DOI: 10.32703/2415-7422-2025-15-1-239-275

UDC 778.51: 778.52: 791.43:93/94

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The movement into cinema as a stage in the cinema development

Abstract. *The development of moving images is a multi-layered abstraction of movement in visual space, based on optical, mechanical, photographic and theoretical innovations. Each stage contributed to the creation of modern cinema in its technical and conceptual forms. The main aim of this study is to identify and analyze how*

scientific and technical discoveries in the fields of optics, physiology of vision, mechanics and chemistry became the basis for the emergence of a new art form – cinema, and also to show how the interaction of science, technology, culture and society contributed to the formation of a completely new system of visual thinking and mass communication. The article analyzes the history of the emergence of moving images – from optical toys of the 19th century to modern digital cinema. The emphasis is on technical, psychophysiological and technological development, as well as on modern directions that continue the evolution. The ideal "frame–interval–frame" (blackout, break) was a breakthrough in the 19th century, but it was digital technologies that gave freedom to the narrative, mixing frames in real time, adding intellectual processing and visual effects. The subject of the study was the study of the formation of scientific, technical and cultural prerequisites that led to the emergence of cinematography as a result of the evolution of knowledge about visual perception and technologies for fixing and reproducing dynamic images. Particular attention was focused on research in the field of physiology of vision, in particular on the phenomenon of persistence of visual image, which explained the illusion of movement between individual frames. The influence of technical achievements on the development of optical devices that simulated image movement, as well as the analysis of experiments with chronography, was considered. The study paid special attention to the invention of recording and projection devices. All this was considered in the context of socio-cultural and commercial processes, such as the emergence of cinemas, fair screenings, and the formation of cinema as a public spectacle. Thus, the subject of the study is not only the technical inventions themselves, but also the deeper processes of interaction of science, technology and culture, which together led to the emergence of a new means of mass communication – cinema.
Keywords: *art; culture; visual art; photography; frame; animation*

Introduction.

The term "cinematography" comes from the Greek words κίνημα ("movement") + γράφω ("to write, depict") – that is, "writing with movement" (Benis, 2023). It is the idea of movement as the essence of cinema – a natural culmination of ancient attempts to convey the dynamics of space and time through serial images, from the camera obscura (Vaniuha, Kyreia, Lemishka, Spolska, & Patron, 2024) to the praxinoscope (Lipton, 2021e) and the first film projector (Kuwahara & Fujimoto, 2022).

The emergence of the moving image – the result of a combination of discoveries in the fields of optics, mechanics, photography and the theory of perception. From primitive devices to digital sensors – cinema has gone from individual demonstration to a global visual environment.

The appearance of movement in cinema has become an extremely important stage in the cinema development, since it turned still images into living art, capable of reproducing reality in dynamics, bringing observation closer to natural human perception. Until the invention of technologies for recording and projecting motion, visual culture was limited to photography, painting, or the sequential viewing of static images that could not convey changes in states, emotions, or actions over time. Movement allowed the image to "come to life" – figures began to move, change facial expressions, and interact with space, and this was a breakthrough not only in the technical sense, but also in the viewer's perception of the artistic image. A person looking at the screen no longer simply evaluated the image, but empathized with it, because movement activated emotional involvement, created the illusion of presence. In addition, it was the emergence of movement that opened the way to the formation of a new language of cinema – montage, close-up, angles, frame duration, rhythm, which became means of cinematic thinking. The ability to capture and recreate movement allowed authors to tell stories using visual means, not only to demonstrate an event, but also to control the viewer's attention, build tension, and reveal characters. In the technical dimension, it was the result of scientific research – from the phenakistiscope, zoetrope, and other optical toys to the invention of cinema by the Lumière brothers. The principle of combining a series of photographic frames that quickly replace each other and create the effect of continuous movement became the basis of cinema as a medium. Historically, movement in cinema became the element that distinguished it from all previous forms of fine art and laid the foundation for the emergence of a new, independent art form – cinema, which combines image, time, and space. That is why the emergence of movement was not just a technical innovation, but changed the very essence of image perception, opened a new sphere of aesthetic experience, and turned cinema into the leading means of artistic and cultural influence of the 20th century.

Scientists believe that the main impetus for the appearance of motion in cinema was a combination of scientific discoveries in the field of physiology of vision, optics and image mechanics, in particular the discovery of the phenomenon of persistence of vision (delay of visual impression) and the illusion of the phi phenomenon (Bloom, 2020; Şerban, 2021; Kontou, Mills, & Menke, 2022). Persistence of vision is the ability of the human eye to retain a visual image for a short time after it has disappeared. It is thanks to this property that, if a series of individual static images with slight differences are quickly shown, the brain perceives them as continuous movement. This phenomenon became the key to understanding how to create the illusion of dynamics using successive frames. Researchers, including physicists, anatomists and opticians of the 19th century, studied the properties of vision and experimented with optical toys – phenakistiscopes, zoetropes, praxinoscopes – that demonstrated simple animation. They proved that the brain "complements" information between individual frames and perceives movement even where it is not physically present. Thus, the scientific understanding of visual perception, the development of photography and mechanisms for synchronizing images in time became the main driver for the creation of technologies that later led to the birth of cinema.

The history of the appearance of movement in cinema has been studied by many scientists of various specialties – historians of science, art historians, film critics, physiologists of vision and engineers (Gilbert, 2020; Lipton, 2021e; Veras, 2022). The subjects of research of these scientists were both technical inventions (optical devices, photography, projection devices) and the physiological principles of motion perception, as well as cultural, social and artistic aspects of the appearance and perception of motion in visual art. Their works allow to understand the cinema development not as a random event, but as a natural result of the interdisciplinary progress of science, technology and culture (Biltereyst, Maltby, & Meers, 2019; Bieberstein & Feyersinger, 2022; Vaniuha, Markovych, Hryhoruk , Matviishyn, & Toporivska, 2023).

The relevance of studying the emergence of motion in cinema from the perspective of the history of science and technology lies in the fact that this process is a vivid example of the interdisciplinary interaction of scientific discoveries, technical innovations and socio-cultural needs, which allows to understand more deeply the mechanisms of the development of scientific and technological progress in general. The study of this phenomenon shows how abstract research in the physiology of vision, optics, mechanics, chemistry of photosensitive materials and even psychology were gradually integrated into practical solutions, which ultimately led to the creation of a new form of communication – cinema. The study of the emergence of motion in cinema also makes it possible to trace how science and technology do not exist in a vacuum, but always interact with social demands, artistic searches and economic conditions. By studying this historical process, one can better understand how ideas from one field – for example, the physiology of vision – can stimulate the creation of fundamentally new technologies in a completely different – media. In addition, this topic is important for understanding how technological revolutions are formed: not only through the discoveries of lone geniuses, but as a result of the long-term accumulation of knowledge, experiments, mistakes, and exchange of ideas between scientists, engineers, artists, and entrepreneurs. By analyzing the emergence of motion in cinema, historians of science and technology receive material for modeling the general patterns of the evolution of knowledge (Barnouw, 1981; Sadoul, 1946; Utterson, 2020), the impact of scientific ideas on everyday life, and for understanding the limits and possibilities of human perception, which still determine the directions of development of modern technologies – from virtual reality to neurocinema. In this sense, the study of the origin of motion in cinema is not only historically interesting, but also methodologically valuable for a deeper understanding of the dynamics of scientific and technical creativity.

The main aim of this study is to identify and analyze how scientific and technical discoveries in the fields of optics, physiology of vision, mechanics and chemistry became the basis for the emergence of a new art form – cinema, and also to show how the interaction of science, technology, culture and society contributed to the formation of a completely new system of visual thinking and mass communication. This study aims not only to trace the technical evolution from optical toys to the cinematograph, but also to explain how the ideas that preceded these inventions were formed, what scientific concepts formed the basis of the technologies and how these concepts were transformed into applied tools capable of influencing culture and society.

Research Methods.

The article analyzes the history of the emergence of the moving image – from optical toys to digital cinema. In addition to reviewing the technical and psychophysiological aspects, a critical understanding of the influence of old technology on modern video and film practices is provided.

The methodological principles of the study of the emergence of movement in cinema from the perspective of the history of science and technology are based on an interdisciplinary approach that combines the analysis of technical, scientific, cultural and social factors. First of all, the historical-scientific method was used, which allowed to reconstruct the development of ideas, concepts and discoveries in the fields of optics, physiology of vision, mechanics, chemistry and photography, which became the basis for the creation of technologies that reproduce movement. Also important is the technical-historical analysis (Rossell, 2004; Strelko & Pylypchuk, 2021; Sayfutdinova & Galiaskarova, 2022), which made it possible to study the designs of devices (phenakistiscope, zoetrope, praxinoscope, chronograph, kinetoscope, cinematograph), the sequence of their improvement, principles of operation, authors and contexts of creation.

The method of source analysis was used (Alforova, Marchenko, Shevchuk, Kotlyar, & Honcharuk, 2021; Ebbrecht-Hartmann, Stiassny, & Henig, 2023; Oiva, et al., 2024), which included the study of archival documents, patents, publications, notes of inventors, scientific articles and memoirs of contemporaries. This made it possible to determine which scientific knowledge was used and adapted to practical needs. No less significant is the socio-cultural analysis (Pylypchuk, O. Ya., Strelko, & Pylypchuk, 2021; Weinberg et al., 2021; Vaniuha, Kyreia, Lemishka, Spolska, & Patron, 2024), which helped to reveal how social expectations, demands for spectacle, interest in the illusion of movement, mass culture and new forms of entertainment influenced the emergence and popularity of technologies that created moving images.

The method of intellectual history allowed to investigate how scientific ideas about vision, time, space and perception were formed, what philosophical and epistemological ideas underpinned technological solutions (Goodwin, 1978; Haenni, 2014; Pylypchuk, O. Ya., Strelko, Korobchenko, & Pylypchuk, O. O., 2022). In addition, the comparative method was used – to compare different versions of devices, approaches to the reconstruction of movement and the explanation of the mechanisms of its perception. An important role in the study was also played by the interpretative approach, which allowed to understand technical artifacts not only as engineering objects, but also as cultural phenomena that carried new meanings and formed new ways of seeing.

Thus, the methodology of this study is based on a set of approaches that allowed to integrate data from the history of science, technology, culture and philosophy, creating a holistic picture of how the appearance of movement in cinema was the result of a complex interaction of knowledge, technology and social context.

Results and Discussion.

Optical toys such as the thaumatrope, zoetrope, praxinoscope, and phenakistiscope were key precursors to cinema, as they first demonstrated the fundamental principles of creating the illusion of motion by rapidly changing static images (Dulac & Gaudreault, 2004; Gilbert, 2020; Kontou, Mills, & Menke, 2022). These devices, invented in the first half of the 19th century, exploited the physiological phenomenon of persistence of vision – the ability of the eye to retain an image for a short time after the disappearance of a stimulus – to create the effect of continuous motion by rapidly rotating or scrolling images. They served not only as entertaining games, but also provided inventors and scientists with a practical understanding of the mechanisms of perception of moving images, laying the theoretical and technical foundation for the subsequent development of devices capable of recording, reproducing, and projecting moving images. It was thanks to these optical illusions that the need for synchronized frame movement and lighting was realized, which ultimately led to the invention of cinema and the emergence of cinema as a new form of art and mass spectacle.

The emergence of optical toys laid not only the technical foundations (change of frames, interference of vision), but also the aesthetic and narrative basis for motion in cinema. They made motion a category that transformed space and time in cinema as a sequence of illusion, and then into the syntax of the narrative. Historiographically, these devices crossed the line from optical experiment to the artistic and production arena of public screenings, preparing society for the cinematic experience.

Thaumatrope.

The thaumatrope is an early optical illusion device invented in 1825 by the English physician John Ayrton Paris, which was an important milestone on the way to the appearance of motion in cinema, demonstrating the principles of persistence of vision and the perception of continuous motion (Wade, 2004; Riede, Johannsen, Högberg, Nowell, & Lombard, 2018; Grasnick, 2021). Structurally, the thaumatrope was a small round or oval cardboard disk image with drawings or illustrations on both sides, attached to two threads at the edges; when the disk was rapidly rotated, the threads twisted, and the images on both sides merged into one in the perception of the eye for example, the image of a bird on one side and a cage on the other rotated so that the illusion of a bird in a cage was created (see Figure 1). This simple mechanism demonstrated the basic principle of the phenomenon of persistence of vision – the ability of the human eye to retain an image for a short time after the disappearance of the stimulus, which became the foundation for the further development of animation and moving images. The thaumatrope was one of the first devices to demonstrate how rapidly changing images could create the illusion of motion, stimulating scientists and inventors to seek new devices and technologies that could reproduce a sequence of frames at a rapid pace.

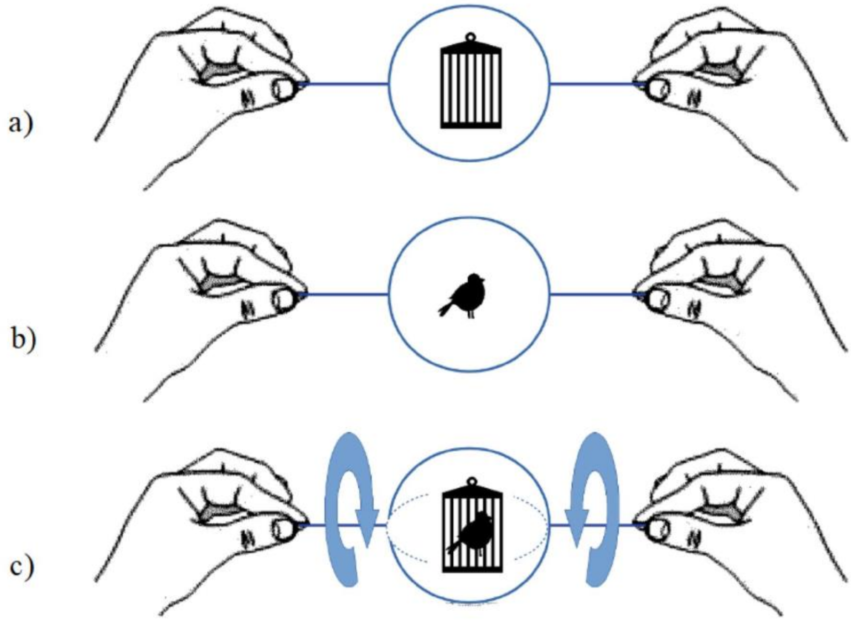

Figure 1. The holographic thaumatrope principle. Two pictures are attached to each side of the disk *(a)* and *(b)*. Attached to the disk are two pieces of string that are rapidly spun between the fingers *(c)*. (Gentet, P., Joung, Gentet, Y., & Lee, 2019).

This invention preceded such optical devices as the phenakistiscope and the zoetrope, and became the conceptual basis for later developments in cinema, where rapidly changing frames created continuous motion on the screen. Thus, the thaumatrope not only became a popular toy of the 19th century, but also played a key role in shaping the understanding of the psychological and physiological mechanisms of the perception of moving images, which ultimately led to the invention and cinema development.

Roget's Discovery.

Peter Mark Roget, a British physician, scientist, and fellow of the Royal Society of London, made important contributions to the scientific understanding of the nature of visual perception, which later played a key role in the development of the technological foundations of cinema. In 1825, he published his work "Explanation of an optical deception in the appearance of the spokes of a wheel when seen through vertical apertures" in the journal Philosophical Transactions of the Royal Society (Roget, 1825). In this work, Roget described and analyzed in detail the optical illusion that occurs when observing a moving wheel through narrow vertical apertures – for example, when the spokes of a rotating wheel appear stationary, changed, or moving in the opposite direction. This observation indicated that the human eye does not record each moment of motion separately, like a camera, but instead retains an image on the retina for a short period of time, even after the object itself has disappeared from view. This phenomenon was called the persistence of visual image, or visual after-impression (Wade, 2004; Galifret, 2006; Lipton, 2021e).

The essence of Roget's discovery was that human vision is not a continuous process of registering the real world in real time, but occurs in the form of short, successive visual impulses that our brain automatically combines into a single picture. This property of vision – a delay in perception and the ability to merge successive images – creates the conditions for the illusion of continuous motion, when individual static images shown at a certain frequency (approximately 16 frames per second or more) are perceived by us as living movement (Anderson, J. & Anderson, B., 1980). Roget was not the inventor of devices for displaying images, but his scientific analysis became the theoretical basis for the construction of optical illusions that imitated movement: the phenakistiscope, zoetrope, praxinoscope and other devices were later created taking into account this visual property described by him.

His work is considered one of the first scientific attempts to explain the physiological mechanisms of illusory movement, and it gained considerable popularity in scientific circles of the 19th century. It was thanks to it that researchers and inventors realized that to create the effect of movement, it is not necessary to make the image literally "move" – it is enough to present a series of images in the correct temporal sequence, using the ability of human vision to synthesize impressions. This is the profound methodological significance of Roget's discovery – he actually transferred research from the plane of the physical movement of an object to the study of the mechanisms of its psychophysiological perception. In addition, the research of Peter Mark Roget had an important influence on the development not only of image reproduction technologies, but also of ideas about the very nature of visual experience. He demonstrated that illusion is not an error of perception, but an important property of the visual system that allows a person to adapt to a constantly changing reality. This discovery became a kind of scientific basis for further observations by Joseph Plateau, Hermann von Helmholtz, Étienne-Jules Marey and other researchers who developed the ideas of visual persistence and worked on devices that allowed not only to study visual illusions, but to transform them into a source of aesthetic and communicative experience. Thus, Peter Mark Roget's contribution to the physiology of vision turned out to be one of the first steps towards understanding the mechanisms on which the entire cinematography would later be built – as a technical system, as an art form and as a new form of cultural expression.

Plateau's Phenakistoscope.

Joseph Antoine Ferdinand Plateau, a Belgian physicist and physiologist, became one of the most prominent researchers in the field of visual perception, and his work was fundamental to understanding the phenomenon of image persistence, a key mechanism underlying the illusion of motion and the cinema development. In 1832, Plateau published the results of his scientific experiments, in which he examined in detail why the human eye and brain perceive a sequence of static images as continuous motion if they are displayed at a sufficient speed. He found that after the visual stimulus disappears, the image does not disappear instantly, but remains on the retina for a short time – about 1/25 to 1/15 of a second (Figure 2). This delay, known as image persistence, allows the human brain to combine individual frames into a coherent picture, creating the illusion of motion (Claudet, 1865; Wade, 2016; Lipton, 2021c).

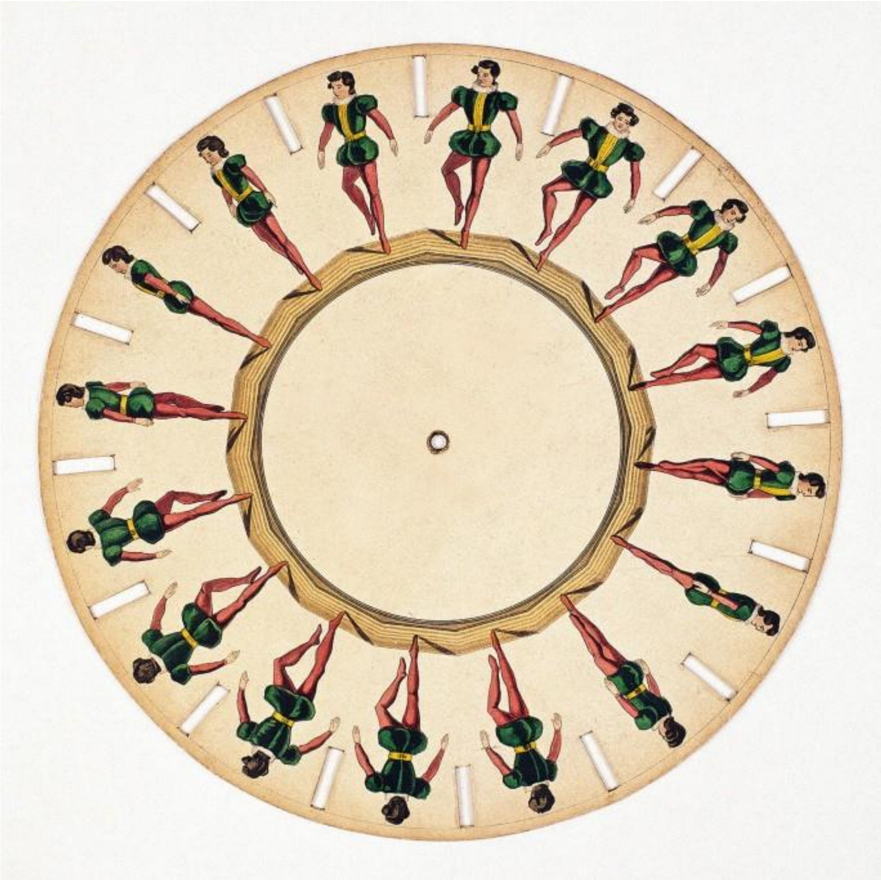

Figure 2. Phenakistoscope (Lipton, 2021c).

Plateau not only theoretically described this phenomenon, but also practically demonstrated it through the invention of an optical device – the phenakistiscope. This device consisted of a circular disk, on which a series of drawings were located around the circumference, imitating various phases of movement, as well as several slits through which the viewer could look at the rotating images. When the disk rotated at a speed corresponding to the persistence of vision, the drawings merged into a continuous moving image. The phenakistiscope became the first mechanism that made it possible to clearly demonstrate the principles that later formed the basis of animation and cinema. His invention can be considered a kind of bridge between the scientific study of visual illusions and the practical application of this knowledge to create moving images. Of particular importance in Plateau's works was the awareness of the role of the image refresh rate. He investigated how the speed of changing drawings affects the perception of movement: if the disk rotates too slowly, the illusion of movement does not arise – a person sees a sequence of separate static images; if the speed is too high, the image becomes blurry and difficult to recognize. Thus, Plateau laid the foundations for determining the optimal technical parameters that allowed achieving maximum realism of the illusion of movement – knowledge that was later used by the inventors of cinema to adjust the frame rate.

The influence of Plateau's research was extremely great and spread widely in scientific and technical circles of the 19th century. His ideas were actively adopted and developed by other scientists and inventors, such as Peter Marc Roger, Hermann von Helmholtz and Edward Muybridge (Galifret, 2006; Ayres, 2021; Lipton, 2021c). Thanks to this, the phenakistiscope and the principle of persistence of visual image became fundamental concepts that allowed the creation of the first optical toys, and later more complex devices for displaying moving images – from the zoetrope to the cinematograph.

The creation of the phenakistiscope was an important breakthrough not only from the point of view of scientific research into visual perception, but also in the context of technological development, since this device demonstrated the practical possibility of using the physiological features of human vision to create the illusion of movement. The phenakistiscope was the first invention to systematically use the principle of persistence of visual image, showing that movement can be reproduced not by actually moving an object, but by rapidly changing successive static images. This was a fundamentally new step, because previously movement in art was recorded only in static paintings, and the phenakistiscope offered the first mechanism for its reproduction in an illusory form.

The phenakistiscope was not a cinema in the modern sense, as it allowed only one viewer to view moving images at a time, through a special hole, and it also had no mechanisms for projection onto a screen. However, it was this invention that initiated a whole series of optical devices – the zoetrope, the praxinoscope, the kinetoscope, which further improved the idea of creating a moving image, and, ultimately, led to the invention of the cinema, which combined the recording, playback and mass screening of films. The phenakistiscope also made an important contribution to the development of an understanding of how to regulate the speed of image changes in order to achieve maximum realism of movement – knowledge that became the basis for determining the standard frame rate in cinema. The phenakistiscope's influence on the emergence of motion in cinema was extremely significant. It demonstrated the basic principle of cinema: movement can be created and perceived through a rapid sequence of images that the human eye and brain automatically process as continuous motion. This principle became the starting point for the development of technologies that later made it possible to capture real movement using photography and reproduce it on the screen. In addition, the phenakistiscope emphasized the importance of harmonious synchronization of the rate of frame change with the persistence time of the visual image – a parameter that became critical in the design and improvement of cinematographic devices. Knowledge of this phenomenon allowed inventors not only to create technologies that are perceived as natural movement, but also to avoid problems with flickering and blurring of the image. Thus, Joseph Plateau's phenakistiscope became not just a scientific experiment or a toy, but the first mechanism that consciously and systematically used the physiological features of vision to create a moving image. This discovery was a fundamental step on the way to the emergence of cinema – a new form of art and mass culture, which changed the way the world was perceived and the methods of transmitting information. Thanks to the phenakistiscope, the realization began that movement could be reproduced and created artificially, and not just recorded natural movements, which opened up enormous prospects for the development of visual entertainment, scientific demonstration, and later the film industry. It was Plateau's phenakistiscope that laid the theoretical and practical foundation, without which the emergence of movement in cinema as a technology and art would be impossible to imagine. In addition to its technical significance, Joseph Plateau's contribution also has a profound scientific nature, since he showed that the perception of reality is an active, complex process in which the physiological characteristics of the nervous system play an important role. His work became the foundation for further research in the field of psychology of perception, neurophysiology, and cinematic art, which to this day continue to influence the understanding of the nature of visual perception. Thanks to Joseph Plateau, we have not only a scientific explanation of how the illusion of movement arises, but also practical tools that launched a new era in the history of human culture – the era of the moving image.

Helmholtz's Works.

Hermann von Helmholtz is an outstanding German physiologist, physicist, anatomist and philosopher of science who left a deep mark on the development of the science of visual perception and played an important role in shaping the theoretical foundations of cinema. His research covered a wide range of topics related to the physiology of the eye, the mechanisms of vision and the processes of processing visual information by the brain (Hwang, 2021; Roberti & Peruzzi, 2023; Duffy, 2024). In particular, he significantly contributed to the understanding of the phenomenon that later came to be called the persistence of visual image – the ability of the visual system to retain an image on the retina for a short period of time after the disappearance of the stimulus, which became a key prerequisite for the appearance of the illusion of movement.

Helmholtz lived and worked in the second half of the 19th century – during the period of active development of physiology and experimental psychology. He combined precise laboratory research with deep theoretical analysis, which allowed him not only to confirm facts that were already known to his predecessors, such as the persistence of visual images, but also to significantly expand the understanding of these processes. He studied how the eye and brain perceive and interpret rapidly changing visual stimuli, investigated the limits and limitations of the visual system, as well as the psychological mechanisms underlying the perception of continuous motion. One of Helmholtz's significant achievements was the study of the frequency characteristics of motion perception – he investigated how the rate of change of successive images affects whether a person will see them as separate static frames or as continuous motion. His experiments showed that there is a certain optimal range of frequency of change of visual stimuli, at which images are perceived as smooth motion, as well as upper and lower limits beyond which the illusion of motion disappears. This knowledge became extremely important for the further development of cinematographic technologies, as it allowed inventors to determine the minimum number of frames per second necessary to create the effect of movement on the screen.

In addition to physiological aspects, Helmholtz also paid attention to the psychological processes associated with visual perception. He considered how the brain actively processes, completes and interprets incomplete or variable information coming from the eyes, and how this processing affects our understanding of movement and space. These ideas helped to explain why the illusion of movement occurs even when information about movement is fragmentary, and laid the foundation for research in the field of cognitive psychology and the theory of perception.

Helmholtz's works became the basis not only for the physiology of vision, but also for such sciences as psychophysics and visual research, which directly influenced the development of technologies for reproducing moving images (Hwang, 2021; Roberti & Peruzzi, 2023). His scientific discoveries provided the inventors of cinema with valuable theoretical knowledge about how best to design equipment for demonstrating motion, what frame rate and exposure parameters would ensure optimal image perception, and how to overcome the optical and physiological limitations of human vision. In general, Hermann von Helmholtz's contribution to the study of the persistence of visual images is that he systematized and deeply analyzed this phenomenon, combining physiological processes with psychological mechanisms of perception. He showed that visual experience is not simply the passive receipt of light signals, but a complex process of active image formation by the brain based on information coming from the sensory organs. His work helped the scientific and technical community to better understand how and why the human eye perceives motion from successive static frames, which ultimately became one of the fundamental principles on which the art and technology of cinematography are built. Thanks to Helmholtz's discoveries, we are able to understand the deep foundations of motion perception and the principles that allowed to transform simple images into a living, dynamic image that still captivates millions of people around the world.

Horner's Zoetrope.

The zoetrope is another of the most famous and important optical devices invented in the mid-19th century, which made a significant contribution to the development of the illusion of movement and became one of the forerunners of cinema. This device was created by the English inventor William George Horner in 1834 (Veras, 2022).

The zoetrope was a cylindrical structure, made mainly of metal or wood, with a diameter of about 20–30 cm and a height of about 15–20 cm. Vertical slots or narrow slits were evenly spaced along the sides of the cylinder, through which the viewer could look inside the device. The inner surface of the cylinder was covered with a series of sequential drawings or images that depicted different stages of the movement of an object or character – for example, a running person, a horse in motion, or a cat wagging its tail (see Figure 3.).

Figure 3. Zoetrope c.1870 (Hadjiafxendi & Plunkett, 2022).

When the zoetrope was rotated on its axis – usually by hand or with the help of a simple mechanism – the observer looked through the slits at the pictures inside. Due to the phenomenon of image persistence – that is, the delay of a visual signal on the retina, which lasts for several milliseconds after the disappearance of the stimulus – the brain processed the rapid change of successive static images as continuous movement. It was this physiological feature that made it possible to create the illusion of a living moving image from a series of still pictures that were actually drawn or printed on the inner surface of the cylinder (Kontou, Mills, & Menke, 2022).

The design of the zoetrope had several important features that affected the quality of the illusion of movement (Türkmen, 2024). First, the slits were arranged in such a way as to ensure a clear separation of the visual signals, avoiding blurring or overlapping of images. Narrow slits not only limited the field of view, but also helped to "cut off" the gaps between frames, allowing the eyes to see only one picture at a time, which significantly increased the effect of continuity of movement. Secondly, the number of pictures and slits was correlated so that at the same speed of rotation they corresponded to the same rhythm of the appearance of frames, which optimized the perception of movement. In addition, the diameter and height of the cylinder were selected for ease of viewing and an effective combination of visual and physiological parameters.

The zoetrope differed significantly from its predecessor – the phenakistiscope – in that it allowed several people to view the illusion of movement at the same time, without the need to look through the eyepiece (see Figure 4). This made the device more convenient and popular in mass use. It quickly became a popular entertainment in Victorian Europe, often demonstrated at fairs, in scientific exhibitions and even used in art installations. This fact contributed to the spread of the idea of a moving image in society and increased interest in further optical inventions.

Figure 4. Students enjoying the illusion of movement in a hand-crafted zoetrope made from a drum at Northern Vermont University's Moving Image Lab. Photo courtesy of Robby Gilbert (Gilbert, 2020).

The influence of the zoetrope on the emergence of motion in cinema was extremely significant. It demonstrated the practical implementation of the principle of sequential reproduction of static frames with a certain frequency, which allows the brain to perceive the image as continuous movement. This principle became key to the creation of subsequent optical devices – such as the praxinoscope, the kinetoscope and, ultimately, the cinematograph. The zoetrope helped inventors realize the importance of the frequency of frames and methods of demonstrating them to achieve a realistic illusion of movement. In addition, thanks to its design, it opened up the possibility of collective viewing of moving images, which became a prerequisite for the emergence of projection devices and mass film screenings (Gilbert, 2020; Kontou, Mills, & Menke, 2022; Veras, 2022).

Thus, the zoetrope became not only an important technical innovation, but also a cultural phenomenon that popularized the idea of the moving image and inspired further developments that later led to the creation of cinema – a new form of art and mass communication. Its invention revealed the potential of human vision and psyche, which allow not only to perceive, but also to actively form images of movement, which is of fundamental importance for the history of cinema and the visual arts in general.

Reynaud's Praxinoscope.

In 1877, French inventor Charles-Émile Reynaud created the praxinoscope, an innovative optical device that significantly improved and developed the ideas laid down by previous inventions, such as the phenakistiscope and the zoetrope, and became an important technological link on the way to the creation of cinema (Lipton, 2021c). The praxinoscope was designed to overcome the main shortcomings of previous devices, in particular problems with image quality and the inconvenience of viewing through narrow slits, as well as to increase the brightness and smoothness of the reproduction of moving images (Turquety, 2015).

Scholars such as Dulac & Gaudreault (2004; 2006) point out that with the advent of the praxinoscope, movement ceases to be a pure illusion – it is transformed into a narrative flow; mirrors and long turns support the principle of plot structuring and the foreshadowing of cinema. In modern media theory (Denson & Leyda, 2016) these cycles are seen as the proto-imagery "loop" of modern GIF animations, pointing to the materialism of movement and repetition as a cultural form.

The praxinoscope design consisted of a rotating cylinder, similar to a zoetrope, inside which were arranged in a circle successive drawing depicting different stages of movement (Figure 5). However, the key innovation was the installation in the center of the cylinder of a system of mirrors – usually a set of flat mirrors arranged around the axis of the cylinder so that each mirror corresponded to one drawing on the inner surface. As the cylinder rotated, the viewer looked into the central part of the device, where the mirrors reflected the internal drawings, creating a clear, unblurred and smooth image of movement. Thanks to the mirror system, it was not necessary to look through narrow slits, which significantly expanded the field of view, increased the brightness and comfort of viewing, and also reduced the flickering of the image.

The operation principle of the praxinoscope was based on the physiological phenomenon of the persistence of visual image, when the human eye retains an image on the retina for some time after the disappearance of the stimulus. The rapid rotation of the cylinder ensured a change of images with a frequency that allowed the brain to combine successive static frames into continuous movement (Cholodenko, 2024). The mirrors in the center of the praxinoscope reflected the image in such a way that each image appeared to be a separate frame, and the sequence was reproduced at the desired speed. This system made it possible to obtain a more realistic illusion of movement than was possible with the help of a phenakistiscope or a zoetrope (Eder, 1945).

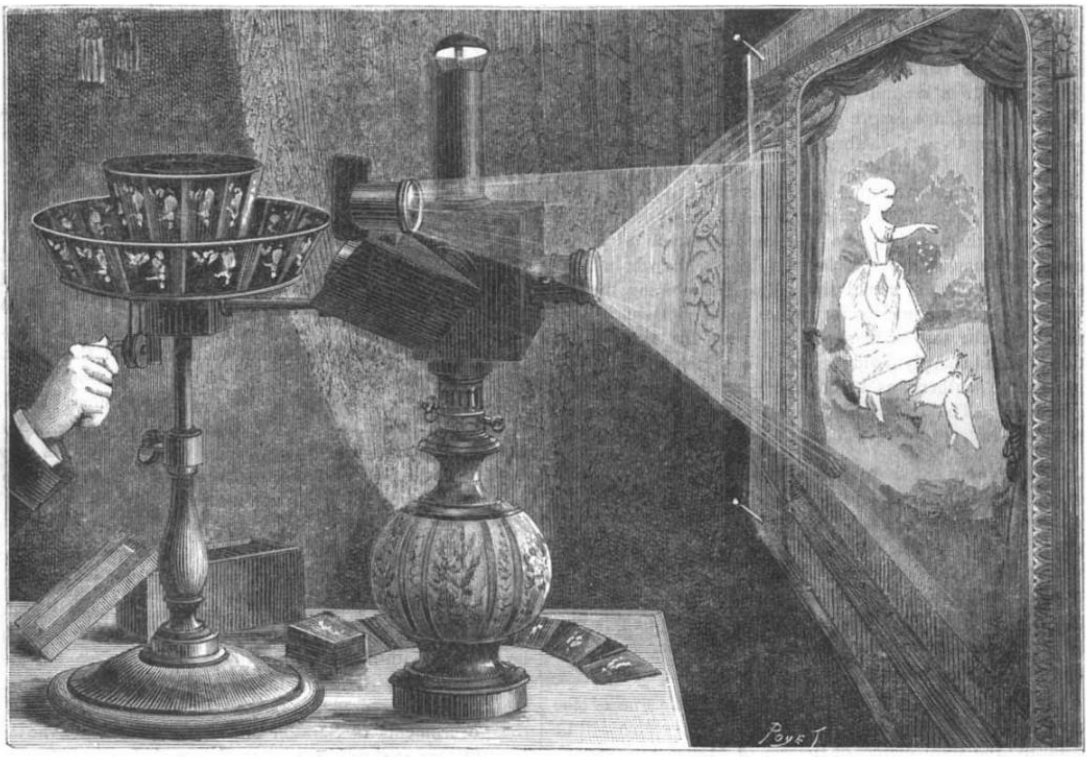

Figure 5. Émile Reynaud’s praxinoscope (Tissandier, 1882, p. 357).

An important advantage of the praxinoscope was that it eliminated the main disadvantage of the zoetrope, associated with a limited field of view and obscuration of the image through narrow slits. The mirrors provided a bright and clear reflection, which made the movement smoother and more natural. This improvement greatly improved the quality of perception of moving images and made the praxinoscope popular with a wide audience. It was widely used for entertainment, educational demonstrations, and artistic experiments, becoming an important tool for the study of movement in art and science (Türkmen, 2024).

The praxinoscope influence on the emergence of movement in cinema was extremely significant and multifaceted. First of all, it became the technical basis for the development of subsequent devices, such as Thomas Edison's Kinetoscope, which combined the recording and playback of moving images. The idea of using mirrors to improve the visual effect inspired inventors to create more complex optical systems in cinema. The praxinoscope also showed that more realistic and attractive movement could be created by improving the mechanisms for displaying frames, which stimulated further technical research and experimentation (Gilbert, 2020; Lipton, 2021e; Türkmen, 2024).

In addition, the praxinoscope contributed to the popularization of the moving image as a new form of entertainment and art, increasing the public's interest in optical illusions and animation. Its convenience and efficiency made it widespread among the general public and stimulated the search for new technological solutions, which later developed into a real cinema. The praxinoscope demonstrated the importance not only of the physiological foundations of the movement perception, but also of technical factors – design and optical elements – that determine the quality of the illusion.

Thus, Emile Reynaud's praxinoscope was not just another optical toy, but a significant step forward in the development of the technique of moving images. It combined scientific knowledge about visual perception and technological innovations, opening up new horizons for the cinema development. Thanks to this device, it was confirmed that improving the methods of reproducing images can significantly improve the perception of movement and bring it closer to realistic. The praxinoscope laid the theoretical and practical foundations that later allowed 20th-century inventors to create modern cinema, which changed the cultural landscape and the way the world communicates.

"Théâtre Optique" by Émile Reynaud.

The Théâtre Optique by Émile Reynaud, invented by French engineer and inventor Émile Reynaud in 1888, was a milestone in the history of the moving image and a real technological breakthrough that greatly expanded the possibilities of demonstrating animated pictures compared to previous optical devices such as the phenakistiscope, zoetrope and praxinoscope (Dulac & Gaudreault, 2006; Kuwahara & Fujimoto, 2022; Cholodenko, 2024). It was the first device that allowed moving pictures to be projected onto a large screen, making it possible for a large audience to view them simultaneously, which significantly influenced the social and cultural significance of the moving image.

The design of the optical theater consisted of several key elements. The basis was a long tape or roll with sequential drawings – this could be a paper or cardboard medium, on which artists manually applied hundreds or even thousands of frames of animation. Each frame on the tape reflected a separate phase of movement, which together formed a continuous sequence. This tape passed through a complex mechanism that set it in motion at a constant and smooth speed in front of a light source. Light from a lamp or mirror illuminated the frames, and a system of optical lenses and mirrors projected the image onto a large screen. This optical system included sets of mirrors that provided a clear and bright display of moving pictures, minimizing distortion and shadow effects (Kuwahara & Fujimoto, 2022).

An important technical innovation of the Reynaud theater was the system for controlling the speed of the tape. Thanks to a mechanical gearbox and a pedal drive, the operator could adjust the speed of the display, which allowed for the creation of various effects of movement – from slow and smooth to fast and dynamic. This was especially important for the transmission of dramatic scenes and plot, which made the optical theater not just a technical device, but an instrument of artistic creativity. In addition, because the tape could contain long sequences of frames, the theater allowed the presentation of entire stories with a beginning, development, and conclusion, which significantly distinguished it from the short cycles of movement in the phenakistiscope or zoetrope (Lipton, 2021e).

The theater's optical system included several lenses that focused the image on the screen, providing high resolution and brightness of the projection. The mirrors were arranged in such a way as to compensate for the distortions caused by the movement of the tape and the angle of projection, which made the image clear and stable. The entire mechanism worked in close cooperation, which allowed the operator to ensure continuity of movement and avoid the flickering or blurring that was characteristic of previous devices (Dulac & Gaudreault, 2006).

One of the most famous films shown at Théâtre Optique by Émile Reynaud is *The Clown and His Dogs* (French: *Clown et ses chiens*), created in 1892. This animated film is considered one of the first in history to be shown publicly on the big screen, even before the advent of the Lumiere brothers' film projector.

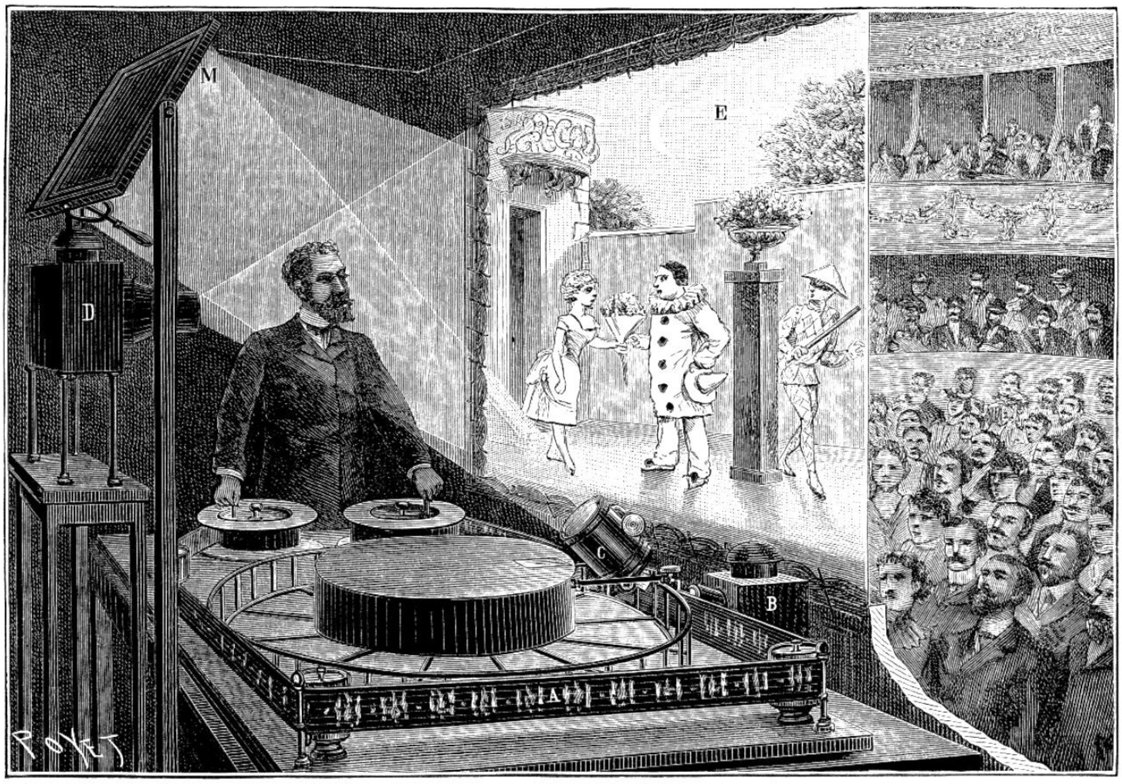

Figure 6. The Théâtre Optique by Émile Reynaud with a scene from *Pauvre Pierrot.* Gravure by Louis Poyet (Tissandier, 1892, p. 128).

The Clown and His Dog featured a dynamic scene of a clown performing tricks with his two trained dogs. The movement was rendered fluidly and vividly by the use of flexible transparent strips of hand-drawn images – approximately 500–600 frames – that were manually moved through the projection mechanism of the Théâtre Optic. This allowed for a continuous illusion of movement, and the action could be stopped and restarted at will – making the presentation more like a theatrical performance than later motion pictures.

This film, along with other Reynaud works such as *Poor Pete* (French: *Pauvre Pierrot*), demonstrated the unique style of early animation based on drawing, and was one of the first examples of how moving images could tell a story rather than merely reproduce real movement.

The influence of Émile Reynaud's optical theater on the emergence of motion in cinema was multifaceted and extremely significant (Cholodenko, 2024). First, it was the first device that allowed moving images to be shown not to a single viewer through an eyepiece, but to a large group of people simultaneously on a large screen. This created a new social format for viewing and formed the basis for mass film screenings. Second, the use of a long strip with a large number of consecutive frames was a direct technical predecessor of the film, which was later used in the cinema of the Lumière brothers and other inventors.

In addition, the optical theater demonstrated that the moving image could serve as an effective means of narration and entertainment, and not just a technical trick. This significantly influenced the cinema development as an art and business, opening the way to the formation of feature films and various genres. Reynaud not only invented the technology, but also created his own animated films, which enjoyed great success, emphasizing the importance of combining technology and creativity (Kuwahara & Fujimoto, 2022).

Thus, Émile Reynaud's optical theater was a critical stage in the development of movement in cinema, combining scientific knowledge of visual perception with technical innovations and cultural practices. This device not only confirmed the effectiveness of using sequential drawings to create the illusion of movement, but also set the standards of projection, mass viewing and narrative structure, which became the foundation for the development of 20th-century cinema. Thanks to Reynaud's theater, new opportunities were opened up for the film industry, which influenced culture and art around the world (Dulac & Gaudreault, 2006; Kuwahara & Fujimoto, 2022; Cholodenko, 2024).

Eadweard Muybridge's Experiments.

Eadweard Muybridge's experiments in motion capture, including his famous photographs of a galloping horse, were not only a sensation of their time, but also laid the foundation for the development of cinematographic technology (Lipton, 2021b). His work exemplified the combination of engineering precision, scientific curiosity, and artistic vision, and of particular value are the technical innovations he introduced in the filming process – initially with 12 cameras, and later with 24 cameras (Türkmen, 2024). Muybridge's first full-scale experiment took place on June, 1878, at the Palo Alto Racecourse, California, on the private property of Leland Stanford (Olson, 2016). The main purpose of the experiment was to prove or disprove the claim that a horse at a gallop would at some point completely lift off the ground. To record this, Muybridge placed a series of 12 large wooden cameras along the horse's path. Each camera was installed at a precise distance from each other (about 50 cm) which ensured the same time interval between exposures (Lipton, 2021b).

The most important technical achievement was the creation of an electromechanical shutter, which was activated directly by the movement of the horse (Papacosta, 2018). Along the track, he stretched thin threads that were connected to electrical contacts. When the horse ran along the track, its chest or legs cut the threads in turn, and each of the cameras was triggered sequentially (almost instantly). The shooting speed was such that each photograph captured the moment of a separate phase of the horse's body movement. The cameras used glass photographic plates that were sensitive to light, and natural sunlight was used as lighting, which required precise calculation of the shooting time.

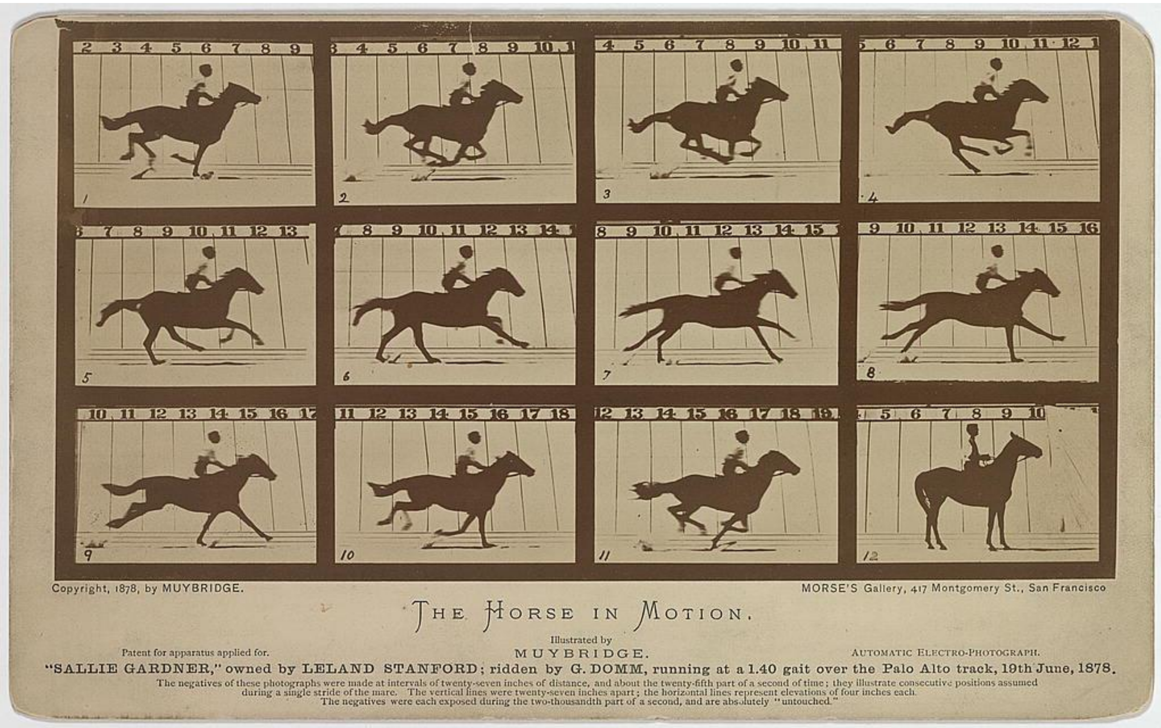

Figure 7. The Horse in motion. "Sallie Gardner," owned by Leland Stanford; running at a 1:40 gait over the Palo Alto track, 19th June/ Muybridge. California Palo Alto, ca. 1878. (Muybridge, 1878).

In 1879, Eadweard Muybridge conducted one of his most famous experiments in the study of motion, in which he first systematically used 24 cameras arranged in a row to record successive phases of dynamic human and animal movement. It was this research project, carried out in California after the successful demonstration of a galloping horse in 1878, that provided the technical, scientific, and conceptual basis for the creation of cinema, which it would become at the turn of the century (Olson, 2016). In 1879, Muybridge built a special pavilion (analogous to a modern photo studio) with a wooden platform along which 24 large-format cameras were installed in an even row at the same height. The distance between the cameras was approximately 30–40 cm, and each was directed perpendicular to the trajectory of the object. Each camera was loaded with a glass photographic plate coated with light-sensitive silver halide, designed for a short exposure.

The key innovation was the use of an electromechanical shutter mechanism, which was triggered directly by the movement of the model. Along the track, Muybridge stretched 24 cords, each of which was connected to an electrical contact that triggered the shutter of the corresponding camera. When a person or animal passed by, its body cut the cords in turn, activating each of the cameras at millisecond intervals. Thanks to this technical solution, an ideal shooting sequence was achieved, which allowed to capture the phase transitions of movement with unprecedented accuracy (Anderson, J., & Anderson, B., 1980).

The shooting was carried out outdoors in bright daylight, since the sensitivity of the emulsions of that time was very low. To compensate for this, the models (horses, dogs, people) moved along a background – a white cloth stretched behind for better contrast with the figure. Muybridge used black markings or stripes on the models' bodies and in the background to facilitate further analysis of the movement (Fresko, 2013). In some series, he began to use three rows of cameras at different angles (frontal, side and rear filming), which allowed not only to reproduce the sequence of movement, but also to study it in volume – this became the forerunner of multi-camera filming and three-dimensional cinema. He carefully processed all the negatives obtained, printed contact positives and composed them on tables that served as scientific illustrations.

The experiment of 1879 allowed Muybridge to make hundreds of unique sequences of movement. He filmed not only animals (horses, bulls, dogs, deer), but also people – men and women of different ages, including naked ones, which made it possible to study the anatomical work of muscles. Such actions as walking, running, jumping, dancing, lifting weights, throwing a discus, watering from a bucket, playing with a child, etc. were recorded.

This experiment in 1879 was the world's first systematic use of multi-camera photography for scientific purposes. It demonstrated the possibility of serializing motion – breaking it down into discrete phases and then reproducing them. All this became the basis for the concept of the moving image, which would later be embodied in film (Smiley, 2023).

Technically and conceptually, these experiments became a bridge between photography and cinema. Muybridge proved that motion could be broken down into discrete, measurable phases, which could then be reproduced again – not in real time, but with the help of a technical device. This laid the foundation for the idea of motion picture film, which in the future also consisted of successive frames. His images became the first "frames" from which the concept of the "moving image" was formed.

Thus, the meticulously planned and technically innovative experiments of Edvard Muybridge with 12 and 24 cameras became critically important not only for the scientific study of motion, but also for the birth of cinema. His research created the model of serialized imaging that underlies any film – frame by frame, movement by movement.

Zoopraxiscope.

In 1879, after a series of successful experiments in motion capture using a multi-camera setup, Edward Muybridge created a unique optical device called the Zoopraxiscope – a device that made it possible for the first time in history to demonstrate moving images to a wide audience by means of projection onto a screen (Faubel, 2015). This device was a logical continuation of his scientific research and at the same time a precursor to the movie projector. The basis of the Zoopraxiscope was a glass disk with a diameter of about 40 cm, on which a sequence of phases of one movement was applied manually or by means of photographic transfer – first in the form of silhouettes, and later in color drawings, reproduced from real photo series by Muybridge (Türkmen, 2024). The images were arranged in a circle, and the disk rotated using a manual mechanism with a friction transmission that ensured uniform movement. To create the illusion of continuous movement, a metal curtain with radial slits was placed between the light source (gas or arc lamp, later electric) and the disc – this was a stroboscopic system that allowed images to appear instantly, without overlapping one another, and activated the effect of persistence of visual image: the viewer perceived static pictures as smooth, living movement(Fresko, 2013) . The projection was carried out through a complex lens system with optical correction to focus and enlarge the image on the screen. To achieve a clear outline and high contrast, dark silhouettes on a transparent background were used, and later – colored figures drawn from the original *Animal Locomotion Series* (Figure 8–10). These discs were made by hand, often based on photonegatives, which the artists carefully converted into contour images that preserved the dynamics of each phase of the movement.

Muybridge conducted public demonstrations of the Zoopraxiscope in London, Paris, Philadelphia, New York, Chicago and other cities, accompanying the shows with comments on the physiology of movement, the theory of vision and the history of his project; the halls gathered hundreds of spectators, and the device itself began to be called a "magic window into motion" (Papacosta, 2018). This allowed him to demonstrate his series of photographs as a moving image to the public, even before the appearance of the Lumière brothers' film projectors. His lectures became the first examples in history of the synthesis of science, technology and visual art. The influence of the Zoopraxiscope on the further cinema development was decisive: technically – it was the first device to demonstrate movement through a sequence of images on a large screen, using a mechanical shutter and a projection system; conceptually – it was the first embodiment of the idea of a "moving image" as a separate phenomenon that could be reproduced, controlled and shown publicly (Faubel, 2015).

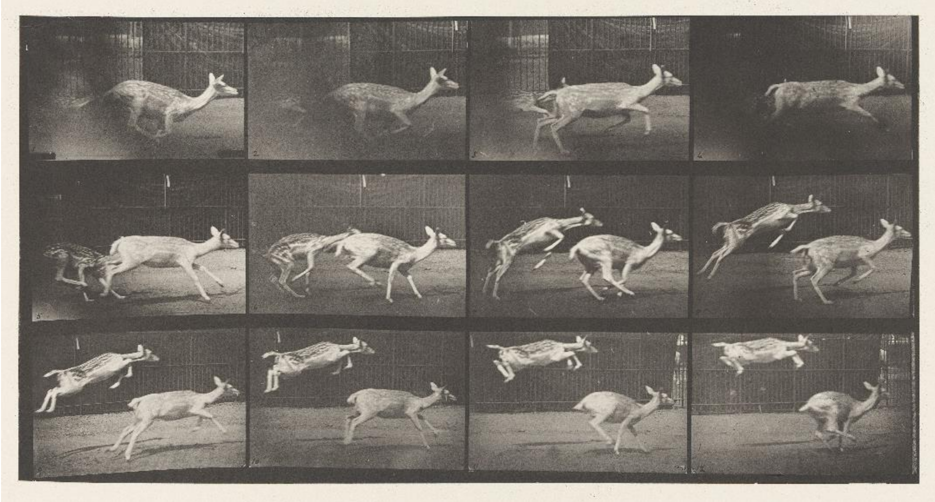

Figure 8. Two deer jumping (Muybridge, 1887a).

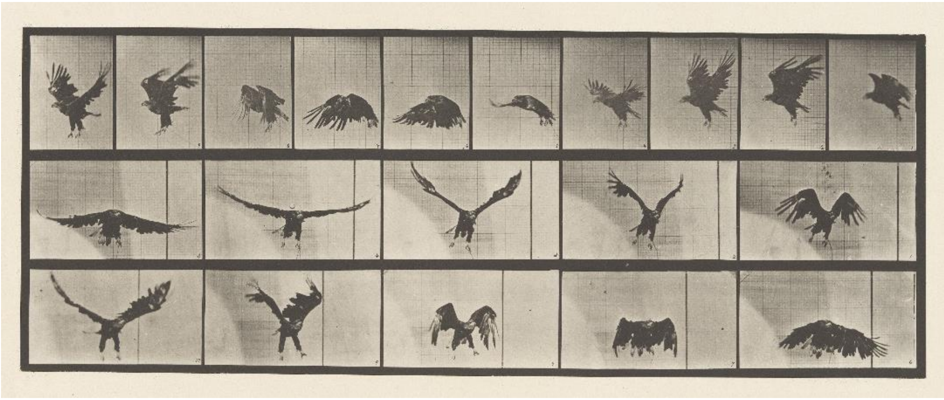

Figure 9. A bald eagle flying (Muybridge, 1887b).

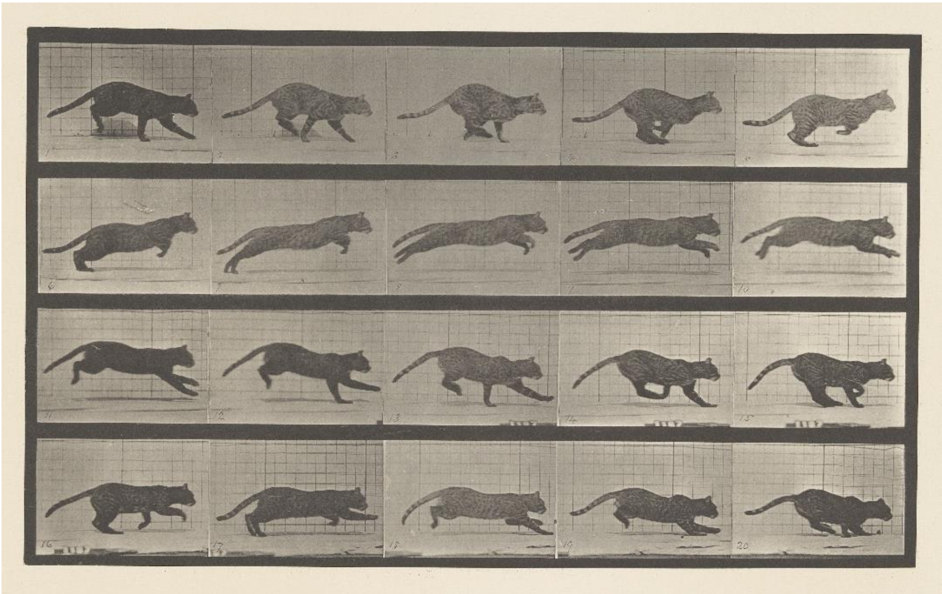

Figure 10. A bald eagle flying (Muybridge, 1887c).

The Zoopraxiscope also introduced the principle of montage – the selection and sequencing of frames to create a desired action; its principles were also directly used in the design of the film projectors of the Lumière brothers, the Skladanowsky brothers, and Edison, which replaced the glass disc with a roll of film but retained the idea of phase sequence, intermittent illumination, and optical magnification. Muybridge, by creating the Zoopraxiscope, not only showed the viewer that images could move, but he created the conditions in which scientific imagery became a source of public spectacle, and the technology of real-time reproduction became the basis for a new way of thinking about visuality and dynamics, which shaped the idea of cinema as art and technology (Schwenk & Wagner, 2010; Fresko, 2013; Lipton, 2021b).

Chronophotographic Rifle by Étienne-Jules Marey.

French physiologist, inventor, and researcher Étienne-Jules Marey made one of the most significant contributions to the development of motion capture and analysis technologies, which directly influenced the birth of cinema. His research, which began in the 1860s and 1870s and continued actively until the end of the 19th century, was focused on studying the mechanics of movement of living organisms – in particular, humans, birds, fish, horses, and other animals (Hoffmann, 2013; Lipton, 2021a; Duffy, 2024). Marey sought not only to record external forms of movement, as did Eadweard Muybridge, but also to study and accurately measure the internal physiological and kinematic processes that generate this movement. In 1882, Marey created a device that would become a landmark in the evolution of visual technology – a chronophotographic rifle (fusil chronophotographique), which allowed taking up to 12 pictures per second on a single photosensitized disk (Figure 11).

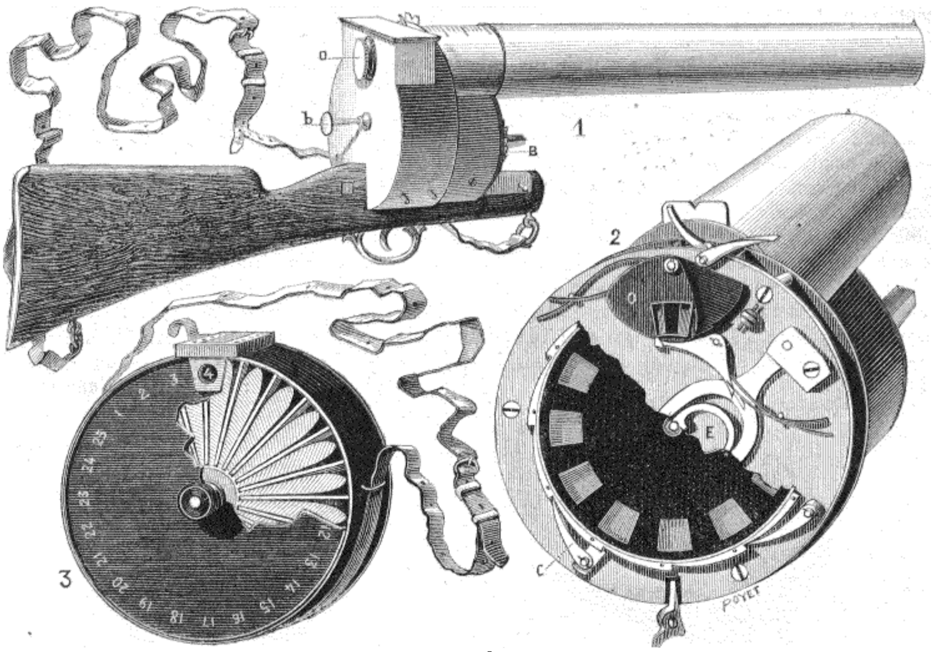

Figure 11. Chronophotographic rifle by Étienne-Jules Marey. Gravure by Louis Poyet (Marey, 1882, p. 329).

The device resembled a rifle in shape: the lens replaced the "barrel", and a round disk with a photosensitive coating – photographic film. When an object came into view, when the trigger was pressed, the disk rotated, and after short intervals of time a sequence of pictures appeared on it – one phase after another. This made it possible to record the entire cycle of movement (for example, the flight of a bird, a jump, a blow with a hand) in a single picture in the form of superimposed transparent figures located in space. Thus, Marey's chronophotography did not simply show movement – it analyzed it with mathematical precision (Duffy, 2024).

For Marey, photography was a tool of physiology. He created *the Physiological Station in Paris* (French: *La Station physiologique de Paris*) in the Parc de Monceau, where he launched complex studies with chronography, mechanography (recording movements on the smoky surface of drums), as well as pulsography, pneumography and other methods of recording bodily changes over time. His approach was deeply scientific: each image carried precise information about the position of the body in space and time, which made it possible to model, decompose and compare movements (Hoffmann, 2013).

The influence of Marey’s research on the emergence of cinematography was extremely profound (Lipton, 2021a). First, his chronophotography formed the basis for subsequent inventions in the field of high-speed photography. It was the idea of a serial image on a single medium that was transformed into the concept of a film with sequentially arranged frames. Secondly, unlike Muybridge, Marey sought not simply to record movement from the outside, but to make it measurable, reproducible and analytically understandable – this formed the technical thinking that would later become characteristic of cinematographers, editors and directors. Thirdly, his ideas directly influenced Georges Demeny – one of his students, who would later invent his own projection systems, which became another step towards the emergence of cinema (Braun & Whitcombe, 1999).

Thus, Marey was not only a physiologist, but also an inventor who, at the border of science and visual technology, created a new form of vision of time. His methods made it possible to decompose dynamics into a sequence of moments, which became the foundation for the cinematic image. If Muybridge showed that movement can be seen, then Marey proved that it can be measured, controlled and reconstructed – and this is what made his chronophotography one of the cornerstones of cinema.

Kinetoscope.

The Kinetoscope was one of the first devices for viewing moving images, invented in the late 19th century, and greatly influenced the cinema development as an art and technology (Turquety, 2015; Lipton, 2021d; Türkmen, 2024). First conceptually described by American inventor Thomas Edison in 1888, it was largely developed by his collaborator William Kennedy Laurie Dixon between 1889 and 1892. Dixon and his team at Edison's laboratory in New Jersey also developed the Kinetograph, an innovative motion picture camera with rapid intermittent, or stopmotion, film movement, for shooting films for their own experiments and, later, for commercial presentations of the Kinetoscope (Turquety, 2015; Gaines, 2023).

The Kinetoscope was a device for individual viewing of short films through an eyepiece, which became an important link between the early experiments with the moving image and the mass popularization of cinema. Structurally, the kinetoscope consisted of a wooden or metal case, inside which was located the mechanism for moving the photographic film, a light source and a system of lenses for focusing the image (Figure 12). A film approximately 35 mm wide, on which frames were sequentially applied, was passed through the exposure unit – a light beam from the lamp illuminated the frames, and through a system of lenses they were projected on a miniature scale onto the eyepiece.

(a) (b)

Figure 12. Edison projecting Kinetoscope (Improved Exhibition Model), 1898. *(a)* This projecting Kinetoscope was used for traveling exhibitions; *(b)* The flyer about the projecting Kinetoscope (Peng, 2024).

An important technical feature of the kinetoscope was the film feed mechanism – an electric motor was used, which drove a toothed shaft with a system of gears and spools, which ensured smooth and precise movement of the film at a speed of about 40 frames per second. To avoid blurring of the image during frame movement, a special cam mechanism was used, which briefly stopped the film on each frame during lighting, which is the prototype of the later shutter in film projectors. This principle of synchronizing the movement of the film and lighting was extremely important for the further cinematography development (Türkmen, 2024). The kinetoscope was compact and designed for one viewer – a person looked into a small eyepiece on top of the device, which limited the mass distribution of this device, but it was this individuality of viewing that created the basis for the further development of film screenings, because it allowed for the first time to see a moving image in real time. Technically, the kinetoscope was the first system to integrate several complex engineering solutions: a mechanism for precise film feeding, frame lighting, and an optical system of lenses for focusing the image on the eye, ensuring smooth movement and high quality of the demonstration.

This device prompted engineers and inventors to look for ways to mass demonstrate moving images – this is how the first film projectors and cinemas appeared, expanding the accessibility of cinema from individual to collective viewing. Ultimately, the Kinetoscope became a critically important milestone on the path from simple optical illusions to the complex film industry, ushering in the era of cinema and laying the technological foundation for subsequent inventions that made possible the large-scale screening of motion pictures and the cinema development as such (Turquety, 2015; Peng, 2024).

Contribution of the Lumière Brothers.

The brothers Auguste and Louis Lumière, French inventors and pioneers of cinema, made a revolutionary contribution to the development of the moving image and cinema in general, creating the cinematograph – a device that combined the functions of shooting, developing and projecting films, which was a decisive step in the formation of the film industry (Galifret, 2006; Cholodenko, 2024; Türkmen, 2024). Their invention, patented in 1895, was a mechanical device capable of simultaneously recording moving frames on photographic film, developing it and projecting the image onto a screen for collective viewing, which was significantly different from previous devices, such as Edison's Kinetoscope, which was intended only for individual viewing through an eyepiece (Peng, 2024).

Technically, the Lumière cinematograph was a compact and relatively lightweight mechanism focused on precisely synchronizing the movement of the photographic film with optical illumination, which guaranteed a smooth and clear image. The film, approximately 35 mm wide, was moved by a gear mechanism that provided stepwise movement of the frames at a frequency of about 16 frames per second – a speed that optimally balanced the efficiency of motion capture and the convenience of viewing. A particularly important technical solution was the introduction of a cam mechanism system (known as a "freeze frame"), which briefly stopped the film during the exposure of a frame, preventing the moving image from blurring (Turquety, 2015). The optical part of the cinematograph included a system of lenses that allowed the projection of a large image onto a screen, providing brightness and clarity that were previously unattainable for the kinetoscope (Türkmen, 2024). The frame was illuminated by a light source (initially these were electric lamps or gas lamps), which directed a beam through the film and lenses, providing uniform and sufficient illumination for high-quality image reproduction. The Lumière brothers also developed an improved polyester film with an emulsion based on silver salts, which was distinguished by high light sensitivity and mechanical strength, which significantly improved the quality of the shooting and increased the durability of the material (Anderson, J., & Anderson, B., 1980).

Their cinematograph was portable and lightweight, which made it possible to shoot movies in various places – outdoors, in interiors, in dynamic scenes, which had previously been impossible due to the bulkiness and limitations of other devices (Turquety, 2015). The most significant technical and cultural breakthrough was the public demonstration on December 28, 1895 in Paris, which is considered the official beginning of commercial cinema; at this event, short films (in particular, *Arrival of a Train at La Ciotat Station* (French: *L'arrivée d'un train en gare de La Ciotat*)) were presented to the public, which caused a real sensation and proved the viability of the new technology for mass entertainment and cultural exchange. By integrating shooting, development, and projection in a single device, the Lumières' invention made it possible to standardize the filmmaking process, making it technologically simpler, cheaper, and more accessible, which contributed to the rapid spread of cinema in Europe and the world. The technical features of the Lumières' cinematograph – from the carefully designed gear drive mechanism and cam shutter system to improved optics and photographic film – laid the foundation for future projectors and cameras that gave impetus to the development of both feature and documentary cinema in the 20th century.

In addition, their device opened up the possibility of collective viewing, which became the basis for the emergence of cinemas and the formation of film culture (Peng, 2024). Thus, the inventions of the Lumière brothers not only ensured the technical realization of the moving image, but also laid the foundation for an entire cinematic phenomenon – from the industrial production of films to the development of cinematography, aesthetics, and film screening as mass entertainment and an art form.

Modern Technological Consequences of the Appearance of Motion in Cinema.

The appearance of motion in cinema is not just a technical progress, it is a triumph of perception, mechanics and cognition. Each step, like a puzzle of history, has made up the unique image of the moving picture that we enjoy today. The principle of "frame-interval-frame", inherent in peripheral mechanical devices, continues to exist in the decoding of event-camera data.

Modern sensors (event cameras) record the change in brightness in each pixel asynchronously, with microsecond accuracy, wide dynamic range and without motion blur – this principle is similar to the mechanical slits of old projections. Comprehensive reviews cover the characteristics and algorithms for these cameras (recognition, tracking, reconstruction) (Gallego et al., 2020). Projection mapping transforms a two-dimensional frame into a three-dimensional experience. The simultaneous projection of images onto an uneven surface creates the illusion of movement in 3D space. It is already used in cinema (e.g., the film *Oblivion*, *Audi* advertising campaigns) and VR installations.The transition to digital video was a turning point not only in the abandonment of film, but also in the rethinking of the very acts of shooting and editing – as generated data encoded in pixels.

From "*A Trip to the Moon*" by Georges Méliès's (1902) to CGI and VR – cinema has expanded its boundaries, combining practical effects and computer animation. Modernity has moved to AI, VR and MR, which leads us from frame puzzles to virtual immersion (Das, 2023). The above image processing principles find their applications in industry for recognizing fast actions and monitoring machines – for example, low-cost systems for SMEs (Walker, Turner, & Oyekan, 2024). These principles also find their application in robotics: systems (reinforcement learning) with event-cameras provide low latency and fast robot response to the environment. These technologies in combination shape the future of AR/VR, robotics, and the video analytics industry. The latest event-oriented cameras reproduce light changes in microseconds, minimizing “motion blur” – just as early mechanical frames avoided flickering through slits. Video projection mapping is based on the principle of “synchronous blinking” of images (dynamic frame streams) to create the illusion of object movement in space.

Conclusions.

This article analyzes the stages of the emergence of a moving image – from simple optical toys to the emergence of cinematographic devices and the psychophysiological justification of motion perception.

The emergence of motion in cinema is based on mechanical principles and psychophysiology. This foundation led to the development of cinematography and modern video tools. All the technologies considered are united by a common logic: “frame → interval → frame”. However, it was only in the early 1890s that devices appeared that offered comprehensive solutions: shooting, storage, viewing and projection. The Zoopraxiscope taught the audience to see photographs as movement, the Kinetoscope transferred this to an individual format, and the Cinématographe made moving images accessible to mass audiences.

Modern cinema is not just the movement of pictures, but simulation, interaction and visual modeling. The basis of the moving image was born from the need to connect individual frames through mechanics and perception. It was this approach that gave rise to chronophotography and cinematography. The present – digital and “event”, from the camera to the sensors – grows out of the ideas of the 19th century, but with a new dimension of reconstruction and coding of movement. Event-camera and projection mapping are logical extensions of the old idea of motion through frames and gaps. These directions are now used in robotics, VR environments, event-based cameras, and real-time projections.

Funding.
This research received no external funding.

Conflicts of interest.
The authors declare no conflict of interest.

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Рух у кіно, як етап розвитку кінематографу

Анотація. *Розвиток рухомих зображень – це багатошарова абстракція руху у візуальному просторі, що базувалася на оптичних, механічних, фотографічних та теоретичних новаціях. Кожен етап сприяв створенню сучасного кіно в його технічних та концептуальних формах. Основна мета даного дослідження полягає в тому, щоб виявити й проаналізувати, як наукові і технічні відкриття в галузях оптики, фізіології зору, механіки та хімії стали основою для виникнення нового виду мистецтва – кінематографу, а також показати, як взаємодія науки, технології, культури й суспільства сприяла формуванню цілком нової системи візуального мислення та масової комунікації. У статті проаналізовано історію виникнення рухомого зображення – від оптичних іграшок XIX століття до сучасного цифрового кінематографа. Акцент зроблено на технічному, психофізіологічному та технологічному розвитку, а також на сучасних напрямах, які продовжують еволюцію. Ідеальний «кадр–інтервал–кадр» (затемнення, перерва) був проривом у XIX ст., але саме цифрові технології дали свободу розповіді, змішуючи кадри в реальному часі, додаючи інтелектуальні обробки й візуальні ефекти. Предметом дослідження було вивчення формування наукових, технічних і культурних передумов, що* *зумовили виникнення кінематографа як результату еволюції знань про зорове сприйняття та технологій фіксації й відтворення динамічного зображення. Особливу увагу було зосереджено на дослідженнях у галузі фізіології зору, зокрема на явищі персистенції зорового образу, яке пояснювало ілюзію руху між окремими кадрами. Розглянуто вплив технічних досягнень на розвиток оптичних приладів, які моделювали рух зображення, а також аналіз експериментів із хронографією. У дослідженні окрему увагу приділено винайденню апаратів для запису та проєкції. Усе це розглянуто в контексті соціокультурних і комерційних процесів, таких як виникнення кінотеатрів, ярмаркових показів, формування кіно як публічного видовища. Таким чином, предметом дослідження є не лише самі технічні винаходи, а й глибші процеси взаємодії науки, техніки та культури, які спільно призвели до виникнення нового засобу масової комунікації – кінематографа.*

Ключові слова: *культура; візуальне мистецтво; фотографія; кадр; анімація*

Received 25.12.2024
Received in revised form 27.03.2025
Accepted 03.04.2025