*УДК 930.1* *DOI 10.18522/2500-3224-2020-4-114-128*

# TOTAL RECALL. SHORT ESSAY ON HUMAN MEMORY[1]

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**Abstract.** This multidisciplinary study focuses on various concepts of memory. Special attention is paid to biological foundations of human memory. The article briefly presents the concepts of declarative and nondeclarative forms of memory and the mechanisms of memory formation, with the special role of early adulthood. Some complex functions reflect also planned future events. In recent years there has been increased interest in prospective memory or remembering to perform actions in the future. The study is arranged around four core topics: memory of apes, humans, humanoid robots and collective memories (nation-state groups). Modern studies regarding memory formation focus on three major research lines: evolutionary development, metacognition and social cognition. Much of what we know about human long-term memory has actually resulted from non-human primates studies. There are several hypotheses for the evolution of advanced social cognition in non-human primates and they have profound impact upon human memory research. On the other hand, new problems arise in the modern understanding of memory processes due to the influence of technology, including replication of human memory in machines and robots. The idea of absolute and unlimited robotic memory, never degrading nor failing, raises new questions for humanity.

**Keywords:** history of research, neurotransmitters, memory formation processes, non-human primates, humanoid robots, collective memories.

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[1] My work was possible thanks to the international academic exchange and scholarship (Östersjösamarbete program) supported by the Svenska institutet, Sweden (stipend no.23394/2019).

# ВСПОМНИТЬ ВСЕ. КРАТКИЙ ОЧЕРК О ЧЕЛОВЕЧЕСКОЙ ПАМЯТИ

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**Аннотация.** Данное междисциплинарное исследование сосредоточено на различных концепциях памяти. Особое внимание уделяется биологическим основам человеческой памяти. В статье кратко представлены понятия декларативных и некларативных форм памяти и механизмы формирования памяти, с особым значением юности. Некоторые сложные функции отражают также планируемые будущие события. В последние годы возрос интерес к перспективной памяти или воспоминаниям о действиях в будущем. Исследование построено вокруг четырех основных тем: память обезьян, человека, человекоподобных роботов и коллективная память (группы национальных государств). Современные исследования в области формирования памяти сосредоточены на трех основных направлениях: эволюционное развитие, метапознание и социальное познание. Большая часть того, что мы знаем о долговременной памяти человека, на самом деле является результатом исследований приматов. Существует несколько гипотез эволюции развитого социального познания у нечеловеческих приматов, и они оказывают глубокое влияние на исследования человеческой памяти. С другой стороны, в современном понимании процессов памяти возникают новые проблемы, связанные с влиянием технологий, в том числе репликации человеческой памяти в машинах и роботах. Идея абсолютной и неограниченной памяти роботов, никогда не деградирующей и не ослабевающей, ставит новые вопросы перед человечеством.

**Ключевые слова:** история исследований, нейромедиаторы, процессы формирования памяти, нечеловеческие приматы, гуманоидные роботы, коллективная память.

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I cannot recall how should I begin. The only excuse to write this paper is that the past beats inside people like a second heart. The more I explore my memory landscape, the more it becomes clear, I cannot control the past. There are memories that time does not erase, however the majority of I though was real, probably never existed at all. Undoubtedly, the ability to recall past events is one of the most profound functions of human brain, associated with complex intelligence and our biological adaptation to life on Earth. Memory is therefore the superior cognitive process that defines the temporal depth of our mental structure. The Greek word for memory is Μνημοσύνη. According to legends, the Titaness Mnemosyne as a goddess of memory and remembrance was the mother of the nine Muses. Ancient cult of Mnemosyne was strongly linked to Asclepius, including rituals of clairvoyance and fortune telling. Today, in the modern information-based and digitalized society, our natural ability to memorize things is shrinking. This short multidisciplinary essay is the story of memory from antiquity to modern times.

It all begun with the man falling off the roof long time ago. In the first century, Pliny the Elder (24–79 AD) described a man who fell off a roof and afterward could not remember his mother, neighbours, and friends. Galen (130–200 AD) described the ventricles as the anatomical key to mental processing. Special *cavities* or *holes* in the brain as main *memory organ* were a later advocated by Nemesius of Emsa (*c.* 390 AD), who misunderstood the work of Galen passing knowledge in his own work *On the nature of man* [Morani, 1987, p. 341–342]. Other Christian authors, such as Posidonius of Byzantium (*c.* 370 AD) agreed and shared such opinions. The perceived role of the ventricles declined during the Renaissance, when Thomas Willis (1621–1675) presented the idea that the cerebellum and brain stem controlled memory. Later, such medics as David Harley (1705–1757) and Charles Bonnet (1720–1793) viewed memory in terms of *vibration waves* that oscillated in the brain.

The first systematic studies of human memory begun in late 19$^{th}$ century. In 1881, the French psychologist Theodule Ribot published *Les Maladies de la Memoire*. Ribot provided systematic description of human amnesic patients, and observations that brain injury causes memory impairment [Ribot, 1906]. This principle has become known as *Ribot's Law*. In 1885, Hermann Ebbinghaus published *Über das Gedächtnis: Untersuchungen zur experimentellen Psychologie*, in which he applied systematic experimental approaches to the study of normal human memory. For example, he showed that some memories are only short-lived while others are last longer, and the amount of repetition can influence the duration of the memory (memory training). American psychologist William James published *Principles of Psychology* (1890) in which he described distinctions between what he called primary memory, defined as information that forms the focus of current attention, and secondary memory, defined as memory that persists much longer.

At the beginning of the 20$^{th}$ century a major debate concerned whether memory was localized to a particular brain area or was distributed throughout the brain as whole. The results from early experimental studies were mixed. In the 1920s Karl Lashley at Harvard University, performed a series of influential experiments with animals (rats in labyrinth) that addressed this debate. Based on results, Lashley formulated the *Law of Mass Action* and concluded that memory was distributed over widespread cortical areas [Lashley, 1929]. This view dominated the field for more than 25 years, until findings from another study transformed our understanding of the localization of memory in the brain.

In 1957, Scoville and Milner described the effects of experimental surgeries of temporal lobe in humans. These surgeries were done in an attempt to relieve a variety of psychiatric conditions, including schizophrenia, manic depressive psychosis, and epilepsy [Scoville and Milner, 1957]. This study demonstrated several fundamental principles of memory organization in the brain. First, it showed definitively that memory could be localized to a particular brain area, namely the medial temporal lobe. Secondly, it demonstrated that memory could be studied independently of other general cognitive functions. It also led the way to more recent demonstrations that the medial temporal lobe has a critical role in establishing declarative memory for facts and events. Study by Scoville and Milner was the catalyst for the ensuing experimental studies focused on defining more precisely the neuroanatomical basis of declarative memory. But was it memory?

## BIOLOGICAL FOUNDATIONS OF HUMAN MEMORY

Memory is the recording, retention, and retrieval of knowledge. It accounts for all knowledge gained from experience, facts that are known, events that are remembered, and skills that are gained (Fig. 1). Memory can be defined also as a series of molecular events. What is memory on molecular level? Consider following example: in a sunny summer day you observe red apples hanging on the tree.

One of them has fallen on the ground. Our brain obtains an information: a) an apple has fallen on the ground; b) an apple was red and read to be consumed; c) the fruit made a *boom* sound hitting the ground, etc. The initial processing of information and *remembering* of the event is possible thanks to NMDA receptors (N-methyl-D-aspartate receptors). When a neuron tries to send a message, an electrical signal is sent, triggering the release of glutamate molecules [Squire and Kandel, 2000].

These neurotransmitters travel across the synapse to the neuron receiving the message [Edmonds et al., 1995]. Single memory is physical; it makes chemical fingerprint. "Freshly born" memory is an activation of NMDA (and other neurotransmitters) on the surface of neurons throughout the brain. This physical change is believed to be the mark of a *memory occurs*. The change happens at tiny gaps called synapses across which brain cells communicate. A memory system therefore may be defined as a particular neural network that mediates a specific form of mnemonic processing [Nowak et al., 1984].

Memory can be divided in various ways. One of the most common approach assumes the existence of declarative and nondeclarative forms of memory [Eichenbaum, 2002]. Declarative memory corresponds to the everyday sense of memory and is responsible for the learning and remembrance of new events. It encompasses both episodic memories (my last vacations, etc.) and semantic memories (knowledge of generic information: the capital of India; the Earth is located in the Solar system, etc.). Nondeclarative memory refers to the many forms of memory that are not retrieved intentionally but reflexively; navigational memory or remembering how to swim or ride a bicycle belong in this category. All further subdivisions of mnemonic processes and memory functions are linked to complexity of human brain.

## THE MECHANISM

Memory does not work like a video recorder or computer. Our brain acts like fastidious collector; sometimes cannot encode or retrieve every aspect of an event perfectly. The memories depend on personal priorities, past experiences, on our expectations, and the current demands. What people remember about given past event also depend on what happened after the event, their biases, expectations, and reports from others. When the state of alertness is high, people tend to narrow their focus to only certain aspects of an event. An example of encoding bias is own-race bias, in which we are better able to identify individuals from our own race than individuals from a different race (esp. in witness testimonies in criminal cases [Brown et al., 1998]. Studies by Loftus and colleagues [Loftus and Palmer, 1974] demonstrated that misinformation introduced after an event can alter our recollection (memory) of the original event. False memories occur more often than we would like to think. Pieces of false information can be also embedded into our minds in artificial manner. In their study Loftus and Pickerell (1995) shown that people who thought extensively about events that never happened to them (e.g., vacation trip with grandfather) began to believe they did experience those events. In such way, human subjects rely on expectations and experience when we attempt to retrieve information.

Another interesting problem is acoustic memory, more specifically music. In seconds, human brain can process and recognize millions of sounds, including their combinations. Memories of sounds, emotions and melodies create a portion of individual musical preferences and personality. Many can recall long-time gone melodies of their youth much better than recent hits. Rubin and colleagues (1986) have demonstrated that over the course of a lifetime, we seem to have heightened memory for personal, cultural, and historical events that occurred during our late adolescence and early adulthood (roughly between the ages of 15 and 30). Investigators have termed this the *reminiscence bump*. We can clearly recall our *first love*, favourite dog or serious bike accident, that happened when we were young (specifically age 15–25). These memories are vivid and *feel* more important than others. Early adulthood is important for memory, especially in personality/identity formation. We shall return to reminiscence bump phenomenon later, discussing collective memories and generational group formation in society.

There are two other interesting processes affecting the way we recall things from the past. First of them has been termed flashbulb memory. Flashbulb memory is a term used to refer to the recollection of extremely significant personal or historical events, fairly rare and typically accompanied by great emotion (e.g. car accident, terrorist attack, war).

Although people are often confident in their memory of the details of a flashbulb event, these events are subject to the same distortions and forgetting as any everyday event. Up to 40% of the details for these events are distorted or misremembered.

Our memory reflects also planned future events. In recent years there has been increased interest in prospective memory or remembering to perform actions in the future, such as remembering to put the garbage out on Monday or to send an email [Einstein and McDaniel, 2005]. Prospective memory has important implications; there are many prospective memory demands in everyday life in both work and non-work settings, and one of the central functions of human memory is to plan for future actions so we can respond appropriately to upcoming events [Klein et al., 2010].

## APES: MEMORY IN NON-HUMAN PRIMATES

There is no doubt that many animals have good memory. The great apes are the closest biological relatives of humans. It is clear that all great apes and humans have shared common ancestry within about the past 12–15 million years [Sarich and Wilson, 1967; Kelley and Pilbeam, 1986]. In most global sense, our memory comes as a result of evolution, and it acts as adaptive mechanism. It serves one purpose: better adaptation in surrounding environment. Endocasts from fossil hominoids and hominids reveal that the brains of *Australopithecus* were similar in size and shape to those of modern chimpanzees, and that a dramatic increase in brain size occurred as *Homo* evolved. Studies of extant great apes (bonobos, chimpanzees, gorillas, and orangutans) in the wild and in captivity have provided evidence on patterns of sociality, behaviour, communication, cognition, and self-awareness. The most obvious difference between the human brain and the brains of chimpanzees and other great apes is size. Whether we consider brain weight, cranial volume, or an encephalization index that considers brain weight relative to body weight, human brains are extraordinarily large relative to those of our nearest relatives [Tobias, 1971; Semendeferi and Damasio, 2000].

Much of what we know about human long-term memory has actually resulted from non-human primates studies. Apes memory is not fundamentally different from humans. Neuronal recording methods in non-human primates such as macaques, have demonstrated that different areas of the prefrontal cortex are specialized for different learning functions. Study in non-human primates contributed to the identification of the role of the hippocampus in memory consolidation [Zola-Morgan and Squire, 1994]. Study done in captive great apes demonstrates that they do have episodic-like memory [Martin-Ordas et al., 2010]; humans and apes share common features in terms of memory lost and deterioration due to aging. Older monkeys more frequently show signs of *forgetting,* which leads occasionally to antisocial behaviours and aggression in their family groups [Manrique and Call, 2015].

Great apes also display deferred imitation (copied behaviour over a variable delay). A two-year longitudinal study in chimpanzees and orangutan demonstrated that both species could display deferred imitation and improved over a two-year period [Bjorklund et al., 2000]. This is a form of social learning [Bandura, 1977], which is highly evolutionarily advantageous, does not require trial and error, and enables an individual to learn skills and new knowledge from others in social group.

Evolutionarily, the key difference is that humans have evolved not only social-cognitive skills geared toward competition, but also social-cognitive skills and motivations geared toward complex forms of cooperation-what we call skills and motivations for shared intentionality [Tomasello et al., 2005]. Humans are thus characterized to an inordinate degree by what has been called *niche construction* and *gene-culture coevolution* [Richerson and Boyd, 2005], as the species has evolved cognitive skills and motivations enabling them to function effectively in any one of many different self-built cultural worlds.

## ROBOTS: REPLICATION OF HUMAN MEMORY IN MACHINES

At the beginning of 21$^{th}$ century, implementation or replication of human memory in machines, especially in humanoid robots, can be seen as difficult, yet feasible task. Today robots are no longer mere curiosities, but have become an indispensable pillar of global industry. From the very beginning our fascination extended beyond mere automation to the possibility of creating an entity with our own form and function. In Homer's *Argosy*, the bronze sentinel, Talos, was created and animated by Daedalus to guard the island of Thera.

According to Jewish legend, certain great Rabbis used programming prowess to instil life in golem, creating a human-like automation that could carry out its master's command. The legend acknowledged that although the *golem* could perform simple tasks, it would never possess *ru'ah*- the breath of life bestowed on humans in the primordial creation. This myth provides an interesting context for examining the past, and future of humanoid robotics. Even in myth, humans recognized the uniqueness of their intelligence and the staggering difficulty of replicating it.

Living organisms, both humans and apes, share certain common features when it comes to brain architecture and memory. One of them is aging. Both humans and apes lose memory as a result of aging and deterioration of brain functions. Theoretically, mechanical memory of robots could last forever, reaching new frontiers of absoluteness and complexity [Turing, 1950].

This vision of *absolute and unlimited memory*, never degrading nor failing, raises hard questions. Is human intelligence more than any encoding can capture, no matter how elegant or complex? Can robots replicate or develop creativity and imagination? Humanoid robotics is not an attempt to recreate humans. Unlike industrial robots, essentially humanoids are made interact socially with people in typical, everyday environments (Fig. 2). The majority of modern robots used in industry, is, figuratively speaking, blind and deaf. They performed task only when/if controlled by human operator [Atkeson et al., 2000]. Humanoid robots are different; they are equipped with great variety of sensing modalities including taste, smell, sonar, thermal imagery, haptic feedback, tactile sensors, a range of motion sensors, and vision. Humanoids learn new tasks by sequencing existing behaviours. A spectrum of machine-learning techniques involves supervised methods where a human trainer interacts with the humanoid, and unsupervised learning where a built-in critic is used to direct learning [Pfeifer and Scheier, 1999]. In future, it is expected that human-shape robots will exhibit (or mimic) emotions (anthropopathic robots), forge relationships with humans, make decisions, and develop as they learn through interaction with the environment. Mechanical replications of cognition and memory seem to be essential in this task.

Many researchers find it ineffective to directly hard-code low-level behaviour with imperative languages like C or C++ and instead use a more biologically motivated technique such as artificial neural networks. In essence, Artificial Neural Networks (ANNs) are algorithms that mimic the biological structure of the brain. Artificial neural networks allow a supervised learning where a designer trains a system's response to stimulation by adjusting weights between nodes of a network [Fig. 3; Goodfellow et al., 2016]. Critics argue that this method fail to fully capture the recursive power of the human brain; it prohibits meta-level learning-the ability to not only generalize but also extend acquired knowledge beyond the frontiers of experience.

Although ANNs do not accurately model cognitive capacities of the human cortex, they do offer a unique and effective way to encode motor skills and low-level behaviour. It may be that, ANNs can provide a foundation on which high-level learning can be built [Michalski et al., 2013]. Other learning techniques such as reinforcement learning and genetic algorithms have also played a role in modelling various levels of learning [Rossi et al., 2006]. In whatever way Artificial Intelligence may develop in future, the need to create better mechanical memory for anthropomorphic machines will accelerate. Our brains are able to forget in a way that robots cannot. The impact of that fact is going to be profound.

## MASSES AND COLLECTIVE MEMORIES

The crowd *per se* has no memory. However, collective memory is frequently considered a representation of the past that is shared by members of a group such as a generation or nation. Instead of neutral knowledge, collective remembering typically involves beliefs, often strongly held, that are tied to identity, and hence they may evoke strong emotions when challenged. The fact that different groups can have quite different accounts of the past means that social identity and the politics of identity typically must be taken into account. The concept of collective memory is often traced to writings of the French sociologist Maurice Halbwachs (1887–1945), who argued that remembering is shaped by participation in collective life and that there are as many accounts of the past as there are collectives [Halbwachs, 1992]. In recent decades, related terms such as public memory and cultural memory [Bodnar, 1992; Lotman, 1990] have emerged alongside of collective memory and are now part of the memory industry [Klein, 2000] in the humanities and social sciences. Despite the fact that collective memory is so widely discussed in the public sphere and academic disciplines, there is little agreement on its definition. In contrast to the study of individual memory, where some concurrence exists on basic constructs and methods, definitions of collective memory, let alone the methods for studying it, vary widely.

In principle, collective memory stays in relation with flashbulb memories. The events, such as the assassination of Martin Luther King, Jr., the 1986 Challenger shuttle explosion, or the Fall of the Berlin Wall in 1989, tend to trigger collective responses. However, Brown and Kulik noted that flashbulb memory is in this case very personalized, and it can be defined as *"memory for the circumstances in which one first heard the news"* [Brown and Kulik, 1977, p. 95]. People tend to remember more clearly what they were doing when they have heard the news (not necessary the event as such). Collective memories are based on narrative retelling, and they serve one major purpose: social construction of groups.

From this perspective the group is a product, rather than a prerequisite of shared memory. This is a line of reasoning that is often traced to the writings of Mannheim, especially his essay "*The problem of generations*" [Mannheim, 1951]. There he argued for the need to follow a romantic-historical, as opposed to a positivist, approach to group membership. Specifically, he argued for the need to view a generation as subjectively constructed rather than a cohort determined by objective dates. From this perspective, generations are *mental and spiritual units* [Mannheim, 1951, p. 289] that come into being because people share historical experience and memories.

Some aspects of knowledge about the past are central to understanding and defining who we are. Just as stories we live by are essential means for personal identity, certain narratives play an essential role in forming collectives such as nation-states. In these latter cases, it is not simply knowledge about the past that is involved; it is knowledge that is crucial to understanding and defining identity and creating self-views [McAdams, 1993]. In this context, Zerubavel (2003) noted, "*acquiring a group's memories and thereby identifying with its collective past is part of the process of acquiring any social identity, and familiarizing members with that past is a major part of communities" efforts to assimilate them*' [Zerubavel, 2003, p. 3]. Assmann (1997) has discussed these issues under the heading of a distinction between history and memory. For him, the latter is vitally tied to contemporary discussions of identity. "*The past is not simply 'received' by the present. The present is 'haunted' by the past and the past is modeled, invented, reinvented, and reconstructed by the present*" [Assmann, 1997, p. 9].

Every nation creates a mnemonic community. Claims about assimilating people into a mnemonic community beg the question of how this is done and when in the lifespan the effort might be most effective. Many researchers highlight a *reminiscence bump* (ages 15–25) as critical time in the formation of a generation [Rubin at al., 1986; Conway and Pleydall-Pearce, 2000]. Moreover, memories formed in early adulthood may have significant impact upon on the political outlook of the whole generations [Mannheim, 1951, p. 288].

Perhaps the most forceful formulation of this point can be found in *Nineteen Eighty-Four,* where George Orwell warned, "*Who controls the past controls the future; who controls the present controls the past*" [Orwell, 1949, p. 204]. While seldom stated in such strong terms, all modern states make an effort to create and maintain collective remembering that will enhance both identity and loyalty. Huntington (2004) took that idea to a new level arguing that a nation is "*more specifically a remembered community, a community with an imagined history, and it is defined by its historical memory of itself"* [Huntington, 2004, p. 115]. An essential feature of remembered communities is need for the *officially recognized* memory.

## WHAT IS REAL? DISTORTION OF COLLECTIVE MEMORIES

For collective memory language matters. The relationship between imagistic and narrative forms of remembering is often formulated in terms of translation. Therefore collective memory is subjected to specific forms of *semiotic distortion* associated with language. In simple terms, the difference is that all people who participated in given historical event have tendency to select facts variously, depending on their own standing in given point of time. What makes collective memory "*collective*" is the fact these narrative tools are shared across the members of a group. Semiotic distributions create probably the biggest problems in modern world history.

Schuman et al. (2005) have recently presented a more elaborated picture of this issue. They examined Americans' account of Columbus over the past few decades and draw an important distinction between what happens with elite revisionists, on the one hand, and popular beliefs, on the other. Consider the following example (Tab. 1) showing the results from surveys of Russians in Moscow and Novosibirsk provided a list of most frequently chosen items for the WWII outline, compared with memories of the Americans in the same age group [Wertsch, 2002]. A striking fact about these two lists and the narratives they suggest is that there is no overlap. Many Russians know about the events on the American list, but they do not view them as central to the narrative of the war. For example, Russians are quite familiar with the episode called opening the second front in June of 1944. For them, this refers to something that was not only a second, but clearly a secondary front (there is no word/term for D-Day in Russian), and it is not considered a major event, let alone a turning point in World War II. Conversely, American students often knew little about events typically listed by Russians. For example, the largest tank battle in history at the Kursk plain is something that has no resonance in American collective memory.

A great deal remains to be studied when it comes to understanding the degree to which collective remembering does or does not change. The line of argument developed by Wertsch (2002) suggests that specific narratives may change fairly quickly, but at the level of schematic narrative templates, there is a high level of conservatism and resistance to change.

Fig. 1. Human memory-selected functions: A) declarative memory: abstract thinking, B) olfactory memory (smells), C) acoustic memory, D) motoric memory, E) sensory memory — taste, F) navigational memory (orientation in space).

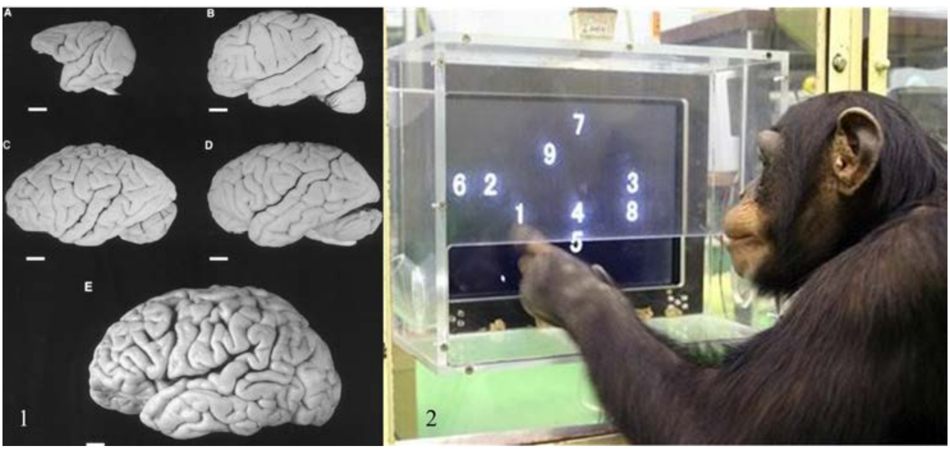

Fig. 2. Lateral views of the left hemisphere of the brains of (A) a 19-year-old patas monkey (*Erythrocebus patas*), (B) a 37-year-old Sumatran orangutan (*Pongo pygmaeus abelii*), (C) a 48-year-old Western Lowland gorilla (*Gorilla gorilla gorilla*), (D) a 45-year-old common chimpanzee (*Pan troglodytes*), and (E) a healthy 82-year-old human; after: Erwin et al.2001; 2.2. A 5-year-old chimpanzee performs a memory test with randomly placed numerals, which are later masked, accurately duplicating the line-up on a touchscreen; photo by Kyoto University, Japan.

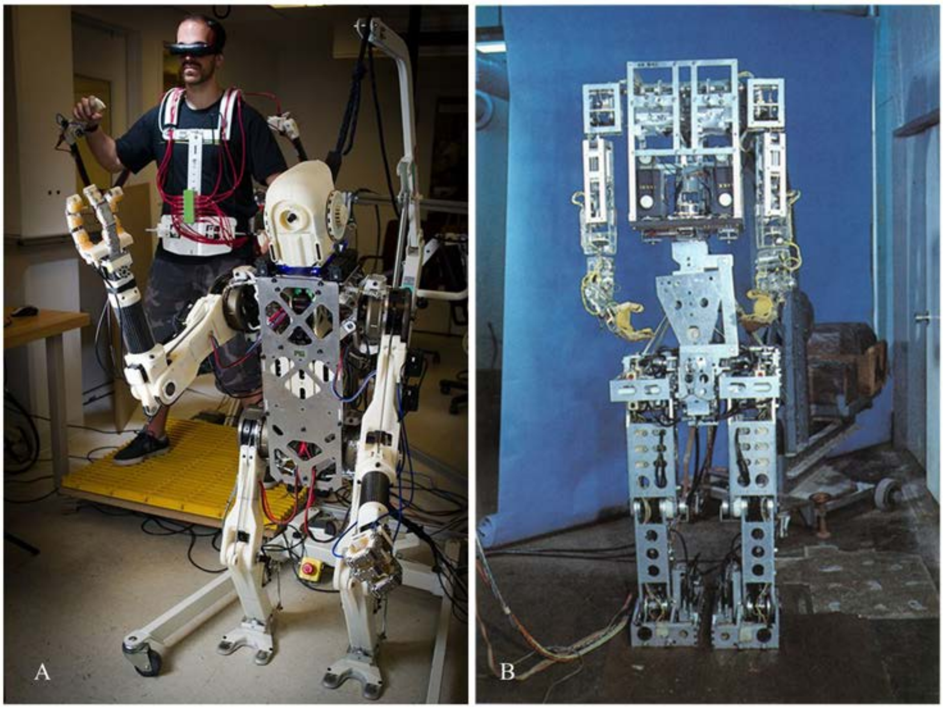


Fig. 3. (A) Humanoid robot learning motoric skills with human operator; (B) Wabot-1: first anthropomorphic robot built in the world, with integrated a limb control system, a vision system, and a communications platform; Tokyo Waseda University, 1973.

Table 1

**World War II — sociological approach: semiotic distributions in collective memories of Russian and American students [after Wertsch, 2002].**

| World War II | |
|---|---|
| Russians | Americans |
| German attack on USSR (June 22, 1941) | Attack on Pearl Harbor (December 7, 1941) |
| Battle of Moscow (winter 1941–42) | Battle of Midway (June 1942) |
| Battle of Stalingrad (winter 1942–43) | D-Day (June 6, 1944) |
| Battle of the Kursk (summer 1943) | Battle of the Bulge (winter 1944–45) |
| Siege of Leningrad (1942–44) | Holocaust (throughout the war) |
| Final Battle of Berlin (1945) | Atomic bombing of Hiroshima and Nagasaki (August 1945) |

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