8. On the History and Aesthetics of Photorealistic Computer Graphics

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Although there is at present a considerable hype around images generated with image generation systems based on machine learning (like Dall-E or Midjourney), photorealistic computer graphics is still a far more important field of technologies and practices for the generation of photo-like images. This field is based on modeling and simulation instead of statistics (on which the AI images are based) and has a much longer history, beginning in flight simulation. It has become increasingly important since the 1970s, especially in cinema as a central component of the special effects needed for many types of entertainment cinema. Today, photorealistic computer graphics are used for essential tasks in architecture (presenting buildings yet to be built), science, advertising and many other fields.[1] There are many companies offering services in photorealistic rendering for customers.[2] Photorealistic rendering allows for the planned construction of images that look like photographs – at least until now, this has been a key advantage in comparison to AI images. In the case of AI images, even with the same prompt you get a different image every time since it is based on stochastic procedures, but this type of image is not useful for many applications. "The driving force behind computer graphics for the past 35 years has been photorealism. The quality of images created using a computer is judged by how closely they resemble a photograph."[3] Although photorealistic rendering is so essential, it has not achieved the attention it should.

1 André Kramer, "Täuschend echt. Fotorealistische Computergrafik in Film, Kunst und Werbung," in *c't* 7, 2018, 136–138.

2 When you google "photorealistic rendering," many of the hits are sites that sell software for photorealistic rendering or offer services in that field, see e.g. https://www.render4tomorrow.com/photorealistic-rendering.

3 Bruce Gooch and Amy Gooch, *Non-Photorealistic Rendering* (Natick, MA: AK Peters, 2001), 1.

In my chapter I want to highlight some important episodes in the history of the technologies and procedures that form the bases for photorealistic computer graphics, as well as fields of practice and related aesthetic strategies. Firstly, I discuss its root in flight simulation, and secondly, I underline that simulation is related fundamentally to realism. Thirdly, I will address the notion of photorealism and discuss some of the properties of photography that have to be simulated to generate a photorealistic image, as the "realism" of the computer-generated images is judged in comparison to photography. Following that, I draw some more generalized inferences on the relation of computers and photography and finish the chapter with a short conclusion.

Beginnings: Flight Simulation

Photorealistic graphics had their beginnings in civil and military aviation. In 1910, the first serious aviation accidents occurred, making it necessary to ensure that pilot training was safer, more effective and less expensive. The first ideas for flight training machines (e.g. the *Sanders Teacher* or the *Billing Trainer*) date from this time.[4] However, it was not until 1931 that the first truly operational flight was available, Edwin Link's *Link Trainer*. Pneumatic mechanisms were responsible for moving the machine, a concept which Link knew about from his father, who manufactured mechanical-pneumatic pianos. These mechanisms also allowed for the simulation of simple actuating forces on the control sticks. The audiovisual imitation of the flight situation itself was limited to a horizon line. There were two ways in which flight training could be further developed. On the one hand, by increasing the "realism" of the audiovisual representation of the flight situation and, on the other hand, by improving the interaction between the machine and the pilot. Initially, attention was focused on the first problem. In 1939, Link, now already in the service of the military, developed the *Celestial Navigator*, which was used to teach bomber pilots how to orient themselves in the starry night sky. This required a sufficiently lifelike imitation of the night sky, which was realized by a movable dome equipped with numerous lights. At the end of the 1930s, Fred Waller – sponsored by the U.S. Air Force – worked with several film projectors and screens to fill the pilot's field of vision with "realistic" images ("Cinerama"

4 Cf. J. M. Rolfe and K. J. Staples, *Flight Simulation* (Cambridge et al: Cambridge University Press, 1986), 14–17.

process). These cinematographic specifications would later be followed by computer graphics (see below). The second problem, that is, the realistic reaction of the training device to the pilot's inputs in *real time* ("interactivity"), required the machine to solve complicated systems of differential equations in the shortest possible time, something which initially could not be mastered.[5]

However, when the U.S. found itself in World War II, the development of computers was accelerated by the military need to *quickly* calculate ballistic tables necessary to predict the trajectories of bombs and projectiles. The result of this effort was the ENIAC, one of the world's first digital computers, completed in early 1946 under the direction of J. Presper Eckert and John W. Mauchly. At about the same time, in 1943, work began at the Massachusetts Institute of Technology on an *Airplane Stability Control Analyzer*, initially designed as an analog computer system. Beginning in 1945, Jay Forrester, the leader of the project group, decided to use the capabilities of digital computers that had just been developed to build a universal flight simulator that could simulate different aircraft as needed, saving an enormous amount of money in the long run.[6] This project, called *Whirlwind*, was the first to use cathode ray tubes as a graphical display. In the process, the first precursor of computer games was also developed around 1949: a bouncing "ball" (a dot) which had to be steered "interactively" into a hole by correctly choosing appropriate parameters.[7] More important than the interactivity here is that this "virtual ball" bounced approximately like a real ball: Woolley calls this event the beginning of computer simulation.[8]

5 I will not discuss the aspect of interactivity in the following. Cf. Lev Manovich, "An Archaeology of the Computer Screen," *Kunstforum International*, vol. 132 (1995), 124–136.

6 Cf. Robert Everett, "Whirlwind," in *A History of Computing in the Twentieth Century*, eds. M. Metropolis et al. (New York: Academic Press, Inc., 1980), 365–384.

7 Cf. *ACM SIGGRAPH 89 Panel Proceedings (SIGGRAPH '89)* (= *Computer Graphics*, vol. 23, no. 5) (New York: Association for Computing Machinery, 1989), 21.

8 Cf. Benjamin Woolley, *Virtual Worlds: A Journey in Hype and Hyperreality* (Oxford/ Cambridge, MA: Penguin Books Ltd, 1992), 51–52. However, Woolley does not mention that the first simulations (so-called 'Monte Carlos') were already carried out from December 1945 onwards as part of the research on the hydrogen bomb on ENIAC, cf. Peter Galison, *Image and Logic: A Material Culture of Microphysics* (Chicago/London: University of Chicago Press, 1997), 689–780.

Computer Simulation and "Realism"

In simulations, "the real process [...] must be *mapped* in mathematics so that it can then be simulated in the computer by means of algorithms."[9] In other words, from measurement data of all kinds and from these derived, mathematically formulable regularities about the behavior of the process, mathematical *models* are constructed, which describe the process with more or less approximation.[10] "Realism," the reference of the mathematical model to the structure of a real phenomenon, is thus the point where computer simulation begins.

Simulations create models of objects and these are seen as *virtual* objects. It is not possible here to outline the whole history of the concept of virtual, but instead I will only outline its emergence and use in the discourse of computer science. The specific usage of "virtual" in computer science has to be understood to get the meaning of simulation, which forms the base for photorealistic rendering.[11] "Virtual" is first used there in the context of research on virtual *memory.*[12] From 1962 at the latest, *virtual memory* took on the meaning

9 Helmut Neunzert, "Mathematik und Computersimulation: Modelle, Algorithmen, Bilder," in *Simulation. Computer zwischen Experiment und Theorie*, eds. Valentin Braitenberg and Inga Hosp (Reinbek bei Hamburg: Rowohlt, 1995), 44–55, here 44, my translation. On the early discussions of the relationship between simulations and nature, see Galison, *Image and Logic*, 738–746 and 776–780. On the various forms of computer simulation, see Michael M. Woolfson and G. J. Pert, *An Introduction to Computer Simulation* (Oxford et al: Oxford University Press, 1999).

10 An example of the fact that generated images are based on data can be found in Ivan Sutherland and Henri Gouraud, "Les Images Electroniques," *La Recherche*, no. 29 (1972), 1055–1061, here 1058, where it is about computer modeling of a Volkswagen car: "Before one can generate an 'electronic image' of an object, it is necessary to enter the definition of the object into the computer. If the object exists, perhaps this can be done by measuring the spatial coordinates of points on the surface of the object" (my translation).

11 See Jens Schröter, "What is a Virtual Image?," in *Yearbook of Moving Image Studies: Trilogy of Synthetic Realities I: Virtual Images*, eds. Lars C. Grabbe, Patrick Rupert-Kruse, and Norbert M. Schmitz (Marburg: Büchner, 2021), 91–104.

12 According to the *Oxford English Dictionary*, the term *virtual memory* was introduced in 1959 in a paper presented at the *Eastern Joint Computer Conference*, see John Cocke and Harwood G. Kolsky, "'The Virtual Memory' in the STRETCH Computer," *Proceedings of the 1959 Eastern Joint Computer Conference. Papers presented at the Joint IRE-AIEE-ACM Computer Conference* (Boston, MA: Association for Computing Machinery, 1959), 82–93. However, in this text *virtual memory* means something different than in the

we know today: The main problem of electronic computers was that memories with short access times were expensive. Consequently, information that was not currently required had to be swapped out of the main memory into the auxiliary memory. *Memory allocation* refers to the process of deciding which data is currently needed in the main memory and which can be swapped out to the auxiliary memory. In the early years of computer programming, allocation had to be carried out by the programmers themselves using appropriate routines. When higher programming languages came into use in the mid-fifties and the programs became more complex, this procedure turned out to be an obstacle. There were a number of proposed solutions, and the concept of *virtual memory* finally prevailed.[13] It is an automatic method of memory allocation that was first used in the *Atlas computer* developed in 1961. Virtual memory creates the illusion of large, available memory. The programmer can dispose of the "address space" or "name space"[14] as if it designated a contiguous memory. Invisibly to the programmer, the computer system assigns the virtual addresses to the real addresses in the "memory space"[15] with the help of an address-translation function.[16] Only the data which are needed by the program in a certain moment are loaded from the computer system into the actual main memory. Virtual memories therefore operate on the basis of the separation of the logical address space from the physical memory space.

This separation of logical structure and material substrate is the core of the virtual, at least in the discourse of computer science. The very difference between software and hardware is, in this sense, a virtualization. A computer executes software – a logical structure – which makes it possible, for example, to simulate another computer (thus creating a *virtual machine*). The scientifically, medically or militarily used computer simulation of a real object or process consists in the fact that – depending on the question – different mathematically formalizable structures are detached from the materiality of the object (with the example *Whirlwind*: the bouncing behavior of a ball from the material

common usage of the term today. The 1959 text describes as a *look-ahead unit that* is now called *cache* memory – a small intermediate memory that reacts particularly quickly and holds data frequently used by the processor.

13 Cf. Peter J. Denning, "Virtual Memory," *ACM Computing Surveys*, vol. 2, no. 3 (1970), 153–189.

14 Ibid., 157.

15 Which includes both real main memory and auxiliary memory (e.g. hard disks).

16 Ibid. 158.

ball made of rubber), in order to serve then as basis of a model (with the example *Whirlwind*: a ball model is generated, that is, a "virtual ball").[17] The models can then be modified, e.g., to predict the behavior of the simulated process under different conditions or, of particular interest, to anticipate the behavior of a possible future process based on the simulated process. Finally, the models and their behavior are mapped to different displays, be they auditory, visual, or even haptic. Here, the visual output does not necessarily have to be "photorealistic" – in the simulation of molecular processes, for example, this would not make sense.

Photorealism

The virtual object of a simulation is therefore a mathematically formalized structure of a "real" object, detached from matter depending on the purpose, and represented approximately in the computer. In flight simulations, i.e. virtual flights, the projected later flight situation must be anticipated as *realistically* as possible to enable adequate preparation. In addition to the interactivity excluded here, this realism refers to the character of the display through which the pilots see and/or hear the "landscape" through which they are supposedly flying and, if applicable, the "opponents" against whom they are supposedly fighting. The structures of "real" visual experience must therefore become able to be virtually modelled. Generated images are thus approximated to "natural vision" by, for example, procedures for generating lighting effects in generated images that draw on empirically gained knowledge about the behavior of light on surfaces: a simulation with which a *virtual light* is generated.[18]

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17 This detachment from materiality refers to the virtual object in relation to the real object, but not to the hardware that underlies any computational process and limits, for example, the computer speed, which can play a crucial role in the simulation of highly complex phenomena.

18 Cf. Axel Roch, "Computergrafik und Radartechnologie. Zur Geschichte der Beleuchtungsmodelle in computergenerierten Bildern," in *Geschichte der Medien*, eds. Manfred Faßler and Wulf Halbach (Munich: Fink, 1998), 227–254, here 250: "Actual, empirical measurements for reflection properties on rough surfaces are namely available in particular detail for radar. It is precisely these empirical curves on which the theoretical scattering fields of Cook/Torrance are based" (my translation). Roch refers here to Ro-

However, it is with flight simulation that the pursuit of *photorealism* begins, something that characterizes large parts of computer graphics. Computer scientists Martin E. Newell and James F. Blinn, for example, write explicitly: "In the mid-sixties techniques for producing photograph-like images of modelled three dimensional scenes started to emerge. The initial motivation for these was in flight simulation, where the illusion of reality is important."[19] That is, computer graphic realism is not completely absorbed in the conception of simulation as a computer model of a real phenomenon, but often encompasses two objectives that are not identical: "The goal of realistic image synthesis is to produce images that are indistinguishable from photographs or from visual impressions of actual scenes."[20] The fact that the goal of creating a computer graphic that reproduces the "natural" visual impression is not always clearly separated from that of perfectly simulating photography or film is evidence of the paradigmatic function of photographic media even in the digital age. Thus, "realistic" means that the image generated is based on the conventions of viewing that have been shaped by photographs and films.[21] Therefore, research on photorealism[22] refers to the adoption of already established conventions from photography and film.

This similarity is simulation insofar as the properties (of certain characteristics) of photography and film are empirically measured and these data are

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bert L. Cook and Kenneth E. Torrance, "A Reflectance Model for Computer Graphics," *ACM Transactions on Graphics*, vol. 1, no. 1 (1982), 7–24.

19 Cf. Martin E. Newell and, James F. Blinn, "The Progression of Realism in Computer-Generated Images." in *ACM 77th Proceedings of the Annual Conference* (New York: Association for Computing Machinery, 1977), 444–448, here 444.

20 Konrad F. Karner, *Assessing the Realism of Local and Global Illumination Models* (Oldenbourg/Graz: University of Technology, 1996), diss., 10.

21 Cf. Gary W. Meyer, Holly E. Rushmeier, Michael F. Cohen, Donald P. Greenberg, and Kenneth E. Torrance, "An Experimental Evaluation of Computer Graphics Imagery," *ACM Transactions on Graphics*, vol. 5, no. 1 (1986), 30–50. The text describes an experiment to evaluate the realistic nature of computer images: A video image of a simple, real-world arrangement of objects and their lighting is presented to test subjects alongside a video image of a generated graphic representing that arrangement: If these can no longer say with certainty what the image of the real arrangement is, the image is considered realistic – under the very constant condition of the video image, which here, although electronic, is counted among the photographic media insofar as it is based on the storage of light.

22 See, among others, E. Nakamae and K. Tadamura, "Photorealism in Computer Graphics – Past and Present," *Computer and Graphics*, vol. 19, no. 1 (1995), 119–130.

used as a basis for the computer models. That is, the photographic nature of photorealism is by no means merely rhetorical in the sense that superficial signs or the "look" of photography are imitated – as, for example, in the artistic current of photorealistic painting, which emerged at about the same time as the first photorealistic efforts of computer graphic artists. Rather, the properties of the photographic (and also cinematographic) apparatus are simulated, and that means, according to the definition of the virtual suggested above, that a *virtual camera* is a real camera – not merely an imitation or even mere fiction – which can be increasingly approximated to its material model, depending on the data available (if a realist camera model is the goal, of course the model can also be willfully altered). This virtual camera is now used to virtually photograph a virtual object field illuminated by a virtual light source.[23] Basically, these are all mathematical structures interacting via mathematical operations.

Virtual photographs or films would therefore have to follow the fundamental characteristics of chemical photography with regard to their visual appearance,[24] of which at least four can be named – photograms excepted.

First, the wealth of unintended details that make up the – as one could say in line with Roland Barthes – "effet du réel."[25] Many generated graphics are classified as not yet realistic enough precisely because they appear too "clean," i.e. show too few scratches, stains and the like on the surfaces of the depicted objects.[26] An analog photograph taken by Lewis H. Hine in 1908 shows many stains, scratches and dirt on the floor which were incidentally in the scene when Hine took the photo (Fig. 8.1). This indexical property of photography is often simulated in photorealistic computer graphics.

23 Cf. William J. Mitchell, *The Reconfigured Eye: Visual Truth in the Post-Photographic Era* (Cambridge, MA/London: MIT Press, 1992), 117–135. Cf. Timothy Binkley, "Refiguring Culture," in *Future Visions: New Technologies of the Screen*, eds. Philip Hayward and Tana Wollen (London: BFI Publishing, 1993), 92–122, 103–105.

24 Montage rules etc. in film are not included here.

25 Cf. Roland Barthes, "L'effet du reel," *Communications*, no. 11 (1968), 84–89, esp. 87–88.

26 Cf. Newell and Blinn, "Progression of Realism," 445–446.

8.1 Lewis H. Hine, Child Laborer, 1908.

Wikimedia Commons, free to use, https://commons.wikimedia.org/wiki/File:Child_laborer.jpg

Secondly, there are the effects caused by the camera optics, especially the image organization according to the rules of central perspective, because computer-generated images could also obey any other projection, but if they want to be photorealistic, they follow the perspective organization handed down by photography and film (see again Figure 8.1 – how the lines of flight recede into the background).[27]

Moreover, computer graphics research strives to simulate not only perspective projection, but also the specific effects of cameras, such as the empirically measurable distortions and focus effects of lenses and shutters, or the shutter speed-dependent motion blur, i.e., the blurring of fast-moving objects (the simulation of "motion blur" refers *ex negativo* to the sharp mo-

27 Cf. James D. Foley et al., *Computer Graphics. Principles and Practice. Second Edition in C* (Reading, MA: Addison-Wesley Longman, 1995), 230–237, esp. 231: "The visual effect of a perspective projection is similar to that of photographic systems and of the human visual system."

mentariness of most photographic images).[28] A photograph by Alvegaspar of a running chicken shows an example of photographic motion blur (Fig. 8.2).

8.2 Alvegaspar, A Chicken Running / Un poulet en train de courir, 2009.

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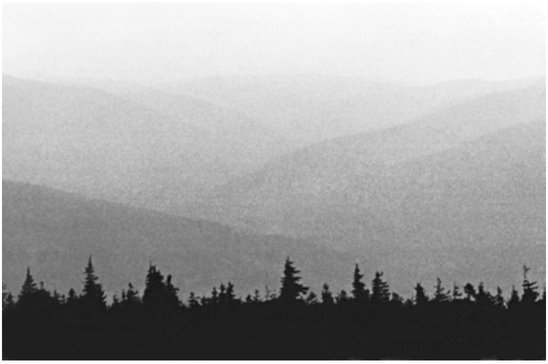
Thirdly, there is the cropped nature of photographic and cinematic images. Except for rare staging strategies found predominantly in the discourse of art that seek to close off the space of these images, images are organized centrifugally – cropped objects, glimpses from within the image space, etc., refer to

28 On the simulation of camera and motion blur, see Michael Potmesil and Indranil Chakravarty, "Synthetic Image Generation with a Lens and Aperture Camera Model," *ACM Transactions on Graphics*, vol. 1, no. 2 (1982), 85–108; "Modeling Motion Blur in Computer-Generated Images," in *Proceedings of the 10th annual conference on Computer graphics and interactive techniques (SIGGRAPH '83)* (= *Computer Graphics*, vol. 17, no. 3) (New York, Association for Computing Machinery, 1983), 389–399. Modeling the effects of lenses is sometimes willfully driven to the absurd – e.g. when 'lens flares' (normally seen as a disturbance caused by the materiality of lenses in photographic systems) are intentionally included in computer graphics. There are many examples for this, one of the most bizarre is in popular Disney-Pixar movie *Monsters Inc.* (USA 2001, Pete Docter). It's especially striking in this movie since the movie is not rendered in only a photorealistic way – instead it combines photorealism (light, shadows, focus and disturbances) and cartoonish non-photorealism in a new way.

various forms of the *off* (see Figure 8.1, in which the machines in the foreground are cropped and moreover – another typical photographic property – are out of focus).[29]

Fourthly, it is the properties of the photographic emulsion itself, e.g., the grainy structure of the image especially in enlargements or very light-sensitive films, that one seeks to virtually model in photorealistic computer graphics (Fig. 8.3: an example of an analog, quite grainy, black and white photo).[30]

8.3 Jacek Halicki, Góry Bialskie, view from Kowadło, 11.10.1980.



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Photographic images can look very different beyond these four basic, if not always equally encountered, characteristics – not to mention the countless styles that have differentiated themselves in artistic photography or artis-

29 The classic formulation of the distinction between a centrifugal and centripetal image still comes from André Bazin, "Painting and Cinema," in André Bazin, *What is Cinema? – Vol. 1* (Berkeley, CA: University of California Press, 1967), 164–169.

30 Cf. Joe Geigel and F. Kenton Musgrave, "A Model for Simulating the Photographic Development Process on Digital Images," in *Proceedings of the 24th annual conference on Computer graphics and interactive techniques (SIGGRAPH '97)* (New York: ACM Press/Addison-Wesley Publishing Co., 1997), 135–142. In their proposal, the authors refer not only to empirically obtained data on the behavior of photo emulsions, but also to the suggestions of Ansel Adams.

tic film. The notion, however, that accompanies many computer graphic artists when they want to produce "photorealistic" images apparently boils down to a "normal" (100 ASA) Kodak color photograph, taken in focus with a standard lens (50 mm), or an image from a "normal" 16 or 35 mm motion picture film.[31]

Historically, the first important technological step towards photorealism was the transition from vector to raster graphics, since only computer images no longer consist only of lines, but exist as a set of individually addressable points – only in this way are filled areas, diverse colors, shadows, etc. possible. Subsequently, new developments in the field of scene illumination and shadowing, object transparency and texture were achieved.[32] One important step was the "Phong shading" method that was developed in 1975.[33] Since highlights were white in Phong's algorithm, the objects looked as if they were made of plastic. Later on, ever more complicated models for lighting and texturing were developed.[34] Finally, the paradigmatic function of photographic images for the development of computer graphics is illustrated in a standard work on computer graphics – a photograph of a scene is compared with a similar computed scene – *quod erat demonstrandum*.[35] However, it should be noted that the origin of computer graphic realism from flight simulation had the consequence that, at the beginning, procedures were developed for the generation of objects like trees or clouds. Thus, realism of a computer graphic image remained "partial and weighted" for a long time.[36]

The convergence of computer-generated to standardized photographic and cinematographic images is – as the example of flight simulation already

31 Ibid, 136, where the authors refer to a "generalized photographic model."

32 In addition to Foley et al., "Computer Graphics," 605–648, a detailed overview of the procedures for generating 'realistic' computer images is also provided by W.D. Fellner, *Computergrafik* (Mannheim et al: Spektrum Akademischer Verlag, 1992), 299–348.

33 Cf. Bui Tuong Phong, "Illumination for Computer Generated Pictures," *Communications of the ACM*, vol. 18, no. 6 (1975), 311–317.

34 See Foley et al., "Computer Graphics," Ch. 16 for a discussing of illumination and lighting – as it was done in 1995. Cf. John F. Hughes et. al., *Computer Graphics. Principles and Practice. Third Edition* (Upper Saddle River, NJ: Addison-Wesley, 2014), Ch. 26 and 27 for a more recent overview. The difference between these chapters shows the rapid development of computer graphics.

35 Foley et al., "Computer Graphics," Plate III.19 (1220).

36 Cf. Lev Manovich, "Realitätseffekte in der Computeranimation," in *Illusion and Simulation. Begegnung mit der Realität*, eds. Stefan Iglhaut, Florian Rötzer, Elisabeth Schweeger (Ostfildern: Hatje Cantz, 1995), 49–60, here 59, my translation; and Geoffrey T. Gardner, "Visual Simulation of Clouds," *Computer Graphics*, vol. 19, no. 3 (1985), 297–303.

showed – institutionally and economically conditioned. From the late seventies on, research on realistic computer graphics was pursued less and less by the military, but to an increasing extent by the film industry. For example, in 1979 Edwin Catmull, one of the leading developers of computer graphics in the 1970s who was in his student times in a university program funded by the DARPA (Defense Advanced Research Projects Agency), went to *Lucasfilm* to head its Computer Graphics Division. There is, of course, a long and impressive history of the use of photorealistic computer graphics in popular cinema, which cannot be discussed here in detail – but one can think of the liquid, reflective robot in *Terminator II* (USA 1991, James Cameron) or the dinosaurs in *Jurassic Park* (USA 1993, Steven Spielberg). In both cases the simulated graphics blend very convincingly into the photographed scenery.

For many military applications, photorealistic graphics are not at all suitable because they provide too much information, which is why complexity-reduced displays are often used.[37] On the other hand, if computer-generated images are to be inserted into a film or even a print advertisement as a *special effect* – unless the artificiality of the images is narratively motivated – they must be sufficiently indistinguishable from the photographic-film context.[38] In the meantime, most of the advances in photorealistic computer graphics are being spurred by the entertainment industry, which does not have to take military interests directly into account.

37 Cf. Foley et al, "Computer Graphics," 605: "You should bear in mind that a more realistic picture is not necessarily a more desirable or useful one. If the ultimate goal of a picture is to convey information, then a picture that is free of the complications of shadows and reflections may well be more successful than a *tour de force* of photographic realism."

38 Incidentally, in view of these functions of photorealistic computer graphics, it is not surprising that among 'artistically' ambitious computer graphic artists a trend towards *non-photorealistic rendering* has emerged, in which, among other things, processes such as painting or ink drawing, but also styles of artists are specifically simulated, cf. Gooch and Gooch, "Non-Photorealistic Rendering." However, these processes are not only used to simulate painting and the like, but also cartoons, which in turn makes the use of non-photorealistic processes interesting for the film industry – not least *Disney* has been researching this.

8.4 Gilles Tran, Image d'objets transparents montrant les capacités du logiciel POV-Ray, rendered with POV-Ray 3.6 using Radiosity. The Glasses, Ashtray and Pitcher were modeled with Rhino and the Dice with Cinema 4D.

http://www.oyonale.com/modeles.php?lang=en&page=40, Wikimedia Commons, free to use.

There are several different software packages to render photorealistic images that are based on and combine different algorithmic procedures for different aspects of the image.[39] Sometimes creative empirical approximations, workarounds and simplifications are used that are "good enough," that is, they look enough either like the real world and/or photographic images of the real world, but sometimes meticulously precise simulations of the physics of light etc. are preferred.[40] The decision about which algorithms are used depends not only on explicit or implicit ideals of "realism," but very often on economical questions of computing resources and available time. Sometimes accuracy is discarded in the light of assumed expectations and perceptual abilities of a potential audience. Sometimes photorealistic rendering is combined with

39 Again: Google "photorealistic rendering" and you will be shown many sites where software to render photorealistic images is offered for sale.

40 Alan Watt, "Rendering Techniques: Past, Present and Future," *ACM Computing Surveys*, vol. 28, no. 1 (1996), 157–159, here 157. Because of economic reasons like limited computer power and computing time, the old-fashioned "Phong shading" (see fn 33) or related algorithms are still used – they produce acceptable results with acceptable costs.

sampled images or textures, for example. And most often, all these aspects and more interfere with one another in many different ways. There is not just one way to render photorealistic images (Fig. 8.4: a photorealistic rendered image).[41]

Functions of Photorealistic Images

The computer-generated images in their currently predominant form refer to a rhetoric of truthfulness stolen from photography and film – whether to support the reality effects of illusionist cinema or to serve as a "truthful" reconstruction or prognosis of events and processes. The latter can be marveled at more and more frequently on television in connection with catastrophic events such as September 11, but also in weather reports. But computer-generated images also actually relate to reality, insofar as they are the visual representation of simulations that replicate real phenomena. For example, images of celestial bodies are generated from data from space probes, which need by no means show what would have been truly visible to humans, but what is operational for a particular practice and thus "true" insofar as is necessary for the purpose.

To the extent that simulations are based on models of real phenomena, they are still images and – if you like – more "realistic" than the images based only on the scanning of the light reflected from the surface of the objects. However, when the models are modified to describe possible or future phenomena, simulations can produce the first images that cannot merely semantically refer to the future – this also distinguishes the virtual from the fictional. Simulators are supposed to provide *predictions* about a future reality in order to place military, scientific or economic action on a secure foundation, i.e. they are supposed to function as a "control environment."[42] In particle physics, for example, the results of simulations of future experiments serve as a standard of comparison against which the results of experiments that are then carried out in

41 Friedrich A. Kittler, "Computer Graphics. A Semi-Technical Introduction," *Grey Room* 2 (2001), 30–35, has shown that two important algorithms for global illumination, ray tracing and radiosity (used in Fig. 8.4), are not compatible with each other, although they are used together today or are even superseded by newer methods. Note, however, that Kittler only discusses global illumination and not photo-specific algorithms for the motion blur and other aspects mentioned above.

42 Cf. S.R. Ellis, "Nature and Origins of Virtual Environments. A Bibliographical Essay," *Computing Systems in Engineering*, vol. 2, no. 4 (1991), 321–347, here 327.

reality can first be evaluated, and this applies not only to early research on the atomic and hydrogen bombs.[43] In architecture, mechanical engineering and design, simulations and resulting photorealistic images are often used to design new products on the computer, to test them, and finally to present them to potential customers before they are actually manufactured. This is another important motivation for the photorealistic orientation of generated images – they fulfill functions similar to those previously performed by advertising photography.

These role model and control functions are particularly evident in flight simulators. Flight simulations are not images of a flight that has taken place, but role models that prepare the pilot for a future flight. In other words, the realistic images generated serve to condition the pilot's reactions and body movements in such a way that the best possible response can be achieved in a later real case: James D. Foley unabashedly refers to "maximizing user efficiency"[44] as a goal of maximizing computer graphic realism (with the aforementioned caveat that too much realism can also be too complex). Seen in this light, simulators continue the use of photographic media in the service of disciplining, which found a particularly striking expression in Frederick Winslow Taylor's and especially Frank Bunker Gilbreth's time-and-motion-studies at the beginning of the twentieth century.[45]

The Continuity of Photography and the Universal Machine

Even if chemical photography were to disappear, the emergence and spread of the computer gave photography a new place in the system of media.[46] Obviously, that is the case with digital cameras. But it is also true for the pho-

43 Cf. Galison, "Image and Logic," 746–752, on the role of simulations in particle physics. Computer-based detectors, by the way, are replacing decades-old photographic techniques such as bubble chambers, etc., in the field of particle physics – and surpassing their analytical potency.

44 Cf. James D. Foley, "Interfaces for Advanced Computing," *Scientific American* (October 1987), 82–90, here 83.

45 Cf. Suren Lalvani, *Photography, Vision, and the Production of Modern Bodies* (Albany, NY: State University of New York Press, 1996).

46 Cf. Friedrich Kittler, "The History of Communication Media," in *On-line. Kunst im Netz*, ed. Helga Konrad (Graz: Steirische Kulturinitiative, 1993), 66–81, here 72: "New media do not make old media obsolete; they assign them other places in the system."

torealistic forms of computer graphics. Even if the computer is to be the new leading medium, the images created with it, both in terms of their appearance and their functions, are still strongly indebted to photography and cinema. The question arose (in the 1990s at least) whether this borrowing is merely a "transitory phase [that is] a historical compromise offered by computers to a public accustomed to visuality."[47] Viewed in this way, all digital photography and all photorealism would have arisen from superficially economic purposes – the distribution of computers – and would soon have to disappear once the *specific* potentials of the computer are generally understood.

However, this is countered by precisely the fact that digital computers, as universal machines, possess no specificity that could prevail in the course of history against the initial borrowing of the new machine from previous machines, for "the digital medium [exists] in its multiform metaphoricity."[48] In various discursive practices, computers stand within the framework of different and sometimes conflicting metaphorizations that circumscribe what purpose the machines are supposed to serve and what they are to be useful for. As a consequence of such objectives, which are also often implicit, computers are each connected to different hardware (peripherals) and each programmed with different software within the bounds of what is technically possible. In the sixties, however, the computer was discovered as a medium long before the media-theoretical discussion of the early nineties.[49] As early as 1967, Michael Noll described the computer *as a creative medium* for the image-generating arts and called for corresponding software and hardware developments.[50] This metaphorization had a long latency period due to economic reasons (i.e. the prices for corresponding technologies) until it became a self-evident conception of computers in our present time. Computers as media can be image, sound, written media – or all at the same time. Seen in this way, they do not possess any media specificity. Instead, depending on discursive practice, they are a different dispositive that opens up certain possibilities

47 Hartmut Winkler, *Docuverse. Zur Medientheorie der Computer* (Munich: Boer Verlag, 1997), 187. My translation.

48 Cf. Georg Christoph Tholen, "Überschneidungen. Konturen einer Theorie der Medialität," in *Konfigurationen. Zwischen Kunst und Medien*, eds. Georg Christoph Tholen, and Sigrid Schade (Munich: Brill/Fink, 1999), 15–34, here 21. My translation.

49 Cf. e.g. Norbert Bolz, Friedrich Kittler, and Georg-Christoph Tholen, eds., *Computer als Medium* (Munich: Brill/Fink, 1994).

50 Cf. Michael A. Noll, "The Digital Computer as a Creative Medium," *IEEE Spectrum*, vol. 4, no. 10 (1967), 89–95.

and closes off others. In this context, program routines that are central to a specific discursive practice can literally sediment into hardware, for any software can become hardware as an interconnection of logical gates, as Shannon had already proved in 1938.[51] A pertinent example here is the development of graphics chips, promoted by the movie and then computer game industries, which cast algorithms for generating images (often in a photorealistic manner) in hardware, thus speeding them up. In that way photorealistic rendering became part of the hardware.

Conclusion

So, instead of talking about the "digital revolution" and "post-photography," instead we should say that "digital photography" and computer-graphic "photorealism" will remain for a long time, because photographic and cinematographic appearing images are – as Manovich laconically stated – "very efficient for cultural communication"[52]? That is, photorealistic image generation takes over and enhances important functions of its photographic and cinematographic predecessors, not only in the entertainment industry, but also in military, medical and economic discursive practices. Namely, in terms of the storage, processing and representation of information, enabling classification, analysis, prediction and thus control and optimization. The persistence of photographic characteristics and the rhetoric of truth in digital media would thus point to an inscription of certain power/knowledge dispositives, not triggered by photography alone, but historically associated with it, in the programmable machine computer. Thus, it is not just about the superficially economic objective of selling more computers, but about more fundamental functions of control. This is symptomatically shown by the fact that the tendency of photorealism results in the quasi-utopian "goal of simulating reality," i.e., rooted in the word *virtual* (inter alia "powerfully"), which flashes up in the discourses on what is referred to as *virtual reality* – which promises in the virtual the unification of the fictive with the real and thus a different, better reality.

51 Cf. Claude Elwood Shannon, "A Symbolic Analysis of Relay and Switching Circuits," *Transactions American Institute of Electrical Engineers*, no. 57 (1938), 713–723.

52 Lev Manovich, *The Language of New Media* (Cambridge, MA/London: MIT Press, 2001), 180–181.