From Deep Patterns to the Origin of Writing and Information Systems

How Information Escaped from the Brain

by

Derek Hodgson

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Dedicated to Professor Malcom Ludvigsen

Also by Derek Hodgson

The Roots of Visual Depiction in Art: Neuroarchaeology, Neuroscience and Evolution

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Prologue

Many years ago, well before its modern renovation, I was at the British Museum in London looking at the marks on the earliest pottery from different cultural heritages. I was struck by the fact that nearly all the designs were of repetitive geometric motifs displaying an undeniable similarity despite the widespread distribution through space and time. This was especially the case for the earliest examples where, generally, the geometric designs tended to be relatively basic. What could be the explanation for such a striking correspondence? The possibility of convergence due to copying through cultural assimilation, I reflected, could not provide a wholly satisfactory answer, as the designs were too remote from each other in temporal and spatial terms. On following up that observation, I consulted the appropriate literature on early pottery designs and found no acceptable explanation for the phenomenon. Of course, there are exceptions to the predominance of particular geometric motifs, but they are few and far between and can be explained by the fact that the results of human endeavour are never straightforward. As I reasoned that an answer was not likely to emerge from any one field, I decided to investigate the issue further by consulting a large number of disciplines from archaeology and anthropology to the history of art, neuroscience and the psychology of perception.

During the time I was engaged in studying the literature, similar geometric motifs began to turn up in the archaeological record. Some exceptionally ancient, even predating the appearance of *Homo sapiens.* That is, they were made by archaic hominins such a Neanderthals, *Homo heidelbergensis* and even *Homo erectus*. The very fact that different hominin lineages were producing similar repetitive motifs reinforces the notion that the patterns are unable to be explained by cultural factors alone. One of the great impediments I had to overcome in looking at the commonalties rather than the differences in designs was the widely accepted idea in anthropological and archaeological circles that most, if not all, artistic behaviour in the past could be sufficiently explained by socio-cultural criteria. On the face of it, that meant there was little room for an approach based on long-standing "innately" defined attributes. However, the insights from the psychology of perception and neuroscience were beginning to demonstrate that there are, indeed, certain underlying heuristics regarding the way the world is perceived and "registered" in the brain that is shared by all humans. It is the way such heuristics constrain or bias behaviour—especially when individuals engage in transformational activities—which supplies an important key to understanding the origins and development of early patterns engraved and painted on various materials. As a result of those insights, I set out to investigate in detail why early and later humans were minded to depict simple patterns across an immense period of time. One of the main themes I will be exploring in this book, therefore, is not only the way the first intentional marks and patterns tentatively arose, but also how such simple patterns gave rise to increasingly complex configurations that were exploited for various functions throughout the long course of human enterprise. As we shall see, such patterns provided the basis for the development of much later information systems including the ability to write and modern technological communication systems.

We begin our investigation as to how information "escaped" from the brain by providing a working definition as to what constitutes information and then highlighting the underlying processes that permit neural networks to encode and transmit information. We then consider the means whereby information became manifest outside the brain in the form of simple lines and decorative motifs, first from a historic perspective and, then—in the light of recent discoveries from neuroscience, archaeology, anthropology and evolution.

Introduction

> *…the pace of cultural evolution has accelerated over time, much of it tied to the ways in which humans have been able to harness and manage information.* (Bentley and O'Brien 2012. p.9)

Three issues need to be addressed before tackling how information became a permanent feature of human ecology, namely, what is the significance of the first marks made by humans, what led to their initial production, and when were they were first made? By exploring the way the brain processes patterns, we will be in a much better position to answer those questions as well as understand how information external to the brain first arose. Many scholars, however, continue to adhere to the view that the most significant event regarding that externalisation occurred with the invention of writing some 5,500 years ago. While writing is obviously a formidable innovation that made the dissemination of information across and between generations more dependable, efficient, and complex than was previously the case, its arrival was nevertheless presaged by a long developmental trajectory that is not given the attention it deserves. The substance of this book will be directed towards examining that trajectory by demonstrating how other equally significant thresholds are just as relevant, well before the arrival of writing. A much longer overview of the archaeological past will, therefore, be required before we are able to determine how information first became a materially derived commodity.

An important issue to be addressed in this book is why the first marks, which appeared hundreds of thousands of years ago, took such a long time to become the basis for communicating complex ideas in a fixed retrieval form. If material culture is defined as a means of storing and transferring information in a relatively stable form within and between generations, its widespread appearance before 40,000 years ago and beyond can potentially be explained by an increasing tendency of humans to propagate graphic information with greater efficiency and economy. This is part of a progression whereby the making of simple patterns led to less time-specific constraints on communicative knowhow—an ability that was to culminate in complex informational expertise.

An interesting question that arises from the above observations concerns the reason why ancient humans were so preoccupied with a set of similar, usually engraved, graphic marks over such an extended period. Consequently, we will also be concerned with the motivation underlying the obsession with simple repetitive marks, as well as how they began to be exploited for a range of purposes in various cultural contexts. Beyond this, we will be preoccupied with examining the way early marks were exploited during more recent epochs, especially the transition from marks to iconic depictions and those that served as a precursor to the first writing. Finally, we will consider the effects and ramifications of some of the more modern information systems. But before setting out to examine the way early theorists attempted to understand the significance and timeline of mark-making, we need to define what is meant by "information".

Chapter 1
Defining Information

Information behaviour is a behaviour that evolved in humans through adaption over the long millennium into a human ability, while also developing over a human lifetime. (Spink 2010, p.4)

What is information?

The definition of information is not straightforward as it depends on context, whether this relates to mathematics, computing, semiotics, genetics, or statistics etc. For our purposes, we will be considering information from the standpoint of pattern perception as it occurs in the brain and as an externalised material phenomenon. From that perspective, information is often defined as that which is transmitted or represented by a certain arrangement or sequence of items that gives rise to new knowledge.[1] Thus, a repetition of a previously received message is not informative, as this would merely say the same thing and increase redundancy. According to Shannon (1948), for information to occur, something needs to be added to what already exists in order to be informative. Thus, that which is duplicated is not surprising but that which changes, is. Similarly, Casagrande (1999, p.5) states, following Shannon and Weaver (1949), that, "A highly probable event allows no freedom of choice and therefore carries little information".[2] That idea is reflected in the fact that what interests the

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[1] Of course, the fact that something remains the same is itself informative but from the perspective of human perception it is that which changes that provides new knowledge.

[2] Shannon and Weaver (1949) define information as a reduction in uncertainty where entropy is also reduced. However, that approach to information seems

visual system is change and not what remains static, which is supported by the finding that when an image is stabilised on the retina it tends to fade but, when movement occurs, the image reappears (Riggs et al 1953). Similarly, what the visual brain seems particularly concerned about is, not what is already assimilated, rather than that which is unexpected, otherwise known as a "prediction error" (Clark 2013).[3] Correspondingly, research has demonstrated that neural activity undergoes a reduction when a stimulus is repeated leading to what is referred to as "repetition suppression" (Grill-Spector 2006).

Of course, information can exist in nature, for example, living systems transmit data in the form of DNA that provides "knowledge" for reproduction and the continuation of a species (Dawkins 1999). On that level, information can be regarded as self-organising. However, the information encoded in DNA only furnishes new "knowledge" when mixing of genes occurs during reproduction or when a mutation arises in a favourable environmental situation leading to the mutated DNA becoming the preferred replicator (Dawkins 1999). In that way, there is a difference between information that is merely replicated and information that updates existing protocols.

From the standpoint of human behaviour, in order to be meaningful, information needs to be interpreted as such by a receiver (Casagrande 1999). As Brookes (1980) states, information alters the knowledge structure of those in receipt of that information. It is how humans respond and interpret information as receivers that will be the focus

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more appropriate to binary systems related to mathematics and computing and is not always appropriate to understanding the pragmatics of human communication (Casagrande 1999).

[3]With regard to cognitive evolution, the ability to exploit such "surprisals", by resetting the "free energy principle" in a given context, can provide a marker of when particular cognitive thresholds were transcended (Walker et al. 2022).

of concern in this book, especially in terms of how the brain processes information and how it is acted upon to create artificial information systems. On one level, human information systems parallel those of adaptive evolution, on another level they are quite different (Bentley and O'Brien 2012). The information processing approach to understanding how extra somatic information systems emerged and developed provides an important means to assess how sense data—from both the natural and social environment—facilitates adaptive processes that were advantageous to humans (Spink and Cole 2007). Indeed, humans appear to have an affective bias for certain patterns of information that is a fundamental part of the human condition (Kaplan 1992). In essence, information behaviour may have evolved as a means of promoting protection in a hostile world through the aegis of competition and cooperation (Spink and Cole 2007). By employing and exploiting artificial information systems, human groups were better able to model their world and, therefore, were more likely to survive and reproduce. As we shall see, this is a process that eventually gave rise to external memory systems. The way early humans were able to convert sense data issuing from the physical and socio-cultural environment into information useful for increasingly adaptive, and not-so-adaptive, purposes is a theme that will be explored throughout the following chapters.

The main theme of this book, therefore, concerns the way information became a means of passing on knowledge across generations. To address that issue, I will demonstrate how information is dealt with in the brain and how this was acted upon in order to externalise its heuristics in a materially retrievable form. By information processing, I refer to the various means whereby information became an externalised product of the brain that permitted early humans to transcend the restrictions of ephemeral and transitory modes of communication such as speech. In fact, speech may have arisen quite early in the human lineage, probably before the first externally mediated information systems ensued, not least because oral communication was vital to social interaction and was probably relatively advanced 500,000 years ago in *Homo erectus* (Rilling 2014a; Levinson 2016). As Deacon (1997) points out, this is because quite complex thoughts can be expressed using a limited vocabulary and syntax. As perhaps the most pervasive and earliest form of information processing in the human lineage, speech is thought to be *one* of the main drivers of brain expansion, especially as an enhanced cortex was necessary to cope with the highly complex social interactions that mark out humans from other primates (Dunbar 2003). Speech therefore provided humans with perhaps the first means of sharing information in a way not available to any other primate. This is supported by recent neuroscience that found Broca's area, one of the main cortical locations for speech production, is divided into two regions referred to as 44 (*pars opercularis*) and 45 (*pars triangularis*). Pertinently, area 44 specialises in the complexities of sentence structure or syntax whereas area 45 is concerned with semantics.

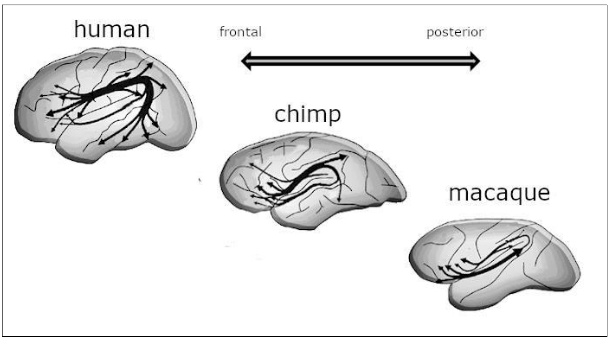

Figure 1. Showing the extent of white matter connecting tracts in the human, chimpanzee, and macaque brain (drawing by author based on Ghazanfar, 2008)

More specifically, area 44 is dedicated to processing the recursive hierarchical structure of language. No other species, including non-human primates, can utilise such hierarchical structures to connect to the left posterior superior temporal cortex where Wernicke's area (for language comprehension) is situated. In effect, thanks to an augmented area 44—and along with the enhanced myelination of the arcuate fasciculus connecting that area with the superior temporal cortex—an efficient, rapid communication system based upon sound came to mark out humans (Friederici et al. 2017). Note that the neural connecting tract (arcuate fasciculus) is not only more pronounced with more endpoints in humans compared to non-human primate but is also denser, and benefits from an augmented myelin sheath that facilitates the flow of information, as shown in Figure 1.

As Hofman (2014, p.4) states:

> These comparative analyses indicate that the evolutionary process of neocorticalization in primates is mainly due to the progressive expansion of the axonal mass that implement global communication, rather than to the increase in the number of cortical neurons and the importance of high neural connectivity in the evolution of brain size in anthropoid primates.

The interesting question is, how did the externalisation of information first arise when an efficient means of communication already existed in the form of speech? Was it invented by an individual accidentally or was this a preconceived act? Perhaps it was a collaborative effort where a group of individuals pooled ideas to produce the first information system. Answers to those questions are crucial, as the first artificial marks provided the platform from which all other information systems sprang, right up to the complex multifaceted communication networks of today. In a way, the earliest marks constitute the very beginning of an interface where information could be shared and retrieved by future generations. In order for material culture to develop, that interface was critical given that human working memory is limited to around four to seven items, whereas speech, though capable of communicating complex ideas through, for example, stories, is relatively transient and imperfect (Bentley and O'Brien 2012). Some archaeologists approach this issue from a restricted theoretical purview, which, to some extent, has hampered a full understanding as to how information became fundamental to human evolution. For example, Davidson (2020) favours a semiotic perspective that sees early marks as constituting the indexical basis for the emergence of iconic depictions. Although the discipline of semiotics is relevant (see later chapter for more on this), it needs to be considered alongside the way information is processed by the brain (Hodgson 2000).

Brain as Information System

> *The human brain contains about 100 billion neurons, more than 100,000km of interconnections, and has an estimated storage capacity of 1.25×1012 bytes.* (Hofman 2014, p.1)

> *Sensory transduction converts energy into information; this information is processed and ultimately converted back to energy as motor output. However, nervous systems also use energy transmitting and processing information, and the faster and more complex computations need to be, the more energy is required.* (Knowles, 2017. p.12)

The eye, which is regarded as an outpost of the brain, is intimately concerned with seeking out information. As already mentioned, this is underscored by the fact that, when light reflected from objects is stabilised on the retina using a mechanical devise, the objects discerned tend to fade (Riggs et al. 1953; Gregory 1966). That is, the brain is interested in that which changes rather than that which stays the same, as change signifies something of interest may have occurred—so much so, that the eye automatically scans the world through rapid eye movements known as saccades. Once something of interest is picked up by the eye and becomes the focus of concern, the brain then takes up the leash in the sense that the information is stabilised so that the inherent complexities become an invariant attribute. At the level of the visual cortex, a dynamic interaction takes place between sensitivity to change and the tendency to offset variance. Those contingencies are processed by specialised neural streams in the tract leading from the eye to the visual cortex known as the magno (movement) and parvo (acuity) systems. In order to accommodate those heuristics, the human cortex has undergone a significant expansion and reorganisation. However, the brain seems to have reached a limit in its enlargement, a limit underscored by the extensive folding of the cortex that occurred to cope with the abundant long and short neural connecting tracts that characterise the cerebral cortex (Hofman 2014). Having said that, it seems that the human brain theoretically has the potential for greater expansion and complexity, but this may be inhibited by problems to do with the number of neurons, the intricacy of the underlying interconnections, as well as thermoregulation (Hofman 2014). Even with a prodigious brain, human informational abilities are somewhat limited due to bottlenecks along the various neural pathways. For example, we can hardly attend to more than one thing at a time or perform two tasks at once (Marois and Ivanoff 2005). One way of circumventing further brain expansion, was to increase the sophistication and complexity of the neural "wiring" by improving conduction speed, increasing the number of neural connections, and refining the way neural systems engage in "crosstalk". At a more detailed level, the way information is transmitted along the neural tracts consists of chemically and electrically charged signals involving on-off thresholds, which are digital in character but also have analogue traits (Debanne et al. 2013). Those signals travel along neurons via action potentials that interface with synapses. Further modulation occurs at this stage thanks to the action of inhibitory and excitatory synapses. But it is not so much the number of neurons that underscores the brain's prodigious capabilities, rather this is a result of the extent and organisation of the neural bundles that connect the cortical neurons, which we now explore in detail.

The amount of information with which brains are capable of coping seems to have increased in various species during evolution. In humans, the amount of white matter tracts connecting neuronal hubs has increased considerably, as indicated in Figure 1. This is underlined by the fact that white matter volume has proliferated relative to brain size, from 9% to around 35% in humans, the highest expression in primates (Hofman 2015), especially within the prefrontal cortex (Schoenemann et al. 2005). As Hofman (2014, p 4) states:

> These findings support the idea that human evolution, after the split from the common ancestor with chimpanzees, was accompanied by discrete modifications in local circuitry and interconnectivity of selected parts of the brain.

The size and complexity of connecting tracts in the temporal cortex also seems to have expanded in humans compared to chimpanzees (Bryant et al. 2019). The fact that the human cortex is characterised by excessive folding (sulci) is believed to be because this allowed more surface area of the brain to be exploited in a confined cavity than otherwise would have been the case—so that the neurons and their interconnections could be optimised (Hofman 2014). The finding that neurons in the prefrontal cortex process information at a more abstract level than those in both the sensory areas and posterior parietal cortex (Nieder 2016), suggests that the higher brain areas, where the association cortex resides, evolved to deal with information in increasingly integrated and abstract ways; what some refer to as a synergistic integrative processor that is at the core of human cognitive abilities (Luppi et al. 2022). Such findings indicate that the human brain benefited from an extensive, and enlarged number, of neural interconnecting fibres in association areas that evolved after the split from our last chimpanzee-like common ancestor (Teffer and Semendeferi 2012). Those fibres do not just derive from sensory areas, which later combine with association regions, but also cross-reference at all stages of the neural hierarchy. This is especially relevant to the higher association areas where massive interaction between connecting tracts provides the ability to hold information in abeyance in order to reflect on events, which seems to underpin consciousness (Dehaene et al. 2006). In sum, the main cortical change that marks out the human brain during evolution appears to be coupled with a proliferation of white matter tracts rather than the number of neurons (Hofman 2014, 2015). As Hofman (2015, p. 71) states:

> If the ability of an organism to process information about its environment is a driving force behind evolution, then the more information a system, such as the brain, receives and the faster it can process this information, the more adequately it will be able to respond to environmental challenges and the better will be its chances of survival.

Thus, mammals with larger brains profit from greater speed of information flow thanks to increasingly myelinated axons, (Wang et al. 2008) and, accordingly, are better able to survive. That trajectory "culminated" in "higher" species, especially humans, where there has been a tendency towards the efficient flow of information in order to maximise and exploit the advantages that come with a complex neural network. That course is underlined by the fact that between the ages of 12 to 30, "human intracerebral connectivity is enhanced as fatty-acid myelin sheaths envelop axons in white-matter nerve-fibre tracts between grey-matter brain areas" (Walker et al. 2022, p.11). Indeed, the underlying white matter interconnections appear to be well organised and not randomly disposed as previously surmised (Hofman 2017). Moreover, in order to accommodate the processing of complex information, those connections appear to have proliferated considerably in the human association cortex (Rilling 2014a).

The primacy of the human brain in this context is underlined by the fact that it is twice the size of a chimpanzee brain at gestation (sixteen weeks). In addition, although chimpanzee and human brains display an increase in the pace of growth, this deviates markedly by twenty-two weeks, with human brain growth continuing apace whereas, in chimpanzees, this diminishes markedly at the same stage (Sakai et al. 2012). Likewise, in early infancy, humans benefit from an upsurge in white matter volume, which is absent in chimpanzees (Sakai et al. 2013). The adult human brain, though characterised by its size, is also noted by the amount of cortical surface dedicated to the association cortex compared to regions devoted to the primary sensory and motor areas (Glasser and Van Essen 2011). Those findings further confirm the fact that more of the human cerebral cortex is specialised for conceptual purposes as opposed to perceptual and motor criteria (Rilling 2014a).

With the evolution of adaptive sensory systems, which developed according to the particular environment in which a species had evolved, so the capacity to process larger amounts of sensory information increased, thereby allowing more humanly influenced intertwined environments to be created thanks to an enhanced ability to manipulate that environment. Indeed, despite the natural environment constituting the main way biological evolution was expedited, a tendency nevertheless arose for intelligent species to become increasingly detached from that environment. Particularly in humans, that procedure has reached a limit in that, as a species, *Homo sapiens* have become almost totally detached from the originating environment, so that cultural concerns can impact on human evolution as much as, if not more, than natural contingencies (Hofman 2017). Thus, in the same way that archaic humans began to externalise anatomical attributes that had previously proved useful to survival (e.g. stone tools as extension of incisor teeth, cooking food as extension of the gastrointestinal system), so that process continued with the outsourcing of the informational brain by way of the first materially-made marks. In that regard, how information first "escaped" from the brain to become a relatively permanent repository of human behavioural aspirations, is a subject with which the following pages will be particularly concerned. However, before delving into the means by which internal brain information became an externalised phenomenon, we need to examine historical approaches that attempted to understand the heuristics that first led to that externalisation.