University of Tehran

Faculty of Visual Arts

# Studying the Role of 3D Computer Simulation in Generating Photorealistic Images

By: Hassan Karbalai Rezakhani

Under Supervision of Dr. Ahmad Alasti

A Thesis Submitted to the Graduate Studies Office

In Partial Fulfillment of the Requirements for

The Degree of Master in Art

Photography

February 2015

**2-1-2 Cinema and Zuse's Machine**

The germ of the idea of "Cinema and the Digital Media" penned by Lev Manovich comes from the idea that "the modern digital computers were born of cinema", and it aims to compare cinema to Konrad Zuse's machine to make us more familiar with this idea. According to Manovich, if cinematography is defined as the art of writing motions, its nature involves the recording and storage of the visible data in the material form similar to a movie camera. The recorded data is processed in the laboratory through various steps and it is read and displayed on the screen using a projector. In the digital machine, the program is written on an external medium where it can be controlled (the films are punched in Zuse's machine whereas they are stored on a hard disk in the modern computers). Hence, the storage medium (the punched film and hard disk) and an encoding method (chemo-optical storage, punched binary holes, and magnetic binary data) are considered to be the important components of the digital machine and cinema. However, given Konrad Zuse's avid interest in the visual arts, their influence on the invention of digital machines, and the comparison between the performances of Zuse's digital machine and cinema, the technological interpretation of Oedipus complex by Manovich, based on which the child (digital machine) murders his father (cinema), sounds acceptable. In a non-tragic twist, it forms the basis for the integration of the media.

Today, fifty years after Zuse's invention, the state-of-the-art media not only allow for the storage of photos, graphical images, motion pictures, sounds, and texts in a different and dynamic material for but also provide for the creation and production of sounds, realistic three-dimensional images, and interactive virtual spaces. It can be, therefore, deemed a

different dimension and a step forward as compared to Manovich's analogy. This different material form can be defined as the conversion of the numerical codes to the basis for storage in the digital machines. These codes can be processed and interpreted. This new material form involves a substantial change. For instance, in media such as photos, films, and texts, the original work can be referred to due to their physical essence. However, when these works are turned into numerical codes, their substantial essence becomes inaccessible and we can only gaze at the numerical codes.

> "Neo: Do you always look at it encoded?
>
> Cypher: Well, you have to. The image translators work for the construct program. But there's way too much information to decode the Matrix. You get used to it. I don't even see the code. All I see is blonde, brunette, redhead. " (The Matrix, 1999)

The reasons for stressing the role of cinema in this text are Manovich's idea about this fundamental role in the history of the computer as well as the characteristics and features that have helped cinema become the most influential medium of the 20th and partly 21st centuries. Over a century, cinema has gradually prepared its global audience for accepting the transformation of the media and has helped us understand the subsequent features of the digital media. Hence, it is believed that many people experienced the digital revolution as a gradual evolution. Cinema gradually made the advocates of the unity of time and space of photos (Vanvolsem, 2011, 154) accept the modification of photos. It reduced the accepted reality to the reality shown by the motion pictures and developed it. It even replaced the original photos with the motion pictures in some cases. Cinema improved the vision of its audience and enabled them to look at the world not solely through their mechanical eyes.

> "I am cinema-the eye. I a mechanical eye and I show you a world that only I can see. Free from the limits of time and space, I adapt myself to any or all parts of the word and I can also record them. My mission is to create a new image of the world, and thus I can discover the unknown world by taking a new approach." (Zabeti Jahromi, 2009)

In his article, Manovich refers to the substantial role of cinema in introducing a number of digital concepts such as sampling, random access, and simulation to us. For example, through a movie camera or a video camera records the images of the reality shown to the camera through sampling. The number of these samples is limited by the minimum duration of the presence of these images on human's retina. On a 35mm roll film, 24 frames form one second

of the film. Therefore, the continuous timeline can be recorded through discrete sampling and recording 1/24 second film frames. In a similar approach, the digital machine uses the sampling technique to convert and store the analog data (image and sound) (Fig. 2-3) (Manovich, 1995). In a digital image, the number of the pixels along the horizontal and vertical directions on a two-dimensional plane determines the precision of the sampling process, whereas, in a digital sound, it is determined by the level of voltage at certain intervals. In the case of analog films, the linear sequence of the images is maintained. In other words, the frames can be displayed sequentially over time. Moreover, in order to access a given part of the films, the frames must be skipped at the speed determined by the video player to be able to access the desired segment of the film. However, the animated or still digital images provide for the immediate or random access, and the person can access the desired part of the sequence or an image in a collection of images.
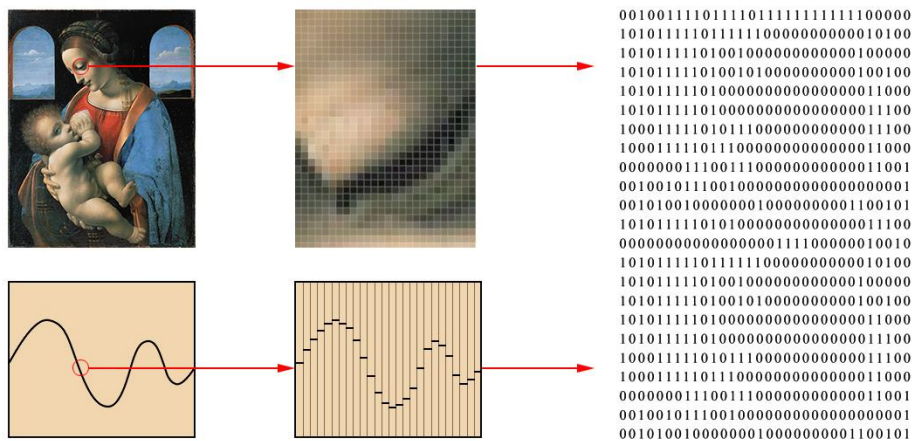


Figure (2-3): The conceptual method of sampling during the conversion of images or sounds to numerical codes (the sound diagram is adapted to the image type) (Oja and Parsons, 2008: 198)


**2-1-4- Baudrillard and Simulation**

Jean Baudrillard, the French sociologist, philosopher, photographer, and theorist, defines the difference between imitation and simulation with regard to theories such as simulation and hyper-reality and states that in an imitation a copy of a physical subject is made, whereas in a simulation it is possible to experience something that lacks physical existence. He based his definitions on the possibility to refer to the original in the physical and material world. He introduced three historical phases or sequences of simulation that reflect his approach to this subject.

**Phase one:** Baudrillard argued that there was an evident difference between the original and its copy prior to the advent of industrialism and it was possible to distinguish the copy from the original by comparing them. For instance, the artist or artisan would make a handmade key, which was obviously a copy of an original key that existed somewhere else and it was possible to refer to it (Fig. 2-5). Due to the difference between the original and the copy, each had its distinctive characteristics and features that rendered them different.

**Phase two:** With the industrial growth and the onset of the industrialist era, it was possible to produce identical copies of a subject. These copies did not differ from each other or the original subject, hence the uncertainty in the difference between the original and the copies. For example, a key factory can make numerous identical copies of a key (Fig. 2-5). Consequently, there is no distinction between the original and the copy.



Figure (2-5): Right to left: The distinction between the original and the copy; copies of the same subject; the model and the code replacing the subject (Hedges, 2010)

**Phase three:** In today's postindustrial era, the model and the code (similar to a computer code) are more important than the "original" subject, resulting in the transformation of the notion of "the original". For instance, every person can use a specific password to access different hardware (security devices) and software (such as the Internet websites) items. However, there is no physical key or an original subject and only a virtual code is used to this end (Fig. 2-5) (Hedges).

Baudrillard valued the notions of imitation and representation equally, and thus there is no difference between the applications of these notions in this regard. However, according to Baudrillard, there are fundamental differences between the notions of simulation and representation, which determine the type of the reality faced by the person. Baudrillard argues that representation occurs more frequently nowadays and it constitutes many of our real-life experiences. To further clarify this point, Warren Hedges uses the flight simulator as an example to interpret the opinions of Baudrillard (Fig. 2-6). In general, the flight simulator

is a device used to teach virtual airplane control. Therefore, this device provides for the "imitation" of a physical entity such as the cockpit of an airliner in practice. However, the same device can "simulate" something that is nonexistent such as the cockpit of a fictional and imaginary spacecraft. Therefore, based on Baudrillard's theories, a simulacrum is a representation consisting of several identical copies and it represents something that is nonexistent without the representation technology. In "imitation", a copy can be assessed against the original version. For example, the ship was shown in Titanic (1997) was comparable to the original ship in 1909.



Figure (2-6): The dual applications of simulation to flight simulation and representation

However, in a simulacrum, the original subject is not accessible beyond the creator's technological world. As another example, in Avatar (2009), the machines, creatures, environments, and technologies do not represent anything, and thus they are considered to be "the original", which is a code or a virtual model commonly known as a digital code. We cannot face the original in our everyday lives without the aid of the simulation technologies. Simulation is also made possible by the analog technologies. For example, a live music performance can be copied on the gramophone records, and since the original can be referred to, it is deemed a form of imitation. However, multi-track recording, which is the separate recording of the sound of the instruments, the singer's voice, and the music effects and their synthesis, yields a form of music that cannot be heard live and thus the final version or product owes its existence to the recording and playing technologies.

Based on the flight simulator example, it is concluded that what Baudrillard believed in is enormously important. It is, in fact, the procedure through which the user experiences the simulation similar to realness whether the simulated subjects match their real existence or not. Hence, if the simulation results in realness, it will be more important as compared to the situation in which it can create an accurate copy of something (that can be referred to a subject beyond the simulation). Fredric Jameson, the American theorist and literary critic who is known mainly as an analyst of the contemporary culture, defines photorealism as an example of the artistic simulacra and suggests that the photorealistic paintings are created by copying a photo, which is itself a copy of the reality (Massumi, 1987). The notion of photorealism is discussed in the following chapter. However, besides Jameson's definition, the functions of the virtual images link the simulation and representation notions explained by Baudrillard with the notions of photorealistic three-dimensional simulation and representation. Similar to the flight simulator, they also set the scene for the visual representation of an existing reference and can also visually simulate something that is nonexistent using the virtual models or codes. Nevertheless, the flight simulator can be compared to the concept of virtual world, because this world can be both a representation of the real world and an unreal simulation of this world that is created based on the structures and notions of the real world.

**2-1-5- Virtual World**

One of the notions mentioned in the previous section was the concept of virtual world, which is not a new concept because humans have always tried to shape their surrounding environments and have tried to frame their own concepts of the alternative worlds by changing the world they have lived in. These alternative worlds are governed by the rules set by their human creators. A virtual world may only exist on the minds of its creators or may be represented via a medium to enable the individuals to share it. The real world certainly influences the virtual world, and although the virtual worlds are fictional spaces, the fine line between the real world and the virtual world is sometimes blurred. Hence, if the virtual world is a model of some places and experiences, it seems to intend to imitate its real-world peer. The virtual world is a real representation of a world that may have physical (actual) existence. Even in the physical world, it is not known whether the being or thing we face is real or a representation (Sherman and Craig, 2003, pp. 40-41). This is demonstrated in Alexandra's

work titled "This Is Not a Pipe" (Fig. 2-30), which is a photorealistic representation of René Magritte's painting. From the qualitative aspect, the virtual world created by Alexandra is more realistic and effective than Magritte's painting because technology has brought us closer to Magritte's idea by polishing the details and messing up the line between the reality and the representations. That is to say, it could be stated that virtuality is not contradictory to reality. Rather, it is the reality itself while there is no need for the opposition between virtuality and reality and it must not be considered an illusory world. In fact, virtuality plays a major role in human's language and thinking. For instance, when a person is asked whether he/she has finished his/her article, the person may say "yes" in response if all of the major and minor activities for writing the article have been performed. However, the positive answer may be a virtual answer because the person may need to check the syntax and spelling of his/her article, add references, and publish the article. In other words, the article is written and exists virtually and the activity is mostly done. Therefore, it could be stated that the article does not contradict its existential reality and this marks the line between virtuality and illusion. That is to say, the illusory existence of the article shows that it is not real. Hence, despite the difference between virtuality and reality, they are both somewhat real. Today, and increasingly in the future, it will not be possible to sharply distinguish between the virtual reality and the actual reality and the technological advancements will put human societies on the boundary line between these two. Computers and computer-based communication networks not only have led to the emergence of the digital culture but also have caused the epidemic of "virtuality". For example, when a person is walking in a city and decides to use an ATM, he/she, in fact, experiences a physical environment as an actual reality, but he/she can also communicate with the virtual world. The ATM brings the person to the virtual banking world, and although it is not possible to interact with a human being similar to the traditional system, the individual experiences the actual reality and virtual reality concurrently. The keypad and the screen, the bank wall accommodating the ATM, the sidewalk, and the keys that are pressed are all elements of the material reality. In addition, the servers and computers inside the building, the ATM controller, and the communication cables form a whole system and are actual entities. However, the communication network to which the person connects is a virtual experience whereas the online banking world and digital money accessed by the person are real. If the world of online banking (virtual reality) tells the individual that his/her account balance is zero, the person will not receive any cash (the actual reality). The virtual reality or the virtual world that communicates with the person through the ATM is where the actual money is virtually stored (or there may be no money due to

system errors). When a person uses an ATM, he/she wants to convert the digital money to real cash, and thus the virtual reality becomes existent through this process. According to Rob Shields, the virtual world is a hidden world that can be fetched through the "lightness of electrons" (Shields, 2002, p. 22). In this case, virtuality is not the same as unreality. In this example, the virtual reality is formed by the material and real technology (Lister et al., 2009, pp. 124-126). An important factor in this example is the type of the link between the person and the virtual world, which is established visually. All virtual spaces and environments are formed from images. In this regard, the Internet is another example of the virtual worlds.
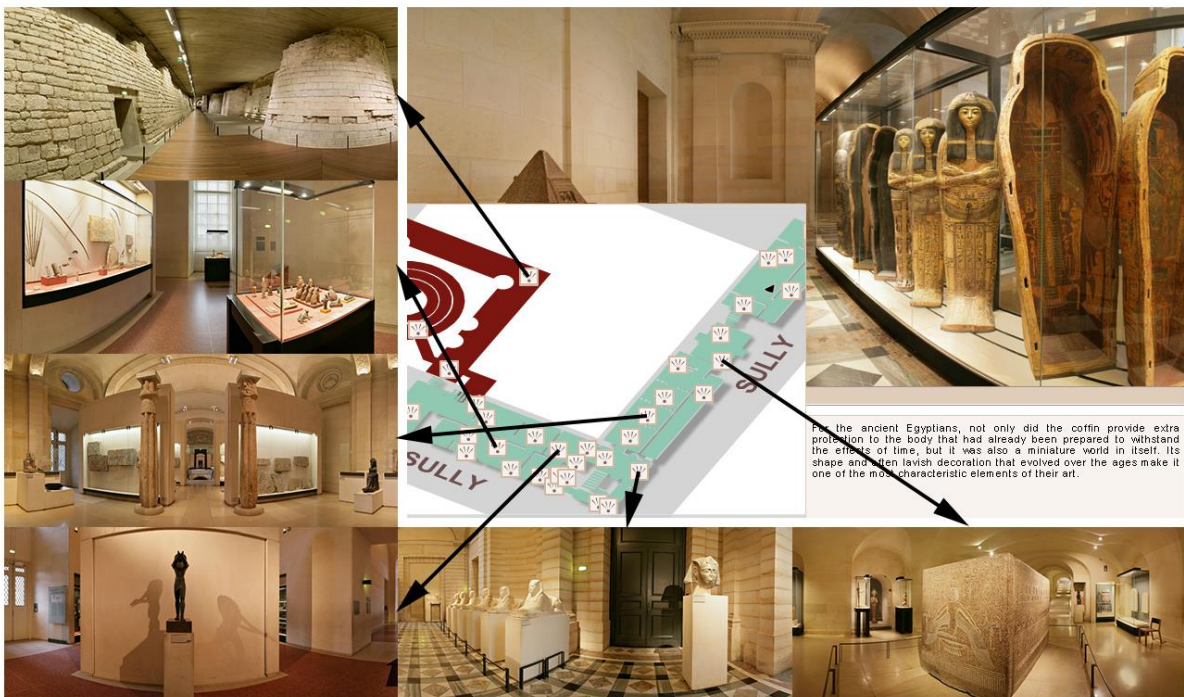


Figure (2-7): A virtual tour of the Louvre Museum, the ancient Egypt section, simultaneous access

Activities such as chatting, training, playing, touring, and shopping, which can be performed in real life, can also be done via the Internet virtual web pages. An individual sits in front of the monitor and connects to the virtual world via a virtual interface controlled by codes (the codes and controller are also virtual). He/she orders "Photorealism in the Digital Age" on Amazon and visits the ancient Egypt section of the Louvre Museum in Paris on a virtual tour. He/she can also have a live video chat with another person in another geographical position and play simultaneously with thousands of other gamers. (According to the Wall Street Journal, the total number of the online gamers that play the League of Legends is approximately 27 million people per day (Sherr).) He/she may take an academic course on

the Coursera website and there may also be other features available in the virtual world. As mentioned, the virtual world rules may be different and even grant the connected user privileges that are not available in reality. For instance, on the virtual tour of the Louvre Museum, there is no need to see the works in each section in a certain order because the users can access all of the works in each section through the codes provided to them (Fig. 2-7). This form of access is a notion introduced as a characteristic of the digital culture by Manovich and was discussed above.

# References

## Farsi References

### Books

Baudrillard, J. (1995). *The Aporia of signs a postmodern reader* (Ahmadi, B. & Haghighi, M. Trans.). Tehran: Nashre Markaz.

Shad Ghazvini, P. (2014). Contemporary Painting of West: From Art Nouveau to Postmodernism. Tehran: SAMT.

Zabeti Jahromi, A. (2013). *Si Sal Cinema* (Persian Edition). Tehran: Nashr e Ney.

Grunberg, A. (2010). *Crisis of the Real* (Ebrahimi Moghaddam, M. & Ladoni, M. Trans.). Tehran: Academy of Arts. (Original work published 2005)

## English References

### Books

Akin, A. (2006). *The Render Engine.* Washington, D.C.:Next Limit Technologies.

Arthur, W. B. (2009). *The Nature of Technology: What It Is and How It Evolves.* New York: Free Press.

Barasch, M. (2013). *Theories of Art: 1. From Plato to Winckelmann.* London: Routledge.

Barnard, E. (2012). *Capturing Time: Panoramas of Old Australia.* Canberra: National Library Australia.

Bhatia, P. K. (2008). *Computer Graphics.* New Delhi: I. K. International Pvt Ltd.

Bolton, R. (1992). *The Contest of Meaning: Critical Histories of Photography*. Cambridge: MIT Press.

Bowen, J. P., Keene, S. & Ng, K. (2013). *Electronic Visualisation in Arts and Culture.* London: Springer Science & Business Media.

Cantot, P. & Luzeaux, D. (2013). *Simulation and Modeling of Systems of Systems.* Hoboken: John Wiley & Sons.

Catmull, E. & Wallace, A. (2014). *Creativity, Inc.: Overcoming the Unseen Forces That Stand in the Way of True Inspiration.* New York: Random House Publishing Group.

Cubitt, S. & Thomas, P. (2013). *Relive: Media Art Histories.* Cambridge: MIT Press.

Curley, R. (2010). *The 100 Most Influential Inventors of All Time.* New York: The Rosen Publishing Group.

Dunlop, R. (2014). *Production Pipeline Fundamentals for Film and Games.* Oxford: Focal Press.

Dunning, W. V. (1991). *Changing Images of Pictorial Space: A History of Spatial Illusion in Painting.* Syracuse: Syracuse University Press.

Dürer, A., *The Painter's Manual.* New York: Abaris Books.

Editors of Life (2003). *Life: 100 Photographs That Changed the World.* Boston: Time Home Entertainment.

Elkins, J. & Naef, M. (2011). *What is an Image?.* University Park: Penn State Press.

Foster, S. & Halbstein, D. (2014). *Integrating 3D Modeling, Photogrammetry and Design.* London: Springer London.

Gahan, A. (2010). *3D Automotive Modeling: An Insider's Guide to 3D Car Modeling and Design for Games and Film.* 1st ed. Oxford: Focal Press.

Ganovelli, F., Corsini, M., Pattanaik, S. & Benedetto, M. D. (2014). *Introduction to Computer Graphics: A Practical Learning Approach.* Boca Raton: CRC Press.

Godse, A. P. & Godse, D. A. (2009). *Computer Graphics.* Pune: Technical Publications Pune.

Hanrahan, P. (2000). *The Rendering Equation.* Stanford: Stanford Computer Graphics Laboratory.

Hassan, R. (2004). *Media, Politics and the Network Society.* Columbus: McGraw-Hill International.

Highton, S. (2010). *Virtual Reality Photography: Creating Panoramic and Object Images.* not mentioned.

Honour, H. & Fleming, J. (1991). *The Visual Arts: A History.* 3rd ed. New York: Harry N. Abrams, Inc..

Hornby, A. S. (2005). *Oxford Dictionary.* Oxford: Oxford University Press.

Hughes, G. (2012). *The Polygons of Albrecht Durer -1525.* Ithaca: Cornell University Library.

Kerlow, I. V. (2004). *The Art of 3D: Computer Animation and Effects.* Hoboken: John Wiley & Sons.

Kirsch, R. A. (2001). *Computer Development at the National Bureau of Standards.* Gaithersburg: National Institute of Standards and Technology.

Langford, M. & Bilissi, E. (2013). *Langford's Advanced Photography.* 8th ed. Oxford: Focal Press.

Lanier, L. (2011). *Maya Studio Projects Texturing and Lighting.* Hoboken: John Wiley & Sons.

Lister, M. et al. (2009). *New Media: a critical introduction.* 2nd ed. London: Routledge.

Logan, J. D. (2013). *Applied Mathematics.* Hoboken: John Wiley & Sons.

Magnenat-Thalmann, N. & Thalmann, D. (2005). *Handbook of Virtual Humans.* Hoboken: John Wiley & Sons.

Manovich, L. (2001). *The Language of New Media.* Cambridge: MIT Press.

Manser, M. H. (2007). *The Facts on File Dictionary of Proverbs.* New York: Infobase Publishing.

Meisel, L. K. (1989). *Photorealism.* New York: Abradale/Abrams.

Mitchell, W. J. (1994). *The Reconfigured Eye: Visual Truth in the Post-photographic Era.* Cambridge: MIT Press.

Morra, J. & Smith, M. (2006). *Visual Culture: Experiences in visual culture.* Abingdon: Taylor & Francis.

Oja, D. & Parsons, J. J. (2008). *Computer Concepts Illustrated, Introductory.* Boston: Cengage Learning.

Paik, K. (2007). *To Infinity and Beyond!: The Story of Pixar Animation Studios.* San Francisco: Chronicle Books.

Paquette, A. (2013). *An Introduction to Computer Graphics for Artists.* London: Springer Science & Business Media.

Payne, D. R. (1994). *Computer Scenographics.* Carbondale: SIU Press.

Reinhard, E., Pattanaik, S., Ward, G. & Debevec, P. (2006). *High Dynamic Range Imaging: Acquisition, Display, and Image-Based Lighting.* Burlington: Morgan Kaufmann.

Sherman, W. R. & Craig, A. B. (2003). *Understanding Virtual Reality: Interface, Application, and Design.* Burlington: Morgan Kaufmann.

Shields, R. (2002). *The Virtual.* London: Routledge.

"simulacrum" *The New Shorter Oxford English Dictionary* (1993)

Strothotte, T. (2002). *Non-photorealistic Computer Graphics: Modeling, Rendering, and Animation.* Burlington: Morgan Kaufmann.

Tajima, K. (2013). *Autodesk Maya: Character Modeling Bible.* Tokyo:Born Digital, Inc..

Tulloch, J. & Blood, R. W. (2012). *Icons of War and Terror: Media Images in an Age of International Risk.* London: Routledge.

Vanvolsem, M. (2011). *The Art of Strip Photography: Making Still Images with a Moving Camera.* Leuven:Universitaire Pers Leuven.

Velho, L., Carvalho, P., Gomes, J. & Figueiredo, L. d. (2008). *Mathematical Optimization in Computer Graphics and Vision.* Burlington: Morgan Kaufmann.

## Articles

Manovich, L. (1997) *Automation of Sight from Photography to Computer Vision.*

Manovich, L. (1993) *The Mapping of Space: Perspective, Radar, and 3-D Computer Graphics.*

Massumi, B. (1987) *Realer than Real: The Simulacrum According to Deleuze and Guattari.*

## Journals

Hertz, P. (2009) 'Art, Code, and the Engine of Change', *Art Journal,* 68(1), pp. 58-75.

Kajiya, J. T. (1986) 'The Rendering Equation', *SIGGRAPH,* 20(4), pp. 143-150.

Manovich, L. (1996) 'Cinema and Digital Media', *Perspective of media art,* pp. not mentioned.

Oliker, A. & Cutting, C. (2005) 'The Role of Computer Graphics in Cleft Lip and Palate Education', *Seminars in Plastic Surgery,* 19(4), pp. 286-293.

## Video

Hedges, W. (2010). *ARTH 330 - Art, Culture, and Technology - Jean Baudrillard's Concept of Simulation and Simulacra.* Southern Oregon University.

## Websites

3DEXCITE, *Advanced Study of Crash Test Simulations.* [Online]
Available at: https://www.rtt.ag/en/work/references/advanced-study-of-crash-test-simulations
[Accessed 13 November 2014].

3DEXCITE, *Augmented Reality presentation.* [Online]
Available at: http://www.rtt.ag/en/work/references/augmented-reality-presentation
[Accessed 14 October 2014].

3DEXCITE, *Customers.* [Online]
Available at: https://www.rtt.ag/en/work/customers
[Accessed 14 August 2014].

ArtecID, *Products - artecid.com.* [Online]
Available at: http://artecid.com/products.html
[Accessed 1 February 2015].

Boeing, *William Fetter's Boeing.* [Online]
Available at: http://www.boeingimages.com
[Accessed 12 August 2014].

Link, *Link Simulation Image Galleries.* [Online]
Available at: https://www.link.com/media/galleries/pages/default.aspx

[Accessed 12 October 2014].

Asisi, Y., *asisi:Panoramen.* [Online]
Available at: http://www.asisi.de
[Accessed 10 November 2014].

Benchwell, M. R., *Benchwell Test.* [Online]
Available at: http://support.nextlimit.com/display/maxwelldocs/Benchwell+Test
[Accessed 6 November 2014].

Benoit, B., *BBB3viz's Photostream.* [Online]
Available at: https://www.flickr.com/photos/bbb3viz/
[Accessed 6 August 2014].

Bernardi, R., *Roberto Bernardi Paintings.* [Online]
Available at: http://www.robertobernardi.com/pagine/paintings.html
[Accessed 23 September 2014].

California, U. o. S., *ICT Graphics Lab.* [Online]
Available at: http://gl.ict.usc.edu/
[Accessed 30 November 2014].

Chaos, G., *VRay Physical Camera.* [Online]
Available at: http://docs.chaosgroup.com/display/VRAY3/VRayPhysicalCamera
[Accessed 27 September 2014].

Ching, S., *Pattern Matters Tangible Paper Infographic on Behance.* [Online]
Available at: http://bit.ly/FPG5gl
[Accessed 29 November 2014].

Congress, L. o., *Migrant agricultural worker's family.* [Online]
Available at: http://www.loc.gov/pictures/collection/fsa/item/fsa1998021556/PP/
[Accessed 12 December 2014].

CyArk, *CyArk Projects.* [Online]
Available at: http://www.cyark.org/
[Accessed 24 June 2014].

Debevec, P., Taylor, C. & Malik, J., *Modeling and Rendering from Photographs.* [Online]
Available at: http://www.pauldebevec.com/Research/
[Accessed 20 July 2014].

Denko, M., *CG Garden.* [Online]
Available at: http://marekdenko.net
[Accessed 6 October 2014].

Deutsches Museum, *Universal computers.* [Online]
Available at: http://www.deutsches-museum.de
[Accessed 25 November 2014].

Enrich, V., *VÍCTOR ENRICH MEDIA ARTIST.* [Online]
Available at: http://victorenrich.com/
[Accessed 2 September 2014].

ESA, *Industry Facts.* [Online]
Available at: http://www.theesa.com/about-esa/industry-facts/
[Accessed 20 November 2014].

Freie Universität Berlin, *Z4.* [Online]
Available at: http://zuse.zib.de/z4
[Accessed 25 August 2014].

Glaser, M., *CARS.* [Online]
Available at: http://www.marekglaser.com/photography/cars/
[Accessed 8 June 2014].

Glaser, M., *How I photograph a car without a car. NEWS.* [Online]
Available at: http://www.marekglaser.com/news/2014/6/5/how-i-photograph-a-car-without-a-car
[Accessed 29 November 2014].

Glaser, M., *Interesting coverage on my flying drone spot NEWS.* [Online]
Available at: http://www.marekglaser.com/news/2014/6/4/interesting-coverage-on-my-flying-drone-spot
[Accessed 26 October 2014].

Graham, P. et al., *Measurement-Based Synthesis of Facial Microgeometry.* [Online]
Available at: http://gl.ict.usc.edu/Research/Microgeometry/
[Accessed 30 September 2014].

Gschmeissner, S., *Electron Microcoscopy's Galleries.* [Online]
Available at: http://www.theworldcloseup.com/image-galleries
[Accessed 12 January 2015].

Hermitage, S. M., *The Litta Madonna.* [Online]
Available at: http://www.hermitagemuseum.org/wps/portal/hermitage/explore/history/historical-article/1850/Madonna+Litta/?lng=en
[Accessed 8 November 2014].

Indigo, R., 2014. *This is not a pipe - Indigo Renderer.* [Online]
Available at: http://www.indigorenderer.com/images/not-pipe
[Accessed 31 August 2014].

Infinite Realities, *Infinite Realities.* [Online]
Available at: http://ir-ltd.net/
[Accessed 22 August 2014].

Infinite, *Infinite, 3D Head Scan and Sculpt.* [Online]
Available at: http://www.zbrushcentral.com/showthread.php?95252-Infinite-3D-Head-Scan-and-Sculpt
[Accessed 15 July 2014].

Jimenez, J., *Next Generation Character Rendering.* [Online]
Available at: http://www.iryoku.com/stare-into-the-future
[Accessed 12 January 2015].

KeyShot, *3D Renderings by Rodrigo Sória.* [Online]
Available at: https://www.keyshot.com/2011/keyshot-3d-renderings-rodrigo-soria
[Accessed 28 August 2014].

Louvre, 2014. *Online Tours.* [Online]
Available at: http://www.louvre.fr/en/visites-en-ligne
[Accessed 14 December 2014].

Mackiewicz, M., *Architectural Visualisation.* [Online]
Available at: http://mimostudio.pl/#!prettyPhoto
[Accessed 5 June 2014].

Manovich, L., 2014. *Phototrails.* [Online]
Available at: http://manovich.net/index.php/exhibitions/phototrails
[Accessed 7 September 2014].

Marmoset, *PBR In Practice.* [Online]
Available at: http://www.marmoset.co/toolbag/learn/pbr-practice
[Accessed 29 June 2014].

Material, *Material Database.* [Online]
Available at: http://www.indigorenderer.com/materials/materials
[Accessed 19 July 2014].

Maxwell, R., *Camera.* [Online]
Available at: http://support.nextlimit.com/display/maxwelldocs/Camera
[Accessed 10 November 2014].

Meniel, B., *Lucky Dragon Bertrand Meniel.* [Online]
Available at: http://www.meiselgallery.com/lkmg/artist/works/detail.php?wid=1192&aid=27
[Accessed 21 July 2014].

MetaEmotion, *Computer Vision Data Mining and Open Source.* [Online]
Available at: http://www.metaemotion.com/en/technology/
[Accessed 17 June 2014].

Metropolitan, T. M. o. A., *Three Miracles of Saint Zenobius.* [Online]
Available at: http://www.metmuseum.org/collection/the-collection-online/search/435729
[Accessed 22 November 2014].

MFX, *All-CGI Location Shot.* [Online]
Available at: http://www.mfx.se/case-cgi-location/
[Accessed 10 November 2014].

MFX, *The Swamp - MFX.* [Online]
Available at: http://www.mfx.se/case-swamp/
[Accessed 3 August 2014].

NIGMS, *NAMD - Scalable Molecular Dynamics.* [Online]
Available at: http://www.ks.uiuc.edu/
[Accessed 5 September 2014].

NoEmotion, *Marek Denko and Peter Sanitra studio.* [Online]
Available at: http://noemotion.net/
[Accessed 8 July 2014].

Ozeri, Y., *AQUABELLA.* [Online]
Available at: http://www.yigalozeriartist.com/
[Accessed 31 July 2014].

Parein, R., *Foodbanks - Rizon Parein.* [Online]
Available at: http://www.rizon.be/Foodbanks
[Accessed 27 December 2014].

Pixologic, *The Venus From the Rhone River.* [Online]
Available at: http://pixologic.com/interview/artist-in-action/venus-zbrush/1/
[Accessed 22 September 2014].

RenderMan, *Linear Workflow.* [Online]
Available at: http://renderman.pixar.com/view/LinearWorkflow
[Accessed 4 July 2014].

Riedelbauch, G., *Albrecht Duerer - virtualterritory.* [Online]
Available at: http://virtualterritory.wordpress.com/2007/05/31/did-albrecht-duerer-got-it-wrong-a-surprise-discovery-in-one-of-his-prints/
[Accessed 2 November 2014].

Saliba, M. M., *Living Room and Dining Room.* [Online]
Available at: http://www.marwanmsaliba.com/living/content/index.html
[Accessed 10 July 2014].

Sherr, I., 2014. *Player Tally for 'League of Legends' Surges.* [Online]
Available at: http://blogs.wsj.com/digits/2014/01/27/player-tally-for-league-of-legends-surges/
[Accessed 15 September 2014].

SIGGRAPH, A., *Overview of Ray Tracing.* [Online]
Available at: https://www.siggraph.org/education/materials/HyperGraph/raytrace/rtrace1.htm
[Accessed 18 November 2014].

Smith, R., *Projects Thonet Factory.* [Online]
Available at: http://www.rachaelsmith.net/projects/
[Accessed 12 October 2014].

SPHERON-VR, *cgi-computer-generated-imagery.* [Online]
Available at: https://www.spheron.com/products/cgi-computer-generated-imagery.html
[Accessed 1 July 2014].

Statista, *Global filmed entertainment revenue 2013 - Statistic.* [Online]
Available at: http://www.statista.com/statistics/259985/global-filmed-entertainment-revenue
[Accessed 16 June 2014].

Studio, H. L., *Benefits.* [Online]
Available at: http://www.hdrlightstudio.com/benefits.htm
[Accessed 19 July 2014].

TEN 24, *Agisoft PhotoScan.* [Online]
Available at:
http://www.3dscanstore.com/index.php?route=information/information&information_id=4
[Accessed 23 January 2015].

TEN 24, *3D HEAD SCANS IN REAL TIME.* [Online]
Available at: http://www.3dscanstore.com/index.php?route=blog/category/home
[Accessed 16 August 2014].

US Navy and Marine Corps museum, *Robert L. Lawson Photograph Collection.* [Online]
Available at: http://collections.naval.aviation.museum/
[Accessed 23 January 2015].

USC, 2014. *Rapid Acquisition of Specular and Diffuse Normal Maps from br Polarized Spherical Gradient Illumination.* [Online]

Available at: http://gl.ict.usc.edu/Research/FaceScanning/
[Accessed 9 January 2015].

USC, I. f. C. T., 2014. *3D Scanning the President of the United States.* [Online]
Available at: http://gl.ict.usc.edu/Research/PresidentialPortrait/
[Accessed 25 October 2014].

USC, *HighResProbes.* [Online]
Available at: http://gl.ict.usc.edu/Data/HighResProbes/
[Accessed 12 August 2014].

VGSales, *Video game industry.* [Online]
Available at: http://vgsales.wikia.com/wiki/Video_game_industry
[Accessed 18 December 2014].

VRayMtl, *VRayMtl.* [Online]
Available at: http://docs.chaosgroup.com/display/VRAY3/VRayMtl
[Accessed 15 October 2014].

Whitelaw, M., *Writing - Mitchell Whitelaw.* [Online]
Available at: http://mtchl.net/
[Accessed 9 November 2014].

ZYNC, 2014. *Zero VFX - Commercials.* [Online]
Available at: https://www.zerovfx.com/#commercials
[Accessed 3 December 2014].

## Movies

*The Matrix.* 1999. [Film] Directed by Laurence Wachowski, Andrew Paul Wachowski.

*Wag the Dog.* 1997. [Film] Directed by Barry Levinson.