History of memory artifacts

Palgrave Encyclopedia of Memory Studies

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Abstract
Human biological memory systems have adapted to use technological artifacts to overcome some of the limitations of these systems. For example, when performing a difficult calculation, we use pen and paper to create and store external number symbols; when remembering our appointments, we use a calendar; when remembering what to buy, we use a shopping list. This chapter looks at the history of memory artifacts, describing the evolution from cave paintings to virtual reality. It first characterizes memory artifacts, memory systems, and the two main functions such artifacts have, which are to aid individual users in completing memory tasks and as a cultural inheritance channel (section 2). It then outlines some of our first symbolic practices such as making cave paintings and figurines, and then moves on to outline several key developments in external representational systems and the artifacts that support these such as written language, numeral systems and counting devices, diagrams and maps, measuring devices, libraries and archives, photographs, analogue and digital computational artifacts, the World Wide Web, virtual reality, and smartphones (section 3). After that, it makes some brief points about the cumulative nature of the cultural evolution of memory artifacts and speculates about the possible future of memory artifacts, arguing that it is very difficult to look beyond an epistemological horizon of more than five years (section 4).

Keywords: memory artifacts, cognitive artifacts, external representations, exograms, cumulative culture

1. Introduction
Our memory systems are characterised by an openness to the world, in that we incorporate artifacts and technologies into our memory practices. Philosopher and cognitive scientist Merlin Donald (1991) argues that the invention of external representations, or "exograms" in his terminology, generated a new stage in the development of cognition and culture, one that is characterised by offloading and storing information in the material environment. In this chapter, I outline the artifacts, technologies, and representational systems that enabled us to offload memory functions onto the environment. The two main roles memory artifacts play is aiding individual users to perform memory tasks (e.g., by using a shopping list) and as a cultural inheritance channel allowing information to be passed on from one generation to the next (e.g., by reading the cuneiform tablet with the Epic of Gilgamesh). The focus in this chapter is mostly on describing the properties of the artifacts themselves and less so on the relation users have to these artifacts. Readers who are interested in the cognitive relation between humans and artifacts should consult the entries on Enactive Memory and Distributed Memory.

2. Memory artifacts and memory systems

An artifact is characterised as a material object or structure made to be used to achieve an aim, it is a material product of intentional agency (Preston 2018). A memory artifact is characterised as an intentionally made object or structure that is involved in memory practices and aids its user in remembering an experience, event, fact, or other unit of information[1]. Individual memory is often conceived as the capacity to consolidate, store, and retrieve information. Remembering is the process of retrieving information that one, at some point in the past, consolidated and stored. Memory as a capacity is closely related to the capacity of learning, which can be characterised as the process of acquiring new knowledge, understanding, skills, and values. Successful learning induces some change in the cognizing agent, but to do so, we need memory. These two capacities are thus two sides of the same coin.

Human memory has several different systems and components (Squire 2009). A distinction is often made between short-term (i.e., working memory) and long-term memory. We can typically hold 4 or 5 items in short-term memory for several seconds up to a minute (Cowan 2001). Long-term memory is divided into declarative and non-declarative. Declarative memories can be articulated or described and have two kinds: semantic and episodic. Semantic memories are propositional in nature, whereas episodic memories (Add cross-reference: Episodic Memory) are experiential in nature, i.e., they are memories of personal experiences with a distinct phenomenology, typically (but not necessarily) visual. Semantic memories can be about one's personal past (e.g., remembering *that* you were born in 1981), but they can also be about general knowledge and cultural-historical events (e.g., remembering *that* Archimedes lived in Sicily). Non-declarative memory has to do with embodied skills such as riding your bicycle (Add cross-reference: Embodied Memory) Such procedural memories typically remain under the threshold of consciousness[2].

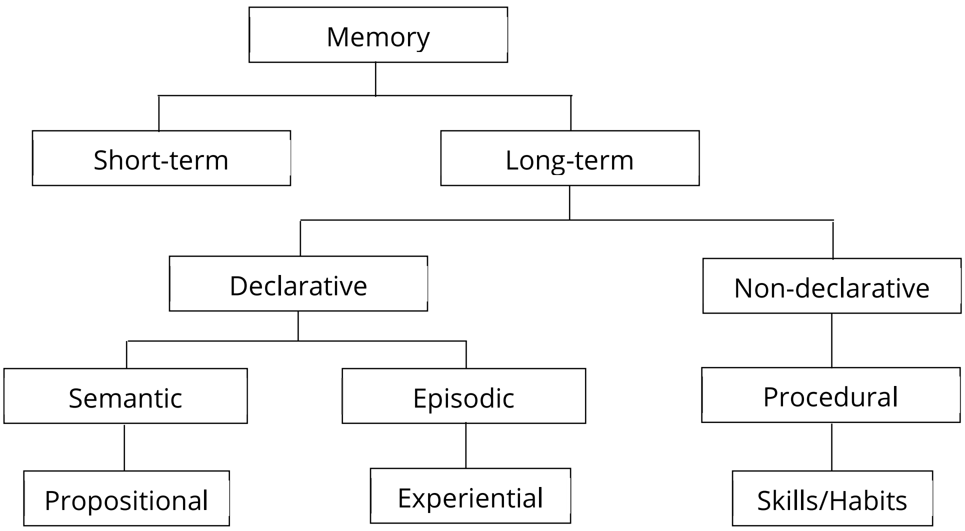

Figure 1. A taxonomy of memory systems.

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[1] I'm using the words "artifact" and "technology" interchangeably in this chapter.

[2] Note that there are other, more fine-grained, ways to carve up our memory systems and capacities (Squire 2004, 2009; for discussion see Michaelian & Sutton 2017).

Memory artifacts can be used to contribute to different memory capacities (Sutton 2015). They can be used to perform problem-solving tasks such as performing a calculation with pen and paper, where the external numerals support working memory. They can be used to remember personal experiences and events such as a photo album, supporting episodic memory. And they can be used to remember cultural events such as reading a textbook to remember (as in triggering a memory that one already has about) some fact regarding WWII, supporting semantic memory[3]. Many of the artifacts described below (in section 3) aid their users not necessarily in remembering experiences, events, facts, or information they already (partly) know, but they help users in learning new information, typically about cultural and historical events. If, for example, I read in a history textbook that the Manhattan Project was done at Los Alamos in New Mexico, I'm not remembering that fact because I didn't know it, so I am learning it. Using textbooks (or other sources) to learn facts is part of a memory practice; in this case, it's an activity with the aim to learn and memorize something.

Institutions such as libraries, archives, museums, and schools (and the memory artifacts that are part of those institutions) store information about the cultural past and, in that sense, function as repositories of cultural memory (Assmann 1995, 2011). So, on a broader characterisation of memory artifacts, libraries, archives, museums, schools, and the artifacts partly constituting these institutions can also be seen as part of the category, even though such artifacts don't necessarily help individual humans to remember information they already know. Instead, they are part of the cultural memory of social groups (Manier & Hirst 2008), allowing information to be transmitted from one generation to the next (Sterelny 2003). So, the two main roles memory artifacts play is to aid humans in performing memory tasks and to provide an inheritance channel of cultural information. The main focus in this chapter is on artifacts that aid learning, memory, and remembering[4]. However, it may be useful to know that artifacts can also be used to aid in other cognitive tasks, including perception, navigating, and reasoning. Artifacts that aid us in performing cognitive tasks have been referred to as "cognitive artifacts" (Norman 1991; Hutchins 1999; Heersmink 2013, 2016b; Fasoli 2018). Memory artifacts are part of this larger category.

3. From cave paintings to virtual reality

3.1 Symbolic practices

The first material traces of homo sapiens externalising their thoughts and feelings in external representations are most likely ancient rock engravings, cave paintings, and figurines[5]. Archaeologists date the first cave paintings back to 42.000 BCE found in both the Franco-Cantabrian region in western Europe and in the caves of Sulawesi in Indonesia

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[3] There may also be relations between artifacts and procedural memory (e.g., by being embedded in perception-action cycles a bicycle may be part of the realization of the procedural memory), but those won't be discussed in this chapter.

[4] For book lengths treatments of the history of external informational systems, see Gleick (2011) and Rumsey (2016)

[5] We have used tools for a long period of time. The first stone tools predate the genus *Homo* and were developed by *Australopithecus* approximately 2.6 million years ago. These Oldowan stone tools consisted of rocks with one or more flakes chipped off. Approximately 1.6 million years ago, *Homo erectus* inherited Oldowan tools and refined them into Acheulean tools, which were hand axes.

(Brum, Oktaviana, Burhan et al 2021)[6]. Approximately around the same time humans started making figurines of animals. The oldest known figurine is currently the Löwenmensch figurine or Lion-man excavated in what is now south Germany, which is dated to approximately 38.000 BCE (Dalton 2003). The exact reason for making cave paintings or figurines is unknown (e.g., informative, artistic, shamanistic, spiritual); they do, however, signal the beginning of a new era in our cognitive development. Whilst humans engaged in symbolic practices such as body painting, adornments, and grave decorations for a much longer period, making cave paintings and figurines demonstrate our capacity to create external pictorial representations. Our capacity to represent the world not just in our mind, but in external material traces marks a breaking point with our evolutionary ancestors and has generated a new stage in our cognitive evolution, creating a shift from internal to external memory storage (Donald 1991).

3.2 Writing

It is estimated that language evolved approximately 2,5 million years ago, possibly to aid the social transmission of tool-making skills (Morgan et al 2015). Writing evolved much later. The first advanced writing systems appeared in Sumer[7] and Egypt, approximately 4000 BCE (Donald 2010). The Sumerian archaic (pre-cuneiform) writing and Egyptian hieroglyphs are generally considered the earliest true writing systems. Writing developed independently in India (3000 BCE), China (1200 BCE), and Mesoamerica (500 BCE). In true writing, the content of a linguistic utterance is encoded so that another reader can reconstruct the utterance written down in a reasonably accurate manner. In Sumer, the first written documents are records of agricultural produce and contracts. Writing evolved from proto-writing where round clay tokens might, for example, contain a pictograph (a symbol that visually resembles what it represents) of an animal and a symbol indicating quantity. These round clay tokens where slowly replaced by flat clay tablets that could contain more symbols. The pictographic nature of proto-writing evolved into more simple and abstract forms. Pictographic symbols can also be seen as rock engravings and on the walls of caves (Mithen 1996).

Through a process of cultural diffusion, writing spread from Sumer to Egypt, Crete, Greece, and other parts of the world (Janson 2012). The Phoenicians (who lived in what's now Lebanon and parts of Syria and Israel) adapted the Egyptian hieroglyphs and developed an alphabet with only consonants. Around 800 BCE the Greeks adapted the Phoenician alphabetic. This alphabetic system has individual characters for both consonants and vowels. The Phoenician writing system was also the basis for Aramaic, Hebrew, Palmyrene, Syriac, and Arabic writing systems. The Greeks took their alphabet to the Etruscans in modern Italy at around 700 BCE who develop the Etruscan alphabet. The Romans were influenced by both the Greek and Etruscan alphabets and created the current roman alphabet that is still used today in Western countries and beyond.

(Written) language is so important for memory and cognition that it has been referred to as "the ultimate artifact" (Clark 1997; Wheeler 2004). When writing was invented a transition

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[6] Archaeologists and anthropologists constantly make new discoveries, often pushing the dates of particular inventions further back into the past. So, the dates in this chapter aren't written in stone, so to speak, but are subject to change.

[7] Sumer is an historical region in southern Mesopotamia located between the Euphrates and Tigris rivers, which is now south-central Iraq.

from an oral to a written culture took place (Ong 1982), which has generated much progress in finance, trade, science, philosophy, engineering, law, and literature. Indeed, many of our current cultural activities would be not possible without writing. The capacity to externalise thoughts by writing them down on clay tablets, papyrus, paper, or a screen allows information to be stored externally and transmitted to others. The transfer of linguistic information has created an exchange of ideas between cultures. One of the great advantages of writing is that it allows to store thoughts in a more reliable and stable medium. Internal thoughts are fleeting and easy to forget. But once a thought is written down and externalised in a clay tablet, scroll, or paper, it becomes a more fixed memory record (Sutton 2010)[8].

3.3 Numeral systems and counting devices

A numeral system is a writing system for expressing numbers. The simplest of such systems is using tallying marks. Currently, the oldest known artifact used for tallying is the Lebombo bone, a tally stick made of baboon's fibula with 29 distinct notches that were deliberately cut into it. It was discovered in a cave in the Lebombo Mountains of Swaziland, dating back to 35.000 BCE. Whilst we don't know this with certainty, it is possible that the tally's represent days or lunar cycles, in which case the Lebombo bone was a mnemonic aid to counting (Darling 2004). A more complicated counting aid is the abacus, sometimes called a counting frame, which was invented in Sumer between 2700 and 2300 BCE (Ifrah 2004). An abacus consists of rows of movable beads strung on wire. One row of beads stands for single digits, the next row stands for double digits, the next row stands for triple digits, etc. These beads can be moved up and down, thereby adding or subtracting numbers. The Inca's and other Mesoamerican cultures used a Quipu to record items. It consists of several strings in a base 10 system. Knots can be tied in different strings representing different units, single, digits, double digits, etc. Unlike an abacus, a Quipu is not used for calculation but merely for storing numerical information.

Tally sticks, abacuses, and Quipu are memory artifacts, as they are external material objects that aid their users in remembering the quantity of certain items. The phrase "memory techniques" could be used for internal or internalised mnemonics (Heersmink & Carter 2020). Consider the following example of Japanese students who have learned to visualize the structure of an abacus in their mind's eye, so to speak, and to internally manipulate the beads as to perform calculations (Negishi et al 2005; de Cruz 2008). The actual material abacus is then no longer needed. The functional properties of material abacuses and internally imagined ones are the same, but their location and realization base is different.

Babylonian (a city in Sumer) cuneiform numerals were one of the first fully developed numeral systems. They were written in clay tablets with a stylus made of reed. It first appeared around 2000 BCE and is the first positional numeral system, which means the value of a particular digit depends both on the representational structure of the digit itself and its position within the number. The Roman numeral system developed around 500 BCE, in which letters were used to indicate quantity (I = 1, V = 5, X = 10, L = 50, C = 100, D= 500, M

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[8] The invention and development of true writing and numeral systems mark the end of prehistory and the start of history. Prehistory starts with the use of the first stone tools and end with the invention of writing. So, these phases in human history and evolution are characterised by the tools and artifacts our ancestors used.

= 1000). Currently, the most used numeral system is the Hindu-Arabic system, which was invented between the 1st and the 4th century by Indian mathematicians. Arabic mathematicians, especially al-Khwarizmi and al-Kindi, adopted the system in the 9th century and Arab merchants introduced it in Europe in the late 10th century. The Hindu-Arabic system is designed for positional notation in a decimal system, which allows any number to be expressed by using the ten digits, the decimal marker, and a minus sign. This system greatly facilitated arithmetic computations, particularly multiplication and division. It also allowed more efficient calculation of the mathematical tables that were needed for surveying, navigation, and the keeping of commercial records (Clawson 2004).

3.4 Measuring devices

The earliest known measuring devices include rulers, the first of which - known as the Nippur cubit rod - was found in the city of Nippur (in Sumer), dating back to 2650 BCE (Duran & Aydar 2012). Other early measuring devices are scales, which have been found in Egypt, dating back to 2600BCE (Rahmstorf 2007) as well as sundials and water clocks. In the archaeological record, sundials have been found in Egypt and Babylon around 1500 BCE (Rohr 2012). The first water clock was found in a tomb of Amenhotep I, who was buried around 1500 BCE. More recent measuring devices include thermometers, accelerometers, pH meters, speedometers, spectrometers, and so on. Such devices allow us to make visible and quantify aspects of our world. The function of measuring devices is to create an external representation, either fixed or in real-time, that allows us to indirectly perceive some aspect of the world that we would not otherwise be able to perceive (accurately) such as length, weight, temperature, acidity, etc. These devices need a quantification system, typically expressed with number symbols. Measuring, quantifying, and mapping our world puts us in a better position to understand and manipulate it, creating enormous progress for virtually all fields in engineering, science, and trade. It is safe to say that the history of measurement and quantification is one that created significant progress for humans (Heersmink 2021).

3.5 Diagrams and maps

A diagram can be characterised as a symbolic representation of information using visualization techniques that show how something works or show the relation between two or more variables. There are different sorts of diagrams. Logical or conceptual diagrams show relationships between items, for example a tree diagram, Venn diagram, or a flowchart. Quantitative diagrams show a relationship between two variables in a continuous range of values often expressed numerically, such as a histogram, pie chart, table, or graph. Schematics, for example, a diagram of a human heart, a map of an area, or a blueprint of a building show the structure and function of some entity. Diagrams play important roles in scientific and engineering practice, but also as, for example, traffic signs.

Maps are probably amongst the oldest diagrammatic representations. Whilst map-like structures have been found on the walls of caves in Europe, the first portable map was invented in Babylonia, dating back to 2500 BCE. It’s referred to as the map of Nippur, which was carved into a clay tablet of 12 x 11 cm. The content of the map is of an area near the city of Nippur, featuring an irrigation network of ditches and canals, which are depicted by lines, along with some towns and agricultural estates, which are represented by circles (Vass 1976). The invention of maps was made possible through a change in spatial perspective. We view the world from a first-personal perspective, looking at the world through our own eyes.

But making a map required the maker to imagine the world from above, from a bird's eye perspective, translating visual first-personal information (perhaps aided with measurements) into a two-dimensional representation of a piece of land, which is a breakthrough in our imaginative skills. The Greeks, Romans, and Chinese have since improved maps, drawing them on scrolls and paper. These maps played important roles for seafarers, travellers, and explorers, but also for governments to indicate borders of lands and property. We now have maps of many things including campuses, cities, countries, oceans, subways systems, complex buildings, and many other structures. The most elaborate map that currently exist is Google Maps and Google Street View, which is a digital interactive map of the entire world, accompanied with photographs.

3.6 Libraries and archives

After writing and numeral systems as well as ways to store the information in clay tablets were invented, these clay tablets began to be collected and organised. Clay tablets in cuneiform have been discovered in temple rooms in Sumer, some dating back to 2600 BCE. These archives largely consisted of the records of commercial transactions or inventories. Particularly noteworthy is the Library of Assurbanipal, which contained more than 30.000 clay tablets in various languages. One of those tablets contained the Epic of Gilgamesh, a masterpiece of ancient Babylonian poetry (Finkel 2019). Another important example was the Great Library of Alexandria in Egypt, which was one of the largest and most significant libraries of the ancient world. Scholars estimate that it contained between 40.000 and 400.000 scrolls. Libraries and archives have since sprung up in all parts of the world and currently most towns, cities, and educational institutions have some sort of library. The role of the library is currently declining, fewer people tend to make use of it, due to the invention of the World Wide Web (Palfrey 2015).

3.7 The printed book

The invention of the printing press significantly increased the production of pamphlets, books, and other informational material, which democratised access to knowledge and information. Before printing, books where handwritten by monks in a Scriptorium, which means "a place for writing", and refers to a room in medieval European monasteries devoted to the writing, copying, and illuminating of manuscripts. This was a time-consuming process. The first movable type printing technology for paper books was invented around 1040 in China by the inventor Bi Sheng. In Europe, it was Johannes Gutenberg who is credited with inventing the printing press around 1436. The printing press itself is not a memory artifact, but a technology to make memory artifacts such as pamphlets, books, and other informational material. The cultural and cognitive significance of the printed book can hardly be overstated. Libraries and the books constituting them contain a wealth of cultural and historical information, constituting part of our cultural memory. It is important to note that most people were illiterate. Globally, in 1800, 85% of people over 15 years of age were illiterate (OECD 2014), in 2010 85% of people over 15 years of age were literate (UNESCO 2013). Global numeracy rates were also very low before 1820 (Crayen & Baten 2010). So, it appears that printed books were initially for the elite and not for the masses.

3.8 Photographs

The camera obscura was invented in China around 400 BCE and has since sprung up in Greece and the Arab world. A camera obscura is a darkened room with a small hole or lens at one side that projects an image on the other side. However, this technology doesn't allow images to be recorded. A photograph is a recorded image caused by light focused through a lens on a sensor, which can be chemical or electronic. The first permanent photoetching was an image produced in 1822 by the French inventor Nicéphore Niépce. Louis Daguerre continued this development and invented a technique called daguerreotyping where a silver plate was used as a chemical sensor. In 1876, Ferdinand Hurter and Vero Charles Driffield invented the first photographic film. Film was at first only able to capture black and white image and was later also able to create colour photos. The first commercially available digital camera that recorded and saved images in a digital format was the Fujix DS-1P made by Fujifilm in 1988 (Emerling 2012). Cameras are now embedded in smartphones (see section 3.12) and thus billions of people take photographs for both artistic and mnemonic purposes. Photographs can aid in remembering personal experiences, in that way aiding in episodic memory. Furthermore, they can be used for more practical memory purposes, for example when taking a photograph of a table of the train times. Photographs also function as cultural memory in history textbooks, museums, and archives (Kuhn 2007; Bate 2010). Photographs exhibit a very high isomorphism between the content of the photograph and what it represents and are therefore uniquely placed to store, convey, and transmit information that is not possible with other representational media such as language (Barthes 1977). The first film showed to a paying audience was made by the Lumière brothers in 1895 in Paris. Video (moving images) developed into the most important media channel in the 20th and 21st century.

(Add cross reference to the entry on Photography.)

3.9 Computation

Most of the artifacts mentioned up to this point, merely contain information, they don't process or compute it. A distinction between representational systems and the artifacts that store and sometimes manipulates them is helpful (Heersmink 2016b). Representational systems include writing, numeral systems, maps, diagrams, and photos. The substrate for storing these representations can be the wall of a cave, clay tablet, papyrus, paper, white boards, microfilms, and computer hard drives. Some artifacts not only store representational systems but can also manipulate them.

Perhaps it could be argued that the abacus was the first analogue computer, as the human-abacus system computes information when the beads are manipulated. More complex early analogue computers include the Antikythera mechanism, which is an orrery used to predict astronomical positions and eclipses, dating back to approximately 200 BCE. Other analogue computers were Charles Babbage analytical engine, which was a mechanical calculator. The ENIAC (Electronic Numerical Integrator and Computer) was the first programmable, electronic, general-purpose digital computer and was invented in 1945. The miniaturization of transistors and other factors have resulted in more powerful, efficient, and usable computers. The use of personal computers (PCs) increased throughout the 1980s and 1990s. Most people now have a PC or some other form of (mobile) computing device like a tablet or smartphone. From a memory studies perspective, digital computers are important because they can store a very large amount of information in a variety of formats.

3.10 The Web

The World Wide Web was invented by Tim Berners-Lee in 1989 at CERN in Geneva, initially to help scientists store and communicate data but soon developed into a global phenomenon we now know as the Web (Naughton 2000). The Web is an information space in which documents and other Web resources are identified by URLs, connected by hyperlinks, and accessed via the Internet, which is a global system of many interconnected computer networks. The material architecture of the computer network itself is sometimes referred to as the Internet. An important informational property of the Web is that it "remediates" pre-existing media systems. Remediation is the incorporation and *re*-representation of one medium in another (Bolter & Grusin 1999). So, whilst newspapers, scientific journals, TV programs, encyclopaedia, databases, archives, textbooks, and maps already existed in an analogue format, the Web has absorbed these media (Heersmink 2016a). From a memory studies perspective, the advent of the Web is very significant. It played a role in creating the information age in which information is easily accessible, democratising access to information and knowledge. Having access to search engines as well as Webpages such as Wikipedia, YouTube, and the countless media outlets, streaming services, databases, and forums have made it easy to get access to information about a variety of topics.

3.11 Virtual and augmented reality

Virtual reality (VR) allows users to be immersed in and interact with a computer-generated 3D environment. The term "virtual reality" was coined in 1987 by Jaron Lanier, but there are some historical precursors to VR technology such as stereoscopic flights simulators build in the 1930s and the Sensorama, which was a theatre cabinet that stimulates all the senses, not only sight and sound. The Sensorama, developed by Morton Heilig in 1962, included stereo speakers, a stereoscopic 3D display, fans, smell generators and a vibrating chair. In 1965, Ivan Sutherland described the concept of the "Ultimate Display", which was a computer-generated 3D world (somewhat like the holodeck in Star Trek). Sutherland was also involved in developing the first head mounted display. VR simulates reality using interactive devices such as goggles, headsets, gloves, and sometimes body suits. It is used in educational contexts and for entertainment (Bown, White & Boopalan 2017). One of the many things VR allows us to do is creating 3D simulations of how the world used to be. We have video recordings of historical events, but VR simulations are potentially more powerful in aiding learning and remembering, due to its immersive and interactive nature. Based on historical and archaeological evidence, it may, for example, be possible to simulate ancient Rome in a VR simulation, thereby learning information that one wouldn't learn from pictures or linguistic descriptions. VR simulations of past events are also used as a reminiscence therapy for dementia patients, aiding such patients to remember personal experiences and events they may have (partly) forgotten (Siriaraya & Ang 2014).

Augmented reality (AR) technology allows for an interactive experience that integrates the real world and computer-generated content. By means of AR glasses, augmented reality technology can generate digital content in one's perceptual field, while still also seeing the real world. The generated perceptual information can be constructive (which means it's additive to the natural environment) or destructive (which means it's masking the natural environment). For example, when performing surgery, AR glasses such as Microsoft's HoloLens, can add or superimpose perceptual information onto the body of a patient, giving information about anatomy, organ sizes, and the location of incisions. One can also use AR glasses to generate and look at a 3D model of the human body, showing the skeletal system, cardiovascular system, nervous system, and so on. This content temporarily masks the real world and is an important learning tool for students and practitioners.

3.12 Smartphones

The smartphone emerged in the late 1990s when cellphones were merged with PDAs (personal digital assistant). Smartphones are amongst the most important technological innovations from a memory studies perspective, as they are the most used memory artifact in the 21st century (Reid 2018). This is largely because smartphones (with internet access) centralise many memory functions that were previously done by other artifacts. Smartphones can store phone numbers, email addresses, appointments, photographs, videos, audio recordings, notes, maps, and provide access to the Web and online databases. This sort of multifunctionality has not been seen before in human history. The effects smartphones have on memory and cognition is now a lively debated topic (Barr, Pennycook, Stolz & Fugelsang 2015; Wilmer, Sherman & Chein 2017).

4. The cumulative nature and possible future of memory artifacts

The artifacts, technologies, and representational systems outlined in this chapter span a timeframe of approximately 46.000 years. In a very broad-brush characterization, the cultural evolution of memory artifacts went from the development of pictorial representation to more systematic pictographs to true writing to portable maps and to cuneiform numerals. After that, ways to organise this information were developed such as libraries and archives. All this – except for the invention of pictorial representation (as far as we currently know) – occurred in roughly the same geographical area, namely Sumer. More efficient ways to make memory artifacts were then invented, namely the printing press, in China and Europe. Analogue computers eventually led to the invention of digital computers, which soon resulted in the Web, VR, AR, and (mobile) computing technologies.

Some scholars have suggested that this cognitive-cultural explosion is due to some genetic mutation (Mithen 1996). However, it is also possible that it is not due to genetics or biology but due to cultural evolution (for discussion see Coolidge & Wynn 2016). Once pictorial representations such as cave paintings and figurines were developed, the ratchet effect accelerated the development of memory artifacts. The cultural evolution of technology is characterised by what Michael Tomasello (1999; Tomasello, Kruger & Ratner 1993) refers to as the "rachet effect", which means that we improve existing tools, artifacts, and technologies and pass on those improvements to the next generation. Each new generation is born into the informational and technological environments created by parent generations. Kim Sterelny (2003) refers to this as "cumulative downstream epistemic engineering". So, once an artifact or representational system is developed, the next generation doesn't have to develop it again. Instead, that generation can improve it and pass the improvements on to the next generation (Fabry 2017; Madary 2022; Buskell 2022). Donald points out that "The memory repositories of culture allow our species to transmit across generations the codes, habits, institutional structures, and symbolic memory systems that are needed to operate a significant portion of the processes of modern cognition in human culture" (2000, p. 20). Before external representations were developed, the amount of information that could be passed on from one generation to the next was significantly more limited. Information was transmitted mostly verbally from one generation to the next and through observational learning. So, the ability to offload memory storage functions onto material artifacts (Risko & Gilbert 2016), didn't just create a cognitive breakthrough, it also created a major cultural breakthrough, because ideas and information could spread much more quickly and widely.

Sterelny (2010) argues that cognitive artifacts, including memory artifacts, haven't been used long enough to have had an evolutionary impact on our embodied brains and cognitive systems. He points out that "Slide rules, pocket calculators, GPS devices, filofaxes and palm pilots appear in one generation and then disappear, sometimes within the same generation" (2010, p. 469). For a cognitive artifact to have a lasting evolutionary impact, we need to use it for many generations. Sterelny seems right in saying that many memory artifacts may not have been used long enough for a specific artifact or even representational system to have had an evolutionary impact on our embodied brains and cognitive systems. We should also consider that most of the world's population was illiterate and innumerate until approximately the 19th century. It's thus doubtful (though perhaps not impossible) that memory artifacts had a significant impact on the evolution of our embodied brains, in that they didn't significantly change the basic structure and workings of our brains over evolutionary timescales. However, we do know that learning to read and write changes the structure of the embodied brain (Dehaene 2010). So, developmentally, learning to interact with memory artifacts (involving writing) can change the structure and functioning of the embodied brain.

The process of cumulative cultural evolution of memory artifacts will continue. At the frontiers of human-computer interaction research (add cross-references Human Computer Interaction), new ways to represent and interact with information are being developed (Dargan et al 2023). Can we make any predictions about the future of memory artifacts? Gordon Moore (1965) observed that the density of components per integrated circuit approximately doubles every 18 months, which is now referred to as Moore's Law. At the time of writing this chapter, transistor technology is approaching some physical limits to further miniaturisation and the linear trajectory of Moore's Law is slowly flattening. This, however, is no reason to think that raw computing power will not significantly increase in the future. There are other ways to improve computing power and storage capacity, for example with innovations in the materials and structures used to make transistors, new transistor architectures, and more efficient transistor integration (Shalf 2020). More importantly, what matters from the perspective of the user is not raw computing power per se, but computational functionality and representational capacity. What's also important to point out is that, for most people, personal computers have now more than enough storage capacity for their documents and photos (but perhaps not for all their videos and music). The miniaturization of chips may result in more storage capacity, but most people don't necessarily need that, and if they do, they may store their data in the cloud. So, on an individual level of information storage, we may be close to reaching a point of saturation, as there is now more storage capacity (on one's hard drive and in the cloud) than most humans need.

One way to try to predict the technological future is by analysing policy documents and patents of technology companies. Google, Microsoft, Apple, Meta, Samsung, and other large companies publish policy documents and file patents that are sometimes publicly accessible.

This approach allows us to "see" three to five years into the future. Predicting the technological future as an epistemological exercise is inherently difficult and it is impossible to look beyond an epistemological horizon (Stahl et al 2010). For example, in 2017 Microsoft launched their HoloLens, which is a pair of mixed reality or augmented reality smartglasses. In 2014, The Verge published an article on HoloLens, and in 2015, WIRED magazine published on article on HoloLens. The patent for HoloLens 2 was filed in 2018. In 2019, it came out and is now slowly being taken up by people in various industries such as healthcare, education, and design. This sort of approach is useful in predicting which cognitive artifacts, including memory artifacts, will be designed in a relatively short time frame. But it seems very difficult to look beyond a horizon of five years based on policy documents and patents.

Technology designers sometimes take inspiration from science fiction literature and cinema. Tim Berners-Lee supposedly was inspired by Arthur C. Clarke's short story *Dial F for Frankenstein* published in 1961. The book tells a short story of an interconnected telephone network that unexpectedly acts like an infant and leads to global chaos as it takes over financial, transportation, and military systems. Likewise, Neal Stephenson's cyberpunk novel *Snow Crash* published in 1992, allegedly inspired Google Earth co-designer Avi Bar-Zeev. The Central Intelligence Corporation in *Snow Crash* developed Earth software, which has a similar function and bird's eye view on the planet. So, perhaps science fiction and cyberpunk may be one source to help predict the informational and technological future (Norman 1993, chapter 8).

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