

# The Enigma of Evolution

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So an enigma a riddle a mystery we're rather fond of enigmas the Romans puzzled over them the Saxons delighted in them one of the oldest books in English is the Exeter book of riddles and unraveling enigmas is in many ways the lifeblood of research so science that unwraps many enigmas now Neil Armstrong wasn't a man of many words but he said mystery creates Wonder and Wonder is the basis of man's desire to understand and we turned to Douglas Adams he suggested that if anyone did actually discover what the universe is for it would instantly disappear and be replaced by something even more bizarre and inexplicable so but you know mysteries aren't just for science I think of James Joyce no doubt does he spread his bread with curdled quark said I've put in so many enigmas and puzzles that it will keep the professor's busy for centuries arguing over what I meant and that's the only way of ensuring one's immortality but then policy has an agreement has mysteries to think of Churchill's prophetic speech in 1939 forecasting the course of World War two and he's set him as a riddle wrapped in a mystery inside an enigma but perhaps there's a key so we seek those keys and this year's Darwin College lecture seat keys to open doors to codes and books doors as are as far apart as emotions and our own origins which of course brings me to tonight's enigma now one of my relatives is a radiologist he once passed an x-ray picture around a group of leading colleagues who were discussing their interesting cases they were puzzled they didn't know that he helped a famous conservationist they said to this x-ray so what's wrong with her nothing well why are you bothering us the answer was none of you has spotted she's an orangutan now.

Charles Darwin's most troubled book perhaps is the descent of man kind of wish he'd known about DNA now tonight we welcome the writer and broadcaster dr. Adam Rutherford whose PhD at UCL was on Darwin's great puzzle the development of the eye and in his lecture tonight on human origins and we have a lot of information on the screen already he will explore how humans are different are we really any more special than other animals so please welcome Adam Rutherford Thank You massa it's a great honor to be invited here Charles Darwin is my intellectual hero I've written five books about his work so far but I was informed rather sternly that this the Darwin College she was not named after Charles

Darwin but uh but after the Darwin family as a whole I'm aware that there are other Darwin's if any of them are here sorry about that yes I'm glad that the theme is enigmas because in all of my work and particularly around human evolution in its relationship to genetics and yes you're quite right I wish Dawn had known about genetics genetics has done nothing but recapitulate the ideas of Charles Darwin over the last hundred and sixty years we're up to now and and it is in the fusion of genetics with evolutionary theory which is the most exciting work that is going on in all of science developmental genetics is the most important science population genetics is a close second.

I say that to acknowledge my colleagues in the audience at Darwin College that I can't quite see at the moment but we'll be having dinner with later and I understand that my friend of mine Sean Carroll is giving next week's lecture physics is okay too but these are the stories I don't propose to give any particular answers to and there is a great enigma at the center of evolution and human evolution and I think that all of my work and over the last 20 years or so has been to explore these questions without giving definitive answers without suggesting specific things that answer the questions that we like to ask such as what it is that makes humans special because I am not that interested in in those sorts of definitive answers which really are the the purview of journalism and storytelling rather science is a constant exploration of these types of questions without giving definitive answers and so if you have come to find out what the answer to what it is that makes us human then I'm told to say that you are in the wrong leg theater the answer to what makes us human is having two human parents and that's having a human genome also works but obviously that doesn't really address the question the real question which is what makes us special what is it about the human condition which is unique is it unique what is it the Enigma at the heart of the human condition many people over the last several thousand years have used this question in order to generate what we sometimes call uniqueness theory so answers to the question of what it is that made us special made us what we are today and they have ranged from the interesting such as speech and language things like fire communications sexual behaviors to the absurd like hallucinogenic drugs or fear of snakes that both of those recently published in the last couple of years as attempt to answer the question about what makes us special but what I want to do and what I do in this book is to just explore the question and in doing so ask well I'll be special and as I said I'm not going to give you any definitive answers to that question but we've gone through a bit of a revolution in human evolution in the last few years and that is primarily because of the introduction of a new data source into the story of us and that is DNA and I guess there's a couple of reasons for that one is just a relentless charge of us understanding how genetics works understanding how that those sequence of letters in our genome are converted into biology physiology and behavior we just have a better understanding of that now there and at any time in history but also there's been the introduction of the DNA the genomes or people who've been dead for hundreds thousands or even tens of thousands of years and as such we look at the genome we can look at our DNA as a sort of record a logbook of all of the sexual encounters of our ancestors now that's not correct is it all of the reproductive successful sexual encounters of our ancestors not quite the same thing and being able to extract the DNA from from the long-dead and compare it to our own and the DNA of other species closely

related or otherwise we can help tell the story of life on Earth now that was largely the story that was largely the basis of my last book before that which was somewhat hubristic I titled a brief history of everyone who ever lived and that deals with the last million years worth of human evolution in this book I tried to deal with just the last hundred thousand years or so so a much more narrow scope there and there is this central question in there which is that as Darwin identified in the Origin of Species that evolution by natural selection is the mechanism by which we see the radiation of life on Earth not the origin of life itself but the reason life is the way it is as we see it today is via his mechanism described in the origin and we are included in that his second greatest work the one that Mary just alluded to the Descent of Man which celebrates its one hundred and fiftieth anniversary next year the Descent of Man is largely focused on this question that he sets up in the Origin of Species ways the only reference to humans in the origin is saying that light will be shared upon upon our own species in the future well that time is now with us and yet there is a central paradox as a central command room at the heart of trying to understand the human condition which is that we are evolved we are part of the biological evolutionary tree of life we have the same cell structure the same DNA the same coding system the same physiology as every other organism that has ever existed in the last four billion years or so and yet here we are doing this and doing all the things that humans do so that's the paradox that's the question that we're exploring it was Charles Darwin who first addressed this who first framed this in a scientific sense in the descent of man in which he says with his typical beautiful prose with our godlike intellect which has penetrated the movements of the solar system with all of these exalted powers man still bears in his bodily frame the indelible stamp of our lowly origin what an excellent phrase there is the paradox we evolved and yet we can do this now as I say.

Darwin was an astonishingly good writer some of the best prose written in the English language he wasn't the first person to express this as an idea though that came from an arguably better writer than Darwin about 200 years earlier it was Shakespeare I think it's reasonable to say that Shakespeare was the better writer than Darwin thank you master in the famous soliloquy from Hamlet what a piece of work is a man how noble in reason and so on in apprehension how like a god it's the same idea as in the descent of man the paragon of animals I wanted to call the book the paragon of animals but my editor said that was pretentious and she was of course right after that line the paragon of animals Hamlet goes on to say what is this quintessence of dust and there is the conundrum again we are merely matter and yet in action how like an angel now I people who are familiar with my work will know that I'm obsessed with movies and I quote films in all of my work liberally and it's got this disease has got to the stage where I don't really even notice that I'm doing it and it takes others to point this out to me and in the final chapter of the previous book a brief history I'd written a sentence which I was really pleased with because it just sounded really good and I sent the copy off to my editor who wrote back well this is this is the line I wrote everyone is special which is another way of saying that no one is and the editor my editor Jenny wrote back to me and said I like the way you've quoted this film I was completely unaware of that can anyone identify what felt no not you Beth can anyone identify what film this is from The Incredibles there it is so in the first three pages in the first three pages

of my book about the the the evolution of culture and humanity in humankind and I quote Darwin Hamlet's and - from The Incredibles but there it is again it's the same expression of this of this this this paradox as I describe it now as I said at the beginning there's been this ongoing revolution in understanding the human story that's been going on for the last 10 15 years it just ramps up with more and more data that we get from genomics and so I think it'd be useful to go over maybe just just go over the last million years of human evolution also in short form just to get us to the point where I think it becomes interesting so we are an African species Homo sapiens emerged in Africa at some point over the last half a million years or so now this is a complex picture for which we have limited data but things like that sentence that we are in African species is fairly unequivocal and supported by lots of different types of of data and it's in contrast to an earlier 20th century idea which was called the multi-regional hypothesis which was the idea that humans the differences that we see between us emerged at different places around the earth and we were not separate species but that we had evolved in different areas around the world we now mostly reject that the latest evidence comes from genetics which shows that the highest genetic diversity meaning the biggest number of differences between people genetically is in Africa so this is a scaled map which shows where genetic diversity is highest on earth and you can see that the biggest chunk of that occurs within Africa and the smallest chunks occur in North America and the Americas in general and New Zealand and this is a sort of recapitulation of our general understanding of the migration Out of Africa that occurred approximately 70 to 80 thousand years ago and the way we represents evolution is that we use evolutionary trees the human evolutionary tree has changed significantly in the last few years so I'm just going to skip through that incidentally and I don't mean to show any ingratitude to my very generous hosts here the poster that was used to advertise this lecture which shows the very traditional the famous image the icon image which is known as the march of progress which it has on the left-hand side it has some kind of earlier ape-like creature you know although the one I'm talking about and then it becomes more upright and more upright until eventually it is a white bearded man with a spear now this is for a French textbook in than in the 1960s and I have two deep problems with it I think is deeply misrepresentative image sorry but I noticed that the Darwin college students also use a version of it but I'd like your version of it if any of you are here it's two things I think are fundamentally wrong with this image the first is that it shows that we know the pathway from earlier quadrupedal Apes to us well we don't we don't know that pathway at all we have some idea of the evolutionary route by which we got to be us today but we don't really know twenty years ago when I was learning this stuff as a as a at school well we definitely knew it then we definitely knew all the pathways from Australopithecus from Lucy all the way to us but with more data that we've accumulated over the last twenty years or so I don't think it's fair to say that we know almost any of those those branching routes the second thing that's wrong with it is implies direction it implies that there is destiny within our evolution that we start off as a chimp like ape on all fours and we progress towards being a nice upright tool using large brains white man and evolution has no direction that it implies that is why I reject it as an image apart from in the advertising of this very lecture which was perfect and excellent okay so the evolutionary tree well this is a sort of rough version of it where we've got a million years ago on the far left and this is today so we are the last remaining human the genus is Homo and

we refer to anything within the genus Homo as as a human homo sapiens is what we are and that's split up into large land masses as we see today you can see that there was an earlier branch of Homo sapiens which sometimes referred to as archaic modern humans but emerged out of Africa earlier now that date keeps changing as well we've known about some Homo sapiens that were found around Central Asia and Israel for a few years now but just last year a team discovered Katarina Havarti discovered a skull embedded in the roof of a cave in Greece edema in Greece and that is now the oldest Homo sapiens outside of Africa we don't think that they left any legacy any genetic legacy but that may change in time but that's the earlier branch of Homo sapiens which migrated out of africa in general we Homo sapiens is an African species and emerged out of Africa but you can see that there are plenty of other humans on this on this tree you all know about the Western the ant atolls in general which we now they were a Eurasian species and we now can separate them into eastern and western and then in 2009 a finger bone the distal tip of the fifth finger of a teenage girl was found in a cave in Siberia along with an unusually large tooth now that is not enough physical remains to designate a new species which is largely based on on morphology on physical remains but it was enough to extract the full genome out of the finger bone and that indicated that this individual was not Neanderthal and was not Homo sapiens but was something else and we refer to those people as their Denise Evans I'm not a big fan of taxonomy over all I'm not a huge fan of the species concepts we'll the main species concepts but this is broadly vaguely useful way to describe human evolution over the last million years or so except it's really not and it's really not because of the introduction of genetics into understanding human evolution the our ability to get DNA out of the denisa and finger-bone our ability to get DNA out of Neanderthals which which was first done in 2009 by Svante Paabo and his team and our understanding of our own genomes and so what genetics is the study effectively of inheritance and sex this is an over 18 audience isn't it and we've got lots of euphemisms we talked about gene flow events and introgression but what we're talking about is sex and what the genetics unequivocally shows is that our ancestors well had sex with a lot of different people that we might designate as different species so what we know is that this tree doesn't look like this what we actually see is that they were gene flow events between the Western Neanderthals and the people who have become Asians and Europeans there were gene flow events between the west and the nfl's and a second occasion and Europeans we know this because it's not the most diverse crowd I've ever spoken in front of but but most Western Europeans carry around about up to 2% Neanderthal DNA which means that now cells aren't our cousin's as we sometimes describe and does that mean there are different species I don't know I'm not sure I care but they were definitely our ancestors because you carry their genetic legacy in you today and we also know that the East and the under tolls had sex with okay modern humans both of those those those branches now being extinct and we know from looking at the denieth ones that they had gene flow events with the East and the end of tails and so that 2% up to 2 percent Neanderthal DNA that you see in white people and the further east you go it gets replaced that number goes down and gets replaced with Denis of and DNA and we also know that the Denisovans also well there it is for the Asian so you know I'm let me talk about evolutionary trees I'm not convinced that they're used that's a useful metaphor anymore because that isn't a tree in the book I just this is Friday night and this



this is what passes for entertainment on the Friday night I suppose in Cambridge in in the book I was trying to find the right word or metaphor to describe this picture of the last million years worth of our story and what I came up with was half a million years worth of excuse me I'm very sorry about that and you might notice there's a branch of the top which I haven't mentioned yet so this is an inferred species sometimes referred to as a phantom species and we know that because when you compare the DNA when you compare the genomes of asked within the and atolls it looks like there is introgression there is there is an injection of DNA from another species that we can't identify all right a phantom species this picture is only going to get more complicated the more we look we don't know what that mystery human was it's probably one that we have already identified from bones but haven't managed to extract DNA from those bones yet watch this space ok so there's a million years worth of human evolution summed up in in one image this will get more complicated and it does show that our ideas about nice clean narratives about how we got from Africa to here today are probably not the most accurate or best way to describe what actually happened which is that people move and they have sex and that's what humans do we are really good at those two things and over that type of timescale and million years or a hundred thousand years or whatever there aren't those nice clean what I refer to as Dad's Army maps where you see a picture of the earth and it's got nice arrows which go we were here once and we moved and we were over here that may happen in the broad sweep of tens of thousands of years but actually it's much much more messy than that which makes the science much harder but much more interesting as well so that's us down at the bottom Homo sapiens now we think that the oldest known specimens of Homo sapiens of our species now come from Morocco about three hundred and fifteen thousand years ago place called Chevrolet Rhodes which was discovered in the 60s and 70s but read ated 2017 at three hundred and fifteen thousand years ago also now this is the earliest example of a specimen which we think is unequivocally homo sapiens think there's a lot of argument within the field about these types of things but I'm happy with that as a description does two things it moves the oldest Homo sapiens from East Africa 200,000 years ago was are the oldest previous known example it moves it in both time and space hundred thousand years older and also from East Africa from Ethiopia to Morocco and what we're now beginning to think is that we're sort of pan-african species that's yeah we want to know if we're I can say unequivocally we're an African species but the next question a reasonable question is well we're in Africa but what it looks like from the genetic evidence and from the archaeological evidence paleontological evidence is that there doesn't there isn't really a central location and nursery for humankind it looks like that there were many different types of humans all around Africa and we're a sort of Gestalt version of that we've got people up in Morocco who look like Homo sapiens we've got plenty of people down in East Africa they look like homo sapiens now the point about showing Jebel Haroun one here is that if you were to meet this person today in this lecture theater if they were shaved and wearing a dress or trousers or just you know we tidied them up a little bit you wouldn't be able to tell them apart from anyone else in this lecture theatre but it's not a comment on the aesthetics of people from Cambridgeshire they were modern humans in in the sense that they looked like us they the variation in their morphology based on this one skull and a few other bones is that they basically look the same as us so that's three hundred thousand years ago so

physically we haven't really significantly changed in more than a quarter of a million years and that's also pretty much true genetically as well much of the variation that we see in and around the people of the world today is relatively relatively trivial relatively superficial we're basically the same as we've been for the last quarter of a million years that's quite a weighted statement but that's what I'm going to go with for now that's a quarter of a million years of relative stasis but what we see from the archaeological evidence when it comes to minds is something fundamentally different we don't really see any great significant movement in archaeological artifacts until within the last hundred thousand years and very much more specifically within the last forty thousand years and then we see things like this so you may have seen this on TV programs and documentaries Lovan Mensch the lion man of Hohenstein startled the illustrations in my book ER by Alice Roberts by the way who is not only excellent TV presenter and scientist she's also annoyingly good at art it's just not really very fair that but anyway though the lion man was discovered in the 1930s in a cave in in Germany and it's carved out of a tusk and we think it's a man based on analysis of the of the genitals it's got seven stripes down its left arm which may or may not have been tattoos but of course the most obvious thing about it is that it's got a lion's head a cave Lions head now apart from being astonishingly beautiful and the oldest figurative art I will qualify that in three slides time the oldest figurative arts no I it's in these types of artifacts are incredibly important for asking a really important question about human evolution because what this demonstrates amongst many other thing is the creator of this the artist I'm happy to call it art the artist behind this has a mind which is not dissimilar to ours today I had it shows enormous foresight in deciding what to carve and choosing the materials to carve great skill it's unlikely to have been unique it probably part of a series this type of level of skill would it be an acquired and culturally transmitted traits but it also shows great imagination this of course is a not a real beast it's a it's a chimera we don't know the significance of cave lines in southern Germany at that time but but obviously they were of cultural significance probably because they try to eat humans a lot but what this shows is that 40,000 years ago there are people on earth whose minds work in a very similar recognizable way to our own today and we see little evidence of this before 40,000 years where we do see it it appears to be sporadically that pops in and out of the archaeological record but from 40,000 years ago days are served and almost a landmark we might refer to some people refer to this as the cognitive revolution.

I don't I don't like that as a term because it's sort of in I think revolutions should take place faster than tens of thousands of years but what it does show is the emergence of what we sometimes refer to as behavioral modernity so us today the people before this are not recognizable in terms of behavior as us today although physically they were whereas the people after this well they're basically us now from this point this is about 40,000 years ago from this point we see lots of artifacts lots of arts the the venus of hohle fels is an example of the oldest example of a series of little figurines which is sometimes which are all collectively known as Venus's this one is about thirty eight thousand years old also from southern Germany they're called Venus's well for a number of reasons the main one being that the first person to find one named it the Venus IMP you deke butt it had a large vaginal slit on the on the statue which is about about this big and often these Venus characters

figurines have exaggerated sexual traits now lots of people speculated about what they were for and because they have exaggerated some of them have exaggerated sexual characteristics there's been a lot of speculation that they are reproductive charms or fertility amulets or something like that there's even been a suggestion that they were pornographic which is not my explanation sometimes people have suggested that they're toys.

I I sort of don't care what they are because it's difficult enough to know the mind of someone you're married to compared to someone who died 40,000 years ago but again they are indicative of behavioral modernity and that's that's why they're important I leave it to other people to speculate as to the motivation of creating such things 38,000 years ago you know by that by the twenty thousand years ago we have the cave paintings in places like Lascaux in France and all over Europe and these depict scenes and much more complicated arts and by this stage you know we're well into cave art now most of our knowledge about about the emergence of these types of artifacts is centered around Europe partly because that's where we studied the most but of course that picture has changed recently in the last few years as well the more we look the more we find and remember Homo sapiens are all over the world by this point they've been in Australia for maybe 60,70 thousand years and researchers in Southeast Asia have begun to identify all cave art from similar sort of time periods this one sees a hand stencil so blown through hollow tubes probably bones red ochre and you can see that there the outline of of hands this is in Sulawesi in Indonesia so that's that moves that means that we have the emergence of burial modernity all over the world roughly the same time and of course science never stops the more we look the more we find and so that I said that the lion man the Levis mentioned homodyne startled was the earliest figurative art that changed two years ago with the discovery of an enormous painting in a cave in in Borneo which is a minimum of 40 thousand years old I know whether you can make this out but this is a bad thing so it's a bovid like a cow an indigenous cow you can see the horns at the front two legs it's actually about that size on the roof of a cathedral-like cave in a remote part of of Borneo so from two years ago the oldest figurative arts is moved from Germany to Indonesia and then just before Christmas in what was my favorite paper of 2019 the same team published the discovery of some cave arts in also in Sulawesi and it was 44 thousand years old now not just moving the date and the time so this is now the oldest figurative art this is also a scene so this is a hunter I strongly urge you to look at this paper or look at the reports of this paper because it's not just one animal it's multiple animals depicted in a hunting scene you can just make out some smaller animals at the front there there are also humans in this large scene which is many metres wide it's been painted over many over a long period of time those humans which appear to have headdresses or mutant heads chicken heads and again.

I I don't pretend and I think anyone should pretend to understand the motivations painting these things but it clearly has some sort of totemic value it is a narrative scene and again even more than just creating a chimera out of a carved tusk what it shows is that we have we now have narrative structure imposed 44 thousand years ago by early humans in Sulawesi it's stunning and important and I love it now so far I only talked about Homo sapiens but in 2018 some known cave art from Cantabria in northern Spain was read ated I've discovered in the 90s and it was read acid this is a cleaned-up version because it's very



faded and the date of this came out at about 60 to 70,000 years old now the only people in Europe 60 to 70 thousand years old and not Homo sapiens they are Neanderthals right so this is part of the I have to point out that this date has been robustly challenged and I'm not sure it's going to stand but for the time being it does but if it is accurate it implies that Neanderthals in Europe Homo neanderthalensis were also displaying traits which are we associate with creativity and behavioral modernity so not only is it not just us in Europe but all over the world it's not just us as a species it's also our closest ancestors stroke cousins are also doing things like this and this is all part of the revision of Neanderthals who have a bad rep for being you know oh fish thugs when actually they were very similar to us and all sorts of behaviors they they did look a little bit different to us.

I think you would be able to spot in the undertow if one was wearing a suit and sitting next to you right now they have big barrel chests larger cranial capacities and ask broader noses but not so unattractive that your ancestors didn't have sex with them anyway the way I've structured the book in trying to explore these questions about the emergence of behavioural modernity the emergence of the things that we think of as being uniquely human is to talk about some aspects of what Darwin identified in the descent of man in some ways and I don't this is a humble brag the book of Hugh my book of humans is a is my modern interpretation of the descent of man and I got a long section on tools I've got a long section on fire I'm going to talk about both of them I've got a section on communications and those three things tool use fire controlled use of fire and language and speech and language those are three things that in the descent of man Darwin identifies as being unique human and so I spent a lot of time talking about those I've also got a section on sex which I will touch on tonight because it's Friday night and you are a grown-up audience but just for tonight I'm get just gonna focus on a couple of those things and the first is tools so we are a technological species we're an obligate technological species meaning that we cannot function without the extension of our abilities via our bodies without crafting our environment to create tools that's sort of you know semiotic academic definition of what a tool actually is we've been a technological species according to the scientific literature for at least two million years with the discovery of a set of tools known as the old one tool set this is a representation of the older one chopper found in Olduvai Gorge in the Rift Valley in the 1960s by the Leakey family in association with what is the oldest member of the genus Homo Homo habilis Homo habilis literally translates from the Latin as handyman or handy person so we are defined our genus is defined as a tool using species of course as I said science never stops it would make my life so much easier if you just did stop doing science for a while because in the 90s the older wooden tool sets the old one choppers were discovered amongst her much older species of knots within the family Homo but an earlier hominin called kenya anthropos platy ops which has a much flatter face but they also found older and tool set alongside those and there are more like three point one three point four million years so we've been two years as longer than we've been humans now that the older one tool set is stable through time and it spreads all around the world for much more than a million years maybe 1.5 million years and we don't see much technological development during that time then we see the emergence of a more sophisticated set of tools referred to as the eschew Liem toolset and these tend to be bigger by faced blades much more diversity

in the types of stone tools that have been found and we also see them spread all around the world wherever we see humans for the next million years or so so the majority of tool use in humans is just to two sets the majority at a time is just two sets that remain relatively static through time and it's only really in the last hundred thousand years or so that we see sophisticated development of tools into the modern era with iPhones now we name geological periods according to stones Neolithic Mesolithic Paleolithic the lytic meaning stones of course tools wouldn't just have been used as stones that tools would have been used to create other tools out of biodegradable material so this question that Darwin asks are we unique as tool users well you know the answer to this because you watch David Attenborough documentaries and the answer is an unequivocal no loads of different species our tool uses obligate tool users as well all of the great apes do it this is an example of an orangutan from Sumatra spearfishing so taking a nice straight stick stripping the leaves and the branches away from it sharpening it with their teeth and then hanging off a branch and stabbing fish they're not very good at it which seems odd to dis an orangutan but some anyway the point being that's all the great apes and many monkeys are obligate tool users as well what's interesting about looking at Tullius across the animal kingdom domain is that the diversity of where tools are actually used so one percent around about 1% of animals are obligate tool users which doesn't seem like a lot but that is you know it's thousands of different species but it's across nine different classes so this is mammals this is primates but it but they also taught there are tool users within the Crustacea within mollusks are in the within bird so you'll know that the corvids such as crow Caledonian crows are particularly adept tool users so nine different classes of animals are to use and this indicates that tool uses not a it's not a single doesn't have a single origin in evolutionary history but it has emerged many times as a as a useful functional thing what daniel dennett refers to as a good trick that's one example I'm going to do two more examples one because I'm quite childish and and that is in reference to a set of crabs that used to be known as boxer crabs because what they do is they pick up an anenome stinging an enemy and they rip them in two and they use them as boxing gloves to ward off either other males if they're competing sexually or to ward off predators and they actually sting them by punching them that they actually look like this in action I've got many examples of these because I find them terribly amusing and my absolute favorites is this one and what do they get called now not boxer crabs but what pom-pom crabs is what they could cause I'm sure this is terribly threatening if you're in another boxer crab but we just find it quite cute so this is one example of a one animal using another animal as a a tool I'm going to take that slide off now because you're not gonna listen to anything I say is right if I leave it out there so that's a that's a distantly related animal that's also using is also an obligate tool user now I sort of mentioned I very briefly mentioned this idea that we are cultural transmitters this is a key idea in in human evolution the thing that we do is that we pass on cultural information units of information to each other and not just in a linear way from parents to offspring but we pass information in all sorts of directions we're doing it now every time you communicate with another human you're passing on a unit of information on multiple units of information and that is something that humans do absolutely all the time we don't see it very much in other species some people don't think we see it at all I think there are some indicators that there is cultural accumulation of of of behaviors between species between individuals within a

species but whatever the answer to that is we do it with literally every breath this this is the thing that is us in the book and I know in front of an educated Cambridge audience there will be very any questions about how clearly I delineate this as an idea but I described us in the book as a species of teacher many animals learn that humans teach now I want to give a counter example possibly a counter example in another mammal where we might see a similar type of behavior and it concerns bottlenose dolphins so you'll know the bottlenose dolphins there's been a pod studied a population studied in Shark Bay in Australia for the last 30 or 40 years and in the 80s it was noticed that a proportion of the sharks in Shark Bay were doing a slightly unusual behavior which has never been seen in any other species which is that they were going down to the bottom finding a conical sponge or a roundish sponge and working it onto they're not the the rostrum that beak and then swimming around wearing a wearing a sponge on their beak this is what they actually look like now it was in the 2000s when divers started going down with these bottlenose dolphins that they began to see the apparent purpose of this slightly odd behavior which is that they're using them as protectors to protect them from foraging from from foraging in rocks and foraging boxer crabs presumably that could potentially scratch up their their their beaks their rostra and therefore cause infection so they're basically wearing a protective mask which seems like an eminently sensible thing to do when we began when the researchers in Australia began to get genetic information from these dolphins that were doing this several interesting and slightly peculiar things emerged from this the first was well the first explained why only a proportion in fact it wasn't just a proportion it was exactly 50% of the dolphins that they had observed were doing this behavior and the reason for that was only the females do it a male has never been observed in Shark Bay doing what is known as sponging and that's quite difficult to explain because it seems like an eminently sensible thing to do and well you draw your own conclusions about why they why the male's don't do it the second thing was that all of the females do this and it's a it's a diverse population there are many of them and so many of them are not particularly closely related to each other and so the implication from this is that this is a tort or at least a learned behavior the researchers in several of the papers describing it think that it's taught rather than learned of course you know mostly dolphins go unobserved but this indicates that this is a culturally transmitted idea so this is females teaching their sisters and daughters to do this behavior why the brothers and fathers don't learn it is still a mystery and there's another thing which emerged from it which is that we can sort of track the evolutionary history of this behavior by the distribution of the of the sponging behavior and it looks like it emerged about six generations ago from an individual so that's about the middle of the 19th century and we refer to that dolphin as sponging Eve so one one morning sponging Eve got up did this got up I don't know where dolphins sleep I've no idea got up works this onto her beak and all of our sisters thought that's a good idea but none of them ended anyway so this isn't that this is an example of cultural a potential cultural transmission of an idea in dolphins in another species of non-human species but we do it all of the time this in a slightly sort of radio for clunky link is going to take me on to the that's tools parked for now it's going to take me on to the next section and one of the things that we I guess sometimes in the public discourse about evolution we don't talk about enough is the importance of the environmental constraints the environment that organisms are in that has a major driving force behind

adaptive change and Francois Jakob the French microbiologist described evolution as a tinkerer which is a lovely phrase and I like that a lot and it should be used a lot but I came across in the writing of this book a phrase from the President Teddy Roosevelt he said do what you can with what you have where you are and he wasn't talking about evolution but I think that is also a really nice Maxim for describing evolutionary change and when you think about dolphins and their relationship to us we use dolphins as morphological analogues for particularly on our our fins and our hands we know that when you look at an x-ray of the bones of the the front limbs of a dolphin they share almost identical bones to our own hands but of course in a dolphin they're fused together and they have flat paddles because they're very good at swimming which means that they can't do this they can't do any of the things that we have in our dexterity which enables and has been a major part of our own evolution as tool users now again this isn't a criticism of dolphins but they're never going to evolve the ability to play the piano or to carve a stone tool and this is the radio for conky link they're never going to evolve the ability to manipulate and control fire sometimes it takes audiences a while to get that one yes yes right now that what that does is that puts them on a different evolutionary trajectory to us which is absolutely fine in this again it's not this is not judgmental but what it shows is the importance of where organisms are there isn't that natural directional progression towards being a tool using upright mammal as we see in the march of progress but in fact dolphins are you know they're very good at being dolphins but they are never going to be on a trajectory which enables fire to be an important part of of their evolutionary story fire is a major significant part of our evolutionary story as Darwin alluded to in 1871 and the reasons for fire being important for us are numerous it allows us to migrate away from the equator so as we move out of Africa and took colder climates allows us to keep warm it also and I think this is probably the most significant contribution of fire to our evolutionary history is that it enables us to cook food which effectively acts as an external digestion so we digest our food before we put it in our mouth which means we can extract nutrients much more efficiently it means we spend less time eating which means that we spend less time at risk of being eaten which is important in freeing up time for us to do other stuff and so almost certainly has a socially cohesive role we don't really have a really robust knowledge of when fire becomes part of our evolutionary trajectory because the archaeological record is not particularly great for it but it may have been around for as long as two three million years as some estimates we're pretty sure that within the last 200,000 years we have effectively a a form of controlled use of fire and with that come a lot of evolutionary changes especially the ability to migrate all over the world and change significantly change our diets so Darwin says fire is uniquely human well we also know that that is not correct either there are many many species which are pyro philic or in plants pyro phytic which means that they are utterly dependent on fire for their life histories we know that our closest cousins chimpanzees particularly in from goli chimpanzees in senegal have a very sophisticated recognition and understanding of fire and there there are annual Savannah fires there and they will stay very close to them dangerously close you might think because obviously fire is pretty capricious and they will wait until the fire has gone down to a level when they can go in and they will patrol through recently burnt areas and they will forage in those areas for semi-cooked critters and will eat them we know that lots of grazing ungulates spend more time in areas where there has

been recent fire because they can see further because if there's if the grass is lower they can see further which means that they can see predators approaching from longer distances.

Meerkats do that you know me when meerkats stand up on their hind legs and look really cute.

I'm doing a meerkat impression that's what they're doing they're looking out for predators and we know in them and vervet monkeys in South Africa spend more time looking out pre-burn areas than they do in Savannah in post-burn Savannah fires so there are a ton of animals which are also obligate fire pyrophilic organisms but maybe we're the only ones who have such a controlled use of fire that we can manipulate fire well that's probably not true and again I'm going to refer to our ancestors than the atolls this was a dig site in Tuscany in Italy from 2018 where some boxwood tools were found so remember that most of the tools that we found find our stone and the reason they're stone is because stone preserves for a long time biodegradable tools get lost in time very easily but this is one of the few examples of wooden tools being recovered from an archaeological dig and what this is it's some kind of Club it's been crafted but you can see that the outside of it has been scorched we think deliberately in order to remove the smallest stems the smaller Brown branches from that now this dates to about 120,000 years ago the only people in Tuscany in Europe 120,000 years ago and not Homo sapiens they are then the Neanderthals so again part of this revision of thinking of Neanderthals is culturally modern or culturally similar to us so it's not just us that has controlled use of fire fire has been part of human life and different species of humans for hundreds of thousands of years so then you say well maybe we are the only species that can start new fires well that was the case until the end of 2017 with the formal scientific publication of three species of birds of prey.

Raptors in Australia now this was written before the current Australian fires and so one must be culturally sensitive to this but savanna fires in Western Australia are part of the natural cycle and have been managed for thousands of years by Aboriginal Australians but it was a bit of a mystery for a long time as to how new fires started and this bears no relevance to the current situation in Australia until this formal publication in this typically literature at the end of 2017 which was that three species of Raptor birds of prey were observed picking up with their talons or their beaks burning sticks from fires and then flying over flying away over man-made or naturally occurring fire barriers such as rivers or roads and then they go and find a nice dry bit of brush and they drop the burning stick into them and then they go and sit up in a tree and as the fire rages small animals run away from this raging inferno only to be picked off and eaten as a moving buffet for flocks of these Raptors Raptors don't tend to flock very much in general but this is one one situation where you get multiple at least three species of different birds of prey flocking together because there is such a moving buffet of delicious fire semi-cooked or semi-chased out animals so again this shifts the narrative once more we're not the only organism that can start new fires this was published in 2017 but of course it has been known by Aboriginal Australians maybe for thousands of years it features in one of the Dreamtime ceremonies it's known as Jerilyn and this describes many many times before that but this is a good example of what's known as iek so indigenous expert knowledge and engaging with indigenous people



to understand things that they might know about because they've lived there for thousands of years and that we only get to publish in 2017 we are we remain the only species that can start a fire from scratch I think if the birds learn that and we're really in trouble how long have I got five minutes right I'm gonna skip Julie the fashionable chimp you can ask me about that later I'm gonna briefly talk about sex there was a large large section on sex in the book and the reason for this I didn't intend to write a book about weird animal sex but it occurred to me I was I was referencing the statistician David Spiegel Hall toes from Cambridge who many of you will know who in his excellent book that joy sex by numbers where he goes through he uses sexual behaviors to talk about statistical techniques isn't it's brilliant and you should definitely read it but early on in the book he describes well if you ask a fourteen-year-old at school what is the primary purpose of sex the answer will be reproduction right that is the biological reason why we have sex and that remains true but when you look at the statistics when you look at the numbers the number I'm gonna be slightly euphemistic here then the number of sexual acts in the UK where we have the best figures for the number of sexual acts that could result in a pregnancy compared to that actually does result in a pregnancy so the proportion of penetrative sex the results in the pregnancy that could is about one in a thousand right so it's statistically pre insignificant so the primary function of sex is swamped by our massive inefficiencies in actually getting pregnant if you add on top of that all of the sexual behaviors that could not result in a pregnancy then the proportion well the primary the primary function of sex is massively dwarfed by the amount of sex that we actually have it's very difficult talking to school audiences about this so the question that emerges from this is maybe maybe that's maybe that's what's makes humans unique we've decoupled sex from reproduction very effectively almost all of the sex that we enjoy is not to do with reproduction primarily so then you ask the question is that uniquely human do we see non-reproductive sex in in animals and I think you're getting the idea here the answer is an unsurprising oh my lord yes it is so root non-reproductive sex is all throughout the animal kingdom and the more we look the more we finds there are dozens of examples in the book some are more graphic than others and I won't go into them some of them are absolutely horrible but I wanted to do two examples and there's a reason for exploring this which is that sometimes we make the mistake of thinking that when we see a behavior which is familiar to us or looks familiar to us that we make the mistake of assuming that that is an evolutionary antecedent for that behavior there's a field called evolutionary psychology which basically does that all the time and I have issues with that as a whole field but I want to use two examples from from animals of sexual behavior which may look a little bit familiar to us but is almost certainly unrelated one of which is easy to understand under our standard models of evolutionary theory the other is a bit of a mystery now who remembers this beautiful scene from David Attenborough's Blue Planet a couple of years ago this is a marine iguana from the Galapagos it's a loop to film so you're gonna see the same thing over and over again brilliant piece of TV this marine iguana is running full tilt to get away from this snake which is going to curl up around it and it was do you remember this it was just a wonderful piece of natural history from Attenborough as we are accustomed to marine iguanas are fascinating species Galapagos of course is a fascinating ecosystem.

There is an element to this which you don't get to see on David Attenborough documentaries for reasons that will become clear marine iguanas the female marine iguanas have a fertility period of one day per cycle per year or their Ani stress and male marine iguanas are highly socially stratified by size so the bigger you are more Alf you are the more you get to have sex and reproduce with the females so there's intense competition for on this one day to have sex with with females and by a handy quirk of nature it takes marine iguanas exactly three minutes to exert to ejaculate so if you're a beta male if you're a smaller male then you very easily you when they attempt to mounts the females they very quickly get physically removed by the larger ones so they've evolved a strategy to compensate for this which is that they vigorously masturbate before they mount the females and tuck spermatophore which is a little pouch of sperm under underneath a pouch in underneath their armpits their forearms and then when they mount the females they just pop the package in immediately so they don't need the three minutes in order to procreate before they get removed so job done so that's an it that's a well understood evolutionary strategy we see behaviors similar to that all throughout the animal kingdom that's one example without I mean let me talk about another one which is absolutely fascinating giraffes beloved of evolutionary biologists for a number of reasons tallest animals Lamarque and Darwin speculated about why their neck was as long as it is and it's not because they do this because they actually don't do this one of the cornerstones of Sciences observation the assumption was that giraffes forage at great heights in order to get the juiciest acacia leaves they don't do it they actually forage its shoulder level so that doesn't actually work as an idea but from a sexual point of view so there wasn't there was a suggestion that's that's maybe these necks along as secondary sexual trade like a peacocks tail the male's you have an exaggerated characteristic in order to compete with each other and indeed competition with each other is something that we see on David Attenborough documentaries and not a lot this is called necking and it's called necking in the literature that's not me calling it necking it's called necking and giraffes are almost always segregated by sex so they have male herds and female herds and they only really get together when the females are on East recessed Asian lasts I think 22 months where a male will follow a female around and lick her genitals in order to establish as she's she's fertile and will attempt to mate over a series of days but that's pretty much the only contact males and females have most of the rest of the time the males are in a male only herd and they do this a lot now this is a spectacular site and people spend a lot of money to go on safari to see this happening in the wild because they've seen it on David Attenborough documentaries what they often are surprised by and a camera man alerted one one of the Natural History units and the BBC's cameramen alerted me to this was that much of the footage that they take of giraffes doing this male giraffes doing this cannot be used because about 70% of the time both protagonists have large unsheath directions and the winner of this battle mounts the loser and penetrates them so these are mayor this is male male homosexual behavior and when the studies were done in the 80s and 90s 3000 hours worth of observation at three locations over two and a half years the calculations came out as this 94 percent of sexual encounters in giraffes are male to male and penetrative that is difficult to understand and it's difficult to explain and we don't have an explanation for it there during that same period many calves were born so reproductive sex is also happening but overwhelmingly giraffes appear to be male male

homosexual and we don't know why and if there any zoologist in the audience and maybe you could speculate about that or even find out but this is an example of well homosexual behavior in nature is pretty much everywhere we've ever looked at any animal it is widespread and in giraffes it is that by far the predominant sexual behavior and we don't know why and that's interesting so that's enough sex for a Friday night to be honest but I and I'm running out of time and I haven't got to the main idea yet but that was merely to indicate that's non-reproductive sex while we engage in that pretty much all the time is also a common behavioral trait in in nature and it ranges to pretty much every sexual act that you can think of animals do it in some form my absolute favorites and I said this on Radio 4 which was a bit of a surprise to my producer is the fruit bat the Indonesian fruit bat where the females perform fellatio during penitence sex and they're upside down as well while they do it so you just worked that out for yourself okay so the cultural transmission idea.

I want to wrap this up because I'm now over time the the idea that we are cultural accumulators that we are teachers rather than simply learners and that the emergence of behavioural modernity is as a result of us being cultural transmitters of information is the central idea in the book it comes it's largely derived from the work of one of my colleagues at UCL Mark Thomas but also Joseph Heinrich said in at Harvard and it is not merely that we are cultural accumulators but this is predicated and relies heavily on population size this is the idea of demographic transition being the sort of key driver of the emergence of these types of complex behaviors and it's not particularly well discussed or well disseminated within within the academic literature.

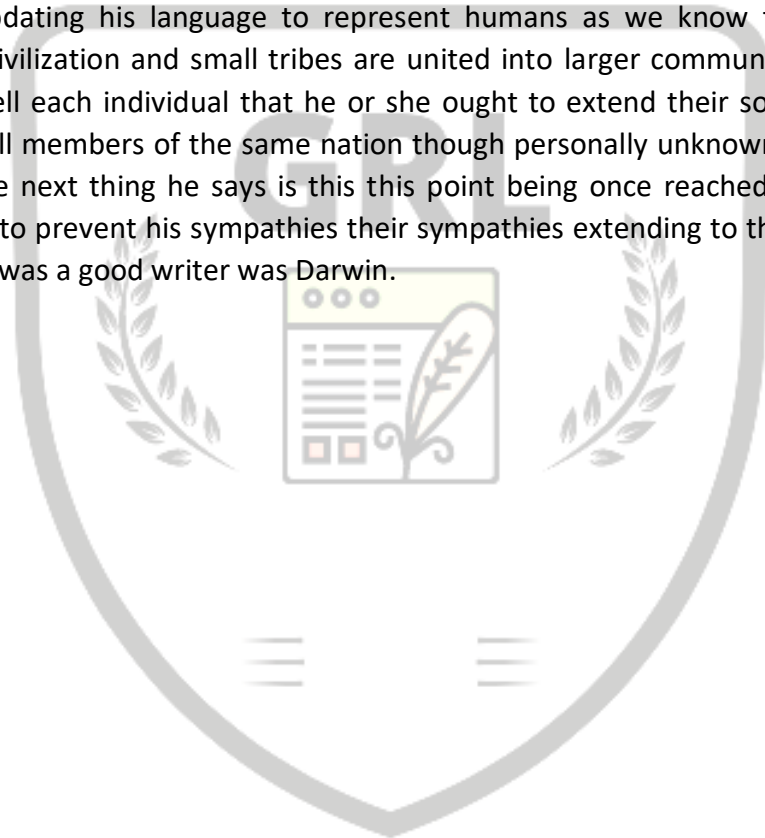
I have ideas why which I explore in the book but I don't have time to go into now but it's just the idea that the larger your population is the more efficient information can be transferred and this kind of works in a sort of an analogous way that you know if you've got a recipe or if you're the lion man Carver in the village or the stone Napa that if you're just telling five or ten people this and you're the expert on this and humans are a species of expert there I don't think there is another species that has such a wide distribution of talents but if you're that expert if you're that guy or / and you're telling this to ten people then the likelihood the probability that they are going to that that information is going to be inefficiently transferred or they're going to forget it or they might will die or before they've passed all that information is higher than if you tell an audience of I don't know five hundred people have many are in here and I'm sure you're only gonna remember that giraffes having sex as a result of tonight but if you pass that information on to someone else there is a higher chance that that as a unit of information is going to become permanent now we don't need this now because we write things down and we share information on the internet or by logging things or whatever but in a time before records the permanence of an idea is incredibly important and it looks like the permanence of an idea which you're culturally transmitting is important.

The population size is important in determining that's that permanence and so the concept of us being cultural accumulators is predicated on population size and we see this in the archaeological record we see the emergence of behavioral modernity in archaeological

artifacts in areas where the population has increased in size probably as a result of climate change and we see it in Europe and we see it in Indonesia and we see it in pockets in Africa and all around the world so you have this idea that we become good at transmitting information permanently at the same time as populations expand now there's a good just to wrap up there is a good counter example which Joseph Heinrichs talks about and it concerns fishing technology so you'll all appreciate if you're if you fish that a hook is better than a spear because once you've got a hook the thing can't wriggle off it and the earliest hooks we know of come from Java and they're about 24,000 years ago and this is the bottom of a conical shell it's just that the hole is where the wet bit would have been the animal would have been but the shell itself has been cut off and these these artifacts are still sharp enough to cut cut flesh so that's twenty four thousand years ago we have the first hooks by ten twelve thousand years ago we have what's known as Magdalenian cultures and we see very fine too harpoons and incredibly sophisticated fishing and hunting hunting tools associated with them now the story of the white one of the the the negative version of demographic transition model of of cultural information comes from concerns Tasmania now this is not a judgment on the indigenous people of Tasmania at all I'm just basing this on the theory and the supporting facts Tasmania ten thousand years ago at the end of the last glacial maximum was part of mainland Australia because the glaciers have sucked all the water out and it's just continuous land and so you have you have people on Australia and what is now Tasmania and there's continuous contact between them as the Seas rise because the glaciers melt Tasmania becomes separated as an island by what we call the bass straits and it has been separated for the next ten thousand years until this day and we don't see very much evidence in fact pretty much none at all of their being communication or transmission between the people who separated onto Tasmania and mainland Australia now when we look at the archaeological record of both Tasmania and Australia pre-separation we see approximately the same number of tools in the same sophistication of tools which included fine toothed hunting weaponry particularly fishing technology and we see in their kitchens we see evidence of them fishing beyond the reef fishing cartilaginous large fish by the time that Captain Cook's men came in 17th and 18th centuries well they actually note in those ships logs that the indigenous people of Tasmania were surprised and somewhat disgusted by the fact that those Europeans were fishing beyond the reef and they were using harpoons and they were taking a large fish and cooking them by this stage indigenous Tasmanian people had reverted to foraging on the on the shorts and they weren't fishing beyond beyond the shore which again is not a judgment they were perfectly happy but what had happened is that they had lost a lot of technologies and when we look at the archaeological record in Tasmania compared to mainland Australia by the time European invaders arrive around Australia their toolset is up into the hundreds as you would expect but the Tasmanian toolset has gone down to around about 12 and so you've seen the loss of information which we the model says is based on the fact that this is an isolated and small population whereas in mainland Australia there is constant communication between large groups of people so this is an example of how smaller populations isolated populations do not transmit information as efficiently and therefore Technol technological progress is different from on mainland Australia and areas where there is a free flow and a free exchange of information and now over time but I've come to the end that's that's the

key idea and that's the idea that I develop in the book whilst talking about sex behaviour and fire and stuff like that and I think it's one of the most important and interesting ideas in the evolution all the best stories in evolution all the best stories and biology do actually start with Charles Darwin and rereading the Descent of Man which I know you're all going to do in anticipation of 2021 next year the hundred and fiftieth anniversary rereading this what happens repeatedly when you work when you read.

Darwin is that you realize that he had these ideas a long time before you did and it's only a short paragraph but he basically describes this idea which has only really been formalized in the last ten years in the academic literature in science itself but it is again in a typically beautiful piece of Darwinian prose that he effectively describes the same thing I'm gonna read this by updating his language to represent humans as we know them as humans advanced and civilization and small tribes are united into larger communities the simplest reason would tell each individual that he or she ought to extend their social instincts and sympathies to all members of the same nation though personally unknown to them there's the key idea the next thing he says is this this point being once reached there is only an artificial barrier to prevent his sympathies their sympathies extending to the P of all nations and all races he was a good writer was Darwin.





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