First paradox –
Doubling of Brain Volume in Homo erectus – yet Only Slow Development of Its Cognitive Phenomena

(First part of a four-part series on human neurosystemic autonomy; see: "A radical new view of man")

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Abstract

A *paradox* of hominization needs to be resolved: Homo erectus experienced a doubling of brain volume, yet the development of its cognition took eons. In almost two million years of brain growth, Homo erectus made only a few *technological innovations*. Therefore, *in Homo erectus*, it seems that the biological process of mutation and selection for the *evolution of the cerebrum* was primarily responsible for the increase in cognition, rather than the accumulation of experience.

The only significant difference between the monkey and human brain is as follows: the proportion of the association cortex increased to 80% during the evolution of Homo erectus. But how can a mere increase in the number of non-specific neurons in the association cortex of Homo erectus explain the cognitive advances that can be observed? The partial patterns of sensory perception that the connectome feeds to the association cortex are evolved *intracortically* into higher cognitions by means of *unspecialized* neurons. These information-providing neural patterns can only be evolved – not calculated – because they are subject to the properties of a complex brain system; and they can only be evolved *processual* because the association cortex has a *non-specific* character – it selects information patterns instead of neural structures.

Thus, the greater the number of neurons, the more *pattern attractors* of order acquisition can be formed, and the higher the cognition. Their number was probably not sufficient in Homo erectus to continuously develop complex cognition. The extreme time periods for innovations in Homo erectus therefore suggest that its cognitive advances were not due to a cumulative learning process, but primarily to the genetically determined increase in brain size and thus neurons. Homo erectus was not human.

Before brain growth stopped in archaic Homo sapiens, *a systemic change* must have taken place *in the evolving cerebrum*. For in the human brain – which remains *constant* – we recognize an *unlimited potential for cognition* and, *above all, creativity* that is lacking in Homo erectus.

Key terms: Homo erectus, Brain evolution, Association cortex, Corticalization, Complex systems, Hominization, Cognitive revolution, Structural constancy

1 Introduction
A paradox raises questions

Meticulous examination of all significant conditions of Homo erectus evolution can shed light on the age-old question of whether the transition from Homo erectus to Homo sapiens can be purely gradual, or whether this undoubtedly gradual evolution did not culminate in a *qualitative leap* – as signaled by the Homo erectus paradox. Furthermore, the question arises as to how the known cognitive advances in Homo erectus correlate with the changes in his cerebrum – which, it should be noted, does not have any specifically new brain structures.

At present, there seems to be general agreement that the accelerating cognitive development of humans, despite the constancy of their brains, would by no means set them apart from animal intelligence in a leap-like manner. It is believed that the use of complex language and symbols, the accumulation of experience, adaptation to cognitive niches, and the co-evolution of genes and culture are sufficient to explain even the levels of creativity in the development of human civilization (Gould 1980; Waals 1996; Hrdy 2009; Pääbo 2014; Trivers 2002; Tattersall 2014; Dawkins 1982; Deacon 1997; Stringer 2012; Tomasello 2014; Richerson & Boyd 2005; Laland 2015; Suddendorf 2013; Meaney 2010; Gilbert, Müller, Uller 2007) (Whereas for Gould, Tattersall, and Stringer, humans remain animals, Tomasello, Laland, and Suddendorf believe that gradual self-development makes Homo erectus unique among humans.)

Who recognized that all these cognitive factors were being used to explain something that cannot be explained without correspondingly *complex* brain processes? For every cognitive phenomenon, no matter how astonishing, must have a neuroprocessual counterpart: so that only humans – not animals – could become capable of developing language and symbol formation in the first place; so that only humans – not animals – are capable of accumulating unlimited experience, to the point of creatively overcoming previous experience; so that only humans – but not animals – can turn every natural material and every natural energy into a ‘niche’ by transforming it; so that humans themselves actively adapt the entire world to their needs, instead of passively being adapted to a niche – as animals do.

This leaves the explanatory element of co-evolution (Lumsden & Wilson 1981, Richardson & Boyd 1985): the fact that co-evolution of genes and culture is impossible does not seem to deter the research community. In Darwin's terms, co-evolution means mutual adaptation through mutation and selection, for example between predator and prey. Acquired characteristics cannot, in principle, be inherited: epigenesis—which is cited as a prime example of the co-evolution of genes and culture—as a mere regulatory phenomenon of the genome does not, however, represent a positive gene mutation through culture: the same gene is merely (de)activated in response to temporary environmental circumstances. Mutations (relating to the brain) still cannot trigger desirable, creative development; conversely, cognitive advances cannot bring about positive genomic change. Co-evolution can only exist on a purely biological level. (Just as co-development can only exist on a cultural level). Anything else amounts to Lamarckism, which asserts the inheritance of acquired characteristics, something that is incompatible with the principle of mutation selection. Culture and experience cannot trigger specific mutations in the genetic material, as these are random in nature. (Of course, genes, e.g., for malaria resistance, can partially influence culture; and culture can cause genes to mutate, e.g., through industrial toxins. But such limited, one-sided effects lead neither to cultural 'development' nor to a specific genetic 'evolution.')

Above all, the tautological explanation of cognitive progress through cognition itself does not say anything about the unexplored brain processes that must take place in order to enable the astonishing leaps in human creativity in the first place. Understanding the highest cognitive achievements without corresponding high brain performance proves to be highly unserious. Thus, neuroscience is left with the task of deciphering a continuous development of cognition in creative leaps that is impossible for all animals – especially with a constant brain.

We have set out here to solve an *initial* paradox: with an enormously growing cerebrum, Homo erectus underwent extremely slow cognitive development over thousands of centuries – despite innovations such as the hand axe and the leap from controlled to artificial fire. This seems all the more astonishing given that, with a brain that has remained *substantially* unchanged since Homo sapiens, there has been a noticeably accelerating development of cognitive abilities in creative stages over the biologically short period of millennia. *(A second paradox, which is the subject of the next part of this series.)*

2 Methodological approach Preparing key components to resolve the paradox of Homo erectus evolution

A Coordinating corticalization in Homo erectus with simultaneously known stages of cognition

Paleoanthropology has so far unearthed nine fossil species of the genus Homo in Africa – primarily of the species Homo erectus – which, taken together, demonstrate an encephalization of the brain from approximately 650 cc to nearly double that amount, approximately 1280 cc, within a period of around two million years:

The skull of Homo habilis (KNM ER 1813 from Koobi Fora, Kenya) approximately 2.1 million years old with a volume of
approximately 650 cc
A skull of Homo rudolfensis (KNM-Er 1470 from Koobi Fora, Kenya) with an age of 1.9 million years and a volume of
750 cc
A skull of Homo ergaster (KNM-ER 3733, Kenya) from
1.9 to 1.4 million years ago with a brain volume
between 750 and 900 cc
The first Homo erectus skull from Lake Turkana.
1.7 million years old with a brain volume of
approximately 850 cc
The Homo erectus skeleton (KNM-WT 15000 from Lake Turkana, Kenya) of the so-called Nariokotome Boy or Turkana Boy,
1.53 million years old, with a brain volume of
880 cc (which would correspond to 910 cc in an adult)
The skullcap (OH 9 from Olduvai Gorge, Tanzania) of a Homo erectus known as 'Chellean Man', aged
1.4 million years and with a brain size of
approx. 1065 cc
The skullcap (OH 12, also from Olduvai Gorge in Tanzania) of a Homo erectus, estimated to be
1.2 million to 800,000 years old with an approximate volume of
only 750 cc
A skull fossil (called Bodo 1 from Middle Awash, Ethiopia), lying between Homo erectus and archaic Homo sapiens,
640,000 +/- 30,000 years old with a brain volume of
1200 to 1325 cc
Although this find was most recently classified anatomically as Homo heidelbergensis (Tattersall 2015), it was previously only known as a precursor or variant of Neanderthals in Europe. Since both Homo heidelbergensis and Neanderthals are considered anatomically difficult to distinguish variants of Homo erectus, it seems more than appropriate to classify the Bodo find from Ethiopia as African Homo erectus.
The 'Broken Hill Skull' find (from Kabwe, Zambia) was initially named Homo rhodesiensis, but was later reclassified as Homo erectus. Its age is estimated at 299,000 ± 25,000 years, and its brain volume is
1280 cm^3.

Specimen	Taxonomic Assignment	Site	Age (years)	Brain Volume (ccm)	Remark
KNM-ER 1813	*Homo habilis*	Koobi Fora, Kenya	~2.1 Ma	~650	Early representative of the genus *Homo*
KNM-ER 1470	*Homo rudolfensis*	Koobi Fora, Kenya	~1.9 Ma	~750	–
KNM-ER 3733	*Homo ergaster*	Kenya	1.9–1.4 Ma	750–900	–
ER 3883 ("Turkana skull")	*Homo erectus*	Lake Turkana, Kenya	~1.7 Ma	~850	–
KNM-WT 15000 ("Turkana Boy")	*Homo erectus*	Lake Turkana, Kenya	1.53 Ma	~880 (child) / ~910 (adult)	Almost complete skeleton
OH 9 ("Chellean Man")	*Homo erectus*	Olduvai Gorge, Tanzania	~1.4 Ma	~1065	Major African specimen
OH 12	*Homo erectus* (disputed)	Olduvai Gorge, Tanzania	1.2–0.8 Ma	~750	Possible subspecies
Bodo 1	*Homo erectus / heidelbergensis*	Middle Awash, Ethiopia	640,000 ± 30,000	1200–1325	Transitional form towards *Homo sapiens*
Broken Hill Skull (Kabwe)	*Homo erectus / rhodesiensis*	Zambia	299,000 ± 25,000	~1280	Late form of *Homo erectus*

One critical point must be made before any evaluation: the data available is still very sparse, and future discoveries could lead to significant differences in the overall assessment. In addition, it must be taken into account in each individual assessment that the dating margins are sometimes considerable. Improved measurement methods in the future may also modify the overall picture in this respect. However, apart from all possible, more or less incidental uncertainties, we can conclude that within 1.8 million years (from approximately 2.1 million to around 300,000 years ago) – from the earliest Homo habilis to the last Homo erectus found to date before the appearance of archaic Homo sapiens – the cerebrum volume of Homo erectus approximately doubled – from 650 to around 1300 cc. According to the current, rather sparse findings, 1.2 million years ago, in addition to "Chellean Man" (OH 9) and his 1065 cc brain volume, a subspecies of Homo erectus OH 12 with a volume of 750 cc appeared, which would indicate a parallel regression in brain size. However, since these are all rare chance finds, more fossil finds could also identify the Homo erectus skull OH 12 as a previously misinterpreted other species of the genus Homo. Overall, the encephalization of Homo erectus reveals an eminent pace for biological evolutionary processes.

One would actually expect to see a corresponding pace of development in cognitive performance. Let us examine the innovative progress of Homo erectus over almost two million years:

First cognitive leap: It is appropriate to begin the genus Homo with Homo habilis, because with this species a qualitatively decisive new step in cognition can be observed: for the first time, a hominin uses naturally occurring stones not only in their uncut form to crack nuts or throw them at predators. Great apes already do this, and it is highly likely that Australopithecines also practiced it. Following the Australopithecines, Homo habilis is the first species of the genus Homo to roughly shape stones with one or two blows, creating so-called choppers (approx. 2.1 million years ago): tools whose sharp edges can be used more efficiently for working materials.

However, it takes about 400,000 years before we see a new innovation – even though the brain volume of Homo erectus has increased by almost a third, namely 200 cc: Homo erectus from Lake Turkana is now producing the first, crude hand axes of the emerging Acheulean stone culture. Found at: Kokiselei 4, West Turkana, Kenya, 1.76 million years ago (Lepre et al. 2011). And: Konso-Gardula, Ethiopia, dated 1.75 million years ago (Beyene et al. 2013). However, this period of almost 400,000 years is too long to assume that Homo habilis or erectus would have transformed a primitive chopper into a roughly shaped hand axe through tiny learning processes passed down through generations to create the firsthand axe.

Second cognitive leap: Around 250,000 years later, there is also evidence of the passive use of naturally ignited fire (by lightning or the sun). The earliest evidence of the use of natural fire comes from Koobi Fora (FxJj20 AB, Kenya, approx. 1.5 million years ago (Bellomo 1994) and Chesowanja in Kenya 1.4 million years ago (Gowlett et al. 1981). The same applies to the first cognitive leap as to the 600,000 years it took the genus Homo, especially Homo erectus, to progress from observing naturally occurring fires, mainly smoldering embers, to their passive use.

If the earliest Homo erectus already possessed elementary rudiments of human thinking, which he increased through tiny learning steps to the thinking potential of Homo sapiens through *cultural* development (not biological evolution) – as strict gradualists claim (Tomasello 2019; Suddendorf 2013; Laland 2017; Deacon 1997; Harvati & Harrison 2006) – then the two stages of cognition mentioned above would have taken thousands, perhaps even tens of thousands of years in communities strongly rooted in tradition – but impossible millennia: after all, his brain volume increased by 400 cc during those 600,000 years. Even in very static human communities, we can observe over very long periods of time that existing skills, habits, and customs vary and modify slightly, albeit extremely slowly; tiny, unconscious fragments of experience accumulate completely unintentionally over long periods of time, eventually resulting in a small, qualitative step forward in experience. Even the smallest learning processes cannot be effectively accumulated in humans over thousands of centuries without resulting in qualitative progress. Consequently, Homo erectus did not yet possess fundamentally human creative abilities.

It is true that we also know of long periods in the history of Homo sapiens during which few cultural innovations were produced: humans remained at the developmental stage of hunters and gatherers for at least 200,000 years, from the appearance of archaic Homo sapiens (if we mark this with the cessation of brain growth) to the first emergence of agriculture in the Fertile Crescent about 12,000 years ago. But despite the same, completely natural stage of reproduction in hunter-gatherer culture, Homo sapiens achieved a multitude of cognitive improvements during these 200,000 years: the Middle Stone Age with scrapers, scratchers, chisels, and knives (Jebel Irhoud); grave goods (Qafzeh, Israel); pierced shells and fish hooks (Katanda, Congo); geometric engravings (Blombos Cave, South Africa); cave paintings (Sulawesi, Indonesia); figurines and musical instruments (Geissenklösterle, Germany); saws and sewing needles; bows and arrows; spear throwers – to name just the most significant innovations; in short, every few millennia, creative achievements can be identified which, due to the shortness of time, can only be attributed to a brain that remained *substantially constant*. We must contrast this multitude of innovations within 200,000 years with only one or two innovations by Homo erectus in 400,000 (hand axe) and 600,000 years (use of natural fire) – and these most likely occurred because of a cerebrum that was almost a third larger and not primarily because of independent creative advances.

The same applies to the approximately 8,000 years from the emergence of agriculture to the emergence of the first advanced civilizations. Although the far more effective reproductive method of agriculture developed very slowly, in several stages, revolutionary innovations were produced during this period: stone temple buildings (Göbekli Tepe, Turkey), house construction (Fertile Crescent), the domestication of animals and cultivation of plants, the plow, pottery, textile production, the wheel, metallurgy, and much more. In other words, cognitive development accelerated within just 8,000 years with a constantly stable brain size – compared to the innovative achievements of Homo erectus over 600,000 years with an enormously expanding brain.

Third cognitive leap: Even more striking in Homo erectus is the time difference between the use of naturally occurring fire and the active ignition of fire: it spanned from 1.5 million years ago (Bellomo 1994) to 780,000 years ago, when the first known controlled use of fire took place in Gesher Benot Ya'aqov, Israel (Goren-Inbar et al. 2004). It therefore took 720,000 years for Homo erectus to progress from passive to active use of fire. However, we must take into account that several very different factors must be specifically identified and brought into functional relation with each other in order to artificially produce fire: Extremely flammable, smoldering material must be sought; a place that is as sheltered from the wind as possible must be chosen; the property of flint to produce sparks when struck together – which had certainly been noticed long ago when striking a hand axe – must be used in a controlled manner.

Consequently, the artificial ignition of fire already required considerable imagination, which cannot have differed greatly from the consciousness of Homo sapiens. However, the brain volume of Homo erectus had increased significantly from approximately 900 cc 1.5 million years ago – when he began to use fire passively – to around 1150 cc 780,000 years ago: by 250 cc, a good quarter. Once again, this discrepancy suggests that this cognitive leap to actively igniting fire cannot be attributed to small, cumulative steps of experience over 720,000 years, but rather to the neurophysiological prerequisite of a further enormous increase in the size of the cerebrum. Even Homo erectus, who first artificially ignited fire, was apparently not yet a fully-fledged human being. This is also confirmed by the last cognitive leap before the archaic Homo sapiens appeared on the scene:

Fourth cognitive leap: The last cognitive leap of Homo erectus before we encounter the archaic Homo sapiens consists in the manufacture of throwing and thrusting spears with stone tips (Wilkins et al. 2012). The site where this was found was Kathu Pan 1 in South Africa and is about 500,000 years old. We therefore record another 280,000 years since the previous cognitive leap, 'artificial fire', 780,000 years ago, before another cognitive leap took place. Once again, this is far too long a period of time to attribute this further step in innovation to the human developmental form of cumulative learning: once again, the cerebrum had to grow by around 100 cc from 1150 to 1250 cc to make this new cognitive leap possible. The next site where projectile points for spears were found is in the Gademotta Formation (Ethiopia) and is between 280,000 and 250,000 years old (Sahle et al. 2013). – This brings us to the predominantly gradual brain growth of Homo erectus, where the archaic Homo sapiens appears in Jebel Irhoud (Morocco), in Ethiopia near Omo and Herto (McCarthy, Lucas 2014) and also South Africa (Florisbad) (Bruner & Lombard 2020). Paradoxically, from then on, the brain volume of Homo sapiens remained fairly constant at around 1,450 cc until the beginning of the Holocene – a *second* paradox.

Cognitive advance	Sites / Evidence	Age (years)	Brain volume (ccm, approx.)	Required increase (ccm)	Time span since previous leap
Chopper production (*H. habilis*)	Koobi Fora (KNM-ER 1813), Kenya	~2.1 Ma	650	–	–
Handaxe (Acheulean)	Kokiselei (Kenya), Konso (Ethiopia)	1.76 Ma	850	+200 vs. before	~400,000 years
Use of natural fire	Koobi Fora (Kenya), Chesowanja (Kenya)	1.5–1.4 Ma	1065	+400 vs. *habilis*	~600,000 years
Controlled / artificial fire	Gesher Benot Ya‘aqov (Israel)	~780,000	1150	+250 vs. before	~720,000 years
Spear making (stone points)	Kathu Pan (South Africa), Gademotta (Ethiopia)	500,000–280,000	1200–1280	+100 vs. before	~280,000 years

This also proves that for the final evolutionary step from Homo erectus to archaic Homo sapiens, his brain volume had to increase again by almost a third from approx. 1,100 cc to 1,450 cc – and thus the number of neurons exponentially – before we can observe a radically new phenomenon of intelligence from the new Stone Age culture of the Middle Stone Age of archaic Homo sapiens: that of a now continuous and permanently *accelerating* cognitive development – with the same brain; which provides the *second* paradox of human intelligence. Even for these 200,000 years of continuous brain evolution in Homo erectus – which roughly correspond to the 200,000 years of continuous higher development of human culture and civilization since the cessation of its brain growth – the following therefore applies: It is impossible that Homo erectus could have possessed human-like learning and creative abilities before the appearance of archaic Homo sapiens: apart from spear-making, we know of no further cognitive progress until the beginning of the Middle Stone Age around 300,000 years ago.

To underscore this statement, we point to an even more astonishing phenomenon in the cognitive activity of Homo erectus, which concerns the characteristic artifact of hominization par excellence: the hand axe of the Acheulean culture (de la Torre 2016). Its form has remained unchanged since its earliest appearance 1.76 million years ago (Lepre et al. 2011) in Kokiselei (Kenya) and Konso (Ethiopia) until the first appearance of archaic Homo sapiens in Jebel Irhoud (Richter, Grün, Joannes-Boyau et al. 2017) or the last Homo erectus of the ‘Broken Hill Skull’ from Kabwe (Zambia) around 300,000 years ago. In almost 1.5 million years, a very clunky hand axe, shaped with a few blows on both sides, has become a slimmer hand axe, flattened by many blows (McNabb, Cole 2015). The only other tools found were large scrapers with a straight cutting edge (Konso-Gardula, Ethiopia), known as cleavers, which are slightly younger, dating back 1.6 to 1.5 million years (Beyene et al. 2013).

This special finding emphatically confirms that if the brain volume of Homo erectus increased from around 800-ccm to around 1,300-ccm – i.e., by a good 60% – during the endless 1.5 million years of hand axe production, then, based on our experience with the evolution of higher mammals – from tarsiers to great apes, for example – we would expect its cognitive performance to have increased correspondingly. However, Homo erectus used these 1.5 million years to craft a rough, symmetrical hand axe from a rough stone. Can we conclude from this situation that Homo erectus achieved this progress in homeopathic doses of learning? Isn't it much more likely that the enormous increase in neurophysiological capacity that developed was the indispensable prerequisite for increased cognitive performance?

If so, this raises an even more difficult question: Why did the Homo erectus brain have to increase by half or a quarter before a new level of cognition could be achieved? A 200-ccm increase to progress from choppers to hand axes; a 400-ccm increase since Homo habilis to progress from observing to using natural fire; a 400-ccm increase since Turkana Boy to progress from using natural fire to igniting artificial fire; and another increase of just under 300-ccm to make the final cognitive leap from the first artificial fire to spear production. The fact that a significant increase in brain volume was apparently required before a new cognitive leap occurred after thousands of centuries obviously requires a more profound explanation than the smallest, cumulative learning steps.

All attempts to explain the Homo erectus paradox (see *"4 Discussion"*) fail to recognize the fundamental problems that arise from the contradiction between extreme brain enlargement and extremely slow but sudden cognitive leaps in Homo erectus. First, the time intervals between innovations are too long to allow for a cumulative learning process similar to that of humans; such a learning process would inevitably lead to cognitive results after at least tens of thousands of years – even in extremely tradition-bound communities.
On the other hand, few cognitive advances take place – but they are strikingly abrupt, with no discernible gradual precursors.

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cumulative learning process similar to that of humans; such a learning process would inevitably lead to cognitive results after at least tens of thousands of years – even in extremely tradition-bound communities.
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Furthermore, we know what none of the research approaches (discussed *in section 4*) focus on, namely that despite its enormous increase in volume, the brain of Homo erectus is neurophysiologically and structurally no different from that of a chimpanzee. Thus, there is no new, previously unknown neurophysiological specialization. On the contrary, it is the enormous growth of the *nonspecific* association cortex that essentially makes encephalization in Homo erectus a *corticalization*.

In order to make profitable use of this empirical information, it is essential to prepare two basic facts for the following analysis that have been completely neglected, if not ignored, in evolutionary anthropology to date: the hypercomplexity of the cerebrum and the *non-specificity* and *intracorticality* of the association cortex.

B Processual consequences of the unconsidered basic fact: Hypercomplexity of the cerebrum

The *most important*, *elementary basic fact* that neuroscience and therefore also evolutionary anthropology should start from is the following: The brain (at least) of higher animals is a *complex system* that – it should be noted – operates in a manner *diametrically opposed* to that of an electronic computer (Edelman 1987, Sporns 2011, Chialvo 2010). Although the term "complexity" is widely used, little consideration is given to the exquisite properties it implies, which preclude any mechanistic and purely formal-logical approach analogous to electrical engineering.

Firstly: All initial conditions of the brain's neural system are *indeterminate* – both its environment and its sensory perceptions, and above all its elementary unit, the neuron; the neuron has thousands of *variable* synapses for signal reception, many dendrites for transmitting them to the cell body, where they are probabilistically processed into a *fluctuating* action potential to be transmitted to different neurons via several axons (Lea-Carnall, Tanner, Montemurro 2023). It could hardly be more *ambiguous*, and the task of neuroscience should be to show how, nevertheless, the orderly states of specific, higher cognition can come about.

Secondly, all of the elementary parameters mentioned – environment, sensory receptors, neurons – enter into *iterative interaction processes* with each other, whereby, as already stated, the individual parameters are all of an *indeterminate* nature. These result in a hypercomplex, and therefore *nonlinear*, system that, in stark contrast to the formal logical-linear system of the mechanics of an electronic computer, is no longer exactly calculable and predictable, at least in the medium term.

Thirdly, this complex, nonlinear neural system, the brain, operates with billions of neurons as elementary units from the bottom up – from indeterminate to definite, from disordered to ordered – and must therefore be understood as a dominant self-regulating system. The simple patterns of this self-regulation lead to states of order in self-organization, which in turn, as we shall see, evolve into higher levels of order in cognition (Kadmon 2025). – The brain system therefore has no clearly defined data, algorithms, or circuit diagrams that could be used to calculate hidden patterns from the top down.

Fourth: The cerebrum forms stable patterns from partial patterns of sensory perception. During further processing – especially with the patterns of memory and the limbic system – the parameters involved fluctuate simply due to the constant change in the environmental situation. This is why an initially stable period of an overall pattern – cognitive performance – undergoes a bifurcation into two possible pattern variants. As the interaction of more or less fluctuating parameters continues, one bifurcation follows another at an ever-increasing rate, which, in mathematical terms, leads to bifurcations. Under these circumstances, the brain's great system performance consists of generating stable cognitive performance again from the constantly emerging pattern variants (Hesse, Gross 2014).

Fifth: However, this stabilization of fluctuating neural patterns despite constant interaction towards more or less clear cognitive performance is by no means always successful. Often, the bifurcations lead to more and more alternative pattern variants and result in a *state of chaos*. In most cases, the simultaneous *processual* evolution of the many pattern variants, reinforced by self-regulation and self-organization, leads back to a selected, more effective neural pattern that is stable enough to be practiced. It is important to understand that the selection and subsequent evolution of unstable pattern variants, which counteracts impending *states of chaos,* is *not a neurophysiological process*, but *primarily a purely procedural one involving action potentials*. However, the mass repetition of identical or similar neural processes also strengthens the neurophysiological structure (especially at the synapses).

Sixth: Since life consists of coping with complex situations, actual phases of chaos repeatedly occur in the cerebrum that cannot be stabilized by the processes of self-regulation, self-organization, or pattern evolution. If the supply of ever new pattern variants continues due to an open problem, so that the neurosystemic state of chaos persists, this chaotic process sometimes *tips over* into an unpredictable new, possibly *higher state of order* that breaks with all previous stable patterns and thus forms of cognition: *a qualitative leap in cognition* has occurred (Chialvo 2010). Such leaps in the quality of cognition (such as the heliocentric world view, the hypothesis of gravitational force, the portioned nature of light waves, etc.) are, in principle, neither calculable nor predictable from the known initial conditions of cognitive problems. This is because they are the *undeducible* results of a complex, informational pattern evolution process – just as the biological evolution of the living world as a whole has always produced completely unpredictable leaps in quality (such as sensory organs, spines, nerve cells, brains, land animals, mammals, association cortex, etc.).

In a nutshell: *due to its complexity*, the performance of the neural system of the brain can neither be calculated nor predicted, especially over a medium period of time. The comparison of the human brain with a computer, which dominates evolutionary anthropology and even brain research, thus proves to be extremely *counterproductive* and essentially misleading when viewed seriously, even if one is merely referring to a model comparison. (Only elementary behaviors such as reflexes, instinctive actions, imprints, etc. resemble exact feedback processes, controlled by circuit diagrams or following feedback loops.) This is because the brain and computers operate *in fundamentally opposite ways*: interactively indeterminate versus mechanically unambiguous, complex versus complicated, bottom-up versus top-down, self-regulating versus controlled, etc.

Taking these facts seriously, the majority of brain researchers and evolutionary anthropologists have succumbed to a mechanistic model for decades, as long as they insist on misunderstanding the human brain as merely a more complicated computer (Changeux 2004; Dehaene 2014; Deacon 2012; Dennett 2017; Hofstadter & Dennett 1981; Pinker 2010; Roth 2016; Gazzaniga 2018; Mainzer 2020). If it turns out that it is precisely the *ambiguous nature* of pattern recognition in the brain (the indeterminate initial conditions), the very *diversification* into pattern variants (bifurcations) that makes prediction difficult, and the very *state of chaos* (attractor formation) into which the potentiating bifurcations can fall, are the basic prerequisites for the almost mysteriously increasing cognitive and creative leaps in human development: At this point, at the latest, it will become abundantly clear that the neural processes of the human brain can only be understood on the basis of the unpredictable properties of complex systems.

C Systemic consequences of ignoring the fundamental fact: Non-specificity and intracorticality of the association cortex

The *next fundamental fact*, which is almost as important and which is notoriously neglected by both evolutionary anthropology and brain research, concerns the *association cortex*. When analyzing the evolution of Homo erectus, it is hardly ever even mentioned (in contrast: Buckner & Krienen 2013; Herculano-Houzel 2016;

on the latter: see *"4 Discussion"*). In fact, it has three extremely significant characteristics:

First, the enormous increase in the size of the cerebrum in Homo erectus is almost exclusively due to the growth of the association cortex, including the frontal cortex. In humans, it occupies up to 80% of the cerebrum, which means that qualitative changes in cognition – imagination, foresight, planning, etc. – in Homo erectus and then especially in humans must be fundamentally related to the functioning of the association cortex.

Secondly, the association cortex is *non-specific* in nature, in stark contrast to the sensorimotor cortex. This means that its approximately 15 billion neurons are not highly specialized like the neurons of the auditory or tactile cortex, but are all more or less *unspecialized* and *standardized*. This alone makes it clear that the higher cognitive abilities of the genus Homo are not the result of improved or new specialized brain structures, but rather of the *interaction* between the sensorimotor cortex, which has remained largely unchanged in apes, Homo erectus, and humans, and the ever-expanding association cortex.

Thirdly, the association cortex does not perform its functions in the same way as the sensory organs and their associated sensorimotor cortex, in which new sensory information constantly flows in from the environment and is processed as needed by highly specialized neurophysiological structures. Rather, the association cortex processes information without coming into *direct* contact with the environment, primarily *intracortically* with the preexisting neural patterns of the sensorimotor cortex, but also of the limbic system and the thalamus or brain stem.

In the following section, *"Results"*, we will analytically address all the questions that have arisen so far with a radically new, *neurosystemically* supported solution that appears plausible. What evolutionary anthropology, which has lost itself in minutiae, has failed to address are the elementary factors underlying the problems developed here. Without clarity on the elementary, the big questions – what is man? What does the constancy of his brain mean? How does it process essentially? Is there a qualitative leap between man and animal? Etc. – can never be answered.

We methodically *compared* brain growth in Homo erectus with the periods of time required to achieve new cognitive abilities. And we methodically characterized the most important properties of the *complexity* of each cerebrum as indispensable criteria for further analysis. We did this in order to methodically link them with the equally important *elementary properties* of the association cortex. This paved the way for further analysis to provide further plausible hypotheses.

3 Results
The solution to the paradox lies in the characteristics of the system complexity of the association cortex

We should move from the surface to the core of the action: the brain. There, a neurosystemic explanation must be found for the extraordinary nature of the facts methodically prepared earlier – abrupt cognitive leaps at very long intervals despite the constantly growing cerebrum. – On the way there, the following problem areas of evolutionary anthropology, which have been virtually ignored until now, must finally be addressed:

Firstly:
The brain of Homo erectus – like that of Homo sapiens later on – differs neither in its architectural structure nor in the specifics of its neurophysiological substance from that of the chimpanzee, the great ape closest to us. So where does the controversial phenomenon of unprecedented creative leaps in humans come from, given that their brains remained unchanged? Decades of increasingly sophisticated experimental brain research have failed to identify any noteworthy original brain structures in humans. It seems time to venture a radically new research approach to questions of cognitive development; questions that this *second* paradox already raises in Homo erectus. A science that always tries only to confirm old beliefs loses sight of the actual goal of science: to eliminate the *inconsistencies* of the old model of reality through essentially new insights. The new research approach should take the bull by the horns and acknowledge what has demonstrably changed noticeably in the cerebrum during hominization: *instead of new, specific neurostructures*, the pure growth of the association cortex and thus an exponential increase in the number of *unspecialized neurons*, which can primarily serve the purely procedural further development of sensory information.

Secondly:
What changed noticeably in the brain during the evolution of Homo erectus was the doubling of the total brain volume; however, this increase in cerebrum size was almost exclusively due to the growth of the association cortex – which Herculano-Rouzel overlooks. If the enormous growth of the association cortex is indeed responsible for our first paradox, then this suggests that we should take a closer look at the systemic consequences of the *characteristic properties of the association cortex*. Above all, these characteristics must be considered in the context of the general functioning of a hypercomplex system, which the association cortex undoubtedly represents.

Thirdly:
It took at least thousands of years for Homo erectus to make each new cognitive leap (hand axe, natural then artificial fire, spear production), while his brain grew

enormously almost continuously (by half, by a quarter, etc.). This led us to the conclusion that his cognitive leaps could not possibly have been due to *cumulative* learning achievements as in humans, but primarily to the *exponential increase in the number of neurons* that accompanied the growth of the association cortex in particular. But how? This raises the serious question: How can a merely – albeit significantly – increased number of *unspecialized* neurons be responsible for a higher level of cognition?

Fourth:
An association cortex evolved because it was able to reintegrate and synchronize the subpatterns of the increasingly differentiated sensorimotor cortex. All cortices together form the neocortex, which has become increasingly larger in the evolution of mammals. A randomly disproportionate enlargement of the association cortex – in Homo erectus – proved to be a cognitive advantage in the selection process (Buckner & Krienen 2013). This is because the virtually unlimited capacity of the association cortex made it possible to filter out the most general perceptions of the same thing from a variety of perceptions and anchor them in memory. At this point, at the latest, it must be clear that this cognitive performance depends primarily on the *properties of an elementarily complex neural system*. The informational subpatterns of sensory perception are reproduced in a fairly stable manner on a probabilistic basis by the fixed framework conditions of the sensory receptors and specialized sensory cells: identical sensory stimuli, identical sensory subpatterns (of edge, texture, movement, brightness, etc.). While these subpatterns have been integrated and synchronized into a consistent perception, the extended association cortex is able to select the most *optimal variant* from the many similar variants of perception, which is then anchored in memory.

How does this *neurosystemic selection* work, given that it is a highly complex system due to the ambiguity of all the factors involved and interacting? Based on partial patterns of sensory perception, the association cortex continuously provides similar neural patterns of individual perceptions. Hundreds, thousands, or more neurons constantly form fluctuating neural patterns that *interact* with each other, whereby the most efficient pattern, which proves itself best in sensory perception, is hierarchically consolidated synaptically. The *purely procedural variants*, which are enormous in number – each neuron oscillates up to 500 times per second through action potentials – are extinguished or become only very weakly synaptically anchored and thus quasi-selected (Meyer-Ortmanns 2023). The principle of biological evolution – less efficient variants are weeded out – clearly continues in the *evolution of information in the brain*. (We humans know the same principle as the snail's pace of conscious trial and error.)

Fifth:
With early mammals and the evolution of the neocortex, *higher, more flexible cognitive abilities* began to emerge that went beyond mere perception and instinc-

tive reactions: With the enormous enlargement of the association cortex in Homo erectus beyond the volume required for highly differentiated yet stable perception, an excess of cortical potential arose. This excess of neurons could be used to explore the stable perceptions of the environment anchored in memory, combined with the cognitive abilities of the limbic system and the brain stem, in terms of possible behaviors. Although we are already dealing with a complex system when integrating and synchronizing the subpatterns of sensory perception, the subpatterns are probabilistically stabilized by *constant feedback via the connectome*.

The situation is different when it comes to higher cognitive performance: this must be achieved purely intracortically by the *unspecialized* neurons of the association cortex, without (direct) stabilizing feedback from environmental perception being possible. (The unspecialized nature of the association cortex neurons ensures, in a sense, that nothing can be changed in terms *of the content* of the sensory information.) – This means that we are *primarily* dealing with the characteristics of the *complex system* of unspecialized neurons shown above; fundamentally with the *iterative interaction* of the initially relatively stable neural patterns of memory, etc., which very quickly enter into a *nonlinear process* (Shew & Plenz 2013).

In accordance with a specific task posed by the existential situation, suitable patterns of perception initially *regulate themselves* on the basis of the memories that provide the framework for this. At the same time, they *organize themselves* into a situation that demands cognition. An example: a smoldering fire, *randomly* available highly flammable materials, flints that experience has shown can be used to strike sparks, wind-protected conditions, etc. With the increasing number of unspecialized neurons, the unstable interplay between the perception of extinguishing fire, the recognition of its merely temporary utility, and the experience of fire sustained by combustible materials becomes more likely to converge, *through a chaotic process, into a new and stable attractor: the emergent, yet initially fragile, concept* of a “permanent fire” (Priesemann, Wibral, Valderrama et al. 20014).

This creates a partial idea of higher cognition, such as the ignition of artificial fire. The same applies to all other necessary parameters. Once all the necessary partial ideas have become reality, the probability increases for Homo erectus that, with even more neurons, the interaction of all individual attractors of a temporary idea through many selected variants of ineffective attractors will produce a fixed attractor of the overall idea of 'artificial ignition of fire' (Cocchi, Gollo, Zalesky & Breakspear 2017). (Of course, this intracortical process of emerging cognition requires the empirical framework of continuous trial and error. – In addition, I present here a hypothesis that arises empirically from the known ambiguous properties of the neural system as a complex model, even if it cannot yet be verified in detail.)

For approximately one million years, Homo erectus utilized naturally occurring large fires that burned down to small residual fires. Evidently, they did not yet possess a lasting and complex imagination that made the enormity of artificially igniting fire conceivable – far beyond nourishing and preserving existing fires. Ultimately, the number of non-specific neurons acquired thus far was not sufficient to go beyond the stable attractors of individual components for the potential ignition of a fire there are particularly flammable materials – the sparks from flint resemble the glow of fine combustible material – smoldering chips can be made to blaze by blowing on them, etc. – to process all components in a complex interactive system. Since there is no logically derivable path from two or more components to a unique result, 'artificial fire', sufficient neurons must first have been created during the blind growth of the association cortex that can perform the *nonlinear interaction process* of several neural pattern attractors of specific factors (Hinterberger & colleagues 2016).

This is because the following applies to every complex system: the more different factors or parameters are involved in the interacting system, the more bifurcations and possible variants of events occur, and the more capacity the system must have in order to try out these rapidly increasing variants. However, if no viable solution emerges through the formation of a stable, permanent attractor, chaos ensues. The *larger framework conditions* prevent chaos from persisting. It is chaos, of all things, that provides the *objectively creative momentum*: only *the state of chaos in the neural system* is capable of pulverizing all previously valid experiences (i.e., stored pattern attractors) in order to generate an *unpredictable solution that cannot be derived mathematically* (Haldeman & Beggs 2005): Controlled ignition – of highly flammable material – in a wind-protected location – by deliberately striking sparks with a flint. (Of course, the emergence of this idea is facilitated by a sufficiently large association cortex through millions of repetitions of the individual steps of this complex process.)

The extremely enlarged association cortex in Homo erectus, with its *unspecialized* neurons and dominant *intracortical* interaction processes of neural pattern variants, provides a classic, elementarily complex system. In this system, the following applies: the more parameters interact, the greater the process capacity must be in order to cope with them. And since the possible interactions and the nonlinearity of the overall system increase exponentially with the increasing number of cognitive parameters, this characteristic of complex systems also explains why the growth of the cerebrum in Homo erectus had to continue for thousands of centuries before another higher cognitive leap was achieved: The more simple cognitive tasks became possible and were practiced due to a gradually enlarging association cortex, the more parameters had to be taken into account interactively in order to achieve higher cognitive leaps. This in turn required an exponential amount of procedural evolutionary power, which presupposed an exponential increase in non-specific neurons. The *processual* mastery of linearly increasing cognitive parameters requires *exponential* neuron growth, which was not given ad hoc. Hence the continuous brain growth before another major cognitive leap occurred rather abruptly.

Sixth:
By the beginning of the Middle Stone Age, when the chipping process used to make the 1.5-million-year-old hand axe was refined into scrapers and scratchers, the brain volume of Homo erectus had grown to around 1,300-ccm. Had this extreme brain growth continued in order to achieve all subsequent cognitive leaps in this way – such as gravers, knives, grave goods, harpoons, etc. to this day – then a physically and energetically unsustainable upper limit would have been quickly reached. But even the swelling of the highly stable pattern attractors in the association cortex, which had grown to 80% of the cerebrum, could not continue indefinitely. Rather, it seems likely that a systemic tipping point occurred in the previously dominant self-regulating basic system. Not least, the cessation of cerebrum growth in the archaic Homo sapiens that appeared 200,000 years ago points to this. At the same time, however, the *second* cognitive paradox emerges: it was precisely with the end of brain growth in archaic Homo sapiens (Rightmire 2004), who replaced Homo erectus, that the continuous development of the Middle Stone Age gave rise to a steadily increasing, even accelerating cognitive development with periodic creative leaps.

The above tables also clearly show that towards the end of brain growth in Homo erectus, brain growth slowed down – while, conversely, cognitive leaps occurred in a shorter period of time. This phenomenon alone supports the hypothesis that a neuralsystem leap was imminent, because a few millennia later, accelerated, sustained cognitive development began – even though the cerebrum remained substantially unchanged.

Significant conclusions from these individual facts

The serious fact is that, beyond the sensorimotor cortex, the limbic system and the brain stem of great apes and Homo erectus, *no original specific cerebral structures* were formed to master higher cognitive leaps, for example. But why were there no original neurophysiological structures for original cognitive tasks requiring increasing imagination? This is by no means because the multitude of possible specific forms of cognition that might be expected would quickly overwhelm the growth of such a brain – even if that had been the case.

Rather, this is impossible for a *fundamental* reason: as we know, our sensory organs are by no means perfect and can only convey a certain spectrum of external reality to us. But they have been genetically adapted to the most general physical and chemical properties of the outside world. And no matter how much the contents of this reality may change creatively – for example, new animal and plant species, but also revolutionary natural phenomena – they remain perceptible to our senses only to a limited extent through arbitrary variation and combination, even if they may be mysterious. (When a tribe of natives who have remained untouched by civilisation sees a camera for the first time, they perceive it in exactly the same way as an ethnologist who has long known and understood it.)

The situation is radically different when it comes to higher-level solutions to cognitive problems – such as fencing in a pasture – or even creative leaps – such as writing or mathematics – for which there are and can be virtually no precursors in previously experienced reality, simply because they are essentially original and artificial products of the imagination based on chaotic thought processes. Why? Higher cognition does not have a cause-and-effect chain that can be learned quickly – such as: spear kills antelope – which could be experienced concretely at all times. Higher cognition deals with *fictional realities that cannot be anticipated by the senses*. The non-sensual relationships, dependencies and interactions of this task must be played out – also by means of imagination – as possibilities or probabilities that are not yet real; in the most difficult cases, even seemingly insurmountable contradictions must be played out by means of the bifurcational evolution of complex patterns through phases of chaos, which makes a seemingly unrealistic, creative solution possible. The *non-specificity* and *intracorticality* of the gigantic association cortex alone guarantee the success of such *substantially purely processual* cognitive leaps.

The biological evolution of all animal species could allow genes to mutate randomly for an infinite amount of time – *yet a specific neurophysiological structure* for writing, mathematics, metallurgy, spindles, looms, etc. would never emerge. This is precisely because cognitive innovations are preceded by an original, creative *evolution* of mere information through *purely procedural* means. *(In the third part of this series, we will see how a completely abstract and symbolic conceptual space of autonomy can make use of unpredictable phases of chaos)*. In short, for worlds that are neither neurosystemic nor concretely derivable or calculable from what already exists, there can in *principle be no biologically evolved, specific neural structures*. The decades-long search for *specific* neurophysiological brain structures for human intelligence, such as *specific* genes or gene variants that are, *so to speak*, *precisely* responsible for human creativity, no longer seems to be methodologically effective.

Now the disproportionate enlargement of the association cortex makes evolutionary sense: the biological trial-and-error process of the genus Homo demonstrated that the abstract, cognitive solutions offered by the massive interaction processes of the non-specific and intracortical association cortex proved to be concrete and real – not always, but often enough.

But if, analogously to the extremely growing association cortex, permanently stable pattern attractors of imagination increase massively, can the previously dominant self-regulating and self-organising neural system continue to process unimpaired as before? And since the increased cognitive abilities of Homo erectus occurred more frequently after long cognitive pauses, should the growth of the association cortex not continue? As is well known, the opposite occurred: despite the cognitive advantages achieved up to that point, the enlargement of the association cortex ended about 200,000 years ago.

This is a very strong indication that *processual* a *systemic change* took place in the association cortex before the end of cerebrum growth. And this suspicion is reinforced by the upcoming, *opposite* cognitive phenomenon: With the transitional archaic Homo sapiens, an incessantly accelerating cognitive *creative development* announces itself, despite – no: because of – a substantially constant cerebrum in Homo sapiens. This *second* paradox can hardly be explained other than by a previous, *processual systemic change*.

4 Discussion

As a prime example of a paradox, the slow cognitive development of Homo erectus despite enormous brain growth did not go unnoticed by scientists. However, the various approaches to solving this paradox are extremely disparate and none of them are particularly convincing, seeming more like ideas born of embarrassment:

– *One* attempt at an explanation refers to the fact that small, scattered populations would stabilise sufficient tool function through strong binding traditions (Powell, Shennan & Thomas 2009). This explanation overlooks the fact that the same can be said of the early populations of Homo sapiens hunters and gatherers until the Revolution; yet these populations created one innovation after another on widely separated continents over thousands of years – without their brains having to grow in size.

The *next* explanation is decidedly bold: it simply claims that thousands of years of stasis did not mean cognitive stagnation, because Acheulean technology required expertise and successive planning with heavy involvement of the prefrontal cortex (Stout, Toth, Schick & Chaminade 2008). Hardly anyone disputes the high level of Acheulean skill; however, this line of thinking ignores the fact that a culturally developing Middle Stone Age culture undoubtedly required *increasingly higher* specialisation and *even more extensive* planning – but without any brain growth in a much shorter period of time.

– A *third* explanation is rather fantastical, without any convincing evidence to support it: hand axes would function as social or even sexual signals, which would undermine the conservative nature of attractors; or hand axes would be the result of neutral processes around functional plateaus, which is why their production would be subject to stasis (Corbey, Jagich, Vaesen, & Collard 2016). – These authors do not consider why flint production in the cultural development of early Homo sapiens – with the innovative production of saws, harpoon tips, handle axes, etc. – was not subject to this attractor plateau, despite the stasis of the brain, in order to weigh up the two against each other.

A *fourth* attempt to explain the stasis in hand axe production among Homo erectus describes the phenomenon correctly, but consists of a black box: a late tuning of working memory would cause the very slow transition to the faster cognitive development of Homo sapiens (Wynn & Coolidge 2005). – *Firstly*, this proposal overlooks the fact that innovations did occur in Homo erectus, but at very long intervals – thus ruling out slow tuning of working memory as an explanation for abrupt leaps in cognition. *Secondly*, they do not address the question of what cognitive benefits tuning working memory can actually achieve and how the end of this tuning in Homo sapiens could even enable accelerated cognitive development.

The fact that the simplest and most obvious explanation is often the correct one also applies to the theory of hominisation: even though the cerebrum of Homo erectus grew rapidly, cognitive leaps were slow in coming – it simply had not yet achieved the *unique systemic character of the human brain (which is the subject of the third part of this series)*. This hypothesis, which is suggested by the individual facts presented, would explain the paradox of Homo erectus evolution.

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Herculano-Rouzel enjoys an excellent reputation among experts for her numerical scaling of primate brains, as this appears to reinforce the prevailing belief that the human brain is not particularly special. In her seminal work, she concludes:

> „However, our recent studies using a novel method to determine the cellular composition of the brain of humans and other primates as well as of rodents and insectivores show that, since different cellular scaling rules apply to the brains within these orders, brain size can no longer be considered a proxy for the number of neurons in the brain. These studies also showed that the human brain is not exceptional in its cellular composition, as it was found to contain as many neuronal and non-neuronal cells as would be expected of a primate brain of its size. Additionally, the so-called overdeveloped human cerebral cortex holds only 19% of all brain neurons, a fraction that is similar to that found in other mammals. In what regards absolute numbers of neurons, however, the human brain does have two advantages compared to other mammalian brains: compared to rodents, and probably to whales and elephants as well, it is built according to the very economical, space-saving scaling rules that apply to other primates; and, among economically built

primate brains, it is the largest, hence containing the most neurons.“ (Herculano-Houzel 2009, S. 1)

However, a fact-based examination of her statements must lead to the *opposite* conclusion, namely that the human brain is indeed exceptional, particularly in terms of its cellular composition. The data selected by Herculano-Houzel on the neural *composition* of the human brain is accurate, but her analysis *inexplicably* omits *three* crucial factors:

Firstly, the enormous encephalisation effect is missing, which makes the human brain *unique* in the animal kingdom (2.5 times greater in great apes and 5-7 times greater in humans than in mammals of comparable size); her generalisation ‘as one would expect from a primate brain of this size’ obscures this fact.

Secondly is missing, the fact that it was not the cerebrum as a whole (sensory-motor cortex plus association cortex as a whole) but rather the association cortex that underwent the decisive developmental leap: corticalisation (from 50% in great apes to 80% in humans; 6 billion cortex neurons in chimpanzees compared to approximately 15 billion in humans). – The proportion of neurons in the association cortex is *correspondingly higher* in humans. The blanket term ‘cerebral cortex’ and the diminutive figure of ‘only 19%’ obscure what is important: the *non-specific*, fundamentally *intracortical* processing association cortex accounts for almost the entire extraordinary increase in brain size in Homo erectus and thus in humans.

Thirdly is missing, that it is precisely its *non-specific* neurons that enable a processual, qualitatively open, *intracortical* mode of operation. Herculano-Houzel’s data is precise, but it conceals the *exquisite processual nature* of the association cortex – which, unappreciated by her, is growing disproportionately.

Her summary statement on the human brain: ‘... among the economically structured primate brains, it is the largest and therefore contains the most neurons’ is correct, but it ignores the three most important features – the disproportionate number of neurons overall, the disproportionate number of neurons in the association cortex and, finally, its *exquisite* mode of operation.

Taken together, this omission does not miss minor details, but rather the *differentia specifica* of the human brain. The result is not a conscious falsification, but rather an omission of crucial criteria for analysis. This leads us down the wrong track – and thus prevents us from looking for the structural specificity of the human brain where it actually arises: from the *enormously increased number of neurons*, especially in the non-specific association cortex, and its order-creating processes.

(The second part of this series on hominisation will further confirm the indication of a shift in the neural system of Homo sapiens based on the second paradox mentioned several times – brain constancy versus creative development.)

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Last edited in Munich, 25 September 2025

The author declares that there are no commercial or financial relationships that could be construed as a potential conflict of interest.