No. It surprised me too. [laughter] 'Cause it is on some Spanish maps. These are like 1,700 maps, they're not satellite [laughter] maps. It was connected to the Spanish world for a while. But only for a pretty short time, so they didn't really have a huge investment in the place. When they move people out, the jungle stays the jungle. There's not a huge amount of clear cutting. Today, the location of Sac Balam is within this National Park in Mexico, called Montes Azules and it's considered, an extremely remote part of Mexico. There are no trails, no roads, nobody's allowed to live there.

07:25 Sarah: Well, you went with a group of archaeologists to try and visit this lost city. What made them think that, A, they could find it? And B, what would they get out of finding it?

07:36 Lizzie: Despite them existing for... Overlapping with the Spanish colonial state for a couple of centuries, there's really no information about what it was like to live in Sac Balam or any of the other independent Mayan capitals that existed around this time. Sac Balam wasn't the only one, but it was the second to last, to be conquered. They wanna know, who they were trading with. How connected they were to the outside world, how not-connected they were. How did they do this? How did they live, in such isolation, for so long? The reason they thought they could find it is, or the method that they used, was looking at these Spanish documents from the time after Sac Balam had been conquered and Spanish visitors would go and then they would go other places. They would record their routes and how long it took them to travel to different landmarks like certain rivers or certain other towns. So you can reconstruct a possible arc of locations of the city. Basically, we were trying to get as close to that as possible.

08:37 Sarah: So, if you have your starting point and then they say, "Oh, we traveled for seven days." You know about how far they went in a circle?

08:46 Lizzie: Exactly. It's gonna be on one side of the circle and not the other, like you can make some inferences. And they didn't record it in kilometers or anything that we measure of distance we would use, so you'd have to estimate how far they could walk in a day. It's quite fuzzy, but it's a starting point.

09:02 Sarah: You do have a description of what the Spanish... How they described Sac Balam, when they arrived?

09:09 Lizzie: Yeah. It was about 100 houses which were probably made of dough-base, so they will not have survived until now. There were three community buildings, not quite temples but like city halls, and those would have had stone foundations, and that's what the archaeologists are interested in finding. The region today is known for scarlet macaws, the iconic red parrots and, apparently, the Lacandon had semi-domesticated them. And every day at 5:00 PM, they would fly out of the forest and land on all the houses, and the Spanish thought that was amazing. And so do I.

09:43 Sarah: Do you feel like you were able to keep the same pace as the people who had traveled to Sac Balam before when you were looking at previous trips?

09:52 Lizzie: Yeah, it's hard to say. We weren't carrying all of our stuff; They would have been. We did set up base camps. They probably would have been wearing stuff that was really tough to walk around in, you know. Lots of wool and, potentially, metal. This was not easy for them either. That was one of the major things I was thinking about in the jungle. I don't really care about the Spanish conquistadors. I think we pay far too much attention to their experience in history because they're the ones who got to write it. But I was really taken aback by how similar our experience would have been to theirs 'cause, of course, the Lacandon knew what they were doing and we didn't.

10:31 Lizzie: So we were much more similar to the Spanish. And I felt like if you have a city, if you have 100 people hiding out in the jungle against a globalizing empire, it's only a matter of time until they will be found and incorporated into that empire. I came away thinking that that really wasn't true at all. It was so hard to do this that the conquest of Sac Balam, and basically every other place in the Americas was basically a historical accident and a fluke.

11:01 Sarah: The Conquistadors had to rely on locals to help them find the city. Do you think that that's something that the archeologists are gonna pursue as well?

11:09 Lizzie: Help was vital for the Spanish, and it was vital for archeologists now. The one sort of "discovery" that they were able to make on this trip was this classic period Maya ruins which is 1000 years before Sac Balam would have been founded. But this town and the region knew about some ruins in this little patch of forest that they protect as a reserve, and they took the archeologists there. It was really amazing. I've seen a lot of un-excavated archeological sites, and this was a really special one. And they never would have known it was there if the local people hadn't been willing to trust them and tell them about it.

11:47 Lizzie: With Sac Balam, the hard part is that nobody lives in Montes Azules. There are people who go in there, like there are firefighters who might know the reserve. There are people who have lived there as refugees from the Guatemalan civil war. A lot of people took refuge there. There are people who know Montes Azules a little bit better than the average person in Chiapas. But because nobody lives in it, it's just so hard to find those people and it's so hard to find the help that you really need to be able to do efficient archaeology, let's say.

12:20 Sarah: How far did you travel in all of this?

12:23 Lizzie: I think we kayaked 90 kilometers in four days. This was a round trip, so we went upriver 45 kilometers, and that was already from the base camp, I think. A lot of kayaking, like definitely more than I've done in my life. The walking... It was really shocking how slow the walking was. It was about a kilometer an hour, which is, if I'm walking in a city, I go a kilometer in 10 minutes. So, the walking was, I think it was eight kilometers or something in the site. But it was not very long, but it felt like we had climbed Mount Everest.

12:58 Sarah: A lot of archaeology is done with lidar these days, using radar from planes to find hidden structures. Would that be helpful here, in this area?

13:08 Lizzie: It could potentially work. I think it would be really great to do it over Montes Azules. I know the archeologists would love to do that, too. National Geographic funded this huge lidar survey of a very similar place in Guatemala, and it revealed tens of thousands of structures that archeologists didn't know about. The thing about lidar is that it's pretty expensive, and it takes coordination. And also, when you do lidar, you still have to go out to the potential site and see it. So it doesn't totally save you from the explorer, jungle adventure that we had. [chuckle]

13:43 Sarah: What are these archeologists gonna do next? Are they gonna go back?

13:46 Lizzie: Yeah, they are gonna go back, which I found a little bit mind-boggling. But they're really committed to exploring this area of Chiapas and Montes Azules. And what this did was it gave them some information about how fast the Spanish could travel. Maybe it was a little slower than we had thought. Maybe Sac Balam is closer to these landmarks if you have to go so slow. A lot of the information on the satellite maps about the exact routes of the rivers turned out not to be totally right, so it made making a more accurate map much easier. And I think the most important thing it did, probably, was bringing these archeologists in closer contact with the communities down there, both the communities who live in the towns, and the guides themselves who know the reserve very well.

14:34 Lizzie: It takes a lot of work to build that kind of trust. You need to have people agree to show you what they know, especially since archaeology in Mexico, as in so many places, is often connected to the State and official narratives of the country and, potentially, land expropriation and things like that. People can be very wary of archaeologists for pretty good historical reasons. [chuckle]

15:00 Sarah: Yeah.

15:00 Lizzie: So you really have to spend a lot of time there showing them that you care about these places, and you care about the current people's connection to those places, and you're gonna respect that.

15:10 Sarah: Okay. Thank you so much, Lizzie.

15:12 Lizzie: Thanks, Sarah.

15:13 Sarah: Lizzie Wade is a contributing correspondent for Science. She's based in Mexico City. You can find a link to her story at sciencemag.org/podcast. Stay tuned for an interview with Christophe Coupé about the information density of different languages.

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15:34 Sarah: This week's episode is brought to you in part by Kroger. Did you know one in eight Americans struggle with hunger? Yet, 40 percent of food produced in the US gets thrown away. And a lot of that food waste happens at home. When food waste is sent to landfills, greenhouse gases are released. So it's a problem for our planet too. But think about this, if we redirected just one-third of the food we waste to people in need, we would more than cover the unmet food needs across the country while helping to protect the planet. That's what Kroger is doing through their zero hunger, zero waste foundation. Last year alone, Kroger donated 325 million meals to local food banks. And they've got some great tips to help reduce food waste at home too. It's all part of their goal to achieve zero hunger, and zero waste by 2025. Check out kroger.com/zhw to learn more. That's kroger.com/zhw.

16:34 Sarah: This week's episode is also brought to in part by KiwiCo. KiwiCo creates super cool hands-on projects for kids that make learning about STEAM Fun. With a KiwiCo subscription, each month the kid in your life will receive a fun, engaging new project which will help develop their creativity and their confidence. Their projects are designed to spark tinkering and learning in kids of all ages.

16:56 Sarah: All projects, inspiration, and activities are created by a team of product designers, in-house in Mountain View, California, and rigorously tested by kids. Every crate includes all the supplies needed for that month's project: Detailed easy-to-follow instructions and an educational magazine to learn even more about that crate's theme. KiwiCo inspires kids to see themselves as makers, and is on a mission to empower kids, not just to make a project, but to make a difference. KiwiCo is offering Science Magazine podcast listeners the chance to try them for free. To redeem this offer and learn more about their projects for kids of all ages, visit kiwico.com/magazine. That's kiwico.com/magazine.

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17:47 Sarah: Now, we have Christophe Coupé. He's here to talk about his Science Advances paper on the information density of languages. Hi, Christophe?

17:55 Cristophe: Hi.

17:55 Sarah: What questions were you asking in this research?

18:00 Cristophe: The deep underlying question is whether all languages they are equally complex, or whether we could find some languages that would be, let's say, more efficient than others to carry information.

18:10 Sarah: So you wanted to compare across a lot of languages. How many did you look at?

18:14 Cristophe: We paid attention to 17 languages. We tried to pick them in different language families. So we tried to pick up languages that you could find in Europe, but also in Asia. Some they have tones, some don't. Some have many different syllables to build their lexicon, some have less syllable. So there is quite a variety.

18:34 Sarah: In your sample of these 17 languages, some have a lot of syllables, and some have a few. Like Japanese has a few hundred; English, almost 7000. How did you go about lining up these structurally different languages to measure information density?

18:52 Cristophe: For each language, we had 10 participants. So they were asked to read aloud 15 texts all made of five sentences, and in these texts would be about different situation: Pretending to be someone calling a service on the phone, booking for a place at the restaurant, things like that.

19:09 Sarah: What did you measure about those recordings?

19:12 Cristophe: What we measured, basically, is how fast this subjects talked. That is, more precisely, how many syllables they produced per second.

19:19 Sarah: You had a count of that, but then you wanted to see how fast it was in different languages?

19:24 Cristophe: If you take any language... Let's say you take French, for example, some people will speak faster than others.

19:28 Sarah: Right, yeah.

19:29 Cristophe: So we were rather interested in average speech rates. And the way we measured them was to count how many syllables on average people would produce. So for example, we would find that in a language like Thai, people would produce five syllables on average per second. But then if you would compare with other languages, like Spanish, then you would find that the number of syllables per second on average would be significantly higher, like seven or even eight syllables per second.

19:55 Sarah: So you would say kinda simply that they were speaking faster?

19:58 Cristophe: Yeah. It is quite common I would say that people will tell you, "Oh, Japanese people, they talk so fast," or "Spanish people, they talk very fast." When you actually measure it, this is what you observe. They speak faster on average than, let's say, Mandarin speakers.

20:12 Sarah: So did you find a relationship between the number of syllables in the language and how fast people spoke?

20:20 Cristophe: So we did not directly study the connection between the number of syllables and the speech rate. What we are interested in is the amount of information carried on average by the syllables in a language and the relationship between this and the speech rate.

20:35 Sarah: So what kind of relationship did you find?

20:37 Cristophe: What we find is a trade-off. You have some languages where each syllable on average carries quite a lot of information, but then the speech rate tends to be quite low; you don't produce so many syllables per second. And then on the other side, you have languages where syllables are lighter, let's say, in terms of the information they carry, but then on average, speakers, they would produce more syllables per second. So that's the trade-off we observed.

21:02 Sarah: So there's this balance and there's a sweet spot in the center that these languages hover around?

21:07 Cristophe: Right. That's the point. So we measure how many syllables you produce an average per second, let's say in French or in Spanish, and then we know how many bits of information each syllable carries on average in these languages. So if you multiply the bits of information per syllable by the number of syllables per second, then you get the number of bits per second. That is how much information you convey on average each second. And this is where languages actually look quite alike.

21:35 Sarah: Well, let's talk about why that might be. Let's bring in some of our understanding about cognition and the way the brain processes language. How does that, what we understand about that, fit with what you're finding is about these features of language?

21:50 Cristophe: What seems to be the case is that there is a deep connection between how we are able to track speech dynamics with the oscillation of some brain waves. This brain waves, they are... They belong to a range called the theta range. So this 39 bits of information per second that we find on average for our languages, basically, corresponds to these oscillations that we tend to have in the brain. And this is something shared among human beings.

22:17 Sarah: So there's this oscillation in the brain when you're listening to speech?

22:21 Cristophe: Yeah, likely. But actually, when you listen to speech, the activity is very complex. But what it seems is that there is... There are some waves that tend to oscillate at a specific reason and this reason basically corresponds to the 39 bits per second that we observe on average for languages.

22:37 Sarah: If, say, I was trying to convey something that was very complex, I'd talk slower. It seems sensible but it sounds kind of like this is something that's built in.

22:46 Cristophe: In different situation, you may have to slow down because what you try to convey is more demanding communicatively speaking. But actually, in our case, for example, we had this 15 different texts covering different situations, and what we observed when we conducted

our statistical analysis is that there is actually not so much variation from one context of communication to another. You may find that sometimes you need to slow down, but then if you look on average, then you are going to see that there are... There is not so much variation.

23:17 Sarah: Right. Do you think we're maxing out how our brains process language? Or do you think this is just comfortable middle ground?

23:23 Cristophe: It seems it's a comfortable middle ground. Because we all know we can speak much slower than usual and we can speak very fast, and we also observe inter-speaker variation; there are people who can speak extremely fast. So quite often, when you read about this on the Internet, for example, you will find how some people can speak like more than 300 words per minute, it's like that. We were not interested in words but in syllables, but of course there is considerable variation. But what seems to exist is like this comfortable middle ground that, on average, 39 bits of information per second is the sweet spot. It would correspond actually to this neuro communicative properties we talked about a few minutes ago.

24:00 Sarah: So there might also be people who are fast listeners, if you will. That's possible as well?

24:05 Cristophe: That's something we did not investigate. So the variation, when it comes to listening and processing speech rather than producing it. But of course you might also expect variations, at least what we can say is that there is this deep intimate connection between producing and processing speech. So let's say that, for example, as we consider like very fast rate of information, then it's hard for the person who speaks to produce it, and then it's going to be hard for the other one to decode.

24:34 Sarah: Right.

24:34 Cristophe: And then maybe if it's very slow, then the amount of information that is going to be carried will be very low, and that makes, maybe, then the communication system not very efficient. And there is, let's say, a minimal level of efficiency that we require for language to be a good thing, I would say.

24:50 Sarah: Languages change over time. We change how we use words, we change which words we use. How does that work with this idea of a rate of information?

25:01 Cristophe: To be fair, we would definitely need to conduct more studies, and what is a little bit difficult is that we don't have recordings for past centuries. Things like that would be very good, but we don't have them. The idea that we have is that the density of information per syllable, it's something that is connected to the structural properties of the language, while speech rate is something that rather belong to speakers. So our idea is that because indeed languages keep changing, something that is very well known, if a language would change and that it would drastically or significantly modify the amount of information per syllable, what we could expect is that people would adapt their speech rate so that the sweet spot is not lost.

25:42 Sarah: Yeah. Well, did this result surprise you? This is a very large study compared to previous studies that have looked at certain subset of languages or a certain amount of text, you know. Were you surprised that the numbers coalesced the way they did?

25:56 Cristophe: So of course we are quite happy to see the statistical result we get are quite strong, quite significant. I think maybe in a way we were not so surprised because we shared the idea that languages they are equally efficient. Because if like, basically, if a language would be less efficient, it would just change to become more efficient. So despite different strategies in terms of speech rate and information density, the fact that they share this average rate to transmit information, it's something that tells you, "Yeah, indeed languages, they are equally efficient." What is nice is that here we really look at language being used. So we look at it through time rather than trying to compare languages based only on their structural properties.

26:36 Sarah: Thank you so much, Christophe.

26:37 Cristophe: You're welcome. My pleasure.

26:39 Sarah: Christophe Coupé is an Associate Professor in the Department of Linguistics at the University of Hong Kong. You can find a link to his science advances paper at sciencemag.org/podcasts.

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26:51 Sarah: And that concludes this edition of the Science Podcast. If you have any comments or suggestions for the show, write to us at sciencepodcast@aaas.org. You can subscribe to the show on iTunes, Stitcher, many other places, or you can listen on the Science website. That's sciencemag.org/podcasts. There you'll also find links to the research and news discussed in the episode. To place an ad on the podcast, contact midroll.com. This show was produced by Sarah Crespi and edited by Podigy. Jeffrey Cook composed the music. On behalf of Science magazine and it's publisher, AAAS, thanks for joining us.