TIME-CRITICAL ANIMATION: COMICS, CARTOONS, COMPUTERS

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ABSTRACT

Digital animation was originally developed in scientific laboratories, and it was often seen as an ideal tool for scientific research due to its ability to visualize, analyze, and synthesize time-serial data. It was eventually incorporated into the entertainment industry when higher image resolutions made it possible to produce photorealistic digital effects, yet it still has numerous applications in such fields as biology, meteorology, geology, engineering, mathematics, and physics. Through an examination of these scientific applications, this essay will argue that the difference between live-action film and digital animation can be better understood not in terms of the visual properties of the images themselves but rather in terms of the underlying temporalities of their material substrates (i.e., the time-based medium of film and the time-critical medium of the computer). Such an approach not only offers an important contribution to contemporary theories of animation but also explains its continued relevance as a scientific instrument.

Keywords: Photography; Film; Comics; Animation; Digitization; Time.

INTRODUCTION

The practice of animation was both inspired by and based on late nineteenth-century scientific attempts to visualize, analyze, and synthesize the flow of time. Through a series of technical innovations, animators were able to emulate movement in time with increasing accuracy, thereby creating the illusion of life. As historians often note, the development of computer graphics made it possible for animators to create even more realistic effects. In many cases, it has even become difficult to distinguish between live-action and animated films, as live-action footage can be overlaid with digitally rendered backgrounds in postproduction, and the live performances of actors can be grafted onto digitally rendered figures — a practice known as “performance capture”, which employs high-tech recording devices to extract movement, texture, and light from live-action sequences. As animator Philip Kelly Denslow explains, improvements in “compositing techniques” have reduced the “margin of separation between the live action and the not-live action parts of a production”, and in the future “all forms of production will perhaps be as much animation as anything else” (Denslow, 1997, p.2 and 4). Instead of attempting to maintain the separation between these two media, Denslow suggests that it might be more accurate to refer to them both as “animated” pictures, as they were once called prior to the adoption of the term “motion pictures” in the early twentieth century.

The rise of this new hybrid form of animation, which is rapidly becoming the standard in feature film production, was made possible by digital media, which have radically transformed the practice of animation itself. As Lev Manovich explains, this new process of animation “systematically takes physical reality apart and then systematically reassembles the elements into a virtual computer-based representation” (Manovich, 2006, p.33). This process produces “synthetic images” that incorporate a wide range of visual material, including drawings, photographs, video footage, and computer-generated graphics. These images have provoked a crisis among contemporary critics, as they often blur the distinctions between photography and drawing or film and animation. According to William J. Mitchell, for example, viewers generally assume that analog photographs have not been edited or modified: “When we look at photographs we presume, unless we have some clear indications to the contrary, that they have not been reworked” (Mitchell, 1992, p.7). The idea that analog photography is uniquely capable of recording the real was thus based on the perceived indexicality of the image, which was threatened by digital photography, as there is no indexical trace that exists prior to the digital processes through which these images are generated. And because digital photographs consist solely of data, they are infinitely malleable: “The essential characteristic of digital information is that it can be manipulated easily and very rapidly by computer... Computational tools for transforming, combining, altering, and analysing images are as essential to the digital artist as brushes and pigments to a painter” (Mitchell, 1992, p.7). Mitchell’s comparison between computational and drawing tools highlights the fact that there is no essential difference between digital photography and digital animation, which challenges "our ontological distinctions between the imaginary and the real" (Mitchell, 1992, p.225). If the photograph is defined by its indexicality, in other words, then digital photography fundamentally threatens the distinction between photographs and drawings.

The digital fusion of film and animation is often discussed in relation to postmodern theory, as it provides a clear example of the "virtualization" of the modern world. Drawing on the work of Jean Baudrillard, for instance, Alan Cholodenko describes *Jurassic Park* (1993) as a "hyperreal" film in which it is impossible to distinguish between live-action footage and animation. He argues that this indistinguishability represents the most vivid manifestation of "the virtual reality of the postmodern" (Cholodenko, 1997, p.67). J. P. Telotte similarly argues that such "hybrid" animation "foregrounds the sort of reality effect that… marks the postmodern experience and that is congruent with the larger sense of our world as a mediatized realm that frequently seems to resemble a movie set" (Telotte, 2010, p.258). Like Mitchell, therefore, these critics assume that live-action footage represents a recording of the real (based on the indexical quality of filmic images) and that animation represents an expression of the animator's imagination (based on the non-indexical quality of drawn images). By disrupting this distinction, digital animation effectively makes the real indistinguishable from the virtual or recordings indistinguishable from simulations, and it embodies the phenomenon that Baudrillard famously referred to as the "simulacrum" — that is, the simulation of something that has no original, which he diagnosed as a symptom of late capitalism, and which was exemplified most prominently by the creation of Disneyland (Baudrillard, 1988).

This argument is certainly convincing, and it is quite easy to apply postmodern concepts to digital animation — particularly when it is analyzed in spatial terms. In the case of "performance capture", for example, digital animation clearly constructs a hybrid space that is both real and imaginary, as it retains indexical traces of real-life movements while simultaneously converting these movements into spatial coordinates within a purely virtual environment. However, such an approach overlooks perhaps the most crucial element of animation — namely, the relationship between technology and time. I would argue, in contrast, that digital animation reflects a fundamentally different form of temporality that is based on digital signal processing. Unlike film, which processes images at the rate of 24 frames-per-second in order to emulate the speed of human perception, computer-generated graphics represent visualizations of complex calculations, which are capable of registering micro-temporal events that cannot be perceived by the human perceptual apparatus. Instead of threatening the distinction between the real and the imaginary, therefore, digital animation has the potential to provide access to the real itself, which exceeds the human sense of time and can only be registered by technical media. When seen in this light, the difference between live-action film and digital animation can be better understood not in terms of the visual properties of their images but rather in terms of the underlying temporalities of their material substrates (i.e., the time-based medium of film and the time-critical medium of the computer). Such an approach not only offers an essential contribution to contemporary theories of animation, which often place undue emphasis on spatial rather than temporal arrangements, but also explains some of the most salient features of digital animation, such as its continued relevance as an instrument for scientific experimentation and data visualization — functions that were largely impossible during the era of analog animation. The technologies and practices involved in digital animation also have serious implications for the way we understand time itself, as they provide insight into the differences between the human realm of clock time and the technological realm of mathematical or physical time. Through a comparison of the technical processes and practices involved in the production of live-action film and digital animation, the following essay will explore the new temporalities (or “tempo-realities”) introduced by digital media and their potential implications for contemporary conceptualizations of time.

ANALOG ANIMATION AND CHRONOPHOTOGRAPHY

In a lecture delivered to the London Mathematical Society in 1947, English computer pioneer Alan Turing noted that computers were dependent on mechanical clocks, as “a digital machine must essentially deal with discrete objects” and “the clock enabled us to introduce a discreteness into time, so that time can for some purposes be regarded as a succession of instants instead of as a continuous flow” (Turing, 2004, p.382). In other words, the mechanical clock introduced a new notion of time as a succession of discrete moments instead of a continuous flow, which allowed time to be divided into units that could be measured and analyzed. This device was essential to the development of the computer because it allowed digital machines to perform a series of processing steps in precise increments. Before the development of the computer, however, the clock also led to the development of many other time-measuring instruments, which similarly sought to divide time into a discrete “succession of instants.”

In the 1860s, for example, French physiologist Étienne-Jules Marey developed numerous instruments to measure movement, including the pneumograph, which measured respiratory movement; the sphygmograph, which measured circulatory movement; and the myograph, which measured muscle movement. With the help of the odograph, which measured steps taken during walking, and the chronograph, which measured precise time intervals, Marey was able to analyze and graph the physical movements of various animals, including horses, birds, and insects. He was primarily interested in the study of movement because it was the most apparent way to record and measure the passage of time. In 1879 he also became aware of English photographer Eadweard Muybridge’s photographic motion studies, which employed a series of cameras that took photographs at precisely timed intervals. Some of these images were published in the French scientific journal *La Nature*, and Marey subsequently invited Muybridge to Paris to demonstrate his technique. Like Marey's earlier motion studies, Muybridge's image sequences provided "accurate measurements of time events which elude the naked eye", and Marey soon began to produce his own photographs, which he referred to as "time photographs" or "chronophotographs" (Marey, 1895, p.3). He also developed a "chronophotographic apparatus," which employed a flexible strip of film to capture sequential images, and a "chronophotographic projector", which allowed the images to be projected onto a screen. Unlike Mitchell, Marey was interested not in the indexical qualities of these images but rather in the fact that they could be taken at precise time intervals and arranged in linear sequences, thereby converting a dynamic temporal process into a static spatial configuration. He later became convinced that the two-dimensional format of chronophotographs was too imprecise, and he began to construct sculptures that could plot spatial coordinates in three dimensions — a practice that prefigured the development of three-dimensional animation (see Giedion, 1948, 22).

Chronophotography not only became an essential instrument in a wide range of scientific disciplines, but it also enabled the objectification and optimization of movement in the field of scientific management. Beginning in the 1910s, for example, engineers like Frank Gilbreth began to use this technology to study the movements of workers in order to increase the efficiency of industrial production (see Gilbreth and Gilbreth, 1917). In addition to its scientific and industrial applications, chronophotography was also influential in the entertainment industry, as it inspired a host of new optical devices that sought to create the illusion of movement. In 1880, for example, Muybridge copied his sequential images onto the edge of a glass disc and then rotated the disk at a precise speed to create the illusion of continuous motion. When light was directed through the glass, these image sequences could also be projected onto a screen, which allowed him to rephenomenalize the recorded movements during public lectures. This device, known as the "zoopraxiscope", is considered the first motion picture projector. Muybridge demonstrated the device for Thomas Alva Edison in 1888, and the following year Marey also demonstrated his chronophotographic apparatus and projector for Edison while he was attending the Exposition Universelle in Paris. Shortly after Edison's return, he filed a caveat with the U.S. Patent Office declaring his plans to record a series of images on a perforated strip of film that would be drawn through a projector using a claw mechanism to advance the individual frames. This device, known as the "kinetoscope", became the first commercial film exhibition system.

The immediate line of succession between chronophotography and film has encouraged historians to characterize these experiments as proto-cinematic, yet some critics have argued that the functions of these two media were diametrically opposed. For example, Siegfried Kracauer argued that films differ from photographs in that "they represent reality as it evolves in time” (Kracauer, 1960, p.41). André Bazin similarly argued that photography and film diverge in terms of their relationship to time, as photography “embalms time, rescuing it simply from its proper corruption”, while “film is no longer content to preserve the object, enshrouded as it were in an instant, as the bodies of insects are preserved intact, out of the distant past, in amber” (Bazin, 1974, p.8). Christian Metz similarly argued that photography conveys a sense that something “has been there”, while film conveys a sense of “there it is” (Metz, 1974, p.6). Film can convey this sense of living presence because of its ability to capture the dynamic process of movement in real time: “The impression of another time that makes the photograph’s presence seem unreal no longer functions when there is motion. The objects and the characters we see in a film are apparently only effigies, but their motion is not the effigy of motion — it seems real” (Metz, 1974, 8). Even though chronophotography and film were essentially identical in terms of their material form, as they both consisted of linear sequences of images recorded at precise time intervals, critics repeatedly claimed that they conveyed a fundamentally different sense of time, which was characterized as a distinction between images that were trapped in the past and images that were alive in the present. This ontological distinction was due to the static nature of photography, which records movement by converting a temporal process into a spatial configuration, and the dynamic nature of film, which rephenomenalizes movement by converting a spatial configuration back into a temporal process. This tension between the spatialization of time and the temporalization of space also explains why photography was seen as an indispensable tool for scientific research, as it could be used to record, measure, and analyze temporal phenomena, while film was largely seen as nothing more than a medium of entertainment.

While filmmakers sought to resist the objectification and rationalization of time through the temporalization of space, cartoonists sought to continue the tradition of chronophotography through the creation of comic strips. Historians often point out, for example, that many of the earliest comic strips were directly inspired by Muybridge and Marey’s chronophotographic experiments, as they similarly presented linear sequences of discrete images that were designed to capture the flow of movement in time. As Nancy Pedri explains, “comics strive to achieve… the illusion of a coherent, continuous, dynamic movement of action across time” (Pedri, 2015, p.4). She also notes that the use of panels and grids was directly inspired by “Muybridge’s chronophotographic plates, which portray the progressive movement of the photographed subject across a sequence of equally sized frames” (Pedri, 2015, p.3). Thierry Smolderen also notes that the American cartoonist Arthur Burdett Frost, who drew comic strips for Harper’s Bazaar in the 1880s, played a key role in the development of comic storytelling by representing the flow of time in the form of image sequences that were spatially divided — a practice that was directly inspired by chronophotography: “His sequences share an important trait with Muybridge’s first chronophotographic plates: an interest in trying to capture on paper the dynamic curves of spontaneous, natural activity… He understood that Muybridge's regular grid, strictly identical framings, and precisely timed intervals gave temporal, dynamic meaning to the gaps between successive images" (Smolderen, 2014, p.123). Scott Bukatman similarly notes that chronophotography and comics both "present a combination of static images, often infiltrated by visual cues of captured or continuing movement, arranged in temporal sequence" (Bukatman, 2012, p.30). As with chronophotography, therefore, "time in comics is represented as territory in space" and "this dialectic between the stasis of an individual image and the spatiotemporal movement of the sequence is… a conceptual fundament of the medium" (Bukatman, 2012, p.31). Bukatman provides a wide range of examples, including the work of Wilhelm Busch, Adolphe Willette, Théophile-Alexandre Steinlen, and Winsor McCay. Even though their works did not possess the indexical quality of photographs, as they were hand-drawn instead of mechanically imprinted, they were designed to represent continuous movement as a spatial arrangement of discrete images in fixed intervals, which made it possible to visualize and spatialize time itself.

This similarity helps to explain why so many early films were based on comic strips (which were used as storyboards long before this term entered the lexicon of filmmaking) and why the temporal delay between the development of comic strips and animated films was so short (unlike the long delay between photography and cinema). Smolderen argues, for example, that the cinematic remediation of comic strips helped to inspire the development of animation: "Now that the relationship with the new medium was becoming competitive, cartoonists probably recognized that they had to respond to the success of the concurrent medium and mark their territory" (Smolderen, 2014, p.132). This media competition was directly responsible for the first animated film, Émile Cohl's *Fantasmagorie* (1908), as Cohl reportedly saw a movie poster for a film based on one of his comic strips, and when he confronted the manager of the studio (Gaumont) he was immediately hired as a scenarist. McCay also began to incorporate short animated films into his vaudeville stage act, including *Little Nemo* (1911), which was based on his popular comic strip *Little Nemo in Slumberland* (1905–1926); *How a Mosquito Operates* (1912), which was possibly inspired by Marey's motion studies of insects; and *Gertie the Dinosaur* (1914), which was the first film to combine live-action footage with animation (thus anticipating *Jurassic Park* by nearly 80 years). McCay's films are generally regarded as the most significant examples of early animation due to his finely detailed drawings, keen sense of timing, and fluid sense of movement, and his desire to achieve photorealistic effects eventually led to the creation of *The Sinking of the Lusitania* (1918) — an animated film that recreated the 1915 sinking of the British liner RMS Lusitania, which could not have been photographed. Many other early animated film series were also based on popular comic strips, such as Gregory La Cava's *The Katzenjammer Kids* (1916–1918), Frank Moser and Leon Searl's *Krazy Kat* (1916–1917), William Nolan's *Happy Hooligan* (1916–1922), and Charles Bowers and Raoul Barré's *Mutt and Jeff* (1916–1923).

While these early animated films were based on newspaper comic strips, they nevertheless conveyed a fundamentally different sense of time. Unlike comic strips, for example, animators did not attempt to record and dissect movement by breaking it down into a series of discrete images arranged in spatial intervals; rather, they sought to rephenomenalize movement through the projection of image sequences in rapid succession. The adaptation of comic strips for animated films thus represented the conversion of a static process into a dynamic process, which was grounded in the technology of film itself. This parallel between film and animation explains not only why animators almost immediately sought to combine live action and animation — a practice that was largely foreign to the production of comic strips, which rarely included photographic material — but also why the major technological advancements in animation were consistently designed to produce realistic effects that more accurately created the illusion of life.

In 1915, for example, Earl Hurd patented the use of translucent “cels” (short for “celluloid”), which allowed drawings to be layered to produce more realistic compositions, and his partner John Randolph Bray also patented a new technique for naturalistic shading. Later that year William C. Nolan, an animator at Barré’s studio, introduced the technique of using moving panoramic backgrounds to create the illusion of camera motion, and in 1917 Max Fleischer patented the technique of “rotoscoping”, which involved tracing images from live-action footage to produce realistic movement. In 1933 Ub Iwerks also developed the first multiplane camera, which facilitated the movement of multiple backgrounds at different rates to convey a more realistic impression of depth and perspective. In 1937 an improved version of this device was developed by William Garity for Walt Disney Studios, whose films soon set the standard for subsequent animation due to the animators’ efforts to achieve the look of realist art and to incorporate the conventions of classical Hollywood narrative. Otis Ferguson noted, for example, that Disney’s films are grounded in “the realism of the everyday”, as “every incident, every foot of film, is given a solid basis in observation, so that natural action is caught and fixed” (qtd. in Waller, 1980, p.57; see also Thomas and Johnston, 1981). Michael Barrier thus concludes that the form has repeatedly tried to establish “a foundation in fact that would permit audiences…to accept the reality of what was happening in the cartoon they were watching” (Barrier, 1999, p.3). Animators also emphasize that the illusion of life was largely dependent on “time sense”, as Harold Whitaker and John Halas point out: “Timing in animation is ultimately based on timing in nature” (Whitaker and Halas, 1981, p.11). Some animators have even drawn a connection between the technological concept of “animation” and the anthropological concept of “animism” or the belief that inanimate objects can be endowed with a soul. For example, animators affiliated with the Zagreb School in the former Yugoslavia claimed that to animate is “to give life and soul to a design” (Holloway, 1972, p.9). Edwin Carels similarly argued that in live-action films “time is a reproduction of the actuality that was present in front of the camera”, but in animated films “time is a pure product, produced by the interaction of the camera and the projector” (Carels, 2010, p.59). These accounts suggest that animation is even more effective than live-action film at creating the illusion of life because it does not simply simulate recorded movement but rather produces its own movement, which grants the images a unique sense of living presence.

DIGITAL ANIMATION AND DATA VISUALIZATION

Unlike analog animation, which emerged as a medium of entertainment within the nascent film industry, digital animation emerged as a scientific instrument within research laboratories, as it was a natural outgrowth of the development of computer displays and graphics software. In 1963, for example, a graduate student at MIT named Ivan Sutherland developed the first digital animation program, which allowed users to manipulate moving images on a computer monitor using a point-plotter display. When discussing the benefits of such programs, he emphasized their scientific and technical applications:

> “An organic chemist may want to synthesize a particular molecule; he creates a picture of the molecule on a display screen and then initiates a program by which the computer presents a selection of simpler molecules from which the desired substance can be synthesized. An engineer designing a communication circuit asks the computer for a graph showing how circuit response varies with frequency. A physician studying how blood flows through the arteries obtains a plot that reveals high vorticity at exactly the locations where the lesions of atherosclerosis are most common. A physicist programs a computer to illustrate how elementary particles interact with their own electric fields to give his students some feeling for quantum-mechanical behavior. A circuit designer draws a circuit and asks a computer to simulate its operation and to plot its performance in a graph of voltage and current. A feedback theorist describes the location of poles and zeros on a complex plane and watches as the computer plots the root locus. A mathematician enters the equations for conformal mappings and observes the maps produced by each equation.” (Sutherland, 1970, p.57)

Sutherland (1970, p.57) thus predicted that digital animation would primarily be used as a problem-solving device, as it offers “insight into complex natural or mathematical phenomena”.

At roughly the same time, an engineer at Bell Laboratories named Edward Zajac produced the first digitally animated film, *Simulation of Two-Gyro Gravity-Gradient Altitude Control System* (1963), which was based on calculations of the movement and rotation pattern of an orbiting satellite that would have one side always facing the earth in order to receive and transmit radio signals. Like Sutherland, Zajac claimed that digital animation “offers a useful scientific tool, as… it gives the ability to see a process evolve in time" (Zajac, 1964, p.169). Another engineer at Bell Laboratories, Ken Knowlton, created the first computer graphics programming language, BEFLIX (short for "Bell Flicks"), which was based on Fortran — a programming language that was primarily designed for numerical calculations. This language was used by several experimental filmmakers, including Stan VanDerBeek, Frank Sinden, and Lillian Schwartz, although Knowlton emphasized that it was primarily intended for scientific research:

> "This movie language may be used to produce… visual displays for psychophysical experiments, or to produce a more common type of movie such as the expository educational film. The system may also be used to convert the output of computer-performed experiments into visual displays. For example, the person experimenting with heuristics for automatic layout of printed circuits may wish to watch in a movie the computer's attempts to search efficiently for wire paths". (Knowlton, 1964, p.70)

Like Sutherland and Zajac, Knowlton also insisted that digital animation was an ideal tool for scientific research due to its ability to visualize time-serial data, and he claimed that it was most appropriate "for serious scientific movies, for example about atoms, whose cavorting could be scripted by vectors and equations" (Knowlton, 2005, p.10).

When asked to curate a selection of digitally animated films for the Museum of Modern Art in 1968, Knowlton chose to emphasize the artistic rather than the scientific applications of this technology. One of the highlights of this program was Charles Csuri and James Shaffer's Hummingbird (1967), which featured "a sequence of movements appropriate to the bird" that were programmed into the computer. The computer then divided these movements into 14,000 frames, which were printed onto a strip of film using a microfilm plotter. While the subject of this film may have been inspired by Marey's chronophotographic studies of birds in flight, the effect was entirely different, as the images were mathematically transformed so that each line would be distributed at random and progressively reassembled during the film — a precursor to what later became known as "morphing" technology (see Rosen, 2006, p.42). In 1972 a graduate student at the University of Utah named Ed Catmull (who later became the head of Pixar and Walt Disney Studios) digitally scanned a three-dimensional model of his hand to create the film *A Computer-Animated Hand* (1972). This was considered the first 3D-rendered computer image, and Catmull continued to develop smoother curves, improved "texture mapping", and "hidden surface algorithms", which concealed the construct lines of virtual objects (Sito, 2013, p.64). In the late 1970s, a graduate student at the University of Utah named James Blinn expanded on Catmull's technique by creating "bump mapping", which added a more realistic skin surface to polygon structures. Blinn was then hired by the Jet Propulsion Laboratory at NASA to animate the data collected by the Voyager space probes, which had just been launched in

1977. When they reached the Jovian system in 1979, for example, Blinn created a digitally animated film based on NASA's trajectory-plotting data. When electronic images of Jupiter and its moons were received from the probes, he also texture-mapped them onto his planets in order to make them appear more realistic. This animation was then shown on TV news broadcasts, and a similar film depicting the Saturnian system followed soon after in 1981. These films thus combine the two trends that I have been charting here — namely, the visualization of time-serial data and the creation of increasingly photorealistic digital effects — and Tom Sito notes that they were so convincing that "most of the public probably thought they were seeing the real thing" (Sito, 2013, p.50).

Andrew Johnston emphasizes the hybrid nature of early digital animation, as it was often necessary for animators to photograph the images on computer monitors or printouts prior to editing. He thus argues that "these new technologies were eventually built around a mechanics of time taken from cinema" (Johnston, 2020, p.195) and that animators sought to enable real-time interactivity by constructing "a system modelled on a familiar experience of time found in cinema" (Johnston, 2020, p.211), which facilitated its rapid integration into films and video games in the 1970s and 1980s. Unlike its analog predecessor, however, digital animation was not produced by hand; rather, it involved the use of algorithms to generate images from numerical calculations. This not only increased the amount and complexity of information that needed to be specified, but it also meant that the process of animation became dynamic rather than static, as the calculations specified changes in position over time, and these changes did not actually exist until the animation program was implemented, at which point the individual images could be imprinted onto film. Digital animation thus possessed a fundamentally different relationship to time, which was inherent to the time-critical medium of the computer itself. Media theorists like Paul Virilio have referred to this phenomenon as "technological" or "computer" time: "The new technological time has no relation to any calendar of events nor to any collective memory. It is pure computer time, and as such helps construct a permanent present, an unbounded, timeless intensity that is destroying the tempo of a progressively degraded society" (Virilio, 1991, p.15). Ursula Heise similarly argues that the computer operates on the basis of electronic pulses whose speeds create the impression of a continuous present (Heise, 1997, p.29), and Mary Ann Doane points out that the concept of "real time" is often used "to emphasize speed of response or reaction time" of "new computer technologies", which is the basis of its "claim to the real" (Doane, 2006, p.24). These theorists thus describe the difference between analog and digital time as a tension between duration and instantaneity — a distinction that clearly recalls earlier theories concerning the difference between photography and film.

As Friedrich Kittler points out, however, there is no such thing as "real time analysis", as time events cannot be analyzed without a temporal delay: "Real time analysis simply means that deferral or delay, dead time or history are processed fast enough to move on to the storage of the next time window" (Kittler, 2017, p.14). Digital media are only able to create the impression of instantaneity because this temporal delay is less than the smallest unit of time that can be perceived by the human senses: "Technical media… make use of physical processes which are faster than human perception and are only at all susceptible of formulation in the code of modern mathematics" (Kittler, 1993, p.73–74). While analog media operate at speeds that are predetermined by the human perceptual apparatus, such as the technical standard of 24 frames-per-second for film, digital media operate at speeds that far exceed human perception. The difference between analog and digital time thus represents a difference not between duration and instantaneity but rather between simulated and real time: "The direct contrast to real time therefore is not historical time but merely simulated time, with which it is either impossible or unnecessary to keep up" (Kittler, 2017, p.201). Instead of conflating real time with the natural cycles of humanly perceived time, in other words, the computer possesses its own unique temporality, which remains inaccessible to humans. Manovich similarly argues that "the kinds of operations which can be performed on [a computer-generated image] (...) reflect first of all the logic of computer algorithms", so while it may be "cinematographic in its appearance," it remains "digital on the level of its material, and computational (i.e., software driven) in its logic" (Manovich, 2001, p.180). As a result, "*synthetic computer-generated imagery is not an inferior representation of our reality, but a realistic representation of a different reality"* (Manovich, 2001, p.202). This argument has been most recently taken up by Wolfgang Ernst, who similarly argues that digital media are able to simulate the human sense of time, but they actually possess their own unique temporality, as they divide time into segments that are too short to be humanly perceived: "As infinitesimal calculus, the cuts produced by time-discrete sampling and discrete calculation steps are able to foster the illusion of reality as continuity. This implies, however, that reality is perhaps not a becoming at all, but rather a nonlinear fabric of time" (Ernst, 2016, p.86). Like Kittler, therefore, Ernst concludes that digital media do not simply convey a false sense of reality; rather, they are able to access an entirely different reality that is based on mathematical and physical processes and that surpasses the human sense of time.

When applied to the field of animation, the theories of Virilio, Heise, and Doane seem to suggest that digital animation more accurately simulates the human sense of time in order to make it appear immediate and instantaneous, which they might diagnose as a symptom of our waning sense of historicity, our detachment from the real, and our inability to recognize the mediated nature of our sensory experiences. The theories of Kittler, Manovich, and Ernst, on the other hand, suggest a new approach to understanding digital animation — not as the simulation of natural time, as perceived by humans, but rather as the visualization of techno-mathematical time, which is beyond human perception. Such an approach helps to explain some of the most significant features of digital animation, such as its dependence on the computer, which processes time-serial data using numerical calculations, and its dynamic nature, as it does not consist of linear sequences of static images but rather registers micro-temporal changes between discrete states. Unlike analog animation, for example, digital animation does not rephenomenalize movements that have been recorded and stored as sequences of static images; rather, it actively produces movements that only exist in the moment of their technical implementation. In other words, digital animation is a function of time-critical computing processes — an experiment with time by technical means. Even though it is capable of simulating the human perception of time, which is commonly known as “real time”, it is also capable of processing movement with a level of precision that provides access to a reality that is not accessible to human perception, as Ernst explains: “What the digital image loses in terms of indexicality, as compared with the photographic image, returns at the temporal level as a hyperlink in time” (Ernst, 2016, p.156). And even though it divides continuous movements into discrete temporal units, digital signal processing remains “physically authentic” because “on the basis of techno-mathematical scanning theory its inherently discrete moments engage the temporal modes of analog signals themselves” (Ernst, 2016, p.57). While digital animation practices like “motion capture” and “performance capture” produce highly manipulated images that no longer have any referent in the real world, they are still able to record, analyze, and visualize micro-temporal events that cannot be perceived by human subjects or reproduced by human artists. Digital animation thus introduces a new conception of time that is inherent to technical media, and the basis of its claim to reality is the level of precision that it brings to the measurement of time itself.

While the content of digital animation is usually modelled on other forms of mass entertainment, like films and video games, its unique relationship to time is particularly evident when it is employed for scientific research. Unlike analog animation, which is limited to entertainment and educational films, as seen in Fleischer Studios’ *The Einstein Theory of Relativity* (1923) and Walt Disney Studios’ *Our Friend the Atom* (1957), digital animation has a wide range of applications in such fields as biology, meteorology, geology, engineering, and mathematics. It is also significant that digital animation was originally developed in scientific laboratories, and it was only adopted by the entertainment industry when higher image resolutions made it possible to produce photorealistic visual effects. While innovations in digital animation are now increasingly focused on improving these effects, it still remains an invaluable tool for scientists because of its ability to record, analyze, and visualize time-serial data. In 1987, for example, a report commissioned by the National Science Foundation’s Advisory Panel on Graphics, Image Processing, and Workstations noted that digital animation had become “a popular entertainment commodity, as evidenced by society’s enthusiasm for video games, rock videos on television, and special effects in feature films”, but that it still had “great potential for new modes of use” that would facilitate “the process of scientific discovery” (McCormick, DeFanti, and Brown, 1987, p.67). The panel thus recommended the further development of digital animation tools at research laboratories, as “the ability of scientists to visualize complex computations and simulations is absolutely essential to ensure the integrity of analyzes, to provoke insights and to communicate with others” (McCormick, DeFanti, and Brown, 1987, p.65). In recent years one of the most outspoken proponents of scientific digital animation is molecular biologist Janet H. Iwasa, who similarly argues that it can be used not only to communicate complex scientific theories but also to “enable thinking and discovery,” because “a dynamic model or illustration is the best way to effectively explore… a dynamic process” (Iwasa, 2010, p.699–700). She thus refers to digital animations as “thinking tools” that can be used to test hypotheses experimentally (for more on the use of digital animation in biology, see Kelty and Landecker, 2006; Myers, 2015; Thurtle, 2018; Nocek, 2021).

One of the key examples of these scientific applications is the animation of subatomic particles, which Ernst describes as “time-critical events” because their movements are extremely difficult to photograph due to their size and speed (Ernst, 2016, p.46). The analysis of these ultra-short temporal moments thus “requires time-critical measuring media”, like the computer, which is capable of measuring, calculating, and visualizing even the smallest micro-temporal events (Ernst, 2016, p.52). In the past, physicists attempted to analyze the movements of subatomic particles using “cloud chambers” containing supersaturated vapor that would be ionized by charged particles, which made their movements visible as trails of water droplets. Charles Thomson Rees Wilson developed one of the earliest cloud chambers in 1911, and he was able to produce the first subatomic chronophotographs by assembling sequences of discrete images that recorded the movements of vapor trails over time (Wilson 1911). After WWII, cloud chambers were replaced by “bubble chambers”, in which vapor was replaced with a superheated liquid that made the movements of charged particles visible as bubble trails. Donald A. Glaser developed one of the earliest bubble chambers in the 1950s, and he also used triggered cameras to take photographs of bubble trails, which were analyzed to measure the length, direction, and velocity of particles (Glaser and Rahm, 1955). At roughly the same time that Csuri and Shaffer were programming the movements of hummingbirds into their computer at Ohio State University, Georges Charpak also developed a “multiwire proportional chamber”, which was able to record time-serial data from a particle detector using a computer. Charpak’s chamber was essentially a gas-filled box containing several parallel detector wires connected to transistor amplifiers. When linked to a computer, it could achieve a counting rate a thousand times better than any previous particle detector. This invention effectively revolutionized the field of particle physics, as it accelerated and automated the process of recording time-serial data, and it introduced a new kind of particle event display, as photographs were replaced by digital signals that corresponded to the particles produced within an interaction and that could be manipulated in order to isolate individual particles for closer analysis (Charpak, 1978). Over time, researchers developed computer programs that were capable of recording, analysing, and visualizing particle trajectories as three-dimensional moving images, such as the Megatek system at CERN. In the 1980s, for example, two particle detectors were built at CERN to produce collisions of protons and antiprotons, and the Megatek system animated the collision data in three dimensions in order to search for evidence of W and Z bosons. (W bosons were discovered in 1983 with the help of digital animation, and some of these films can be found at videos.cern.ch/record/1049887.) The shift from chronophotography to digital animation within the field of particle physics thus not only increased the amount of data that could be collected and analyzed, as the event displays became increasingly complex and detailed, but it also provided access to ever smaller micro-temporal events, which could only be registered by technical media.

CONCLUSION

While contemporary films often illustrate the increasing difficulty of distinguishing between live-action footage and digital animation, it is not sufficient to diagnose this phenomenon as a symptom of our waning sense of historicity, our detachment from the real, and our inability to recognize the mediated nature of our sensory experiences. As this essay has shown, analog animation only appears to convey a more natural impression of time because its functions were designed to conform to the speed of signal processing within the human nervous system. These analog functions can also be emulated by digital animation, which is often used to create the illusion of an immediate, instantaneous, and unmediated present, yet digital animation has a fundamentally different relationship to time, which is based on the unique properties of digital signal processing. While innovations in analog animation allowed artists to create more convincing illusions of life, innovations in digital animation gave programmers access to the technological realm of mathematical or physical time, which made it possible to record, analyze, and visualize micro-temporal events that were inaccessible to human perception. Instead of understanding digital animation as an artform that blurs the distinction between photographs and drawings or between the real and the imaginary, as its lack of indexicality separates it from the real and its unique temporality distances it from “real time”, it can be better understood as providing more precise recordings of the real, which can be most clearly seen when it is used for scientific rather than entertainment purposes.

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