Chapter 4
The Human Social Brains

We saw how the emergence of biological neural networks, from the simple neurons of ctenophores to *C. elegans'* neural network, appears to be a natural evolutionary process.

In this chapter, however, we'll consider one brain in particular – our own. What drove the development of our hypertrophic neural network?

According to some scientists, there is no answer to this question. Yuval Harari (2014) writes: "What then drove forward the evolution of the massive human brain during those 2 million years? Frankly, we don't know."

A good approach would be to consider the development of our brain under the same light we would consider the development of other brains. In the framework of intelligent systems, it comes natural to consider the evolution of the communication skills of mammals in general, primates, and *H. sapiens* in particular, as a transfer of the cognitive abilities of the species from individuals to the network, just as it happened for unicellular organisms, which are networks of proteins, and complex organisms, which are networks of cells.

The leitmotif of this book is that there wasn't just one single cognitive revolution – typically identified with human language – but rather a continuous increase in the capability of intelligent systems to process and store information. And the revolutions, if we really want to identify any, are the emergence of new forms of life based on the integration of old form of life.

Revolution, therefore, can be seen as starting with the introduction of culture, or information stored by the society and passed on from one generation to the next. And culture, in this sense, was not invented by *H. sapiens* 50,000 years ago. Not even by some of our ancestors 14 million earlier ("great-ape cultures exist, and may have done so for at least 14 million years," van Schaik et al. 2003). The need for a cultural system is tied to the inevitability of death and the need to reproduce.

As mentioned in Chap. 3, death and reproduction are necessary processes that clean superfluous syntax. But a system that was unable to pass on the useful information acquired from one mortal individual to other surviving individuals wouldn't be a great evolutionary success. Intelligent systems have to adopt a mechanism to

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pass on useful information to other systems before they die: this is the only way these systems can evolve into ones that are more and more intelligent.

It's true that today we know organisms can pass on information to their descendants by activating and deactivating genes, but as mentioned above, DNA is a long-term memory, difficult to modify. What's more, it can only be used to pass on information to one's descendants. It is a one-to-very-few communication system.

Culture on the other hand is the capability to store information not in an individual, but in a network. And the greater the communications' capability of the elements in a network, the more information the network can store and process.

So, intelligent systems like uni- or multicellular organisms have two mechanisms for recording new survival strategies over multiple generations: as an individual by adapting the phenotype[1] through genetic modification ("… novel phenotypes arise as a result of environmental induction". Jones 2012), and passing this information to their offspring; as a network by modifying its structure, for instance through Hebbian learning.

In the case of complex organisms, we know for a fact that some mammals adopted social behaviour –an exchange of information between organisms– as far back as the Palaeocene, immediately after the Cretaceous period, the age identified with the extinction of non-avian dinosaurs 65 million years ago. The remains of *Pucadelphys andinus*, a small Palaeocene marsupial mammal, suggest they were polygynous animals with a highly evolved social life living in a pack with the males probably competing with each other (Ladevèze et al. 2011).

We don't know when these behavioural patterns emerged. But essentially, along with social behaviour, at that time mammals had already developed a brain that, when compared to the brain of a dinosaur, is like comparing a Ferrari Testarossa to a Fiat 500.

Although we studied the emergence of the nervous system, we didn't consider how difficult it is, for an organism as a whole, to maintain a brain even as simple as that of Palaeocene mammals, and make it work well. Just as the sophistication of a Ferrari depends on more than just a powerful engine, a mammal's brain also needs just as sophisticated an organism to go with it.

First and foremost, a powerful brain tends to also become an information processing centre, and therefore a *single point of failure.*[2] All it takes to put it out of action is a relatively light shock, so the brain needs a strong and costly skull to protect it. What's more, as is the case with every powerful motor, it requires a notable amount of energy (in the case of *Homo sapiens* and some dolphins (Martin 1996) it weighs just 2% of the body weight but requires 20% of the energy absorbed by the organism).

In addition, energy is required continuously, because the brain, unlike muscles, cannot store nutritive substances. If the brain is left without nutrients and oxygen

[1] Phenotype: "The set of observable characteristics of an individual resulting from the interaction of its genotype with the environment." (Oxford English Dictionary)

[2] A part of a system that, if it fails, will stop the entire system from working (https://en.wikipedia.org/wiki/Single_point_of_failure, verified 5 May 2019)

for just a few minutes, it suffers irremediable damage, exactly like modern data centres would be damaged if they were suddenly deprived of electrical power.

Also like data centres, because of the amount of energy consumed, our brain heats up – something that poses problems in the design of the skull and circulatory system. The very definition of "mammal" includes the presence of a cerebral neocortex and a particularly well-developed cerebral cortex (Borrell and Calegari 2014). Both these areas can only function thanks to a sophisticated body temperature regulating mechanism, which birds, reptiles, fish –and of course dinosaurs– don't have.

In short, in terms of a cognitive revolution, the real revolutionary leaders were some obscure vertebrates who started investing in the cognitive organ some 200 million years ago: "What is beyond dispute is that the earliest mammals themselves did have significantly enlarged brains … brain size in Mesozoic [248 million to 65 million years ago] mammals lay within the lower part of the size range of the brains of living mammals. This represents an overall increase of some four or more times the volume of basal amniote brains, and presumably involved the evolution of the neocortex, the complex, six-layered surface of the cerebral hemispheres that is one of *the most striking of all mammalian characters*" (Kemps 2005).

Why a More Powerful Brain?

Understanding the origin of the mammals' brain is fundamental if we want to understand the origin of our own. According to some anthropologists, our brain has only really been useful in the last few thousand years: "For more than 2 million years, human neural networks kept growing and growing, but apart from some flint knives and pointed sticks, humans had precious little to show for it." (Harari 2014).

Looking at it from this point of view, the brain appears to be a mere exercise in sexual energy-wasting (Miller 1998), which by chance, and only in the case of *Homo sapiens*, around 50,000 years ago produced symbolic thought. Just like birds that grew wings for no obvious reason, and then by chance found they could fly.

But the brain is a costly investment. According to Wheeler and Aiello's (1995) *expensive-brain hypothesis*, many complex organisms, in order to afford an increasingly more powerful brain, have in fact reduced, as they have evolved, the mass of other energy-consuming tissues like the digestive system and muscles. *Homo sapiens*, with their thin body and short intestine, is an excellent example.

If the brain was so useless as Harari wrote, this investment would appear to make no sense. A useless, costly brain, that needs so much energy it forces an organism to reduce organs essential for its survival like muscles and the digestive system cannot have laughed in the face of natural selection for hundreds of millions of years.

If a mutation, whatever the cause, is prejudicial to *fitness*, it's hard to imagine why it would be adopted by the entire species.

To justify the introduction of the brain we can imagine a few possibilities.

First, it could be that the brain initially develops like a parasite, to the detriment of its host organism. The brain "decides" it will have the host organism mate only with other similarly hyper-cerebral conspecifics.

In this case, a useless brain – the one indicated by Harari – will come out on top anyway, in spite of the process of selection: any organism able to increase its cerebral capacity to the detriment of other organs will be taken down this path by its parasite-brain.

This may be the case, but perhaps the brain evolved for a more noble cause, like its cognitive abilities. The brain's problem-solving capabilities could represent a profitable return on the investment. In fact, for many years "it was assumed that brains evolved to deal with essentially ecological problem-solving tasks" (Dunbar 1998): it's cold, so instead of waiting for selection to favour hairy people the brain invents clothing.

Another evolutionary push, not necessarily an alternative to the one above, could be Dunbar's *social-brain hypothesis*. Dunbar shows that the evolutionary push towards a more powerful brain in primates derives not from the need for cognitive abilities, but from more sophisticated *social* skills. More and more organised *Homo* societies made this genus a success, despite the atrophy of the organs.

Dunbar's hypothesis could, and perhaps should, be extended to include mammals, the first organisms that made a serious investment in the brain: "human culture cannot be disassociated from social life, and therefore from humanity's *mammalian* and primates foundation" (Sussman 2017).

So, getting back to the reason why mammals in general, and primates and *Homo* in particular, have such a powerful brain, we have three possible hypotheses:

1. The brain of mammals, like an internal parasite, developed to the detriment of other organs, even though this wasn't really necessary.
2. Brains evolved to become more and more powerful to improve *problem-solving* capabilities.
3. Same as above, but in this case to create more complex societies.

Obviously, none of the three hypotheses can be discarded completely, but the social component, the third, appears to have carried more weight than the other two. Isler and Van Schaik (2008) analysis on mammals and modern dinosaurs – birds – shows that the brain, when unable to favour collaboration, is more of a liability than an asset.

In practice, the body needs to reduce its energy requirements when the whole organism cannot exploit the advantages that derive from the ability to collaborate with others of its species. This means for instance reducing the digestive system in mammals or the pectoral muscles in birds.

The "maximum rate of population increase[3] is negatively correlated with brain size only in precocials [offspring born relatively mature and mobile, e.g. ducks] and

[3] The *maximum intrinsic rate of increase* is the per capita birth rate minus the per capita death rate for a population (Cole 1954).

semi-precocials, but not in altricials or semi-altricials [offspring requiring total care, like eagles]" (Isler and Van Schaik 2008). In other words, birds with a high encephalization level but a scarce ability to pass information on from parent to offspring, reproduce *less* than those that, with a brain of the same power, create a parent-offspring bond.

Note that Isler and Van Schaik do not think their study contradicts the expensive-tissue hypothesis:

> The observed trade-off between the maximum rate of population increase and both absolute and relative brain size supports the notion that this trade-off is caused by an energetic constraint, especially since it disappears in lineages where the mother's energetic burden during reproduction is alleviated through helpers. Thus, our results fully support the expensive brain hypothesis, which predicts that relatively large brains can evolve only when either energy input increases. (Isler and Van Schaik 2009)

In practice, if energy is available, organisms, and rightly so, will develop their brain and pick the low-hanging fruit that derives from problem-solving skills. But "during mass extinctions large-brained taxa are especially vulnerable," and precocial animals, considering the same cerebral energy consumption, are more vulnerable than altricial animals:

> But what change of lifestyle would allow the evolution of larger brained lineages? Our results show that, as predicted by the expensive brain hypothesis, allomaternal energy inputs during offspring production are one critically important factor. (Isler and Van Schaik 2009)

In a similar analysis, this time focused on mammals and primates, Isler and Van Schaik (2012) proved that the brain of the genus *Homo*, without a significant capability for collaboration, would already have been unsustainable already 1.8 million years ago, when the successful *Homo erectus* started colonising the whole planet.

In short, Fisher's idea – that societies formed so natural selection could improve the species – could not be further from the truth. Societies, made up of individuals with a communicative and collaborative brain, are an essential instrument in order to be able to afford even more powerful brains. Mammals' brain can afford to be so powerful precisely because it's so spectacularly collaborative.

Human brain in particular appears all the more extraordinary not for its calculation capabilities, but for its communication capabilities. Just as neurons probably first appeared as intelligent cells, able to report the presence of food, then showing their "true colours" when they learnt to communicate, forming neural networks, the brain in turn was born to be an information processing centre that then went on to become the key to success of some species – *Homo sapiens* first and foremost – when it learned to communicate.

This success is evident also in consideration of the biomass on the planet for different organisms, shown in Fig. 4.1

Even excluding *Homo sapiens* and the animals humans have domesticated, the biomass of mammals is three times that of surviving dinosaurs (the birds). Mammals

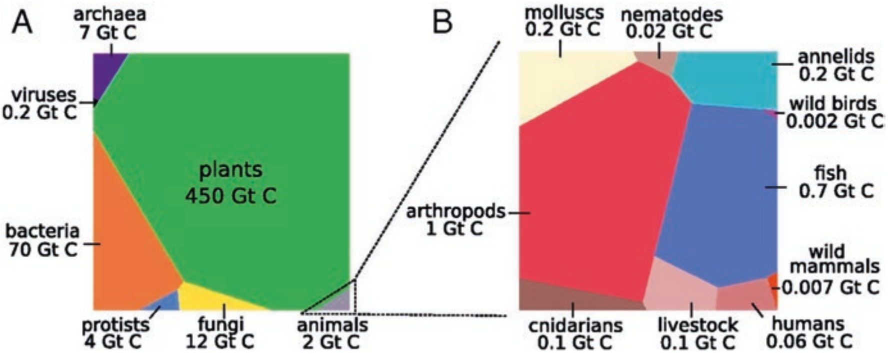

Fig. 4.1 Graphical representation of the global biomass distribution by taxa (Bar-On et al. 2018)

today, with *Homo sapiens* leading the way in a *de facto* dictatorship, represent the vast majority of terrestrial vertebrates.[4]

The success of mammals is the success of an evolutionary strategy aimed at developing an organ that doesn't merely excel in processing information: it does a great job of exchanging information too, and therefore creating networks that can quickly store and process information necessary for survival.

The Primates' Brain

Isler and Van Schaik (2008) analysis of birds appears to be convincing, and Isler and Van Schaik (2012) extends these conclusions to primates. The importance of their studies can hardly be overestimated. Until the last century, anthropology considered the social behaviour of primates to be less important than the creation and use of tools. The number of results for "primate social behaviour anthropology" and "primate tool use anthropology" on Google Scholar shows the complete disinterest of the post-war generation in the social relations of primates compared to the use of tools: 800 compared to 17,000 hits.[5]

But in time, around the year 2000, articles on social relations surpass those on the use of tools. Today, the figures are 90,000 for social relations compared to 50,000 for tools. Dunbar's *social brain hypothesis* was published in 1998.

Ape the tool-maker and ape the social animal are representative of the second and third hypothesis for the emergence of the brain – problem solver or social instrument.

It makes sense that paleoanthropologists gave initially more weigh to the tool-maker. The reason for making tools is evident: an increase in energy gain.

[4] There are less vertebrates than arthropods, such as insects, spiders and crustaceans, however.

[5] Analysis carries out with Google Scholar, 27 february 2019.

For both man and chimps this is certainly true. *Homo habilis* fed on marrow by cutting bones open with flint tools, and chimpanzees obtain high calorie foods such as honey, termites, marrow and brain from their prey by using specific tools to do the job.

But is not as simple as it looks. Simple energy gain cannot, for example, explain the inventiveness of the gorilla. Far from stupid, the gorilla doesn't (as far as we know) use any tools to increase the amount of food it has access to (for that matter it has plenty of leaves to feed on). A gorilla does, for example, create tools to help it move through water (Breuer et al. 2005). Millions of years of evolution to develop a brain that weighs half a kilo with its relative energy requirements that only comes up a stick to help you cross a stream isn't exactly an excellent investment.

But the brain did not give gorillas just that. The mammals' brain, in general, performs *two* tasks. The first is to find solutions to the problems found, a task often performed by one or a few individuals. The second is the cultural absorption of the information acquired, in other words storing information in the same society using communications mechanisms like imitation.

Gorilla didn't develop their brain to invent a stick to cross a stream, but to communicate: some populations communicate using rudimentary sign language (Kalan and Rainey 2009).

Although archaeology was established specifically to study the use of tools by primates (Haslam et al. 2009), it emphasises the importance of conformist transmission mechanisms – in practice learning through imitation or allelomimesis as mentioned in Chap. 2 (Luncz et al. 2015). In a sense, the invention of the tools by the brain is the finger pointing at the moon, but the moon is the society.

In conclusion, as is the case for mammals in general, the primates' brain is first and foremost a social brain, and has been for a long time. The ability to live in communities made it possible to store information not only as individuals, but as a society. Individuals die and lose information, societies don't, or at least not so fast.

Something similar happens with ants, although while ants have developed a sort of distributed brain and the information in the same dies with the swarm, mammals, and primates in particular, have created a network that can not only share information quickly within the same, but also keep it for millions of years.

Although on a different scale, this isn't introducing anything new compared to what was described for unicellular, multicellular organisms and insect superorganisms in the previous chapters.

What Makes a Homo

Paraphrasing "The Big Lebowski" (Coen and Coen 2009), the question "What makes a *Homo*, Mr Lebowski?" has no easy answer. As in the sorites paradox (or paradox of the heap), in which we don't know when to start calling "a few grains of sand" a "heap of sand" but do recognise the two as being different, in palaeoanthropology it's hard to define exactly when the brain of the ape lost ground to that of *Homo*.[6]

But today it's easy to see the difference between the two brains: *Homo sapiens* brain is the one that has by far come up with the most complex tools *and* societies.

While mammals are the organisms that have invested the most in the brain in order to communicate, and therefore store and process information in a network of organisms, *Homo sapiens* is the mammal par excellence: the one that has taken its ability to communicate to new limits, and is still pushing those limits.

The truth is, a martian anthropologist would probably call ourselves *Gens communicans*, and not *Homo sapiens*. *Homo,* more than any other complex organism, continues to aggregate into complex structures thanks to new communication media, creating a global network of people – a single tribe, *gens*. We are an organism that started to create a new level of aggregation: that of the meta-organism, an organism made up of complex organisms.

So, instead of attempting to define the moment in which the genus *Homo* appeared, a problem that's as paradoxical as a heap, we can try to analyse the process that's made us what we are. In other words, a species with some apparently unique characteristics, such as highly symbolic thought and the use of extremely complex languages, with which we can send highly informative messages in an efficient way.

And as in the sorite paradox, there won't be the first *Homo*, but instead a continuous evolution from hardly communicative (for our own standards) apes to hyper-communicative *Homo*. We need therefore to analyse the emergence and evolution of language.

Above, we saw that a more and more demanding brain developed into a brain that was not only able to autonomously solve certain problems, but also communicate. This is because the ability to connect with other individuals means being able to store and process information as a network. And being part of a communication network means being pushed into communicating even better.

It seems improbable that the changes our body had to go through in order to develop the use of spoken language all happened by chance (Lieberman 2014). Not only a more powerful brain was necessary. The tongue, the soft palate and the glottis underwent major transformations which, together, made it possible for *Homo sapiens* to speak. As each transformation requires the activation of various genes, we cannot say there's one single "language gene".

Again, considering life as the evolution of intelligent systems leads us to the conclusion that these systems can learn new ways to extract energy and pass information on to descendants, also by activating and deactivating genes. It's certainly not a new idea, and was also upheld by Darwin, who "admits use and disuse as an

[6]The paradox is similar to the definition of pornography in US Supreme Court Judge Potter Stewart's ruling: "I know it when I see it" (Jacobellis v. Ohio 1964).

important evolutionary mechanism" not once, but as many as 12 times (see Ernst Mayr's introduction to the *Origin of Species* quoted in Noble, 2010).

On the causality of variations, in the fifth chapter of the *Origin of Species,* Darwin writes:

> I have hitherto sometimes spoken as if the variations – so common and multiform in organic beings under domestication, and in a lesser degree in those in a state of nature – had been due to chance. This, of course, is a wholly incorrect expression, but it serves to acknowledge plainly our ignorance of the cause of each particular variation … The greater variability of species having wide ranges than of those with restricted ranges, lead to the conclusion that variability is generally related to the conditions of life to which each species has been exposed during several successive generations.

Similarly, in the case of language, not only is there no need to wait for casual variations to make *Homo sapiens* a talking ape "by chance", once again it would appear we must accept a certain level of Lamarckian evolution.

"[Lamarckism] is not so obviously false as is sometimes made out", writes Maynard Smith (1998). "A statement that is all the more significant from being made by someone working entirely within the Modern Synthesis [neo-Darwinist] framework. His qualification on this statement in 1998 was that he couldn't see what the mechanism(s) might be. We can now do so thanks to some ingenious experimental research in recent years" (Noble 2015), thanks to the discovery that "epigenetics can provide a new framework for the search of aetiological factors in complex traits" (Petronis 2010).

The Anatomy of Language

Homo sapiens' organism went through many changes so we could talk the way we do today. In the anatomically modern *Homo*, Daniel Lieberman (1998), (2014) associates the growth of the frontal brain lobes and the hypertrophy of the neocortex located immediately behind the eyebrows, as a possible cause of our faces becoming flatter. While the first feature is a sign of frontal lobes with a greater capability for symbolic reasoning, the second makes room for a vocal tract divided into two parts, a horizontal and a vertical part of the same length – a feature necessary to articulate certain sounds (D. Lieberman 1998).

No other species of the genus *Homo* shares these two features with *Homo sapiens*, so it's highly probable that none of our forefathers could articulate sounds the way we do.

This, however, doesn't mean we were the first to to communicate using some language. As mentioned above some wild gorillas have autonomously developed a form of sign language. The genus *Pan* (bonobo and chimpanzees) uses vocalization to transmit information on available food or the quality of the same (Taglialatela et al. 2003), (De Waal 1988), (White et al. 2015).

Although gorillas and *Pan* have also been going through a process of evolution since our evolutionary lines split, as today their encephalization quotient is lower than that of an *Australopithecus* three million years ago. It would therefore be plausible to believe that similar abilities have been in the curriculum of Hominidae for just as long.

This leads many paleoanthropologists to exclude not only the cognitive revolution of *Homo sapiens* 50,000 years ago, but also the one two million years ago, which according to Louis Leakey led to the emergence of the genus *Homo* (Leakey et al. 1964): “there is no clear evidence of the quantum leap in intelligence and social complexity that Louis Leakey assumed when he first encountered Homo habilis” (Christian 2011).

There wasn’t a group of *sapiens* which, by chance or out of necessity, suddenly found it had a “language gene” –a gene of such a reproductive success that it started a new human race.[7]

The cognitive revolutions of Homo sapiens was, in reality, just an evolution, as in the sorite. From some very basic communication capabilities (expressions, attitude, smell) that cannot be defined as language, to today hyper-communication era.

There is another information revolution which makes a good example, because it has not taken millions of years but hundreds: the “IT revolution”.

The IT revolution has been less sudden than we first thought. We might start from Blaise Pascal’s seventeenth century calculator to the tabulators used to take censuses in late nineteenth-century America, electromechanical calculators, silicon chips, printed circuit boards, and integrated circuits. But none of these technologies resulted in an immediate quantum leap. The first calculators that used semiconductors to compute their results were less powerful than electromechanical calculators, and when the evolution of these could go no further, silicon took over and growth continued. The amount of information we can process with machines has been increasing, in an exponential but continuous way, year after year, since the microchip, or since Pascal calculator, or we could say since the abacus or writing were invented, depending on what you want to consider the origin of the process. In the end, this is “computer science”, so we should analyse the emergence of computing, which surely goes back to the Sumeri mathematicians, and so on.

If we take a look at our own built-in computer, the brain, the story isn’t much different: “Our data suggest that the evolution of modern human brain shape was characterized by a directional, gradual change” (Neubauer et al. 2018).

In order to understand how our organism allowed language to emerge, we should remember that language itself is an emergent property (Everett 2017). Apparently, everything that concerns our brain is an emergent property, as our neurons are not good for much except communicating with each other.

In the book that introduced modern artificial neural networks, Frank Rosenblatt (1961) writes: “Individual elements, or cells, of a nerve network have never been

[7] If we’re to take recent history as an example, human society seems more inclined to reward in reproductive terms violent political leaders rather than peaceful geniuses: Einstein, Dirac, Fermi and co. didn’t start a new subspecies of *Homo genialis*, while Genghis Khan was such a reproductive success that today his genes can be found in approximately 8% of the males in a region stretching from Northeast China to Uzbekistan”, (Zerjal et al. 2003).

demonstrated to possess any specifically psychological functions, such as 'memory', 'awareness', or 'intelligence'. Such properties, therefore, presumably reside in the organization and functioning of the network as a whole, rather than in its elementary parts".

What goes for memory, awareness and intelligence can be said of language too: it's an emergent property of the brain, not the product of a gene that appeared by chance. Excluding divine intervention or pure luck, as we did for the origin of life (Chap. 2), the origin of language may also have been through autocatalysis mechanisms, with neurons and synapses instead of water and an electrostatic field.

In exactly the same way as biological cells emerged from some proteins being able to act as a catalyst for the folding of other proteins, language probably derived from the brain's ability to interpret what occurs in the environment, in a more and more sophisticated way

According to Everett's hypothesis (2017), inspired in turn by Charles S. Peirce's semiotic progression, language initially evolved from *indexes*, in other words indications that something is happening. Smoke indicates there's a fire, tracks that an animal passed that way.

Next steps are *icons*, like the stone an *Australopithecus africanus* was probably carrying around three million years ago – the Makapansgat pebble. Natural elements worked the stone to make it look like a face, and for this reason, the hypothesis is that it was picked up and kept as a kind of amulet or bauble by the Australopithecus.

Then there were *signs* – intentional and arbitrary – and so on, gradually, up to the development of modern language.

What's important to emphasise here in terms of hypotheses like Everett's – or Szathmáry's (2001) *language amoeba hypothesis* – is that language is an emergent property of the brain and as such (like every emergent property) didn't appear suddenly, out of the blue, but through a *bootstrapping*[8] or autocatalysis process. This occurred, thanks to the ability to note, and exploit, minor coincidences: smoke-fire, fire-hot, hot-food smells good,[9] an ability that resulted in the emergence of new cognitive tools.

As mentioned above, this isn't much different from the development of networks of neurons, created to detect the presence of organic material. Hundreds of millions of years ago neurons, which until then had been used to detect glutamate in the

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[8] One fundamental concept in computer science (although introduced in physics) is bootstrapping. Bootstrapping, in reality, is just another name for autocatalysis, as described in Chapter three with reference to the emergence of cells, but it's also commonly used to explain the growth of systems based on information. This comes from the absurd idea that you can pull yourself up by your bootstraps. On the basis of classic mechanical principles, bootstrapping is impossible, because it creates energy. But, in the case of information and acquiring energy, the process is natural: even a minimum amount of information lets you acquire a little energy, which lets you store a bit more information, and so on.

[9] Without digressing on the use of fire, Wrangham (2009) reports that chimpanzees feed on seeds toasted by natural fires.

environment, a sign of the presence of material that could be used as food, started producing and exchanging glutamate as a means of communication.

The brain took the same path, and *Homo's* brain more than any other. The *problem-solving* capability of the human brain lets it recognise indexes that most other animals miss, just like the neurons that were the only ones that could detect glutamate. *Homo* started with the ability to distinguish indexes, then used this ability to communicate, eventually creating cognitive networks, societies, the equivalent of neural networks of brains.

In time, the ability to recognise indexes was refined: the brain started recognising an albeit casual representation of something that really existed. If a pebble with two holes and its chipped mouth reminds the brain of a face, it will probably do the same for my mates' brain. The ability to turn an icon into a sign is, in a certain sense, the ability to turn the function into an object – to create communication tools.

Indexes and icons in turn therefore act as catalysts for the emergence of complex structures, like signs. This is the *bootstrapping* process. There is no need then to imagine a cognitive revolution that coincides with the birth of language. The use of even an extremely crude form of language lets human societies store and process much more information than other mammals.

The autocatalysis in this case is that, also a primitive form of language – like that used by gorillas – produces a more organised community, more advanced in cognitive terms, and therefore better able to obtain food than others. And the more the communicative society is successful, the more the individual is forced to become more communicative.

The reason why is important that organisms can change their phenotypes in response to environmental stimuli throughout the book, is that this mechanism is essential to explaining the emergence of language: "the origin of human language required genetic changes in the mechanism of epigenesis in large parts of the brain" (Szathmáry 2001).

In the case of language, environmental stimuli are social stimuli. Autocatalysis is the ability of society to force the individual to use instruments for communication – and therefore, if necessary, epigenetic modification.

Agriculture and Cognitive Social Networks

Another myth that's been busted in recent years, along with that of the cognitive revolution, is the myth of "the invention of agriculture". The idea that there was a moment in which some *Homo sapiens* understood they could grow a plant by planting a seed. The cognitive revolution suddenly made *Homo sapiens* special, but it was the agricultural revolution that decreed the demographic success of the populations that "invented it", the Fertile Crescent first followed by Europe and Asia.

But as Marvin Harris (1978) pointed out 40 years ago, agriculture was probably more the product of necessity than a stroke of genius.

Our forefathers had already colonised a considerable part of the planet's land mass thanks to the social and technological success of *Homo erectus*. The same thing happened with *sapiens*, who developed the abilities of *erectus*. But why so widespread? Because a *Homo* population hunting and gathering needs a notable extension of land to avoid exhausting natural and renewable resources.

The need changes from region to region, but if we consider, as Lieberman did (2014), that a tribe of 20–30 people needs at least 250 square km of land, this translates into an extremely low sustainable population density. To give you an idea of what this would mean, a territory as vast as France for example, even without considering the presence of mountains and less productive areas, could sustain a population of no more than 70,000 – a thousandth of what it does today.

This explains why *Homo's* reproductive success pushed the species to every corner of the planet. If, as surmised by Lieberman (2014), an *erectus* woman on average gave birth to five children, half of which would survive, the growth rate of the population is 0.4% per year.

This doesn't sound like a lot, but it is exponential growth: at this rate, the population doubles every 175 years. A tribe that initially occupied 250 square km, in 4000 years would have grown to occupy an inhabitable surface area of 150 million square km – almost all the dry land that could be used by man. On the basis of a more conservative estimate of our population growth capabilities, Lieberman (2014) estimates that it took *Homo erectus* 100,000 years to spread from Ethiopia to Georgia.

In practice, the advantage with hunting and gathering is that, as it's sustainable, it requires less effort than farming – the first requires no work to transform the environment, the second on the other hand does. But in the case of hunting and gathering, the number of people in the population must remain below sustainable limits. Harris (1978) explains some hunter-gatherer behaviour – female infanticide and the martial tendencies of males – by the need to remain within demographical limits.

Once the *Homo* system had occupied all the available space – the planet – it was forced to stop expanding and had to find a balance. On the one hand there would always have had to be a sufficient number of individuals for inter-tribal and intra-tribal collaboration (the first to renew the gene pool). But, on the other hand, as soon as collaboration made excessive population growth possible, this had to be stopped, through abortion and feuds for example.

Paleontological studies suggest that we have been fighting wars, or little wars (guerrilla) for at least 10–50,000 years (Lahr et al. 2016). But it has probably always been so: aggressiveness must emerge when renewable resources are scarce. When the environment can no longer sustain the *Homo* population, it tends to limit itself to avoid shortages that could lead to severe consequences such as famine.

Agriculture can be considered an alternative to population control. If we modify the environment, it can sustain a larger population.

The "discovery" related to the introduction of agriculture isn't botanical, but once again, social, anthropological. It's difficult to imagine that gatherers 20,000 years ago didn't know that plants grew from seeds (Harris 1978), quite the opposite: although there isn't just one single category of "hunter-gatherers" (Testart et al. 1982), the term “gatherer” is typically used to refer to populations with a more sophisticated botanical culture than that of sedentary populations committed to agriculture (Schultes, Raffauf 1990).

It was therefore necessary to start using agriculture when the fragile balance that was reached when all the available space had been occupied was upset. There may have been many causes of this upset, although climate change has recently been accepted as the principal cause (Richerson et al. 2001). As Cohen (1977) explains: “an imbalance between a population, its choice of foods, and its work standards which force the population either to change its eating habits or to work harder, or which if no adjustment is made can lead to the exhaustion of certain resources.”

Agriculture made it possible for man to exploit his intellectual and social skills even more: “crop cultivation fosters association, a desirable goal for our sociable species. At the same time, farming promotes individual ownership and accumulation of material possessions; it makes it easier to have larger families.” (Smil 2008).

In practice, agriculture acts as a social thickening agent, as well as being the most reliable method for obtaining food. As mentioned above, the maximum intrinsic rate of increase of *Homo sapiens* was only made sustainable thanks to the unique collaboration capabilities of the species: the more individuals manage to collaborate, the more our species is a success. Agriculture, which requires consistent, coherent communities, means the cognitive abilities of the *community*, of the network of *Homo sapiens*, can explode. Larger and more organised communities encourage the evolution of language, for example with the introduction of the mathematical language, and of communication and information storage, for example writing (Rubin 1995).

“Once food production had thus begun, the autocatalytic nature of the many changes accompanying domestication (for example, more food stimulating population growth that required still more food) made the transition rapid” (Diamond 2002).

Unfortunately the emergence of agriculture, despite the fact that it increased the amount of available energy, didn’t make humans abandon their warlike tendencies, quite the contrary. As various tales tell, from Cain and Abel to Romulus and Remus, “[farming] facilitates warfare” (Smil 2008). With a relatively inexhaustible supply of food (when compared to hunter-gatherer populations), the better-organised, more technologically advanced populations were able to expand at the expense of the weaker ones, with relative ease.

Hundreds of books have been written on Alexander the Great’s skills in terms of military strategy, but – in terms of information processing – the invention of torsion-spring catapults by the Macedonian army would appear to be just as important as the visionary capabilities of their commander. Without his unbridled ambition Alexander couldn’t have conquered an empire, but in a war of sieges, the Macedonian catapults – war machines that could fire projectiles weighing dozens of kilograms at targets hundreds of meters away – were probably just as decisive a factor (Ferrill 2018).

Agriculture made wars of conquest a profitable endeavour. The accumulation of energy, from cereals, means immediate payback to cover the cost of war. Furthermore, rigid social organisation into classes introduced by farming communities –

impossible for hunter-gatherers – favoured the absorption of conquered populations into the new empire: the ruling class might be sacked of its riches, but it was still the head of the organisation. The army was put to death or incorporated into the ranks. The productive classes – peasants – were in the same position as the ass in Aesop's "The Ass and the Old Peasant", with the peasant begging the ass to fly with him as fast it could or else they would be captured by the enemy: "Do you think they'll make me carry heavier loads?" "Oh, well, then," said the Ass, "I don't mind if they do take me, for I shan't be any worse off." (Aesop 1994).

In practice, with the advent of agriculture, war was transformed from a means of population control to an instrument of conquest: great states absorbed weaker ones, to create the first great empires.

Empires and Networks

The autocatalytic nature of the domestication of plants and animals can actually go beyond "more food stimulating population growth that required still more food", as Jared Diamond wrote (2002). Agriculture acted as feedback mechanism allowing *more people together, who communicate more, who increase their technological expertise, which allow even more people to live together, who communicate more…*

We have seen how the evolution of language into a more and more sophisticated instrument makes it possible for more and more intelligent societies to emerge: able to store information, self-sufficient and self-organising.

When we set up communities of thousands of individuals, a new form of language appeared, mathematics. The power of the mathematical language lies in the use of an extremely powerful syntax that can be used to process a previously unthinkable amount of information.

We've seen how complex the "simple" symbol π is. If mathematicians have been obsessed about it for millennia, is because the importance of that number is second only to 0 and 1. The effectiveness of mathematics in natural sciences – in other words in the ability to model and therefore predict our environment – is intimately related to π, as summed up by Eugene Wigner's tale (1960):

> There is a story about two friends, who were classmates in high school, talking about their jobs. One of them became a statistician and was working on population trends. He showed a reprint to his former classmate. The reprint started, as usual, with the Gaussian distribution and the statistician explained to his former classmate the meaning of the symbols for the actual population, for the average population, and so on. His classmate was a bit incredulous and was not quite sure whether the statistician was pulling his leg. "How can you know that?" was his query. "And what is this symbol here?" "Oh," said the statistician, "this is pi." "What is that?" "The ratio of the circumference of the circle to its diameter." "Well, now you are pushing your joke too far," said the classmate, "surely the population has nothing to do with the circumference of the circle."

But the truth is that the situation described by Wigner appears to be optimistic: many people find it hard to understand that the ratio of the circumference of the circle to its diameter is constant, and will be flummoxed by the fact that said ratio is an irrational (and transcendental) number.

Really there's no need to resort to π to have an idea of how unnatural it is for *Homo sapiens* to use mathematical language. Many *Homo sapiens* find it hard to understand that 3/5 is more than half. It's absolutely normal: the human brain is intrinsically non-mathematical – more *communicans* than *sapiens*. "A bat and a ball cost $1.10 in total. The bat costs $1.00 more than the ball. How much does the ball cost?" Everyone, at least for a few seconds, will come up with the answer "10 cents".

We're cooperative primates, with an innate sense of justice, not of mathematics. A chimpanzee, like a person, is happy to work for an apple until it sees its neighbour receives a banana for the same work (De Waal 1996). The ultimatum game[10] experiment shows our sense of justice is innate, and independent of our culture.

"The moral law in us" is, in other words, a common trait. But gazing at "the stars in the sky" and imagining their origin, as did Immanuel Kant, is less so.

The *social* success of mathematics is therefore not due to the fact that, like the spoken word, it's used by the entire population: it's due to the fact that it's the best tool at our disposal for managing public affairs:

> Most pristine state structures depended on organized violence, on religious institutions, etc., and mathematics did not enter. At least one major exception to this rule can be found, however: the earliest "proto-literate" state formation in Mesopotamia of the late fourth millennium, intimately connected to a system of accounting that seems to have guaranteed an apparent continuation of pre-state "just redistribution". (Høyrup 2009)

Not by chance, the word "statistik" was coined around the middle of the eighteenth century to describe the analysis of state data (Achenwall 1748). Mathematics, since the first Sumerian empires, has been society's instrument of management: it first appeared with agriculture 10,000 years ago (Høyrup 2009) and was used to organise society in a relatively fair way.

The passion felt by some *Homo sapiens* for mathematics doesn't, in most cases, derive from the fact that they know it will be useful: for some *Homo sapiens*, mathematics, and logical-deductive reasoning in general, is merely a source of pleasure. When the Sumerians were founding the first civilization, mathematicians gathered data on the position of the planets knowing that in some cases it would take generations to paint a complete picture (Tabak 2004). They worked in the hope and with the conviction that humanity – or in any case the part of the same that dedicated its time to quantitative knowledge – would one day be able to comprehend more complex natural mechanisms than those they could strive to understand with the data acquired during their lifetime.

As a form of language, mathematics, or science in general, is also an emerging property of a community. Something that will survive the individuals.

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[10] One player, the proposer, is endowed with a sum of money. The proposer is tasked with splitting it with another player, the responder. Once the proposer communicates their decision, the responder may accept it or reject it. If the responder accepts, the money is split per the proposal; if the responder rejects, both players receive nothing. Both players know in advance the consequences of the responder accepting or rejecting the offer. (https://en.wikipedia.org/wiki/Ultimatum_game)

The Expensive-Class Hypothesis

In the Aztec's "cannibal kingdom" described by Harris (1978), the aristocracy – a combination of the military, priests and mathematicians – had no scruples about keeping most of the population just above subsistence level. Then they would use them as meat to be butchered.

The situation in the Fertile Crescent was completely different. Sumerian slaves were mostly foreigners (Mendelsohn 1946), and there are no traces of ritual cannibalism.

The difference between the two societies wasn't genetic, obviously, but environmental. "Mesoamerica was left at the end of the ice age in a more depleted condition, as far as animal resources are concerned, than any other region" (Harris 1978). The Fertile Crescent, on the other hand, as emphasised by Diamond (2002) "yielded what are still the world's most valuable domestic plant and animal species."

In practice, the Sumerians probably found themselves with a group of priest-mathematicians who, thanks to the presence of resources that were easily exploitable through technological developments, soon turned into a technocracy that made it possible for the society to quickly consolidate itself and expand.

The Aztec aristocracy, on the other hand, found themselves in a situation in which the only way to survive was to become a parasite, considering society as the environment from which they would extract the energy necessary for survival: peasants were considered both workforce and livestock.

We can draw an analogy between these two cases and the brain in Isler and Van Schaik's analysis (2009). The information processing centre – brain or government – is a liability when energy sources are scarce, and in these cases behaves like a parasite – in other words it continues to exist at the expense of the other organs/classes, part of the same organism/society.

Information processing centres are not only more intelligent, they need more energy too. When energy can be extracted from outside the system, there's no reason to "eat your neighbours". But in times of hardship, the first survival strategy is to exploit productive sub-systems.

The increase of inequality in networks is a phenomenon that's been subject to a great deal of study. As pointed out by Dorogovtsev and Mendes (2003), in a society in which wellbeing decreases, the level of inequality increases.[11] Seen as intelligent systems, government or the brain not only need more energy, they're also in the position to subjugate the rest of the organism to obtain it.

Although new technologies, from the brain to mathematics and computers, are developed in periods of opulence – like the electronic calculators developed in post-World War II America – the same technologies will be used to the disadvantage

[11] Dorogovtsev and Mendes measured the level of inequality, and rightly so, not with indexes like the Gini coefficient, but by measuring the exponent of the power-law which describes the distribution of wealth (see Appendix 1). The greater the absolute value of the index, the greater the inequality.

of the common good and to the advantage of the governing minority in times of need.

We'll take a look at how *Homo sapiens* evolved after the invention of language, and how human societies evolved through the evolution of communications' instruments in the next chapter: in practice, whether cells or societies, systems that can effectively process information can exist as a parasite in another system (the Aztec ruling class or Dyson's RNA) or as organisational centres for the system as a whole.

In the following chapter we'll see how something similar is happening in modern *Homo sapiens*' societies with the emergence of today's IT giants.