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Evolution of the Human Cognitive System and Human Civilizations Viewed as Phase Transitions of the Primate Brain's Neurobiological Mechanisms

Rafael Vieira Bretas, Yumiko Yamazaki and Atsushi Iriki
RIKEN Center for Biosystems Dynamics Research, Japan
atsushi.iriki@riken.jp

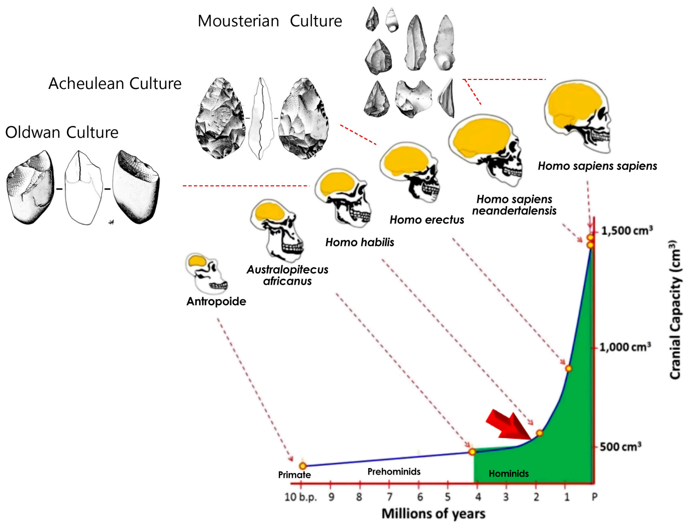
The brain capacity of human ancestors underwent two phase transitions, resulting in the emergence of modern civilizations: (1) The emergence of the primate cerebral cortex, with its unique characteristic of additional cortical areas accompanying size expansion; and (2) the replacement of natural selection as the main evolutionary mechanism by "Triadic Niche Construction", an interactive expansion of ecological, neural, and cognitive niches. The latter seems to have been triggered by the use and manufacture of tools, which led cognitive capacities to exceed the threshold for the emergence of language and self-consciousness that eventually allowed the formation of modern civilizations through intentional modification of the environment. Elucidating these developments would enable us to predict a third phase transition, which may be induced by the current explosion of artificial intelligence, accelerating human cognitive capacities to cross the next threshold required to overcome the "Limit of Growth" that our current civilization seems to be facing.

La capacidad cerebral de nuestros antepasados humanos experimentó dos fases de transición, lo que generó el surgimiento de civilizaciones modernas: (1) El surgimiento de la corteza cerebral de los primates, con su característica única de áreas corticales adicionales que acompañan a la expansión de tamaño; y (2) el reemplazo de la selección natural como el principal mecanismo evolutivo por la "Construcción de Nicho Triádico", una expansión interactiva de los nichos ecológicos, neuronales y cognitivos. Esto último parece haber sido desencadenado por el uso y fabricación de herramientas, que llevaron a las capacidades cognitivas a superar el umbral para el surgimiento del lenguaje y la autoconciencia que finalmente permitió la formación de civilizaciones modernas a través de la modificación intencional del entorno. Aclarar estos desarrollos nos permitiría predecir una tercera fase de transición, que puede ser inducida por la actual explosión de la inteligencia artificial, acelerando las capacidades cognitivas humanas para cruzar el siguiente umbral requerido para superar el "Límite de Crecimiento" que nuestra civilización actual parece estar encarando.

The brains of human ancestors were developed through preadaptations with (1) a tendency for gradual expansion, (2) the potential for gene-culture (through vocal communication) coevolution, and (3) the unique characteristic of novel cortical areas being added along with volumetric enlargement. These brains encountered an opportunity for phase transition (Evolution du volume cérébral des Hominidés, n.d.) when ancestral hominids started making and using stone tools (Figure 10.1). Despite the human brain not being an outlier among those of primates in regard to its cellular composition and size, the manufacturing and usage of tools could have induced fundamental differences, such as the corticalization of motor control, combined with an already moderately advanced cognitive and vocal communication capacity. Thus, tool usage led to the development of the human mode of language in our ancestors through the allocation of overlapping and recently expanded brain areas.This consequently provided the means for the transmission of knowledge and eventual formation of modern technological civilizations. We previously proposed the theory of triadic niche construction (Iriki & Taoka, 2012)—an accelerated positive feedback loop for expansions among (i) neural (brain), (ii) cognitive, and (iii) environmental niches—as the mechanism responsible for such phenomena. In other words, human evolution is characterized by continuous processes of adding new modalities of cognition, including the manufacturing and usage of tools and linguistic faculties, supported by dramatic brain expansion and the accompanying addition of new functional areas. Such extended brain functions have driven rapid and drastic changes in the hominin ecological niche, which have in turn demanded further brain resources to adapt to them.

Figure 10.1.

Cranial capacity of hominids and lithic technology.



*Note.*Transition of cranial capacity (vertical axis) along the evolutionary process of various ancestral prehominids and hominids (horizontal axis). Adapted from (Evolution du volume cérébral des Hominidés, n.d.). Inset illustrations of a skull and brain depict representative hominids plotted on the graph. Brain expansion suddenly accelerated when *Homo habilis* started manufacturing and using stone tools (oblique red arrow). Insets of stone tools (top left) depict the development level of stone tools in each culture. Oldwan culture: The earliest widespread stone tools were simple, usually made with one or a few flakes chipped off with another stone, and used by *Homo habilis*. Acheulean culture: Stone tools characterized by distinctive oval- and pear-shaped "hand-axes", manufactured and used by *Homo erectus*. Simple syntax in vocal communication, a primitive form of human language, is thought to have been required for the transmission of this culture. Mousterian culture: Technically complex and significant archaeological industry of lithic tools developed from *Homo sapiens neanderthalensis* through early *Homo sapiens sapiens*. Complex and rich semantic contents and syntax, close to modern human language, were necessary for the transmission and inheritance of this culture. Adopted with permission from (Bretas et al, 2019, Figure 1).

Thus, in this manner, the evolutionary mechanism has shifted from passive "natural selection" to an active triadic niche construction phase, which has led and continues to lead humans' cognitive, communicatory, and technological capacities into a continuous innovation loop throughout its history. Human language emerged during this shift in the evolutionary force, featuring an additional layer over the existing animal proto-language layer. Language then became a powerful instrument in this continuously accelerating triadic niche construction. Despite understanding the connection between language and evolution, some critical factors remain unknown: For instance, how did this accelerated expansion exceed the "threshold capacity" for the emergence of a novel mode of communication (human language) derived from (and in addition to) the original mode (animal language)? What was this threshold and how was the emergence of discontinuous qualitative differences induced from continuous quantitative differences? Extrapolating these developments would further enable us to predict the next phase transition, which may be induced by the current explosion of artificial intelligence, accelerating human cognitive capacities to the next threshold required for a novel mode of civilization.

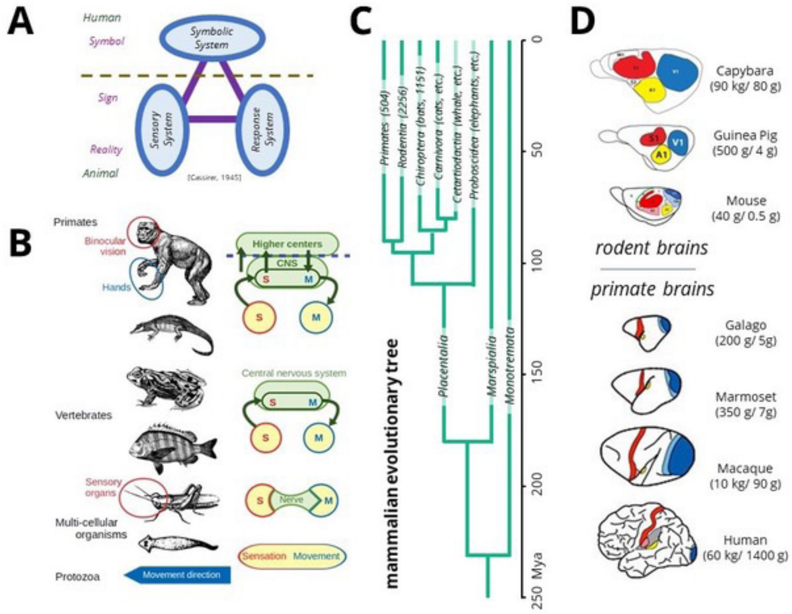
The First Phase Transition: The Uniqueness of the Primate Brain Among Mammals

The brain is a rostral-most ampulla of the nervous system that emerged during animal evolution for processing information to regulate various internal (via the autonomic nervous system) and external (via the somatic nervous system) bodily movements. While animals' bodies evolved to become larger and more complex, the nervous system also increased in size and complexity to connect input (sensory) and output (motor) organs to survive in and adapt to given environmental conditions. As evolution has proceeded, species one after another have appeared equipped with a neuraxis, higher centers, and eventually brain and cerebral cortices (Figure 10.2B). Such enlarged brain parts, initially devoted solely to sensory-induced motion generation, gradually developed the capacity for cognition and communication, and some species acquired language-like capacities. Finally, in humans, overlaying sensorimotor processing machinery formed a symbolic system (Figure 10.2A) that is predominantly governed by human language (Cassirer, 1944).

While numerous preadaptations of brain mechanisms seem to be implemented in multiple animal species that exhibit language-like vocal communications, why has human language emerged only in our evolutionary lineage? Was there anything special about primate brains? The three most successful (radiated in most numbers of species) extant mammalian orders (Figure 10.2C) (Estrada et al., 2017) have in common an ecology largely dependent on different sensory modalities (i.e., haptics in rodents, audition in bats, and vision in primates). The design of their brains could thus be different, adapting to different styles of interactions with their environments. A comparison of various-sized brains of primates and rodents (Dooley & Krubitzer, 2013; Ventura-Antunes et al., 2013), primates' closest mammalian order (Figure 10.2C), clearly depicts such differences (Figure 10.2D). Larger primate brains possess more different cortical areas (Fox et al., 2005; Kaas, 1997; Petrides & Pandya, 1999), whereas larger rodent brains remain rather straightforward analogous expansions of smaller brains (Dooley & Krubitzer, 2013). In the case of primates, maintaining sensory and motor precision, despite an increased body size without a proportional increase in spinal and peripheral fibers, could have been a significant factor in brain expansion and corticalization (Herculano-Houzel et al., 2016). Thus, once conditions became permissive, primate brains

Figure 10.2.

Evolution of the nervous system



Note. **A**: Cassirer's philosophy of the human being (Cassirer, 1944); the worlds of humans and animals are divided by the horizontal dashed line in the center. Animals experience the world through a direct connection of sensory and response systems, surviving through the detection of their current environment and optimally responding to it. These systems link only the physical environment and information encoded intrinsically therein. Humans possess a symbolic system in addition to the animals' sensory and response systems. A symbolic system can process abstracted symbolic cognition, which is disconnected from the subject and information in the real physical world, although it relies partly on it. **B**: Evolution of the animal nervous system; it first emerged to regulate bodily movements within an environment by connecting input (sensory) and output (motor) functions, originally linked directly within the cell in protozoa. As evolution made animals' bodies larger and more complex, the nervous system also increased in size and complexity to connect input (sensory organs accumulated at the front of the body in the moving direction) and output organs (motor organs located around the center of gravity of the body for efficiency), now separated by a substantial distance. Along the continuous evolutionary process, neurons were grouped closer together for efficiency and information processing speed, forming the central nervous system and eventually the telencephalon and cerebral cortex. The nervous system, initially devoted solely to sensorimotor processing, developed an overlay machinery of higher centers able to manipulate symbolic information detached from the physical environment (top right diagram; note that this structure resembles Cassirer's philosophy of the human being depicted in A). **C**: Phylogenetic tree of mammalian orders (vertical axis indicates millions of years in the past, from top to bottom). Rodentia (2256 species), Chiroptera (1151 species), and Primates (504 species) are the three most radiated orders among extant taxa (Estrada et al., 2017). Rodents are phylogenetically the most proximal order to primates, diverging less than 100 million years ago. **D**: Diagrams illustrating different brain organizations between rodents (top) and primates (bottom). Colored areas in the brain indicate primary sensory areas (red: somatosensory; blue: visual; yellow: auditory) in representative extant primate and rodent species of different body (first number in brackets) and brain (second number in brackets) sizes. Note the difference in the proportion of these primary (colored) and associated (in white) areas in differently sized brains between primates and rodents (Dooley & Krubitzer, 2013). Adopted with permission from (Bretas et al, 2019, Figure 3).

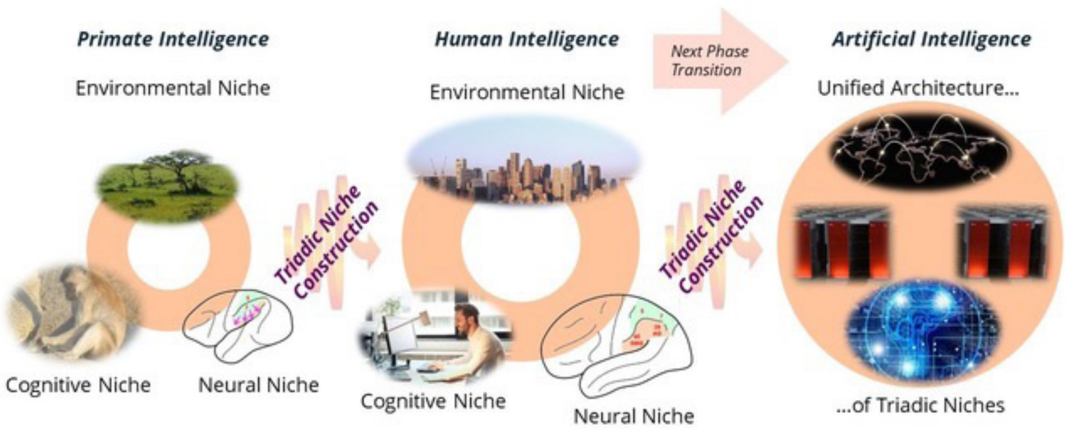
were ready to incorporate additional brain areas, thereby additional novel functions, one after another. Although the mechanisms of how this unique feature is implemented in the primate brain during evolutionary processes remains yet unknown, this constitutes the first major phase transition-like preadaptation that occurred in mammalian brains.

The Second Phase Transition: From Natural Selection to Triadic Niche Construction

As described above, brains of human ancestors were furnished through preadaptations with (1) a tendency of gradual expansion, (2) the potential of gene-culture (through vocal communication) coevolution, and (3) the acquisition of the unique designing principle of developing additional novel cortical areas along expansion. Such a brain encountered an opportunity for the next phase transition when ancestral hominids happened to start making and using stone tools (Figure 10.1). The usage and manufacturing of tools, when combined with already moderately advanced cognitive and vocal communication capacities, led our ancestors to develop a human-mode of language, which later allowed the eventual formation of human civilization. We have proposed the theory of triadic niche construction (Iriki & Taoka, 2012) as a mechanism to realize such phenomena (Figure 10.3). That is, human evolution is characterized by continuous processes of adding new kinds of cognitive capacity, including those relating to the manufacturing and use of tools and to the establishment of linguistic faculties. These processes were supported by a dramatic expansion of the brain that accompanied the addition of new functional areas, with such extended brain functions driving rapid and drastic changes in the hominin ecological niche, which in turn demanded further brain resources to adapt to it.

Figure 10.3.

Triadic niche construction feedback loop.



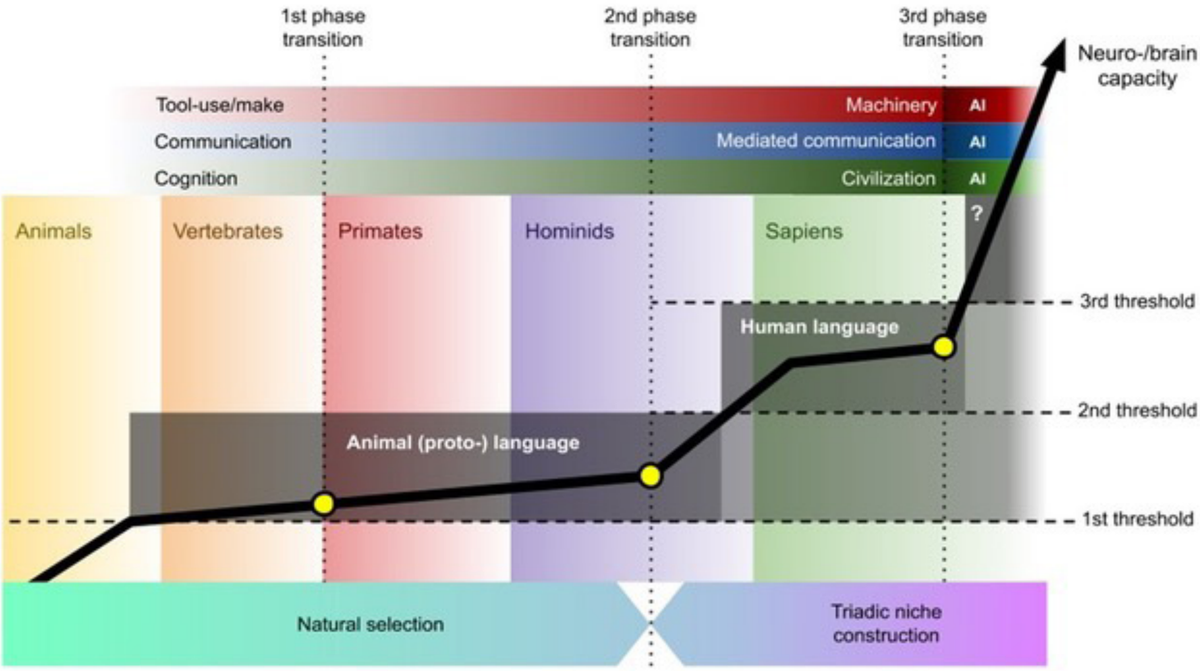
Note. Schematic depicting the concept of triadic niche construction (Iriki & Taoka, 2012), a continuous process of the addition of new types of cognitive capacities (cognitive niche), supported by brain expansion along with additional functional areas (neural niche). Those extended brain functions drove rapid and drastic changes in the environment (ecological niche), which in turn demanded further brain resources to adapt to them. Thus, a positive feedback loop was formed among the three niches, each of which would have continuously expanded through such interactions. A primitive form of triadic interaction in ancestral primates (left small open circle) gradually expanded through triadic niche construction, forming that of modern humans (middle larger open circle). The recent explosion of AI technologies may in the future link, subsidize, and replace human brain capacities, unifying different niches into a single interconnected architecture (right filled circle). Adopted with permission from (Bretas et al., 2019, Figure 4).

Thus, in this way, the phase of evolutionary mechanisms has shifted from passive "natural selection" into active triadic niche construction, which led human cognitive, communicative, and technological capacities for continuous innovation throughout its history. Human language, which emerged among these interactions and constituted an additional layer over the existing animal proto-language layer (Figure 10.4), would have made for a powerful mediator in such a continuously accelerating triadic niche construction (Iriki & Taoka, 2012).

Several critical factors yet to be known include how this accelerated expansion exceeded the "threshold capacity" for the emergence of a novel mode of language (human mode) deriving from and in addition to the original mode (animal language), and what such a threshold was and how those emergences of discontinuous qualitative differences have been induced based on continuous quantitative differences. The accumulation of knowledge through animal language studies is expected to provide an insight into this emergent property.

Figure 10.4.

Phase transitions of neuro-/brain capacity.



Note. Diagram illustrating the relationships between neuro-/brain capacity (vertical axis), evolution timeline (horizontal axis, not to scale, boxes represent different types of animal), phase transitions of brain mechanisms (vertical dotted lines), and hypothetical brain capacity thresholds (minimum level required) for the emergence of novel modes of language (horizontal dashed lines). During evolutionary history, phase transitions of brain mechanisms occurred twice and another third phase transition is expected in the near future. For most of the timeline, natural selection (bottom of graph), a passive combination of genetic mutations and environmental changes, dominated as the main evolutionary force. The first phase transition (the addition of new functional areas in the primate brain following size increments) precipitated qualitative changes in the manner in which primates interacted with their environment (Iriki & Taoka, 2012). In unison with more complex tool development, the mechanism of triadic niche construction (bottom right of the graph) accelerated changes in the hominid ecological niche (second phase transition), consequently becoming an active evolutionary force. This resulted in a swift increase in brain capacity, creating the ideal substrate for human language to develop (middle gray shadow, second threshold). Continuous improvements in earlier tool usage/making, communication, and cognition (top of graph) are eventually expected to merge into a unified architecture with the aid perhaps of AI (third phase transition). This trend of brain capacity increasing in the near future, taking human language through a third phase transition, may lead to a more efficient, and still unknown, mode of language (top gray shadow marked "?", third threshold). Adopted with permission from (Bretas et al., 2019, Figure 2).

In humans, recent changes in diet, geographical dispersion, and population density have been inferred as the main causes for the recent rapid selection of multiple genes, some of which relate to lactose digestion in adults, tolerance to temperature extremes, and disease resistance (Laland et al., 2010). As evolutionary pressures mounted, the hominin brain also enlarged rapidly (Grabowski, 2016; Torrey, 2019, pp. 35–36, 59–61). Thus, the brain is not an exception to the biological principle that useful organs enlarge when supplied with increased demands and resources, such as the need for behavioral plasticity coupled with a richer diet (Riska & Atchley, 1985; Grabowski, 2016). As to how such genetic traits can be selected in only a few generations, extragenomic evolutionary mechanisms may account for the fast rate of change by exploiting latent features. The development of rich linguistic cultural diversity allowed post-Neolithic humans to adapt to swiftly changing ecological conditions (Roffet-Salque et al., 2018); new opportunities arose for genomic adaptation because augmented behavioral plasticity provided a buffer for natural selection processes (Crispo, 2007; Waddington, 1953). This process allowed for the rapid colonization of novel niches and demographic expansion, namely gene-culture (language) coevolution.

The Third Phase Transition: An Ongoing Shift by Artificial Intelligence

As depicted in the previous sections, the human brain, with the distinct cortical areas that characterize primate brains, together with its products, including civilization, economy, and industry, are all subserved by and based on the "principle of growth" (Meadows et al., 1972). While environmental resources could have been reasonably regarded as infinite when the human/primate population was small, we have now become conscious of the "limit of growth" (Meadows et al., 1972) after substantially exploiting terrestrial resources at the maturity of the Anthropocene (Crutzen, 2006). However, humans cannot be free from the "principle of growth" as long as they are a primate species. There could be a way to solve this problem by applying the theory of triadic niche construction (Iriki & Taoka, 2012)—i.e., to create novel dimensions of mental space with abstract and spiritual axes such as value, quality, or happiness, enhancing the human sense of a unified self the same way as the development of religion, seduction, or empathy did when humans developed a theory of mind (McNamara, 2009, pp. 28-29, 247; Torrey, 2019, pp. 35–36, 59-61). This novel cognitive niche could be exploited through the usage of human language-based mental functions (Cassirer, 1944).

Another further efficient and practical way to overcome the limit of growth is to expand such abstract niches with the aid of artificial intelligence (AI). The recent explosion of AI technologies has already begun linking with, subsidizing, and sometimes even replacing human brains. It now seems possible to unify different domains across cognition, technology, and environment into a single interconnected architecture (Figure 10.3), thereby accelerating the speed of triadic interactions close to an infinite level. In this architecture, novel dimensions to constitute abstract/

symbolic niches will be constructed and exploited to the theoretical extremity. By directly extrapolating the lessons reviewed over the previous sections on the transition from animal language to human language, it could naturally be assumed that we are now in the midst of experiencing a third phase transition, leading to the eventual exceeding of the next threshold capacity of our brain function required for the next mode of language to emerge in the near future. Such a next novel mode of "language" might be based on in silico algorithms or programming of sorts to be built overlaying the bases of animal and human languages (Figure 10.4), assisting humans in overcoming the natural limits that governed the evolution of the brain until now (Dunbar, 1998, pp. 197–199, 203–207).

Conclusion

The semantic richness and syntactic complexity of human language far exceeds that of the communication and cognition of non-human animals, most likely due to the vastness of the human brain (Dunbar, 1993). However, fundamental brain machinery subserving human and animal linguistic functions should share common fundamentals, where latent capacities that lead to such quantitative and qualitative differences should reside, through preadaptations in animal brains in precursory forms. A sudden phase transition-like explosive expansion seems to have happened in the paleolithic hominid brain (Figure 10.1; Evolution du volume cérébral des Hominidés, n.d.), which coincided with the onset of making and using various stone tools. This rapid expansion would have driven the human brain to cross a putative threshold capacity required for the human mode of language to emerge, which is thought to have coevolved with the development and transmission of stone tool cultures.

As summarized in Figure 10.4, animal proto-language emerged as a rather advanced communication/cognition ability when brain size exceeded the first threshold capacity during its gradual expansion through natural selection. Thereafter, brain structures and functions subserving language faculties went through two phase transitions (first and second phase transitions) in the animal proto-language period (lower shaded block) when gradual expansion continued, with some species exhibiting tool-using abilities. The first phase occurred when the primate brain (in which the mode of brain expansion shifted to allow additional new brain areas to emerge upon expansion; arrow in Figure 10.1) encountered tool usage by ancestral hominids. The second phase happened when the evolutionary mechanisms (formerly passive natural selection) shifted into a novel mode of active triadic niche construction—interactively accelerated expansion of neural/brain, cognitive, and environmental niches. This resulted in an explosive increase in brain size during which the threshold brain capacity for human language to emerge (second threshold) was easily surpassed. The reciprocal advances in tool usage and language allowed the transmission of technological knowledge required for the formation of human civilization (Corbalis, 2014). These processes can be immediately extrapolated to predict the future of human language and the consequent cultural and social changes, namely the expected third phase transition, perhaps aided by the development of artificial intelligence. In this way, human language can be viewed as an intermediary layer of a three-layered structure based on the proto-language of non-human animals with the next additional mode of language by artificial intelligence to be superimposed when future AI-aided brain capacity exceeds the next putative threshold capacity (third threshold).

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References

Bretas, R. V., Yamazaki, Y., & Iriki, A. (2019). Phase transitions of brain evolution that produced human language and beyond. *Neurosci Res*.pii: S0168-0102(19)30488-2. http://dx.doi: 10.1016/j.neures.2019.11.010

Cassirer, E. (1944). *An Essay on Man: An Introduction to a Philosophy of Human Culture*. Yale University Press.Corballis, M. C. (2014). *The recursive mind: The origins of human language, thought, and civilization.* Princeton University Press.

Crispo, E. (2007). The Baldwin effect and genetic assimilation: Revisiting two mechanisms of evolutionary change mediated by phenotypic plasticity. *Evolution, 61*, 2469–2479. http://dx.doi.org/10.1111/j.1558-5646.2007.00203.x

Crutzen, P. J. (2006). The "anthropocene". In E. Ehlers, & T. Krafft (Eds.), *Earth System Science in the Anthropocene* (pp. 13–18). Springer. http://dx.doi.org/10.1007/3-540-26590-2 3

Dooley, J. C., & Krubitzer, L. (2013). Cortical plasticity within and across lifetimes: How can development inform us about phenotypic transformations? *Front. Hum. Neurosci., 7*, 620. http://dx.doi.org/10.3389/fnhum.2013.00620

Dunbar, R. I. M. (1993). Coevolution of neocortical size, group size and language in humans. *Behav. Brain Sci*., 16, 681. http://dx.doi.org/10.1017/S0140525X00032325

Dunbar, R. (1998). *Grooming, gossip, and the evolution of language.* Harvard University Press.Estrada, A., Garber, P. A., Rylands, A. B., Roos, C., Fernandez-Duque, E., Fiore, A. D., Nekaris, K. A.-I., Nijman, V., Heymann, E. W., Lambert, J. E., Rovero, F., Barelli, C., Setchell, J. M., Gillespie, T. R., Mittermeier, R. A., Arregoitia, L. V., de Guinea, M., Gouveia, S., Dobrovolski, R., Shanee, S., Shanee, N., Boyle, S. A., Fuentes, A., MacKinnon, K. C., Amato, K. R., Meyer, A.

L. S., Wich, S., Sussman, R. W., Pan, R., Kone, I., & Li, B. (2017). Impending extinction crisis of the world's primates: why primates matter. *Sci. Adv., 3*, e1600946. http://dx.doi.org/10.1126/sciadv.1600946

Evolution du volume cérébral des Hominidés. (n.d.). Retrieved January 29, 2019, from http://www.linternaute.com/science/biologie/dossiers/06/0608-memoire/8.shtml

Fox, M. D., Snyder, A. Z., Vincent, J. L., Corbetta, M., Essen, D. C. V., & Raichle, M. E. (2005). The human brain is intrinsically organized into dynamic, anticorrelated functional networks. *Proc. Natl. Acad. Sci., 102,* 9673–9678. http://dx.doi.org/10.1073/pnas.0504136102

Grabowski, M. (2016). Bigger brains led to bigger bodies?: The correlated evolution of human brain and body size. *Curr. Anthropol., 57,* 174–196. http://dx.doi.org/10.1086/685655

Herculano-Houzel, S., Kaas, J. H., & de Oliveira-Souza, R. (2016). Corticalization of motor control in humans is a consequence of brain scaling in primate evolution: Corticalization of human motor control. *J. Comp. Neurol., 524*, 448–455. http://dx.doi.org/10.1002/cne.23792

Iriki, A., & Taoka, M. (2012). Triadic (ecological, neural, cognitive) niche construction: A scenario of human brain evolution extrapolating tool use and language from the control of reaching actions. *Philos. Trans. R. Soc. B Biol. Sci., 367*, 10–23. http://dx.doi.org/10.1098/rstb.2011.0190

Kaas, J. H. (1997). Topographic maps are fundamental to sensory processing. *Brain Res. Bull.,* 44, 107–112. http://dx.doi.org/10.1016/S0361-9230(97)00094-4

Laland, K. N., Odling-Smee, J., & Myles, S. (2010). How culture shaped the human genome: Bringing genetics and the human sciences together. *Nat. Rev. Genet., 11,* 137–148. http://dx.doi.org/10.1038/nrg2734

McNamara, P. (2009). *The neuroscience of religious experience.* Cambridge University Press. Meadows, D. H., Meadows, D. L., Randers, J., & Behrens, W. W., III. (1972). *The Limits to Growth.* Club of Rome. Retrieved January 29, 2019, from https://www.clubofrome.org/report/the-limits-to-growth

Petrides, M., & Pandya, D. N. (1999). Dorsolateral prefrontal cortex: Comparative cytoar-chitectonic analysis in the human and the macaque brain and corticocortical connection patterns. *Eur. J. Neurosci., 11,* 1011–1036. http://dx.doi.org/10.1046/j.1460-9568.1999.00518.x

Riska, B., & Atchley, W. R. (1985). Genetics of growth predict patterns of brain-size evolution. *Science, 229,* 668–671. http://dx.doi.org/10.1126/science.229.4714.668Roffet-Salque, M., Marciniak, A., Valdes, P. J., Pawłowska, K., Pyzel, J., Czerniak, L., Krüger, M., Roberts, C. N., Pitter, S., & Evershed, R. P. (2018). Evidence for the impact of the 8.2-kyBP climate event on Near Eastern early farmers. *Proc. Natl. Acad. Sci., 115,* 8705–8709. http://dx.doi.org/10.1073/pnas.1803607115

Torrey, E. F. (2019). *Evolving brains, emerging gods: Early humans and the origins of religion*. Columbia University Press.

Ventura-Antunes, L., Mota, B., & Herculano-Houzel, S. (2013). Different scaling of white matter volume, cortical connectivity, and gyrification across rodent and primate brains. *Front. Neuroanat., 7,* 3. http://dx.doi.org/10.3389/fnana.2013.00003

Waddington, C. H. (1953). Genetic assimilation of an acquired character. *Evolution, 7,*118–126. http://dx.doi.org/10.1111/j.1558-5646.1953.tb00070.x

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