Chapter 2
Photosensitivity shaping hybrid systems

> "Anything said is said **by** an observer."
> Humberto Maturana [1]

The nature-culture divide has long grounded Western thinking and remains strong well beyond the confines of anthropology. Since media artworks have often been produced in the intersection of this dichotomy, I have thus far not distinguished between organic and man-made photosensitive elements. They are, however, an essential element of the aesthetics of contemporary media artworks, and this chapter is dedicated to analysing their hybrid condition. This analysis will look at the unfolding materialities and operations of the organic and machinic photosensitive elements deployed within and by media artworks, considering them as operating systems rather than enclosed objects.

Most living organisms are light sensitive, and photobiology has several branches that cover photosensitivity in plants, unicellular organisms, invertebrates, human and non-human vertebrates, etc. Within the field of sensor engineering, the variety of photosensitive electronic components, sensors and other technical ensembles is no less impressive. Due to the immense variety of photosensitive elements, therefore, the analysis is initially narrowed down to focus on light-sensing as vision, and, even more specifically, the confrontation of eye and camera.

Additionally, other aesthetic explorations of photosensitivity with non-human living organisms are acknowledged from a post-humanist perspective. Aside from the general relevance of hybridity, they point towards a sort of decoding and recoding that human beings enact upon the environment and all its constituent parts through the creation of complex interspecific engagements.

Following a similar structure as the first chapter, the discussion is focused on the materiality and modes of operation of specific selected cases, highlighting relevant issues for the comprehension of media art aesthetics.

1 Maturana, Humberto apud Foerster, Heinz von. At each and every moment, I can decide who I am. In: Poerksen, Bernhard. *The certainty of uncertainty.* Charlottesville,VA USA: Imprint Academic, 2004. p. 12.

2.1 Light-sensing as vision

Photosensitivity as the core aspect of vision is a complex topic that requires an essentially cross-disciplinary approach. Interactions between the component parts of a system are more complex than the parts themselves. This principle of the theory of complexity is what makes it possible to distinguish the physiology of the eye from visual perception. Although both are intertwined, they are not the same thing, as psychologist and neuroscientist Richard Langton Gregory (1923-2010) has shown in his book *Eye and brain* (1998)[2] by compiling the results of a rich variety of experiments conducted on vision and cognition.

In evolutionary terms, the diversity of photoreceptors and their developments that preceded what we call eyes is immense. Simpler forms of photoreceptors can be reactive to the presence of or changes in the intensity of light, which is the case with several unicellular organisms, plants and funghi. The development of more complex forms led to adapted cells that are sensitive to movement. According to Gregory, *"these cells may be scattered over the skin (as in the earth-worm) or they may be arranged in groups, lining a depression or pit, which is the beginning of a true image-forming eye"*[3]. According to the latest biological taxonomy, image-forming eyes are a feature only of molluscs, arthropods and vertebrates.[4]

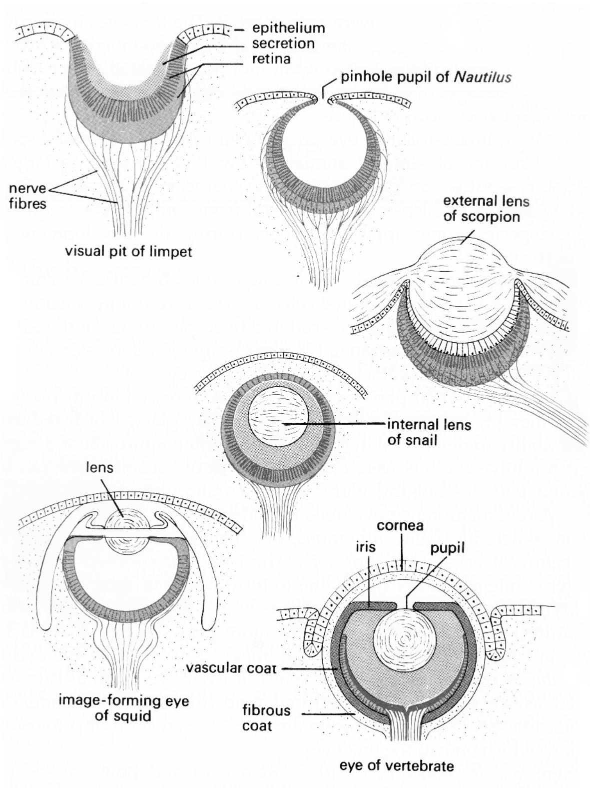
From a biological perspective, an eye is a physiological structure able to form an image; otherwise, light-sensitive structures are simply called photoreceptors. In the animal kingdom, the rich diversity of light-based sensorial apparatuses called eyes are classified according their anatomy and the type of image they generate (see fig. 2.1). Thus, there is no standard eye, the forms are elected through evolutionary principles conforming to the context in which they emerge.

On the cultural level, the diversity of interpretations and paradigms of the eye and vision have depended on the cultural contexts and empirical possibilities of a given time and place. For a couple of centuries in antiquity, philosophers defended the emission theory of vision, which held that visual perception was possible because light was emitted by the eyes onto the objects. The Presocratic philosopher Empedocles (495- 444 b.C. ?) thought the world was formed of four basic elements – fire, earth, water and air – and believed that the goddess of love, Aphrodite, cre-

2 Gregory, Richard Langton. *Eye and brain: The psychology of seeing*. 5th edition. Oxford/Tokyo: Oxford University Press, 1997.

3 Gregory 1997: 25.

4 Gualtieri, Paolo. Rhodopsin-like proteins: the universal and probably unique proteins for vision. In: Musio, C. (Ed.) *Vision: The approach of Biophysics and Neuroscience.* Series on Biophysics and Biocybernetics. Vol.11 – Byophysics. Singapore, New Jersey, London, Hong Kong: World Scientific, 2001. p. 23.



2.1: Diversity of eyes' anatomies; Source: Gregory 1998: 26.

ated the human eye[5] using these four elements, making vision possible only after lighting the element fire on it. As the media theorist Siegfried Zielinski (1951-) has observed:

> Empedocles combines poetically the anatomical components of the eye – retina, pupil, vitreous humor – with the most important factor for perceiving the other: the notion of perception as a continuous flow presupposes the existence of a rich, burning energy within that is inexhaustible. [6]

5 Zielinski, Siegfried. Attraction and repulsion: Empedocles. In: *Deep Time of the Media: Toward and Archaeology of Hearing and Seeing by technical means.* Cambridge, MA/London, England: The MIT Press, 2006. p. 47

6 Zielinski 2006: 47.

Also according to Zielinski, Empedocles made no distinction between understanding and sensory perception, considering the roles of the senses and perception as active ones. Media artist and designer Joachim Sauter(1959-) and the ART+COM Studio[7] used a similar conception in the artwork *Zerseher* (1992), in which the observer, while looking at the image of the artwork, simultaneously transforms, destroys and deconstructs it. The piece is also a didactic materialization of the cybernetic concept of the second-order observer and the acknowledgement of subjective vision. The observer necessarily influences and is part of the observed system, and, through the feedback loop between artwork and the eye of the second-order observer, a creative power of vision that endows the eye with attributes akin to the wonders of the ancient emission theory is revealed.

2.2: Participant at the artwork *Zerseher* (1992), by Joachim Sauter and ART+COM Studio. Courtesy of the artists.

The emission theory remained a main model of explanation for centuries, until Euclid asked how it could be possible that the light emitted by the eyes could reach the stars instantaneously every time we blinked. The intromission approach that followed, by contrast, focussed on the receptive side of the eye, stating that vision was based on the reception of light reflected by external objects. Although emission theory is now considered a fallacy in current scientific discourse, intromission theory can also lead to the understanding of vision as something passive, and the

7 Available at <https://artcom.de/project/zerseher/> Accessed August 23rd 2017.

eye as a mere input organ. Yet the visual system also cannot be reduced to the optical functions of an eye since the brain and the other senses play a crucial role in the process. Perhaps what Empedocles believed was the emanating fire of the eye can be interpreted as the highly complex levels of information provided together with the rest of the body gesture – e.g., the surrounding muscle system of the face and all the symbolic layers that anatomical and physiological characteristics can convey.

Artistic explorations of the eye's photosensitivity and the forces behind light-matter interaction that overcome the idea of passive or active roles are also found outside of media art. One elucidative example is the Japanese theatre-dance butoh, whose proposal, roughly summarized, is that dancers are danced rather than dance; i.e. that they be entirely open and susceptible to influences of both the inner and outer environments. Yoshito Ohno (1938-), son of butoh co-founder[8] and dancer Kazuo Ohno's (1906-2010), stated this perogative as follows:

> We, as performers, need to give careful consideration to how the eye and the body interact. It is essential to grasp where exactly the eye is located and how it functions. Moreover, there are things that cannot be seen with eyes. For a butoh dancer, the entire body must become a receptor organ for light.[9]

The post-World War II context in which butoh, literally "the dance of darkness", emerged lends this statement added significance. Aside from the physiological aspect, there is a symbolic level involving the search for light. Through its slow, hyper-controlled movements that reflect the endeavors of a body to resist fixity and efforts to define it, butoh's aesthetics manifest life's active materiality. Endowing the whole body with the qualities of the eye can also be understood as aesthetically embracing the complexity of what science terms the embodied mind. This is an approach that blends the physicality of sensorial phenomena and the abstraction of cognitive processes – what in other historical and philosophical contexts has been called 'spirit' or 'soul'.[10]

In the context of modern science, the pioneering experimental studies on vision by Hermann von Helmholtz (1821-1894) represented a turning point in our understanding of visual perception[11], preparing the path for the current scientific model of vision and the accompanying challenges regarding the embodiment of perception. Further studies on the physiology and psychology of vision also called

8 with Hijikata Tatsumi (1928-1986).

9 Ohno, Kazuo; Ohno, Yoshito. Kazuo Ohno's World: From Without and Within. Translated by John Barrett. Middletown, CT: Wesleyan University Press, 2004. p. 24

10 Lakoff, George; Johnson, Mark. *Philosophy in the flesh. The embodied mind and its challenge to western thought.* New York: Basic Books, 1999.

11 Crary, Jonathan. *Techniques of the Observer – On Vision and Modernity in the nineteenth century.* Cambridge, Massachusetts/London, England: MIT Press, 1990.

attention to cultural differences, with the recognition and reproduction of forms becoming understood as subject to cultural idosyncracies. An example of which, for instance, is seen in the contrast between the affinity to rectilinear and rectangular forms in Western urban society and the circular perspective of the South African Bantu ethnic group.[12]

From the large array of models found in nature, the human eye has been the main parameter for the construction of optical media devices, which, in turn, have served to better our understanding of the human body and senses. As Friedrich Kittler (1943-2011) asserted in his lectures on optical media: *"we knew nothing about our senses until media provided models and metaphors"*[13]. Kittler's statement[14] is to a certain extent in line with early assertions of constructivist epistemology, also represented in Giambattista Vico's (1668-1744) axiom. By introducing the Latin aphorism *Verum esse ipsum factum* (what is true is what is made/done), Vico meant that one can only understand what one has produced[15] – an important paradigm for media artists, whose creative process frequently starts with the physical construction of conceptually challenging objects, installations and performances.

The following sections provide a technical discussion of the material and operative elements of the eye and camera – the primary references for organic and machinic vision – as a background for discussing photosensitive hybrid systems in media art.

2.1.1 Elementary structures, concepts and operations

Anatomical, physiological and projected structures

The human eye is both the primordial human reference for photosensitivity. To this day, the anatomical and physiological properties[16] of the human eye are often understood and modelled through the metaphor of a camera – Plato's cave with a lens, as Gregory puts it, although his book sets out to deconstruct such a poor metaphor.[17] The problem with this type of simplification is that it does not provide

12 Gregory 1997: 150.

13 Kittler 2010: 34.

14 A contemporary counterpoint to Kittler's reducionist perspective on the understanding of human senses and cognitive processes is the work by media theoretician Wendy Hui Kyong Chun, who discusses software and hardware as an interplay between visible and invisible, using analogies ranging from computer science and biology to broader cultural and economic relationships. Chun, Wendy Hui Kyong. *Programmed visions: software and memory.* Cambridge, Massachusetts/London, England: The MIT Press, 2011, p. 101.

15 Bredekamp, Horst. The Picture Act: Tradition, Horizon, Philosophy. In: *Actus et Imago. Bildakt at the Warburg Institute.* Berlin/Boston: Walter de Gruyter, 2014. p. 10.

16 Here anatomy is understood as the study of the structure and relationship between the body parts, whereas physiology is the study of the function of body parts and the body as a whole.

17 Gregory 1998: 1.

a hint of the complexity found in the tiny elements that comprise the human eye. The human eye is a typical vertebrate eye, which works in close partnership with the brain. Though many animals have more complex eyes, humans have the most evolved brain, and it plays a crucial role in our visual perception. The human eye is a sphere of flesh filled with a gel called vitreous humour between the adjustable pinhole called the pupil and the retina. The pupil is surrounded by a coloured iris and by refractive elements that form a lens complex comprised of the cornea, the aqueous humour and the crystalline lens. Historically, the spherical piece has continuously inspired philosophers, writers and poets to write about it[18], as well as lovers to fall in love.

The figure below illustrates the common anatomical model of the human eye presented in biology books today:

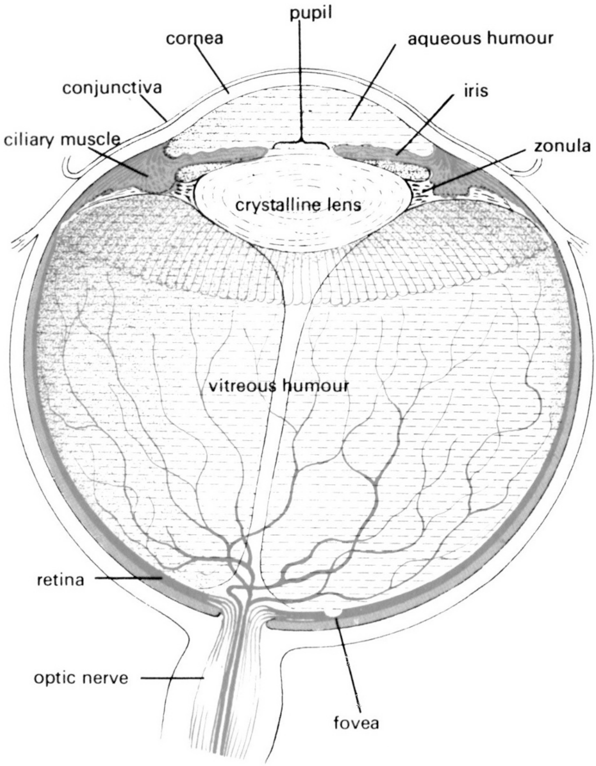
Of special interest here is the retina (from Latin *rēte*, meaning "net"), the thin light-sensitive tissue placed on the opposite side of the pupil, where the images from the outer world are formed and captured.[19] It is also where the confusion between what is seen and what is thought occurs, which constantly requires the other senses to provide evidence telling it whether or not what is seen is valid according to a common shared reality.

However, the main retinal functionality – its role as an interface quality for the photoreceptors' activity – is invisible to the naked eye. The discovery of retinal cells only became possible after the developments in microscopy, namely, the invention around 1835 of the ophthalmoscope, an optical instrument dedicated specifically to the visualization of the eye fundus. Observations made through the new device, however, did not assure complete objectivity. The very first descriptions were strongly biased by the researchers' imagination. Natural scientist Gottfried Reinhold Treviranus (1891-1837), for instance, reported that light-sensitive cells directly faced the light. According to Gregory, further research revealed that before reaching the rods and cones, the light rays have to cross the tissues of blood vessels and other layers of supporting body cells and nerve fibres. This explains why when human eyelids are closed the image seen is predominantly red. Studies on embryology attribute this characteristic to the fact that vertebrate retina originate from the surface of the brain.[20]

18 Especially noteworther here are George Bataille's *L'histoire d'oeil* (1928) and Merleau-Ponty's *L'oeil et l'esprit* (1964).

19 In the aforementioned didactic metaphor, the retina plays the role of a film or of an image sensor in a camera: it is the structure in the human eye responsible for transforming the image formed from projected external objects into information that can be read by the brain. In material terms, luminous input data is transduced/translated into neural-coded signals (electric pulses) by photosensitive cells called rods and cones.

20 Gregory 1997: 53.



2.3: Schema of the anatomy of the human eye; Source: Gregory 1998: 36.

Curiously, also using the metaphor of a film camera, Gregory contends that the evolutionary path that provided this feature to human eye was a "mistake":

> Optically, the retina is inside out, like a camera film put in the wrong way round (Figure 3.20) [2.4 here]. Given the original 'mistake' however (which seems to result from the embryological development of the vertebrate retina from the surface of the brain), the situation is largely saved by the nerve fibres from the periphery of the retina.[21]

This is another example of how the human construction of technical apparatuses plays an important role (perhaps even serving as an evolutionary strategy) in the understanding and organization of the body and the surrounding world. A man-

21 Ibid.

2.4: Illustration representing the retinal structural layers; Source: Gregory 1998: 54.

made device, namely a camera, becomes the parameter of what is 'normal' and what is a 'mistake' made by nature. A similar phenomenon occurs with the use of the concept of software, specifically in the interchanges between biological and computing knowledge. Based on the work of historian of science Lily Kay (1947-2000), media theoretician Wendy Hui Kyong Chun (1969-) asserts that in the 1950's there was an expressive paradigm shift in the discourses of molecular biology by absorbing the informational metaphors nourished by concepts from techno-sciences, such as cybernetics, bionics, and informatics. The shift mainly consisted of the displacement of the rhetoric of 'biological specificity', formerly dominated by mechanical lock-and-key metaphors. This phenomenon became even stronger with the development of genetic engineering, when scientists began to contend that *"genes transferred 'information' and the correlation between nucleic acids and proteins catachrestically became a 'code'"*.[22] Chun's criticism of the displacement of biology, in which *"bodies became reduced to messages"*,[23] is similar to Katherine Hayles's critique in *How we became posthuman* that information was categorized as something *"conceptually distinct from the markers that embody it, for example newsprint or electromagnetic waves"*[24]. Considering the rapid rate of technological advances, their criticism is a reminder of why it is important to look at the materiality of things, even when developments are happening on a scale that humans are not able to sense. This is a challenge not unlike the current challenge for media artists to find compromises in the interaction between the materiality of bodies and machines.

Returning to the structural features of the retina, the larger or smaller concentration of photoreceptor cells divides the retina into specific parts. The optic disc, for instance, is a tiny blind spot present in each eye, marked by the absence of those cells; it is also the place where the optic nerves are located, which are in charge of transferring the electric pulses to the brain.[25] A larger concentration of optic nerves is found in the retinas' central area, the fovea – a teeny pit not much bigger than 1mm^2 that enables the high accuracy of human vision. Interestingly, as a biological evolutionary solution to what Gregory called a "natural error", in the fovea the internal layers of the retina are laterally displaced, in order to optimize the reception of light stimuli and to avoid noise production by the blood vessels and other tissues.

Located on the outer edges of the retina, rod cells are responsible for the reception of small-intensity light and for peripheral vision. Cones, in turn, highly abundant in the fovea, are further classified into three kinds of cells, with each type responding to visible light of different wavelengths on the electromagnetic spectrum. Long cones respond to light of long wavelengths, peaking at the colour red; medium cones peak at the colour green; and short cones are most sensitive to wavelength of the colour blue[27]. An up-to-date depiction of these cells can be seen in the following figure:

Rod and cone cells are embedded with visual pigments, whose molecular activity was already introduced in the previous chapter. Visual pigments share the

22 Chun 2011:104-5.

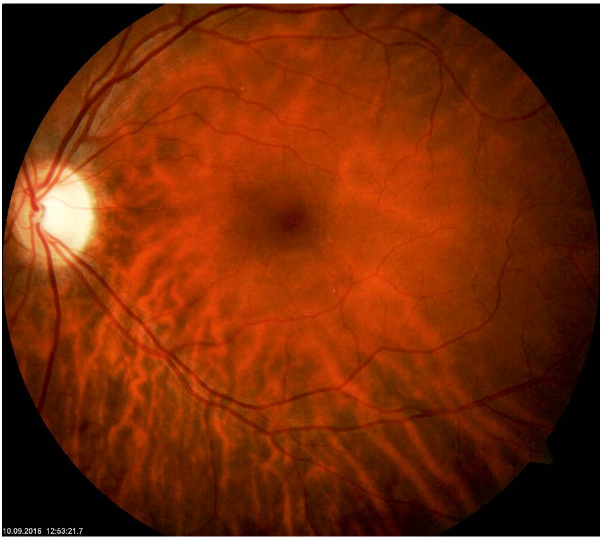
23 Ibid: 105.

24 Hayles 1999: 25.

25 According to Kittler, *"the blind spot where the optic nerves leave the eye – was only first discovered by physiological experiments in the seventeenth century".* (Kittler 2010:136)

26 Curiously Ars Electronica Center's device for photographing the eye fundus of visitors was not able to make pictures of my blind eye's retina. This is another concrete example of how technological development plays a significant role in determining normativity.

27 Guyton & Hall 1996: 577-589.



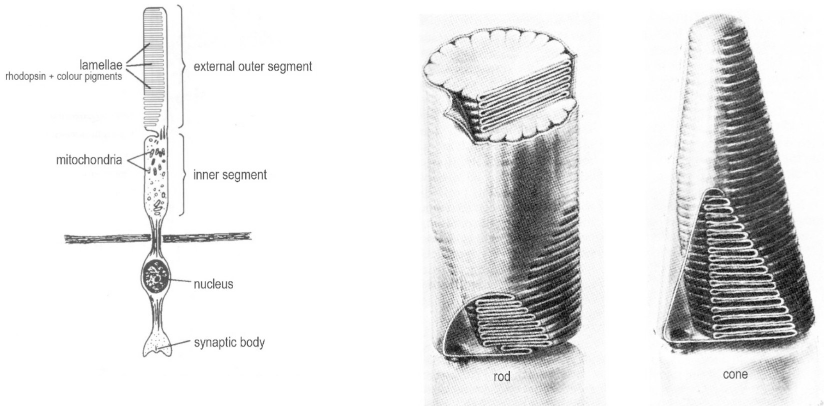
2.5: Picture of the author's retina.[26] Highlights for the blood vessels in red rhizome shape, the optic disc (yellow spot on the left side), the point of exit for ganglion cell axons leaving the eye, the highest acuity area called fovea and the macula (blind spot) Photo: Ars Electronica's Brain Lab, 2016.

same structural features, formed by an opsin (a group of light-sensitive proteins) plus an apoprotein and a chromophore. In the rods of human eyes, as in the eyes of the majority of vertebrates, photosensitivity occurs as the result of the reaction of a light-sensitive receptor protein named rhodopsin[28], which is a highly specialized G-protein[29] coupled receptor (GPCR) able to detect a single photon.

The first known studies on the properties and functions of rhodopsin were published in 1876 by physiologist and histologist Franz Christian Boll (1849-1879). This directly followed the discovery by biologist Max Schulze (1841–1915) that vertebrates' eyes present the two kinds of aforementioned visual receptors; and it, in turn, was followed by the more detailed studies of physiologist Wilhelm Kühne (1837-1900) and his co-workers. Kühne determined the makeup of rhodopsin and postulated its

28 Etymological roots from the ancient Greek ῥόδον (rhódon), meaning "rose", due to its pinkish color, and ὄψις (ópsis), referring to "sight" <https://en.wiktionary.org/wiki/rhodopsin> Accessed September 5th 2017.

29 Guanine nucleotide-binding protein that works as a molecular switch/relay.



2.6: Schematic diagrams of the anatomic structure of the rods and cones. A generalized conception of the important features of a vertebrate photoreceptor cell (left) and the anatomical differences between the structure of rod and cone outer segments (right); Source: Adapted from Young 1971 apud Guyton et al 1996: 578-9.

protein part. His experiments and observations on photochemical reactions with rhodopsin proved that it was dependent on both wavelength and light intensity.[30]

Physiologically, the photo-bleaching chain processes in rods and cones are similar, aside from using slightly different pigments[31], and their principle is like that of an on-off switch. Rods are initially turned on and light turns them off. The phototransduction cascade of the rhodopsin is essentially based on the isometrization of the retinal molecule from its 11-cis to its all-trans form. This shift triggers a series of molecular changes in the rhodopsin molecule that provoke the hyperpolarization of the cell, closing its ion channels and turning the rod cell off.[32] Furthermore, as reported by biophysicist Paolo Gualtieri, the retina-opsin complex has an intense absorption band (340nm-640nm) and its light isomerization operation is very efficient (less than 1picsec) due to its: barrierless excited state potential surface; high signal-to-noise ratio; remarkable structural changes that enable the reliability and reproducibility of signals; and its derivation from ß-carotene, which is broadly distributed in the natural world.

The extreme accuracy of the eyes would not be effective if the cells did not also count on the quantum efficiency of rhodopsin: *"Approximately 20% of photons at a wavelength of 500nm that strike the human retina lead to a transduction event, an efficiency*

30 Giese, Arthur C. (Ed.) *Photophysiology General Principles; Action of Light on Plants.* New York/London: Academic Press, 1964. p. 9.

31 Guyton & Hall 1997: 579.

32 More detailed information of the process at Guyton & Hall 1997: 580.

comparable to that of best photomultiplier tubes"[33]. Here again, the understanding of biological models is driven by the comparison between organic and man-made devices, by means of invoking the most photosensitive man-made element yet invented. Photomultipliers are phototubes[34] *"capable of multiplying the single photoelectrons several million times, each time generating a larger current pulse"*.[35] Through the presence of a series of dynodes – electrodes with a voltage level between that of the anode and the cathode – the electrons are accelerated in a chain process producing kinetic energy.

More accessible comparisons to the way photosensitive matter is implemented in contemporary devices are the semiconductor-based image sensors Charged-Coupled-Devices (CCDs) and Active Pixel Sensors (APSs/CMOS) used in digital cameras, both of which *"are pixelated metal-oxide semiconductors. They accumulate signal charge in each pixel proportional to the local illumination intensity, serving a spatial sampling function"*[36]. According to the biophotonics experts Rainer Riesenberg and Andreas Wuttig: *"CCD image sensors are an array of photodiodes with an internal capacitance for accumulating photocharges and a capability to shift these charges through the array"*.[37] CCDs were created in 1969 as an analog shift register for data storage purposes. They were originally intended to replace the former magnetic memories, and its subsequent use as image sensor was a secondary but revolutionary development. Media theoretician Sean Cubitt's (1953-) definition of a CCD in the end notes of *Practice of Light* (2014) is useful for situating the device within the larger context of technological developments in media history:

> The CCD chip of a digital camera comprises a p-doped (positively charged) thin crystalline lattice deposited on a transmitting layer. Light arrives from the lens onto the lattice, each cell of which acts as a capacitor accumulating an electric charge according to the value of light referred to as luminance, arriving at that cell. The charges at each pixel are in effect the latent image, similar to the undeveloped filmstrip in a traditional camera. The array is linked to a control circuit that, after exposure, instructs each capacitor to pass its charge on to its neighbour. The last capacitor in the array then passes its charge to an amplifier that converts the charge into voltage. The process is repeated until all the charges have been con-

33 Ibid.

34 Phototubes are among the man-made light detectors that work based on the photoelectric effect. They consist of a gas-filled or vacuum tube with a cathode and an anode. (Riesenberg, Rainer; Wuttig, Andreas. Optical Detectors. In: *Handbook of Biophotonics. Vol. 1 Basics and techniques.* Weinheim, Germany: Wiley-VCH Verlag: 2011. p. 299.

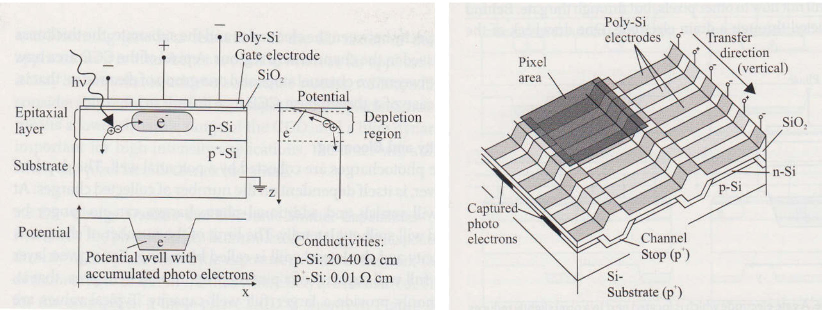
35 Ibid: 299-300.

36 Litwiller, Dave. CCD vs. CMOS: Facts and Fiction. In: *Photonics Spectra.* Lauring Publising CO. Inc. January 2001.

37 Riesenberg & Wuttig 2011: 322.

verted to voltage, digitized, sampled, and stored – in a matrix sharing the same grid structure – by the underlying CCD semi-conductor.[38]

The illustrations below of a single pixel unit in a CCD by Riesenberg and Wuttig (Fig. 2.7) clarify Cubitt's description. As a metal-oxide semiconductor (MOS) device, its base (substrate) is made of a relatively good conductor in certain conditions (e.g. silicon) and is coated with a layer of a metal-oxide (e.g. silicon dioxide) and an insulator. On the very top, there is a polysilicon, a highly pure form of silicon.[39]



2.7: A pixel unit in a CCD; Source: Riesenberg & Wuttig 2011: 323.

Silicon is a special material because it can be doped with small amounts of other materials in to modulate its electrical properties. Depending on the type of chemical bonds, it is possible to produce p-type or n-type material to embed in a photodiode[40]. Similarly to carbon, silicon has four valence electrons that it can share with other chemical elements to form bonds. If bound to another silicon atom forming a crystal, there are neither extra electrons nor places where electrons are

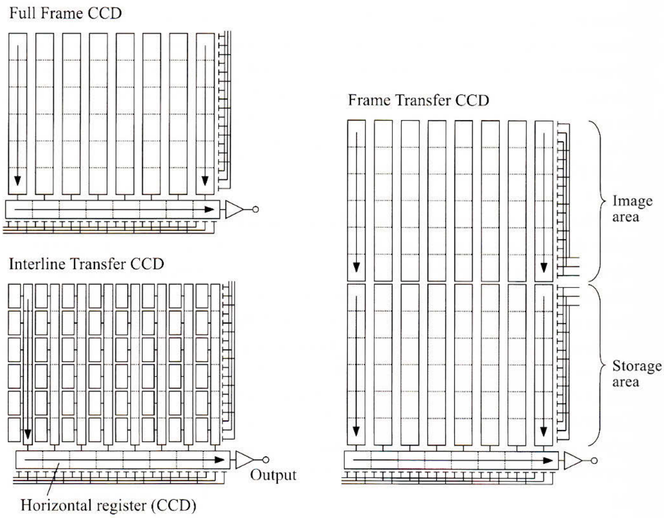
38 Cubitt 2014: 276.

39 Also called polycrystalline silicon, used as a raw material by the solar photovoltaic and electronics industry.

40 In the Handbook of Biophotonics, a basic type of photodiode is defined as "*formed by a p-n junction in a semi conductor, that is, by a contact between a p-doped region in which charge transport only takes place in the form of hole conduction, and an n-doped region, where electrons are responsible for charge transport. Between these two regions an insulating zone without free charge carriers builds up due to diffusion processes of electrons and holes, because free electrons will recombine and be captured in the p zone (loading it negatively) and free holes will the same in the n zone. Inside the insulating zone, called the depletion zone, an electrical field is generated due to the capture of the two types of charge carriers on the two different sizes of the p-n junction. Finally, the system o n zone, p zone, and depletion zone effectively forms a charged capacitor. Similarly to the case of photoconductor, incident light with a photon energy higher that the bandgap energy E_G generates electron-hole pairs, which without an electrical field would diffuse through the device but with an electrical field will generate a photocurrent*". (Risenberg and Wuttig 2011: 323)

missing.[41] The situation changes when adding other elements (impurities) to a semiconductor in order to produce or modify its properties. Introducing the element galium, for instance, which has only three electrons available for bonding, means that the molecule formed will have three normal bonds and one bond with a 'hole', i.e. missing an electron. This condition generated a sort of "musical chairs" among the neighbouring electrons, as this hole is able to move around just a freely as a mobile electron. This characterizes a p-type material, whereas a material with extra electrons is named a n-type material.

Once these technical details have been clarified, the fundamental key to the operation of a CCD also becomes clearer: Through the incidence of luminous stimuli, the movement of the available hole or the free electron can be directed. The way the electric current is conducted through the lattice, and posteriorly to the rest of the circuitry, has a direct influence on the architecture of the image sensor, as exemplified in the pictures below:



2.8: CCD's charge transfer modes; Source: Riesenberg and Wuttig 2011: 323.

Furthermore, the differences in the architecture of image sensors are what generate distinct data quality, as can be observed in the differing modes of transferring charges between CMOS and CCD image sensors. For each complete exposure

41 Peterson, Courtney. How it works: The Charged-Coupled Device, or CCD. In: *The Journal of Young Investigators.* 1999. Available at <http://www.if.ufrgs.br/~marcia/ccd.pdf> Accessed October 12th 2016.

in a CCD, each pixel's charge is transferred sequentially in packages to an output structure – where the charge is converted to voltage, buffered and sent to an off-chip;[whereas] in a CMOS, the charge-to-voltage conversion takes place in each pixel.[42] This difference has direct implications for both chips and the device's capabilities and limitations, which are evaluated for each context according to parameters like responsivity, dynamic range, uniformity, shuttering, speed, windowing, anti-blomming, biasing and clocking, reliability and, if relevant costs.

This brief summary scientific and technological developments already enable one to better understand how the manipulation of photosensitive matter on the atomic level works. One can also notice a sequence of correspondences: a pixel corresponds to a retinal photoreceptive cell; the lattice to the whole retina; the transmitting layer to the optical nerve. Yet, although these metaphors might be didactically useful for explaining the operations behind the processes, the physico-chemical laws and processes in each case are, in fact, not the same: since retinal cells evolved from brain cells, they are able to operate locally as logical gates, but time processing in retinal cells is much slower than in image sensors due to its chemical basis.

What organic and machinic structures certainly do have in common is the human approach to them, specifically regarding the processes of abstraction through which we understand specific phenomena and construct new cultural objects. It was the convergence of a series of discoveries – ranging from the physical properties of semi-conductors, through the mathematical operationalization of lattices to the physiological observations of the retina – that made the construction of CCD and its subsequent use as an image sensor possible. Organisms and man-made devices for generating and processing data through light variations seem to be distinct, but follow similar operating patterns. These patterns have been astutely observed, categorized and analysed by information engineers such as Claude Elwood Shannon (1916-2001) and the media-archaeologist Friedrich Kittler and his followers, who view the basic operations – capturing, processing, storing and transmitting – as ruling mechanisms in information exchanges within and between biological and technological systems. The theoretical framework of cybernetics additionally emphasises the circularity inherent in these processes.

Resolution and verisimilitude

The search for the maximal resolution of viewing machines (photo or video cameras) reflects the desire to find technical solutions that most closely approximate human visual perception, thereby closer to verisimilar modes of representing reality. This is apparent in the way digital three-dimensional models and animations

42 Litwiller 2001.

are aesthetically handled in the visual arts. Instead of taking advantage of the freedom of unreal physical situations, the techniques are frequently used for the sake of hyperrealist special effects in entertaining movies.[43] This is part of a long tradition of creating devices and techniques marketed as a means of achieving the 'most real' experiences, while masking their limitations. Stereoscopic devices and their volumetric tactile appeal, for instance, are sold as "*some of the most pervasive means of producing 'realistic' effects in mass visual culture*"[44], when, in fact, it is a technological apparatus based on eliminating the connection between the human senses of sight and touch.

Despite the discourses marketing great advances towards achieving the 'most real effects', current optical apparatuses are far removed from the qualities of a human eye. The efficiency demonstrated by visual pigments in chemical reactions is optimized by the considerable amount of actants in the process: A human eye has approximately 100 millions rods and each "*rod has approximately* 4^*10^7 *rhodopsins*", which represents a much higher resolution photo-sensor than that of amphibians, which have only 10^7 rhodopsins per rod.[45] The human retina has an even higher resolution when compared to a contemporary device from the machinic world: a "*high-resolution photographic purpose CCD chip CCD595 from Fairchild Imaging has a pixel number of 9216x9216, giving a total about 85 megapixels*"[46]. In this case, a whole CCD chip has a bit more than double the quantity of units of a single rod. Furthermore, the resolution attained by the human eye is by no means the only indicator of its magnificence or its limitations. Their flexible features and adaptability endow eyes with almost magical abilities. For instance, unlike the specialized tissue architecture of a retina, a digital camera's pixel-based image sensors present a limited Cartesian arrangement, simply due to production facilities and the need to be profitabile. This condition leaves the quality of image sensors highly dependent on the photosensitivity of semiconductor materials and the size of the image sensors themselves. Solving this problem is one of the promising avenues of research for scientists working with photosensitive biomaterials.

Operations

Fragmenting: forming, processing, transmitting and converging

The concept of resolution can also be comprehended as resulting from the process of fragmentation that both bodies and media have been subjected to since at least

43 Klein, Norman M. *The Vatican to Vegas: A history of special effects.* New York: The New Press, 2004.

44 Crary 1990: 9.

45 Gualtieri 2001: 27.

46 Riesenberg and Wuttig 2011: 315.

the nineteenth century. The increasing accuracy of scientific studies on living bodies led to the emergence of physiology, and the knowledge produced in this field has directly informed the development of diverse media devices. This cultural mechanism is in line with Vico's axiom that one can only comprehend what one has constructed. However, to construct, one also needs to abstract, isolate, fragment. This is the observation underlying Vilém Flusser's media theory based on the cultural history of abstraction and philosopher Peter Sloterdjik's (1947-) metaphor of the knife[47] to epitomize the human attitude toward the world. Specialization inevitably involves a movement towards abstraction, and therefore fragmentation.

In *Techniques of the observer* (1990), art critic Jonathan Crary (1951-) depicted this phenomenon in relation to vision and optical media. Crary depicts the path leading to the abstraction of vision, and how the work of Helmholtz and his contemporaries on human vision was part of efforts to describe the functioning of living beings in precise physicochemical terms.[48] One of the consequences of the fragmentation of the senses has been the separation of the seeing act into two parts: forming and processing images. Whether in retinas or in image sensors, photosensitive elements bridge the two distinct processes of image formation and image processing.[49]

A device that remained for centuries the reference for image formation in media history was the camera obscura.[50] Mirroring the processes that occur in the eyes, the insertion of photosensitive elements into the *camera obscura* opened up several paths for image processing and, through its further fragmentation, potential means of image transmission, which caused drastic changes to the nature of images themselves.

The technological longing for long-distance image transmissions that culminated in the invention of television and its derivative serial image techniques, enabled image formation independently of a pinhole and a black box. The idea that an image could be fragmented before being transmitted harks back to the work of the French engineer Maurice Leblanc (1857-1923), who in 1880 proposed that they could be broken into lines, translated into electric signals, and later be sequentially reconstructed in a receiver apparatus[51]. In Germany, among inventions that fragmented images into lines, especial attention should be devoted to Nipkow's disk, a device developed by Helmholtz's young student Paul Gottlieb Nipkow (1860-1940).

47 From the original excerpt in German: "*Der Mensch ist ein Tier, das schneiden kann*". (Sloterdijk 2015: 40)

48 Crary 1990: 148.

49 Crary 1990; Fournier D'Albe 1924.

50 Crary also depicts how the camera obscura and its derivative techniques and devices together with the emergence of physiology contributed not only to the abstraction of vision but also to the makeup of the modern observer.

51 Parrika 2012: 41.

On his patent, the inventor wrote that *"the purpose of the apparatus described here is to make an object at location A visible at any location B"*[52]. The experiment is simply the concretization of the human abstractive gestures described by Flusser, especially the transition from a three-dimensional captured image, through a linear unidimensional form, to the zero-dimensionality of electric current. In Kittler's words, *"Nipkow imposed the discrete line form of a book or telegram onto images with sweeping success."*[53] It is crucial to note that the experiments of that epoch were mostly fuelled by the discovery of selenium's photosensitive properties, which played a significant role as an interface in the discoveries and inventions concerned with image transmission.[54]

In the media-archaeological artwork *A Parallel image* (2008)[55], artist Gebhardt Sengmüller didactically makes a variety of issues related to media technologies of image formation and image transmission tangible in a single piece. As shown in figure 2.9, Sengmüller's installation offers the audience a material magnification of a space between the sensing of an image and displaying it somewhere else. Sengmüller suggests the simplest but most impractical way of connecting image capture and transmission – processes that are commonly hidden in the darkness of the electronic black boxes found in photo and video cameras, televisions, digital displays and so forth.

2.9: *A Parallel Image* (2008), by Gebhardt Sengmüller. A: Overview; B: Detail of lamps in the monitor side (output); C: Detail of LDRs (Light-dependent Resistors) lattice (input). Courtesy of the artist.

52 Rings 1962: 37 apud Kittler 2010: 209.

53 Kittler 2010: 210.

54 Primitive forms of television are also discussed at Fournier D'Albe 1924: 75-83.

55 Sengmüller, Gebhard. *A Parallel Image.* <http://www.gebseng.com/08_a_parallel_image/> Accessed October 8th 2017.

According to the artist's statement:

> This media-archaeological, interactive sculpture is based on the fictive assumption that the currently still valid principle of electronically transmitting moving images, namely by breaking them down into single images and image lines, was never discovered. The result is an apparatus that attempts a highly elaborate parallel transmission of every single pixel from sender to receiver. This is only possible by connecting camera and monitor using about 2,500 cables. Unlike conventional electronic image transmission procedures, A Parallel Image is technologically completely transparent, conveying to the viewer a correspondence between real world and transmission that can be sensually experienced.[56]

A *Parallel Image* casts doubt on the standard principles behind optical devices, whose procedures cannot be perceived by the human senses. The artist imaginatively poses a 'what if' question as a strategy for causing reflection on how media work, their historical development and their aesthetic appropriations. Sengmüller elegantly subverts the principles of black boxes by expanding and opening them. The invisibility of the light path is made tangible through the floating mass of 2,500 shining copper wires. Despite their clearly metallic materiality, a quick glimpse at the workmanship reveals a quasi-convincing organic aspect, amplified by both the lightness and the fragility of the extremely thin copper wires.

There are also other technological and aesthetic subversions: the LDRs lattice that resembles a CCD or a CMOS image sensor does not operate like one; and the fetish with display resolution for achieving a more verisimilar experience plays absolutely no role in the reception of *A parallel image*. Last but not least, Jussi Parrika's comment on the piece confirms the effectiveness of the sequence of frustrating subversions entangled in the artwork: Firstly, *A parallel image* is absolutely unrelated to any of the norms of technological consumerism, where electronic technology is usually packaged in sleek opaque cases.[57] Secondly, the installation setup does not permit the visitor to directly access the image she is producing. The spatial conditions Sengmüller designed create an interaction modality in which the reactivity of the system and its mirroring effect between sensors and actuators denies the participant immediate gratification. A second and third participant are are necessary for one to decipher how the installation functions as a whole.

Although Sengmüller's piece does not address image processing, it indirectly suggests that sensing and image forming make no sense when separated from another linked system(s). Whether in the retina or in image sensors, image processing is only partially local. At the same time, there is no inner eye in the brain nor any analogous structure within the integrated circuits of the camera (or the system to

56 Ibid.

57 Parrika, Jussi. *What is Media Archaeology?* Malden, USA: Polity Press, 2012. p. 41.

which it can be connected). Light sensitive cells in the retina are responsible for translating the luminous stimulus into electric pulses to be read and processed in the brain. Human visual perception is special precisely due to this eye-brain combination. In fact, as Gregory explains, retinal cells are extensions of brain cells:

> The retina has been described as an outgrowth of the brain. It is a specialized part of the surface of the brain which has budded out and become sensitive to light. It retains typical brain cells which are functionally between receptors and the optic nerve. (…) Some of the data processing for perception takes place in the eye, which is thus an integral part of the brain. [58]

In comparison to predators, for instance, the local efficiency of human eyes is not that optimal and is highly dependent on the brain's data processing.[59] Therefore, although there is some local processing in the human eye, the act of seeing does not happen exclusively in the retina or in image sensors. For this reason, visual perception is more analogous to visual computing than to the mechanism of a camera. Research into how humans and animals learn how to see, and even into what happens when this faculty is limited or damaged, has contributed immensely to refining the understanding of the eye-brain relationship and how raw luminous stimuli are transformed into meaningful information for human beings.

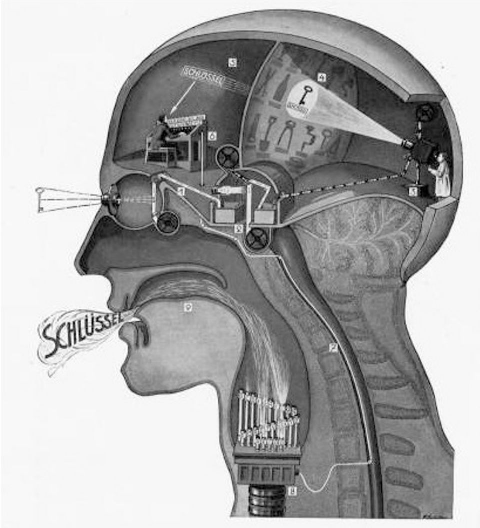
There are major differences in the way images are processed in electronic cameras depending on the context in which these devices are intended for use, and these processes have been continually reviewed and recombined in light of the new scientific discoveries and inventions that formed the standards of each era. While the development of series of optical media devices has been used both to enhance the human sense of sight and to profit from its limitations, their creation exemplifies the mutual influences and overlaps between natural and man-made models. Picture 2.10 below shows the role of media as imagined at the beginning of the 20th century[60], when cinematographic metaphors were used to model relationships between seeing and language:

With the eyes of today one notices how naïve human understanding of vision was at that time, and one can easily imagine that we are probably still using metaphors that are not appropriate to describe the phenomenon of vision in its entirety, as our construction of models is still subject to the limits of our media.

58 Gregory 1997: 53-4.

59 It has not always been obvious that vision and other sensations and perceptions are dependent on the brain's activity.

60 Zielinski, Siegfried. *Deep time of the media: Toward an archaeology of hearing and seeing by technical means.* Cambridge, Massachusetts/London, England: MIT Press, 2006.



2.10: Der Sehakt. Example of the use of media as metaphors for explaining the process of seeing; Source: Kahn 1929, Vol. 4, plate VIII apud Zielinski 2006: 49.

The translation of the image formed in the eye into electric pulses represents another potential way to bring organic matter into closer contact with a machinic and computational perspective. However, neuroscientists insist that organic and machinic correspondences are neither adequate nor suitable. Among the reasons are the countless material specificities of biological elements; the electric conduction through chemical processes, for instance, besides being sometimes reversible, are much slower than those in transistors and copper wires. On the other hand, if the zero-dimensionality of computation is also found in living beings, it might provide the ground for the dissolution of the image as a representation that results solely from vision. Sound artists are also constantly incorporating image-based associations in their compositions, using metaphors from the visual arts, referring to sound as sculpture that can be composed in an additive or subtractive ways, etc.

Zooming out to collective aesthetic manifestations, one emblematic artistic movement that highlights the enthusiasm of artists for the emerging possibilities created by scientific and technological development is video art. Video art flourished at the end of the 1960s, with the aspirations of video artists[61] ranging from freeing both artist and artworks from the traditional representational canons of

61 Meigh-Andrews, Chris. *A history of video art: the development of form and function*. Oxford/NewYork: Berg, 2006. pp. 73-74.

the visual arts, to making political statements against what had been done in the TV broadcast industry. They were at the same time spurred on by contemporary theoretical perspectives, such as those of the media theorist Marshal McLuhan (1911-1980), cybernetics and information theory[62]. On the one hand, considered as an intermediate and transitional stage between television and digital computing, the aesthetic language of video is strongly based on the potentialities of the fragmented aspects of this media, which are reflected in the mergence of its technical, conceptual and aesthetic layers[63], as is evident in McLuhan's famous statement *"the medium is the message"*.[64] On the other hand, there were those, such as the scholar Henry Jenkins (1958-) and the TV producer John Wyer[65], who saw audio-visual media history as a path towards media convergence and believed that the fragmentation processes of media would also subsequently lead to the dissolution of the isolation of senses and thus favour synaesthetic aesthetic experiments. This also explains the intimate relationship between video art and experimental music. Together with the ephemeral quality of the media itself, video art can also be read as an art movement related to process-based artwork, aligned with principles also embraced by the Situationists and the Fluxus group.

Although the primary stimulus for the "man with a camera" was the sense of sight, the zero-dimensionality of electronic media and its potential open connections with other media led to more radical experiments with space-time variables, enabling a camera to be used to break free of the constraints of realism. A master in overcoming these constraints by addressing the very materiality of video in his lyrical film-making practice, was the avant-gardist Stan Brakhage (1933-2003). In his *Metaphors on vision* (1963)[66] Brakhage formulates the core of his aesthetic statement around the hypothesis that: *"if vision is the highest value of film, then camera (and its man) must allow visions to occur rather than force them (by script) upon subjects."*[67] From this point of departure, the artist created *Anticipation of the night* (1958), a video composed of reflections on *"the nature of seeing; how one encounters a sight, how it is recalled, how it affects later vision, and where it leads the visionary"*.[68]

The emergence of electronic image sensors and the operations related to them opened the way for brand new means of expression that have become ubiquitous

62 Meigh-Andrews 2006: 101-110.

63 Just to recapitulate, video technology inaugurates image processing on several levels, such as non-linear and real-time editing, application of filters and other effects, modulation, loops, etc.

64 McLuhan, Marshal. *Understanding media*. United Kingdom/New York: Routledge, 1964/2001.

65 Meigh-Andrews 2006: 8.

66 Brakhage, Stan. *Metaphors on vision.* Film Culture: 1963. Scanned from the collections of Niles Essanay Silent Film Museum. Fremont, CA Available at <https://archive.org/details/metaphorsonvisio00brak> Accessed October 10th 2017.

67 Brakhage 1963: 8.

68 Ibid.

and taken for granted in todays digital age. Art historians and critics who have addressed core issues of video art aesthetics, for instance, naturally related it to its technical aspects. For technical reasons, it is also well known that for many artists video art represented a liberation from standard mainstream[69] ways of making both cinema and visual art; it served as a means to transgress the traditionally established language of the art and cinema industries. This became easier as the necessary equipment became lighter and more compact and portable. Video art simultaneously destroyed and reinvented the tradition of image production, also incorporating new techniques of imaging, such as x-ray, thermic and magnetic resonance images.

The intent here is not to establish a connection between the history of video art and the corresponding technical developments of the equipment; many authors have already covered this, as well as the political and activist aspects of video art history and aesthetics. What is important to the argument of this thesis is making the freedom behind machinic aesthetics explicit, bringing to attention the aesthetic uses that have become not only easier to implement but more accessible: the latent image in the CCD, e.g., opens possibilities for recombination and reinvention, even, if the artist desires, as something other than an image. The presence of photosensitive electronic devices in the arts has challenged artists to turn exact and objectivist knowledge and technical operations into enquiries, doubts and uncertainty. Through purposeful displacement and unlikely reconnections, that artists' decisions represent what Flusser termed straining off the possibilities of the apparatuses[70] in the search for symbolic and interpretative openness and desirable levels of uncertainty.

In summary, the human fragmentation of the world can be considered on several levels and constitutes, at the very least, the abstractive mechanism of Western thinking. The zero-dimensionality of media does not operate independently; it is a human invention[71] to enhance the possibilities of manipulating, combining and organising matter – material as well as symbolic. Both materially and symbolically, therefore, fragmenting stems from a biological feature that has been instrumental in shaping human culture. It is a strategy that mankind uses to accomplish a series of tasks – understanding, comparing, classifying, constructing, analysing, deconstructing, reconstructing, etc. In approaching the structural levels of the human eye and optical sensors, a similar process is underway. Rather than striving

69 For female artists inclusive, through the rising and diffusion of feminist voices.

70 Flusser, Vilém. *Filosofia da caixa preta*. São Paulo: Annablume, 2011.

71 On the implications of the invention of the concept of zero see: Deacon, Terrence William. Calculating with absence. In: *Incomplete Nature: How mind emerged from matter.* New York/London: W.W. Norton&Company, 1992.

to discover similarities, more can be achieved by acknowledging differences and learning how to deal creatively with them.

Filtering, mapping and noise reduction

The path between retina and brain, between image sensor and microprocessor is made possible by operations that cannot be explained solely through the anatomical or architectural qualities of isolated elements. In this sense, the scientific paradigms that emerged and suggested that problems can be handled holistically while taking into consideration the interdependence of the parts of the whole were extremely useful for dealing with problems created by new technological and scientific discoveries.

Experiments and theoretical attempts to understand vision also take part in the process of rationalization of sensation and its many intangible psychic affects. The endeavours by Gustav Theodor Fechner (1801-1887) and Ernst Heinrich Weber (1795-1878), who attempted to formulate a *"mathematical equation that expressed a functional relation between sensation and stimulus"*[72], is an example of this process. Studies with this objective have endeavoured to measure and mathematically formulate the relationships between objectivity and subjectivity, revealing that, although the firing rate of receptors increases as the intensity of light is increased, the *"sensation of light does not increase as quickly as the intensity of the physical stimulus"*[73]. Fechner's law suggests a logarithmic relationship between the actual change in physical stimulus and the perceived change.[74] This, in turn, has been interpreted as suggesting that photosensitive cells play the role of filters.[75]

A primitive sample of machine vision developed by the physicist Paul Weston (1935-) at the Biological Computer Laboratory (BCL), a seeing-counting machine called *Numarete* (1960), already demonstrated the difficulties and challenges faced in attempting to mimic the above-mentioned filtering quality of organic photosensitive cells. *Numarete* is a simple but very instructive example of the interplay between photosensitive materials and applied mathematics and represents one of the countless possibilities of man-made filtering operations.

Able to count the objects placed onto it, *Numarete* was supposed to be a simulation of a Pitts-McCulloch cell network, operating through the arrangement and

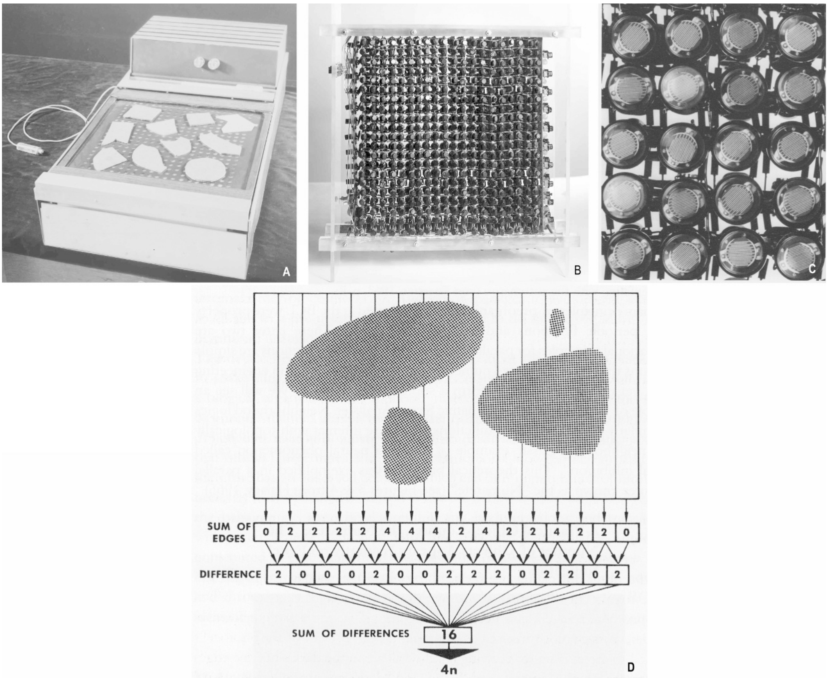
72 Crary 1990: 145.

73 Ibid: 146.

74 Experiments done with the horseshoe crab limulus polyphemus, whose eye receptors are connected directly to separate nerve fibres, showed similar results. (Gregory 1997: 92)

75 According to Gregory, *"the highest number of impulses a nerve can transmit is under a thousand per second, while the frequency of light is a million million cycles per second. The problem is: How are the high frequencies of light represented by the slow-acting nervous system?"*. (Gregory 1997: 122)

interconnection of photoresistors and electronic elements that could assume one of two states (on or off, or 0 and 1)[76], as show in the picture below:



2.11: *Numarete* (1960), by Paul Weston. A: The device; B: Array of LDRs (Light-dependent resistors); C: Details of the LDRs; D: Schema of mathematical operations made by the machine. Courtesy of Paul Weston and Heinz von Foerster Archive, Institute of Contemporary History, University of Vienna.

Understanding photosensitive cells as filters, i.e. as membranes that select what the internal system can (or cannot) administer, is pertinent to the issue of how the form and function of living bodies are the result of an evolved solution to absorb and transform a specific range of high frequency radiations (far higher than nerves can directly follow) into a visible spectrum. Every organism needs to limit the amount of input data according to the body's limits and survival needs. For the same reason, the processing activities of eye-brain cells are split in phases, presenting different anatomical characteristics according to the path that the electric

76 A more detailed technical description of Numarete can be found at: Weston, Paul. A walk through the forest. In: Müller, Albert. (Ed.) *An unfinished revolution? Heinz von Foerster and the Biological Computer Laboratory | BCL 1958-1976*. Wien: Echoraum, 2007. pp. 93-96.

pulses pass through. According to Gregory, the *"pre-processing funnels 120 000 000 receptors down to 1 000 000 optic nerve fibres, no doubt reducing the thickness and stiffness of the optic nerve so that the eye movements are possible"*[77]. Similarly, from the perspective of image sensor engineering filtering could be considered as an optimal manner to process a huge amount of information. In a very simplified way, this is also what the mathematical model behind the *Numarete* does (see frame C at figure 2.11).

The correspondences between the form and filtering function of cells also reveal a sort of media specificity[78] of each part of the body. This fact was of notable interest to cyberneticists. While conducting studies on frogs' vision between 1958 and 1960 at MIT, cyberneticist Humberto Maturana (1928-), in collaboration with Jerome Ysroael Lettvin (1920-2011), a specialist in neurophysiology and electronics, *"realized that the shape of the nerve cells and the retina specified what the retina saw, so to say."* [79]

Neuroscientist António Rosa Damásio (1944-), in *Self comes to mind* (2010), describes a variation of the filtering method of eye-brain cooperation through the immediate correspondences between the retinotopy and the activated patterns in the visual cortex, suggesting the notion of mapping as a metaphor to explain the dynamics between sensorial input and brain stimulation. Suggesting that the concepts of image, map and neural pattern are interchangeable, Damásio analyses equivalences between the two-dimensional square grid architecture of retinal neurons and the three-dimensional cerebral cortex. According to his findings, the inscription of lines on a brain map is the *"result of momentary activity of some neurons and of the inactivity of others"*[80] and *"can be rapidly drawn, redrawn and overdrawn"*[81]. He explains:

> The same kind of 'drawing' also happens in an elaborate outpost of the brain called the retina. It too has a square grid ready to inscribe maps. When the light particles known as photos strike the retina in the particular distribution that corresponds to a specific pattern, the neurons activated by the pattern – say, a circle or a cross – constitute a transient neural map. Additional maps, based on the original retinal map, will be formed at subsequent levels of the nervous system. This is because

77 Gregory 1997: 55.

78 As demonstrated by experiments conducted by physiologist Johannes Evangelista Purkinje (1787-1869), retinal photoreceptors have certain specific features – the cones are anatomically and physiologically more apt to filter the light spectra when the eye is light-adapted, whereas the rods are more apt to filter the light spectra when the eye is dark-adapted. (Gregory 1997: 90)

79 Maturana, Humberto R. Interview on Heinz von Foerster, Autopoiesis, the BCL and Augusto Pinochet. In: Müller, Albert; Müller, Karl H. (Eds.) *An unfinished revolution Heinz von Foerster and the Biological Computer Laboratory | BCL 1958-1976.* Wien: Echoraum, 2007. p. 41.

80 Damasio 2010: 66.

81 Ibid: 67.

> the activity at each point in the retinal map is signalled forward along a chain culminating in the primary visual cortices while preserving the geometrical relationships they hold at the retina, a property known as retinotopy.[82]

Damásio's interpretation of eye-brain dynamics asserts that, although abstracted into electric pulses, the information provided by inputs preserves a spatial quality of the senses, and by extension perception and memories, inside the body.

Filtering and mapping features, from either biological or machinic systems, are also indirectly related to the notion of noise reduction, a mechanism usually working to optimize input data in order to turn it into more useful and/or meaningful information for the system. In fact, *"all sensitive detectors are subject to random noise, which degenerates signals, and limits the sensitivity of detectors"*[83]. Confirming the cooperative work between eye and brain, it is known that even after light stimulation on the eyes has ceased, neural activity continues to occur in the brain. Therefore, finding strategies to reduce the harmful effects of noise is an everyday task of living beings.

According to studies on experimental psychology, moreover, *"the smallest difference in intensity that can be detected in the retina is proportional to the background intensity."*[84] This demonstrates the relativity and quasi-instantaneous adaptability of the human eye to a variety of light conditions. In Gregory's words:

> the old idea of a threshold intensity, above which stimuli need to be if they are to have any effect on the nervous system, is wrong. We now think of any stimulus as having an effect on the nervous system, but only being accepted as a signal of an event when the neural activity is unlikely to be merely a chance increase in the noise level. (...) The problem for the brain is to 'decide' when a given increase is merely noise and when it is due to the increased intensity of the signal. If the brain accepted any increase from the average activity, then we could often 'see' flashes of light that are not in fact present.[85]

In this sense, the recalibrating feature of vision works as a strategy to generate perception constancy, as a biological reaction against irrelevant repeated signals.[86] On the one hand, the eye's adaptability and its noise reduction features might also constitute a body's strategy to optimize the consumption of energy. On the other hand, although living beings find ways to reduce the harmful effects of noise, it is unavoidable that the visual system's internal noise increases with age, causing

82 Ibid: 67.
83 Gregory 1998: 93-4.
84 Ibid: 94.
85 Ibid: 95.
86 Ibid: 149.

gradual loss of visual discrimination as well as subsequent problems with motor control and memory.[87]

Noise reduction strategies in machinic systems, setting aside their role in the optimization of energy consumption, can be approached as an arbitrary adjustment aimed at finding a compromise between input signals and a certain verisimilitude to human perceptive skills. Although it is known that engineers have been struggling to achieve the most efficient results for media and communication technologies, as already noted long ago by Claude Shannon and Warren Weaver (1894-1978) in their *Mathematical Theory of Communication* (1948), *"mediation is not necessarily efficient, in the sense of translating data from A to B undamaged"*[88]. In technological environments, moreover, noise is understood as an intrinsic characteristic of any system, i.e. as a permanent condition of communication[89]. Although organisms and machines are subject to the same rules of the physical world, noise reduction is a matter of survival for living entities, whereas for communicational devices this is not the case.

Furthermore, considering that the intense and dynamic *"changes in the brain maps also reflect the fact that we ourselves are in constant motion"*[90], due to the eyes' movements and biofeedback processes, the recalibrating feature of vision becomes even more powerful, providing a degree of adaptability that even the smartest robots by Boston Dynamics still do not possess. This also explains why recent computational neurotechnology studies on the syntax of behaviour have focussed on the perception-action loop and on the role of movement, which neuroscientist Aldo Faisal considers crucial for decoding intentions.[91]

In addition to this systemic perspective, one can also observe that the initial scientific impetus to artificially segregate image forming from image processing has been recently dissolved by the mergence of computer vision and machine learning techniques. In this connection, it is intriguing to think about Jonathan Crary's critique of the pragmatic approach of the 19th and 20th century psychophysicists and and its possible relevance to the current approach to vision engineering.

Concerning media art, it is worth questioning what kind of knowledge paradigm media artists are adopting to make their audience – to use Crary's terms – "manageable and predictable". A frequent challenge in the development of sensor-based artworks is the problem of removing noise from the sensor in the interest of

87 Gregory 1998: 95.
88 Shannon & Weaver 1949: 3.
89 Serres 2007 apud Cubitt 2014: 9.
90 Damasio 2010: 67.
91 Faisal, Aldo. *Perception, action and the grammar of behavior.* Lecture held at WO/MAN MIND MACHINE Interdisciplinary Conference at the Einstensaal/Berlin-Brandenburg Academy of Sciences and Humanities on June 13th 2016. The event was co-organized by *Die Junge Akademie* and The Israel Young Academy.

both the stability and intelligibility of the system's reactivity. Decisions on this level cannot be made without some notion of a 'model visitor'[92] and have direct influence on the openness and fluidity of the system. Depending on the context, it can be desirable to have either a precise and clean, hence less noisy, or a random, dirty and unintelligible, therefore noisier, reaction from the programmed system. These choices concern fine adjustments that artists must think about in order to make their artworks more or less communicative. There is no unanimity on this topic because such decisions depend on the context and on how knowledge is implemented and actualized in praxis. Artists are free to incorporate previously developed optical tools in a more diverse and critical way. It is also, however, the responsibility of artists to analytically reflect upon the level of noise they use in their artworks.

2.1.2 Parameters of vision

Image formation and processing relies on a variety of parameters concerning the elements to be detected, or perceived, such as shape, brightness, contrast, depth and perspective, among others. This section will address the parameters of colour and movement detection in order to enhance understanding of the close relationships between human vision and optical media. Colour and movement have been chosen for three main reasons: (1) the immediate functions of photosensitive cells, (2) their pertinence in the process of unboxing media history through the lens of photosensitive materials and (3) their strong resonance in media artworks.

Colour detection

The ability to perceive colour emerged relatively late in the evolutionary process of mammals, dating to the existence of primates. Like vision itself, the perception of colour is the product of a shared phenomenon happening between object (or surroundings), eye and brain. Understanding this phenomenon requires distinguishing colour as sensation and colour as wavelength (or set of wavelengths). Newton's experiments at Trinity College, in Cambridge, which lead to the compilation of his book *Optiks* (1704), were important to drawing this distinction. The physician's discovery that white light was made up of all the colours of the spectrum triggered the subsequent development of the wave theory of light, which holds that each monochromatic colour corresponds to a given frequency of radiation. While the dual nature of light (wave-particle) is acknowledged as the current scientific paradigm, the radiation spectra named light is not coloured *per se* but rather is the source through which sensations of brightness and colour can be perceived by a suitable eye and nervous system working in cooperation. Therefore, technically speaking,

92 Direct teference to Umberto Eco's (1932-2016) concept of 'model reader'. Eco, Umberto. *The Role of the Reader: Explorations in the Semiotics of Texts*. Bloomington: Indiana Univ. Press, 1992.

it is preferable to refer to colours as 'hues', which essentially depend on subjective impressions.[93]

The subjective aspects of visual perception stand out even more when colours come into play. How does one know that the sensation of what one calls blue is the same for someone else? Although humans have the same type of retina, one cannot conclude that people see the same colour. This is a great and unresolvable paradox for studies on colour, despite the constant efforts to objectify what is essentially – physiologically – subjective. This fact has not always been obvious and its realization is part of the history of discoveries related to light and human vision. Furthermore, it reveals the influence of subjectivity in cultural formation and the importance of colour perception to visual aesthetics. A classical example of the cultural layer of visual perception is the ability of Eskimos to distinguish sixteen shades of white. Besides the ability of the eye to adapt to light conditions almost instantaneously, specific environmental factors have a demonstrable influence on the perception of colour. The highly accurate adaptation to light conditions is still very difficult to achieve in seeing machines. It is not accidental that professional video cameras offer the manual set up of white balance, a feature that in human eyes is so natural and automatic that it is very hard to even think about it. Perceptual psychologist Rudolf Arnheim (1904-2007) has related the example of how humans can simultaneously perceive a white sheet of paper close to the window in daylight and a similar one on the nightstand close to an incandescent lamp. The colour white works as the ground reference for the desired colour temperature to be recorded in digital video cameras. However, in the course of media history adjustments of this level have not been easy to achieve. The diversity of techniques implemented in the history of colour photography and moving images[94] demonstrates that both colour perception and the implementation of colour in media devices are in fact also a sort of filtering process.

According to Friedrich Kittler, it is very likely that the development of colour images in media technology – the RGB system, as well as luminance and chrominance – only became possible after the discoveries made from research on the photosensitive cells of human eyes.[95] In this process leading roles have been played by the work by Thomas Young (1773-1829) and Hermann von Helmholtz (1821-1894), both of whom are responsible for the trichromatic colour vision theory, also known as the Young-Helmholtz Theory. [96] This theory was further developed by Ja-

93 Gregory 1997: 84.

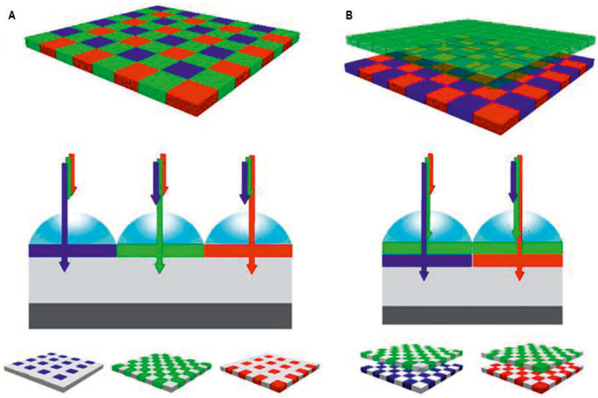
94 Flückiger, Barbara. *Timeline of historical film colors*. Since 2012. Available at <http://zauberklang.ch/filmcolors/> Accessed September 23rd 2018.

95 Kittler 2010: 36.

96 The theory defended the view that human eyes presented *"three colour-sensitive kinds of receptors (cones) which respond respectively to red, green and blue (or violet), and that all colours are seen by a mixture of signals from the three systems."* (Gregory 1997: 126) According to Gregory, the

mes Clerk Maxwell (1831-1879), who in 1861 demonstrated one of the first documented colour photographic images. The implementation of the trichromatic theory of vision into image techniques remains the basis of most colour images in optical media today. As with the techniques for enhancing the resolution of optical devices, the issue of colour has also been accompanied by the search for the maximal verisimilitude of the device's response, i.e. as close as possible to human vision.

On a CCD, for instance, the technique found to apply the trichromatic theory of colour in single-chip digital image sensors was Bayer masking, a system that consists of an array of colour filters placed over a square grid of photodiodes, as depicted in figure 2.12:



2.12: Schematic diagrams of the CMOS colour image sensors using Bayer mask colour filter. A: Conventional two-dimensional CMOS colour image sensor. Each pixel measures the intensity of light passing through B, G, and R colour filters; B: A three-dimensional, multi-stacked, organic-on-Si hybrid CMOS colour image sensor; Source: Nature 2015.

Bayer masking, however, does not guarantee image quality in agreement with the exigencies of the quest for verisimilitude. Media historian and theoretician Sean Cubitt has observed that:

> In addition to Bayer masking, expensive models code colour by splitting the light with a prism toward three separate CCD chips, but high-resolution chips are still very expensive, so that 3CCD architecture tends to be used more in high-end video

process of isolating the basic response curves has been surprisingly difficult for the available technology of the time. More recent and specific books on the physiology of vision since the 1960s have determined precise measurements of the curves. (Guyton et al. 1997: 582)

> than still imaging. Another solution, using a rotating filter, is useful only for still image of immobile objects: any movement of the object produces colour-fringing effects.[97]

Discussions of possible better and more efficient solutions are unfruitful in the realm of art, since the choice of one or another type of equipment is always subject to the constraints of circumstance and not merely the concepts and aesthetical values being developed. One can imagine the "colour-fringing effects" referred to by Cubitt being easily incorporated in video art as a form of glitch aesthetics, for instance.

Furthermore, the apparent failure of those artificial colour systems is due to the narrow perspectives that ignore that seeing is done not only by the retina but by the combination of eye and brain. Specificities of photosensitive cells in the eyes help to figure out how the body can achieve various neural responses for different light radiation frequencies. However, that is only a very tiny part of a complex system, whose mystery is constantly challenging neuroscientists and other researchers engaged with the subject. Neuroscientists have also speculated that the brain deals with visual characteristics in specialized 'modules', with neural channels dedicated to form, movement, stereo depth, colour, and so on. According to Gregory, for instance, *"processing form and colour is largely separate physiologically, colour being by 'broad brush' low spatial frequency channels, operating quite slowly"*.[98] However, due to the astonishing plasticity and complexity of the human brain, it is still dubious to reach conclusions about any absolute features of the brain regions. The current categorization of visual area[99] as a core part for the perception of colour is still uncertain, despite lots of research on its mechanisms, constancy of locations and functions.[100]

In addition, returning to media history, the scientist Edwin Herbert Land (1909-1991), the inventor of the instant Polaroid camera, raised the issue of the complexity of colour perception and the concomitant participation of the cognitive faculties. Land has demonstrated that *"what is true for colour mixture of simple patches of light is not the complete story for all perception of colours. Odd things happen when the patches are more complicated, and when they represent objects"*[101]. Land's experiments on colour vision in more complex empirical contexts have contributed to the theory of colour perception to the extent of offering an alternative system to the Young-Helmholtz

97 Cubitt 2014: 276.
98 Gregory 1998: 71.
99 Guyton et al 1997: 665.
100 Cowey, A. Heywood, C.A. There is more to colour than meets the eye. In: *Behav Brain Res.* 1995 Nov; 71(1-2): 89-100.
101 Gregory 1998: 133.

trichromatic system. Moreover, by reducing the projected colours in the experiments to only two wavelengths, he also discovered that an ample range of colours could be perceived when they were associated to patterns or pictures.[102]

To a certain extent, what Land suggests marks a convoluted return to what Jonathan Crary noted about the emergence of a new modern observer through optical studies and the invention of new optical apparatuses. In order to depict the process through which cutting-edge attitudes placed perception as the primary object of vision, Crary calls attention to the work of past figures such as Johann Wolfgang von Goethe (1749-1832), Arthur Schopenhauer (1788-1860), John Ruskin (1819-1900) and Joseph Mallord William Turner (1775-1851)[103].

Goethe, by closing the hole of the camera obscura, began the neglect of its supposed objectivity, affirming that the three primary colours were not in the nature of light, but rather in the constitution of man. Following Goethe's lead, the young philosopher Schopenhauer, published his treatise *Über das Sehn und die Farben* (1816), a reflection on the active role of the retina in the process of colour perception. Schopenhauer's propositions and the emergence of physiology as a field of study also aided the consolidation of the notion of subjective vision and the parallel deconstruction of the objectivist approach modelled on the camera obscura. It was only natural that such reflections on the physiological and philosophical grounds of subjectivity resonated in the arts. J.M.W. Turner, by merging the image of eye and sun through a circular structure (the sun, the pupil, the retinal field) in his painting *Light and Colour (Goethe's Theory) - The morning after the Deluge* (1834) explicitly represents the sun and the retinal process of vision, directly citing the influence of Goethe's work on afterimages in the title of his piece.[104]

Contradictorily, although the emergence of physiology can be interpreted as the spread of rationalization over the human body, these examples simultaneously show that it led to the emergence of subjectivism, as the studies on colour perception intimately associated with physiology revealed its many idiosyncracies. Through a series of empirical studies on afterimages on the retina, scientists realized that what is seen is conditioned by the retinal structure and how it functions. When the photo-pigments present in retinal cells are bleached by light and chemically stimulate the receptors, despite how efficiently the recovery of the initial state of the photo-chemicals within the cells occurs, it does not happen immediately[105].

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102 Ibid: 133-4.

103 Crary 1990: 138.

104 Crary 1990: 139. Curiously, some of the scientists who conducted experiments on the eye and the retina have suffered severe loss of the living retinal cells in their own body. Sir David Brewster, Joseph Plateau, Gustav Fechner have damaged their own eyesight while staring into sunlight in order to research retinal afterimages. (Crary 1990: 141)

105 Gregory 1998: 57. Moreover, according to Gualtieri, the photobleaching effect of the Rhodopsin (probably the unique type of protein for vision), as a complex series of reactions,

The remaining images caused by these phenomena are called after-images, which can be positive or negative, depending on whether the eye is adapting to light or darkness.[106] According to Kittler, a positive after-image

> occurs when the eye continues to see an object in the same place a moment after it has already disappeared or moved away. This happens because the stimulation of the nerve fibers only wears off gradually, and the after-image remains in the same color as the original image rather than the complementary color, as with a negative after-image.[107]

Although the in-between quality of seeing has been recognized in both intromission and extramission theories since ancient Greece (as, e.g., in what Claudius Ptolemy (c. AD 100 – c. 170) in his *Optics* (unknown year) called 'visual flux')[108], it was only with the emergence of physiology that explanations of how subjectivity influenced the perception of colours were formulated. This fact supports Kittler's argument that the limitations of human senses prepare the terrain for media development and that it is through the knowledge of the causes and effects of after-images, persistence-of-vision[109] and phi phenomenon[110] that the creation of illusionistic media devices has been stimulated.

One can see the phenomenological stream in philosophy as an attempt to find a compromise between the usually opposed objectivism of the exact sciences and subjectivism of philosophy. Through the publication of the iconic book *Phénoménologie de la perception* (1945), Maurice Merleau-Ponty (1908-1961) refused the Cartesian division of body and soul as well as the separation between consciousness and world and subject and object – dichotomous relationships that have held sway in epistemology up to the present day. From the perspective of phenomenology, any sort of absolute analysis of colour perception will fail. Artworks dealing with colour perception, whether by distorting, emphasizing, heightening or removing a certain human ability, inability or disability, can also be understood and analysed as the materialization of phenomenological thinking. Moreover, dealing with doubt, relativity and perceptive confusion is pervasive in the arts, a field that has

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provokes the expulsion of the isomerized chromophore from the binding protein site. The whole recycling process of the protein lasts around twenty minutes. (Gualtieri 2001:25)

106 Kittler 2010: 146.

107 Kittler 2010: 149.

108 Smith, A. Mark. "Ptolemy's Theory of Visual Perception: An English Translation of the 'Optics' with Introduction and Commentary." In: *Transactions of the American Philosophical Society*, Vol. 86, n. 2, 1996, pp. iii-300.

109 Often shortened to POV, it refers to the 1/8s of the image permanence on the retina after exposure to light.

110 Described by Gestalt theoretician Max Wertheimer (1880-1943), the phi phenomenon theory refers to the human cognitive ability of completing the gaps between static images and thus allowing movement perception. (Gregory 1998: 118)

historically been partially based on the exploration of illusions and other sorts of tricks to deceive and expose the limits of the human senses.

Desvio para o vermelho (1967-1986)[111] by Cildo Meireles (1948-) is a masterpiece proposing a 'red shift' for the visitors, consisting of an installation that embraces a variety of layers of interpretation simultaneously through its three sessions: *I: Impregnação* (impregnation) (Fig. 2.13); *II: Entorno* (surroundings) and *III: Desvio* (deviation). Meireles, considered by art historians and art critics as a conceptual artist, provides visitors with a perceptual and immersive experience in a room completely decorated in red, opening up an aesthetic experience of the physiological, emotional and symbolic developments with which the colour red can be associated.

2.13: *Desvio para o vermelho. I: Impregnação* (1967-84), by Cildo Meireles. Mixed media. Variable dimensions. Photo: Eduardo Eckenfels. Courtesy of the artist, Galeria Luisa Strina and Inhotim.

As soon as one enters the room *I: Impregnation*, an unusual feeling is prompted by the experience of being immersed in a monochromatic environment. Slowly as one's retina adapts to it, one starts to perceive a huge variety of shades of red. The

111 The artist first thought about this artwork in the second-half of the 1960s; however, it was only at the beginning of the 1980s that he started working concretely on it. It was assembled for the first time at the Museu de Arte Moderna in Rio de Janeiro in 1984. A version of the installation has been permanently exhibited at the contemporary art centre Inhotim, in Brumadinho, Brazil since 2016.

first step is an essentially sensorial experience and refers literally and directly to the physiological aspects of the sense of sight and its ability to filter and accommodate colour. The room reveals that perceiving colour not only depends on the wavelengths and intensities of the stimulus, but also on differences and intensities within the details and the specific regions, shapes and patterns to which they are associated. A seeing machine could certainly detect and classify all those shades of red much faster than a human, but it nevertheless lacks the joy of perceiving the self-regulating and learning processes of a living body.

What happens next is that the dominant sensorial experience gives place to reflections on the symbolic openness suggested by the emotional and ideological appeal of the colour red – ranging from love and violence to leftist ideals.[112] Moreover, 'red shift' in astronomy, whether or not this connotation was intended by the artist, signifies a shift in the spectra of very distant galaxies toward longer wavelengths (toward the red end of the spectrum), an indicator, according to physicists, that the universe is expanding.

Rooms *II: Entorno and III: Desvio* complement the physiological-symbolic experience. An enigmatic scene of a leaking bottle spreading a red liquid on the floor (*II:Entorno*) is an intermediate space on the way to *III: Desvio*, a dark room where an afterimage experience is offered, followed by the discovery of a sink, where a red liquid flows from the tap. Once adapted to red colours, entering the dark room offers the visitor unusual abstract images that are translations of the chemical compensations in the retina and brain, and constitutenafter-effects resulting from the previous immersion in the red room. Each section of the installation's name suggests a strong mix of material and conceptual elements. According to curator and art critic Caroline Menezes (1979-),

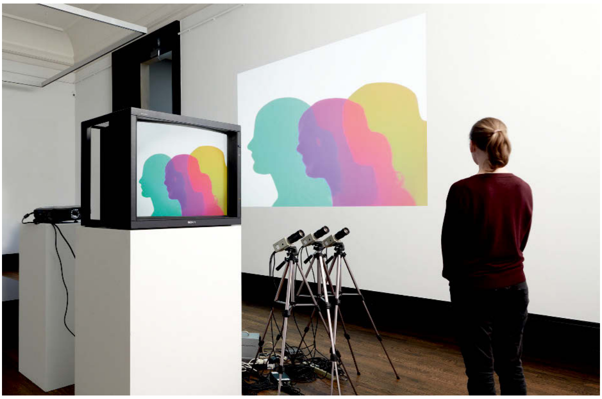
> each element composing Meireles's installations unpacks parables and tales as if to test his audience's ability to discover meaning. Establishing a strong poetry of substances, this seductive approach enlists viewers to draw out narratives by using their senses and perception.[113]

In the context of media art, colour issues and their interplay on the technical level also became creative material for pioneer video artist Nam June Paik (1932-2006) in his *Three-camera participation* (1969/2000) (Fig. 2.14). In this installation the artist

112 The artist has declared in an interview that he could have done it in blue or yellow and that no specific political orientation was intended in this artwork. (Menezes, Caroline. Materiality and Memory: An interview with Cildo Meireles. In: *Studio International*. March 28th 2009. Available at <http://studiointernational.com/index.php/materiality-and-memory-an-interview-with-cildo-meireles> Accessed November 7th 2017.

113 Menezes, Caroline. Cildo Meireles: From Sense to Concept. In: *Studio Internacional*. <http://studiointernational.com/index.php/cildo-meireles-from-sense-to-concept> Accessed November 7th 2017.

created a closed-circuit video, in which three adjacent cameras capture real-time images of the visitor(s). Each camera captures a colour channel, and the three single images are merged while projected onto the wall and displayed in a monitor set off to the side.



2.14: *Three-camera participation* (1969/2001), by Nam June Paik. Kunsthalle Bremen – Der Kunstverein in Bremen. Photo: Tobias Hübel. © Nam June Paik Estate.

The artwork plays with the visual perception of the audience through mirroring, colour-decomposition effects, displacement, and object multiplication, revealing how the senses of sight and touch are intimately connected. The simple play with the video colour system offers a confusing and challenging sense of presence that simultaneously addresses the subjective and objective aspects of colour perception. On the one hand, the form chosen by Paik is a reference to the fragmentation of the senses and their elements, a procedure inherent to the objective method of scientific investigation. On the other hand, the fragmentation can only be perceived through the subjective experience within the installation. The superimposed images created from the video's three primary colours (RGB) makes Paik's work conceptually and technically instructive in the context of media history. The artwork was displayed as part of the 2014 exhibition *Schwindel der Wirklichkeit* at the *Akademie der Künste* in Berlin, whose stated aim was to present artistic strategies and methods focussing on the visitor's perception and the confrontation with oneself.

Movement detection

The most immediate association to come to mind concerning the relation between light-sensitive matter and movement is the birth of cinema through the illusion of movement generated by the animation of photograms. Media historians often relate the emergence of time-based media technologies (film, television, video and others) to Éttiene-Jules Marey's (1830-1904) experiments on chronophotography and Eadweard Muybridge's (1830-1904) experiments on animal locomotion and invention of the *Zoopraxiscope* (1879). These examples illustrate the repeated fragmentation of media sources into elements (film frames, tv lines, digital image's pixels) that cannot be perceived as such by the naked human eye. Referring to the invention of a device in television's pre-history, the Nipkow's disk, Kittler stated:

> Nipkow also knew about the inertia of the eye and its unconscious ability to filter out the image flicker either physiologically through the after-image effect already employed by film, or more generally or mathematically through the integration of individual pixels.[114]

The chemical basis of the photoreceptors responsible for the afterimages and the POV phenomena's effects makes the perception of movement essentially stroboscopic, a quality that attributes a necessarily temporal quality to vision. Therefore, an observer's sensations are necessarily dependent on a sequence of stimuli registered by the individual photoreceptors in the retinal receptive fields, which are, therefore, spatio-temporally linked with the neural networks of the brain.

From the perspective of the media spectator, as Rudolf Arnheim has shown, movement is the visual parameter that most attracts human attention. Considering the general specialization of retinal photoreceptors, rods, rather than cones, are more active agents in movement detection, as they have a higher concentration in the peripheral area of the retina. Recalling the functional sectors of the retina, it is the high concentration of cells in its central area that permits humans to focus and see details of objects in the central region of the sight field. The information received from the peripheral cells, on the other hand, is more related to rougher sort of visual information: *"Movement is seen, but it is impossible to identify the object, and there is no colour. When movement stops the object becomes invisible"*[115]. This instinctive feature is, however, enough for triggering a reflex movement, activating the eye muscles to turn the attention (the foveal region) towards the moving object. Looking ahead, one can perceive something moving, without being able to recognize precisely what kind of object it is. After its immediate detection, the decision about whether the object is stationary or moving is made in the brain. These kinds of choices depend on their hierarchical relationships, which are defined according to their frames, variability and intensity, as demonstrated by studies on human vi-

114 Kittler 2010: 209.
115 Ibid: 98.

sual perception, such as those conducted by the Gestalt researchers Karl Duncker (1903-1940) and Erika Oppenheimer (1910-2003).[116]

Given the inherent spatio-temporal quality of movement perception, one can consider the photosensitivity of human eyes as one of the key determinants of the concepts of time and memory in Western thinking. On the one hand, the eye's photosensitivity and ability to detect movements[117] imply the perception of time passing, which happens precisely at the very moment of perception due to its sequential nature. On the other hand, human perception of movement is a biological feature that continuously turns the external stimulus' sequential quality into a spatial quality, creating by extension the notion of memory. Since every perceived moment constantly modifies the previous ones, each perceived event finds its place in the spatial structure of memory. This is because brain and nervous system's material assimilation of electric pulses happens through spatial- rather than time-based patterns.[118]

The information provided thus far all points to understanding the eye not as a mere image-forming black box but, rather, as an important organ participating in the thinking process. Experiments such as those conducted by psychologist Celeste McCollough Howard (1927-) in the 1960s on vision scaling and adaptive abilities as biological strategies avoiding bodies own errors, demonstrate how the human eye-brain act enables us to make sense of the world. The power of eye-brain cooperation has become clearer through the efforts of technicians engaged in developing optical devices to take on intriguing problems concerning the differences between the eye's and camera's ways of seeing. These differences become even more intriguing when observing the perception of movement instead of colour perception. Questions such as *"Why the visual world does not swing round with eye movements, though it does when a cine camera is panned around a scene"*?[119] convey the highly accurate and still very mysterious work of the human brain.

Although optical engineers do their best to approximate human perception by simulating more and more 'realistic' effects, one can still easily distinguish the qualities of an eye's images from those of a camera. These differences lose their importance, however, when the image itself is not the final goal of the optical device. Such devices are frequently implemented in technical ensembles due to their operative functions rather than image quality. In their efforts to achieve more successful results, engineers working on machinic vision systems have also been exploring anatomical and physiological elements found in the vision systems of other animals. According to Gregory:

116 Arnheim 1980: 372-3.
117 Together with the auditory perceptual system.
118 Arnheim 1980: 368.
119 Gregory 1998: 114.

> A detailed model has been suggested for the compound eye of flies and is the basis for a system in aircraft that detects drift due to wind blowing them off course. This movement detector was developed by biological evolution millions of years ago, and has now been discovered by applying electronics, to be useful for technology. This is a nice example of backwards and forwards bio-engineering.[120]

A highlight of the technical tools for computer vision currently available is the library OpenCV (Open Source Computer Vision), a series of applications that implement different methods according to developers' needs. One of the motion tracking methods available at OpenCV library that is closely related to the fly's vision system is 'optical flow', a specific technique based on the recognition of apparent motion of objects, surfaces, and edges in a given image, calculated through relative changes in the frames over time. In the 1940s, psychologist James J. Gibson (1904-1979) promoted what he termed an ecological approach to vision[121] and introduced the concept of optical flow to describe the relationship between visual stimuli and animals moving through the world. In computer vision, optical flow encompasses techniques used in image processing and navigation control, such as motion detection, object segmentation, time-to-contact information, calculations of focus expansion, luminance, motion compensated encoding, and stereo disparity measurement.[122]

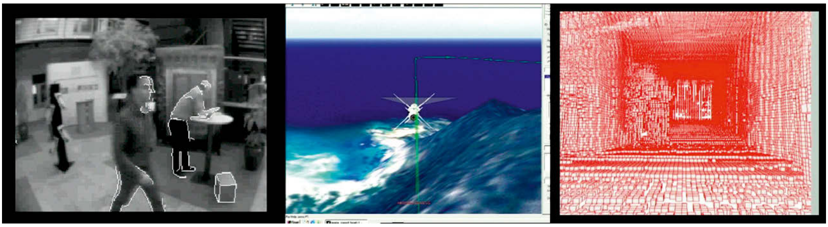
Another computational method often used to detect movements is blobs detection, which consists of identifying shapes in a digital image that can be distinguished by any property (colour, brightness, etc.) in relation to its surrounding pixels. The movement of the shape can be tracked by the constancy of those properties in a sequence of frames. This sort of algorithm and the equipment required to run it and its scanning features share much in common with the previously discussed control and surveillance issues. Preoccupations with these issues were materialized in the 1960s and 70s in video installations of different forms by artists like Bruce Nauman (1941-), Dan Graham (1942-), Michael Snow (1929-) and others, and have since been constantly revisited in the arts in relation to the contemporary technological context. This can be seen, for instance, in Harun Farocki's (1944-2014) trilogy *Eye Machine* (2001-2003) (Fig. 2.15: I, II and III), which explores the contemporary *modus operandi* of warfare by inserting military image-based technologies into everyday civilian life. His work inevitably touches on the political dimension of machine vision. Using images taken by technological devices ranging from the

120 Gregory 1997: 100-1.

121 Gibson's ecological theory of perception considered not only the individum's perceptual systems, but rather their relationship with its specific environments. According to Gregory, Gibson experimental work on depth and form, for instance, was based on modeling a dynamic 'optical array of light'. (Gregory 1998: 9)

122 Vijayarajan et al. Automatic detection of moving objects using Kalman algorithm. In: *International Journal of Pharmacy and Technology.* Vol.8 Issue 3, Sept 2016. pp. 18963-18970.

suicide cameras embedded in missiles in the Gulf War in 1991, to robots in the production line, less invasive surgery equipment and autonomous driving systems, the artist simultaneously invokes the benevolence and perversity of the operations behind such images, whose beauty, if existent, is merely the result of chance.



2.15: Frames extracted respectively from the video series *Eye, machine I* (2000), *Eye, machine II* (2002) and *Eye, machine III* (2003), by Harun Farocki. © Harun Farocki GbR.

Farocki's work shows how the ubiquitous and pervasive use of technological devices turned previously hierarchical control systems into self-regulating systems as well, as civilians also came to adopt these devices for their private security.

To date, there are plenty of artworks based on machine and computer-vision and the management of the visible that do not establish any kind of interrelationship with the human sense of sight. The relationship between computer vision and art has gone beyond seeing. The representational and symbolic qualities of the images produced play absolutely no role in the functional computer vision aesthetic systems, which serve as instruments for measuring, mapping and acting upon a situation. In other words, the values conveyed by an image change when imaging techniques and purposes change. In most current cases where computer vision has been implemented, what is represented in the captured images (or how they are composed) has been less relevant (if relevant at all) than if the system handling them is properly working. The medium is not necessarily the message.

Studies focused on the use of machine/computer vision in art have identified two main paradigms: (1) artworks based on the reconstitution of a concrete space and the localization of objects, followed by an action that is triggered if a predefined condition is met[123]; and (2) those based on pattern recognition in a vast amount of images and the connection of these images' formal characteristics with a

123 Just to mention a few, as listed by André Mintz: The pioneer *Video Place* (1969), by Myron Kruger; and more recent classics *Text Rain* (1999), Camille Utterback e Romi Achituv, *Tensión Superficial* (1998) de Rafael Lozano Hemmer, *Hand from above* (2009), by Chris O' Shea. Mintz, André. Máquinas que veem : visão computacional e agenciamentos do visível. In: Menotti, Gabriel; Bastos, Marcus; Moran, Patrícia (Orgs.) *Cinema apesar da imagem*. São Paulo: Intermeios, 2016. p. 162.

semantic network.[124] The serious issues of control and surveillance become playful features in exhibition spaces when artists use this technology to create augmented mirroring effects. In this sense, such technology is a double-edged sword. On the one hand, it can enable an audience to experiment and discover new body patterns; on the other, the programmed system of which it is a part can be so closed as to lead to a sort of domestication of bodies.

Media artist and engineer Golan Levin (1976-) states that the challenge facing computer vision is overcoming the informational opacity of images,[125] suggesting that this is only possible through such corporeal and material experiences themselves. In this sense, media artworks play an essential role to address the complexity of the problem. Understanding works like Harun Farocki's *Eye-machine* series also requires an awareness of machine and computer vision techniques. As media theoretician Geoff Cox (1960-) observed in his text *Ways of machine seeing* (2016):

> if algorithms can be understood as seeing, in what sense, and under what conditions? Algorithms are ideological only inasmuch as they are part of larger infrastructures and assemblages.
> But to ask whether machines can see or not is the wrong question to ask, rather we should discuss how machines have changed the nature of seeing and hence our knowledge of the world.[126]

Cox reminds us here that it is still human beings who build the seeing machines, thus it is still human beings, influenced by ideologies and values, who are ethically responsible for making the decisions embedded in the tracking algorithms and the outcomes of the machine's performance. An exemplary case of this is found in the contrasting uses of eye-tracking technology. On the one hand, eye tracking has been used as promising method for marketing. On the other hand, there are initiatives such as the *EyeWriter* (2009) project collaboratively[127] developed for the

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124 This technique is often associated with machine learning systems. In the same article on computer vision and the management of the visible, Mintz hightlighs the artwork *I'm Google* (2011-) by Dina Kelberman. (Mintz 2016: 169)

125 Golan, Levin. Computer vision for artists and designers: pedagogic tools and techniques for novice programmers. In: *Journal for Artificial Intelligence and Society*. Vol. 20 n. 4, 2006. pp. 462-482.

126 Cox, Geoff. Machines of Seeing. In: *Unthinking Photography*. Nov, 2016. Available at <https://unthinking.photography/themes/machine-vision/ways-of-machine-seeing> Accessed February 25th 2017.

127 Conceived by Mick Ebeling and developed by artists and engineers from the Free Art & Technology Lab, Graffiti Research Lab and OpenFrameworks teams, including Zachary Lieberman, Evan Roth, James Powderly, Theo Watson and Chris Sugrue. The initiative has been awarded in several contexts. Further information available at <http://eyewriter.org/> Accessed October 2nd 2017.

graffiti activist Tempt1, who was diagnosed with a disease that has left him physically paralyzed, except for his eyes. Based on accessible cameras and open source computer vision software, the created eye-tracking device (Fig. 2.16) enabled the artist to paint using his eyes' movements.

2.16: Tempt1 wearing his eye-tracking device; Source: The EyeWriter Project.

2.1.3 Hybrid visions

Eye-tracking systems inevitably involve the physical coupling of organic and machinic ways of seeing. They are also an instructive example of the implementation of biofeedback loops in hybrid technical ensembles using photosensitive elements.

The *Eyewriter* project is an example of hybrid vision in which an eye-tracking system was implemented to achieve utilitarian ends. Yet the work is equally powerful on a symbolic level. Through the symbiotic relationship established between eye and camera, eye movements are tracked and translated into beams of light that can be controlled by the artist. It explores the eye, not as a controlled, passive or reactive organ, but rather as a creative and emancipatory one. In this sense, the project, like *Zerseher* mentioned earlier in this chapter, seems to reference the ancient 'emission theory' originally proposed by Empedocles.

Machinic structures are getting closer and closer to the human retina in more than just a metaphorical sense. While discussing the impact and effects of former optical mass media on the audience, Kittler observed: *"telepresence can thus be described as an invasion or conquest of the retina through an artificial paradise"*[128]. Due to

128 Kittler 2010: 223.

the strong eye-brain connection, by "conquest of the retina" Kittler meant also the conquest of the human cognitive faculty. More recently, in light of the fact that vision and touch are intimately connected,[129] the conquest of the audience's cognitive faculties has extended to the tactile sense through touch screens and other tangible interfaces. Even the whole body moving through the world is becoming involved through applications based on data from the Global Positioning System (GPS) available in any smartphone. Technology critics and enthusiasts alike have suggested that among the reasons for the failure of Google Glass is that is that it isolates the sense of sight.[130] Recently, Sony patented contact lenses that, if successful, will enable the user to record images by blinking their eyes. Except for use by those with corporeal disabilities, it is not difficult to imagine that it might suffer the same fate as Google Glass.

The complexity of the aforementioned cases and the impossibility of stopping techno-cultural development make it imperative to overcome an apocalyptic view of the relationships between media (and, by extension, machines) and people. People are the creators of media and can invert, subvert and reinvent media devices' purposes, operations and frequently dominating modes of interaction.[131]

Despite the huge advances in machine learning, distinctions between organic and machinic entities remain, and scientific efforts continue to be constantly and intensively applied to dissolve them. The machinic implementation of the knowledge gleaned from research on retinas – ranging from the light-sensitive colloids of films to the most up-to-date pixel-based image sensors – shows, however, that organs and man-made devices with similar purposes (image forming and processing) nevertheless present distinct forms of functioning:

> The nerve signals are in the form of electrical pulses (action potentials), which are the brain's only input and its only output. They depend on alteration in the ion permeability of the cell membrane (Figure 4.4). At rest, the inside of an axon is negative with respect to the surface; but when a disturbance occurs – for example when a retinal receptor is stimulated by light – the centre of the fibre becomes positive, initiating a flow of current which continues down the nerve as a wave. It travels much more slowly than electricity along a wire: in large fibres it travels at about 100 metres per second, and in the smallest fibres at less than one metre per second. The thick high-speed fibres have a special fatty coating – the myelin

129 Gregory 1998: 151-153.

130 More about this discussion at Harrasser, Karin. *Körper 2.0: Über die technische Erweitbarkeit des Menschen*. Bielefeld: transcript, 2013. pp. 78-80.

131 If something is against something this can be reduced to specific groups of people against other groups of people, ranging from work relationships to international warfare.

> sheath – which insulates the fibres from their neighbours and also serves to increase the rate of conduction of the action potentials.[132]

Since, as Gregory demonstrates, the differences are based on the materials through which electric current is transferred, the challenges for creating hybrid entities, and therefore hybrid forms of vision, center around minimizing the differences and finding symbiotic ways and contexts for the materials to cooperate beginning on the atomic scale.

While reflecting on the differences between the nature of machinic and human ways of handling memory, Simondon proposed that the coupling between human and machine can only occur if a common coding ground between both types of memories is found. Like Flusser's theory of the zero-dimensionality of electronic media, Simondon suggests that a synergy between systems can be consolidated through the establishment of a code convertibility in the informational exchange between them.[133] This paradigm both authors present defines the basic condition for the possibility of hybridizations between machinic and organic elements.

In addition to the aforementioned *EyeWriter* project, there are other artists working on devices interfacing organic and machinic vision. The 'eyeborgs' Rob Spence, Miikka Terho and Neil Harbisson, e.g., each deal with different types of visual impairment. Filmmaker Rob Spence[134] replaced his lost eye with a bionic eye composed of a wireless video camera that provides so-called subjective shots on demand. Terho[135], in turn, inherited retinitis pigmentosa, a disease that caused the photoreceptors in the retina to irreversibly to die out. After becoming severely blind at the age of 35, he volunteered to be implanted with an array of 1500-microphotodiodes in the macula, the most photosensitive part of the retina, in order to partially rescue his sense of sight, heavily relying on the plasticity of the remaining nervous system to which they were attached.[136]This sort of retinal implant is only available for cases of diseases that cause the loss of photoreceptors but do not destroy the functionality of retinal neural tissue. The implant consists of series of modules: an image sensor, an image processing and/or amplifying unit, and

132 Gregory 1998: 69.

133 Simondon 1958: 173.

134 Spence produced out of his experience the short film *Deus Ex The Eyeborg Documentary* (2011). (Harrasser 2013: 29) The documentary has been commissioned to promote the video game *Deus Ex: Human Revolution*, whose protagonist is also an eyeborg. More information about Spence experience available at <http://www.eyeborgproject.com/> Accessed July 15th 2018.

135 Finnish Miikka Terho has been a reference for Rob Spence while researching possibilities for developing his bionic eye.

136 Zrenner, Eberhart et al. Subretinal electronic chips allow blind patients to read letters and combine them to words. In: *Proceedings of The Royal Society B.* October 2010. Available at <http://rspb.royalsocietypublishing.org/content/early/2010/11/01/rspb.2010.1747.full> Accessed July 15th 2018.

an array of eletroctrodes, whose function is to artificially stimulate the remaining neural cells in order to bypass the degenerated photoreceptors.[137] This technical ensemble puts in question the very complex interface functionality of sensors, addressing the interdependence between the sensorial apparatus, the external world and the cognitive processes happening inside the brain.

Neil Harbisson[138] was born with achromatopsia, a congenital disease that causes people to see in black and white. Dealing creatively with his partial visual impairment and taking advantage of the artificially constructed common ground between a photosensitive device placed in front of his head and his own perceptual faculties, Harbisson incorporated a device that translates surrounding colours into sounds. According to the artist, the experience brought him a new sense of "hearing colours", a synesthetic experience that will be further discussed in the third chapter dedicated specifically to light-to-sound translations.

Scientists all over the world are currently working on obtaining patents on combinations of human eye and machine vision, whose possibilities have been greatly enhanced by the power of nanotechnology and the development of biomaterials.

In the 1990s, pioneering developers of image processors called artificial retinas[139] anticipated still current problems in the field, pointing out that the main challenges were mostly related to the separation between image sensing (executed by a camera) and image processing (executed by a computer). In contrast to the real-time reactivity of human retina, which simultaneously combine these activities, the performance of previous machinic vision devices was frequently limited due to low camera frame rate or transmission rate. Thus, instead of specific functional devices, such as silicon retinas, vision chips, focal plane processors or any other type of space and time filtering device, people then working in the field sought to merge their functions in a single technical ensemble with multiple features: image sensing, image processing and learning capabilities.

Neuroscientist Jakob Macke, head of the MackeLab at the Research Center Caesar in Bonn, Germany, although admitting that studies in Convolutional Neural Networks (CNNs) revolutionized computer vision and machine learning, believes

137 Hornig, R.; Velikay-Parel, M. Retina Implants. In: Inmann, Andreas; Hodgins, Diana (eds). *Implantable sensor systems for medical applications.* Oxford, Cambridge, Philadelphia New Delhi: Woodhead Publishing, 2013. pp. 469-496.

138 Harbisson is a cyborg activist currently involved in the Transpecies Society, in Barcelona. Although giving lectures on the pop science scene, a technical and scientific look at his proposal reveals many gaps in his sci-fi narrative of being the first eyeborg of the world. Simple practical details of his implant have not been clarified by the artist, neither in writing nor in an interview. His producer rejected a proposed interview in an e-mail.

139 Kyuma, Kazuo et al. Artificial retinas – Fast, versatile, image processors. In: *Nature*, Vol. 372 Nov 10th, 1994. pp. 197-8.

that despite surprising correlations, there are still more differences than similarities between organic and machinic ways of seeing. According to Macke, advances in neuroscience in recent decades were not based on the attempt to imitate the operations of the human cognitive system but rather on using advanced computational skills to process a huge amount of data and find patterns.[140]

Also because of enhancements in computer vision systems made since the 1990s, retinal implants have improved exponentially.[141] However, no prosthetic retina built and successfully implemented thus far has been able to provide image quality analogous to human vision, which entails the joint-collaborative work of no less than 130 million photoreceptors. In this sense, the technical fetish for high-resolution is found in the industry of retinal implants too, suggesting that the core endeavour is the human exigency to artificially attain its own observational ability.

2.17: Simulation of visual perception through a retina implant;
Source: Hornig & Velikay-Parel 2013: 473.

In the 2010s, advances in nanotechnology have contributed to the creation of hybrid bio-organic interfaces for neuronal photo-activation, for instance, as an alternative technology to bionic eyes that have been making progress as a means to compensate for full or partial blindness.[142] According to Ghezzi et al., the main challenge here is to create hybrid structures able to perform *"reliable transduction of*

140 Macke, Jakob. "Making sense of light: Processing visual information in Neural Systems" Lecture held at *Wo/man mind machine* - Interdisciplinary Conference organized by *Die Junge Akademie* & The Israel Young Academy. Berlin-Brandenburg Academy of Sciences and Humanities. June 14th 2016.

141 According to Hornig and Velikay-Parel, *"retina implant consists of an image sensor, a processing and/or ampliflying unit, and a set of electrodes"* and was firstly implemented in 1996. (Hornig and Velikay-Parel 2013: 469)

142 Rojahn, Susan Young. What it's like to see again with an Artificial Retina. In: MIT Technology Review. May 9th 2013. Available at <https://www.technologyreview.com/s/514081/can-artificial-retinas-restore-natural-sight/> Accessed November 10th 2017.

information carried by light into specific patterns of electrical activity in visual information processing networks".[143]

In relation to photosensitive biomaterials, the technically attractive molecular function of rhodopsin-like proteins is useful for developing photoreceptor devices and opto-electronic detectors. Their behavioural properties in relation to photovoltage, photocurrent, colour and refractive index are favourable for optical information storage and processing, the conversion of sunlight into chemical energy and light-driven proton translocation.[144] Naturally these innovations on the molecular level have a direct impact on the implementation in the macro structure of organs and other applications, which heightens the complexity, especially concerning vision. A counter example can also be seen in the successful 3D printing of the synthetic tissue of cardio cells, which when it was subsequently charged electrically caused a small piece of flesh to start beating.[145] Through the same biotechnological flow, bionic eyes and other kinds of prosthetic retinas are slowly becoming available on the market.[146] Nevertheless, in contrast to bio-printed cardiovascular tissue, which simulates the mechanical response of the muscular movements, the case of artificial retina involves a complex integrated cognitive activity, since seeing is not merely an optical phenomenon occurring inside the black box of the eye. According to ophthalmologist and biomedical engineer Mark Salaman Humayun, among the implants that use electrodes to interface with the body, such as a pacemaker or the cochlear, the most troublesome is the retinal prosthetic, which requi-

143 Ghezzi, Diego; Antognazza, Maria Rosa; Dal Maschio, Marco; Lanzarini, Benfenati, Fabio; Lanzani, Guglielmo. A hybrid bioorganic interface for neuronal photoactivation. In: *Nature Communications* 2:166 Macmillan Publishers. Jan 18, 2011.

144 Gualtieri 2001.

145 Dvir, Tal. *Nanodevices for Actuating and Monitoring Engineered Cardiac Tissues*. Lecture held at *Wo/Man Mind Machine* - Interdisciplinary Conference at the Einstensaal/Berlin-Brandenburg Academy of Sciences and Humanities on June 14th 2016. Event co-organized by *Die Junge Akademie* and The Israel Young Academy.

146 The first retinal prosthesis with European approval for clinical and commercial use dates from 2011. Graham-Rowe. A bionic eye comes to market. In: *MIT Technology Review*. Article available at <https://www.technologyreview.com/s/423216/a-bionic-eye-comes-to-market/> Accessed November 10th 2017. One example of artificial retina, depicted at MIT Technology Review: "Argus II, has three main parts: a glasses-mounted video camera; a portable computer; and a chip implanted near the retina. The video camera sends image data to the computer, which is worn on a belt. The processor converts the image data into electrical signals that are beamed to a chip implanted near the retina. The signals are then sent to an array of 60 electrodes that stimulate the retinal cells. These electrodes essentially do the work of the light-sensing cells that have degenerated. So far, the system can't help patients make out different colors, but it can provide them with enough visual sensation to sense the outlines of things nearby." Bourzac, Katherine. Rewriting life. Bionic Eye Implant Approved for U.S. Patents. In: *MIT Technology Review*. February 15th 2013. Available at <https://www.technologyreview.com/s/511356/bionic-eye-implant-approved-for-us-patients/> Accessed November 7th 2017.

res biocompatibility with a much higher number of connections, protection from overheating and adaptability to the eye's movements.[147] Facing these challenges, scientific communities are experimenting with biosynthetic materials as well. Recently, a young doctoral student named Vanessa Restrepo-Schild (1993-) at Oxford University's Department of Chemistry produced a synthetic, double-layered retina, made of hydrogel and biological cell membrane proteins. Mimicking the shape and function of the human retina, the bio-fabricated tissue is able to produce a grey scale image and is ostensibly more compatible with the human corporeal environment in addition to being biodegradable. Analogously to the trajectory of media history and development, the next steps of the research are to implement colour and shape detection and conduct implants in animals and humans.[148] This case clearly exemplifies human efforts to find common ground for the communication between natural and synthetic entities. In this sense, building machines seems to be an intermediate step on the way to understanding how organic elements work, confirming Kittler's position that humans knew nothing about their own senses before media provided the metaphors for modelling them.

Recent cross-disciplinary conferences such as *The eye and the chip* have brought together specialists from all over the world to discuss the improvements and challenges currently being faced at the intersection between nanoelectronics and neurobiology. However, it is still difficult to evaluate how much the promising hybrid-vision entities will impact the cultural aspects of everyday life. Parallel expressions in media art using such advanced hybrid-vision techniques are still unknown or have not been widely enough diffused

The success and efficiency of the many potential technical solutions for retinal prosthetic devices being developed for utilitarian purposes depends to a large degree on the kind of blindness the patient has, which, e.g., may not be caused by problems related to the retina. Despite the promising researches on eye and retinal engineering, it is impossible, as contemporary studies on the intersection between neuroscience and philosophy recognize, either to establish a clear division between cognition and the sense of sight or to isolate any of the senses. This, indeed, was already addressed by Merleau-Ponty as the basis of his phenomenology of perception in the mid-1940's. The eyes, metaphorically described as the "window of/to the soul"[149], continuously exchange information with the brain and the whole

147 Humayun et al. (Eds.) *Artificial sight: Basic Research, Biomedical Engineering and Clinical Advances.* New York: Springer, 2007.

148 Oxford student creates first synthetic retina In: University of Oxford Website. Available at <http://www.ox.ac.uk/news/2017-05-04-oxford-student-creates-first-synthetic-retina> Accessed November 7th 2017.

149 Reference to the Brazilian film *Sobre a janela da alma* (2001), by João Jardim and Walter Carvalho.

body. Indeed, herein lies the core of what 'being' might mean: the reciprocal and simultaneous activities of parts within a whole.

2.2 Photosensitivity beyond human subjectivity

In the arts, posthuman and new materialist perspectives[150] have been being actualized for decades under the label of bioart[151] and other derivative more or less connected to media art, depending on the background of the artists engaged with the issue. Photosensitivity, as a material phenomenon outside the human sensory apparatus, has been continually addressed in art through the use of bacteria, plants, animals, chimeras, cyborgs, and so forth.

2.2.1 Skotopoeisis: Plants as agents

As demonstrated in the case of the anthotypes discussed in the first chapter, the use of plants' photosensitivity in media history can be found much earlier than the recent use of their sensory apparatuses in real time audio-visual installations and performances.[152] Plants' photosensitivity, unlike that of the human eyes, is not based on image forming, but it is an essential characteristic of their existence. Besides their dependency on light for making photosynthesis, plants contain a series of versatile light-based self-organizing mechanisms, which are occasionally metaphorically understood as the 'sense of sight' of plants. Sensors placed at the tip of plant stems, for instance, allow them to notice the direction of light, triggering the growing process towards the light source – a mechanism called phototropism. Another feature of their 'sense of sight', called photoperiodism, takes place in the leaves and manages the flowering process according to the amount of red light or

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150 Advocated by Geoff Cox, among others, who states: "*we should not try to oppose machine and human seeing but take them to be more thoroughly entangled – a more 'posthuman' or 'new materialist' position that challenges the onto-epistemological character of seeing – and produces new kinds of knowledge-power that both challenges as well as extends the anthropomorphism of vision and its attachment to dominant forms of rationality*". (Cox 2016)

151 Although adopted by specialists to refer to their field of actuation, the use of the term "bioart" is debatable. It is generally used to refer to artworks made by the hybrid profiles of 'researcher-scientist-artists", who stress the potentialities of diverse biotechnologies (or biological knowledge) for symbolic and aesthetic appropriation. For more details about the complexity of the topic, see the interview with the curator Jens Hauser available at <http://www.digicult.it/news/dialogues-on-bioart-1-a-conversation-with-jens-hauser/> Accessed March 29th 2017.

152 Weil, Florian. *Artistic human-plants interfaces.* Master thesis defended at the Universität für künstlerische und industrielle Gestaltung. Kunstuniversität Linz. 2014.

the length of darkness. Phytochromes[153] in plant leaves filter the red light spectrum and operate like a light activated switch. Depending on the kind of red light, the flowering process may be turned on or off.[154]

A contemporary artwork based on the photosensitive characteristics of plants that considers posthuman issues is the performance *Skotopoiesis*[155] (2015), by Špela Petrič (1980-), which was part of the series *Confronting Vegetal Otherness*. The artist stands in front of a strong beam of light and produces a shadow in a field of germinating cress. After nineteen hours of performance divided into twelve and seven hours over two days, the plants placed in the shaded region become pale yellow. This effect is produced by the action of the phytochromes, whose signalling can activate or deactivate the synthesis of chlorophyll, for example. Simultaneously, the decrease of light stimulus triggers the production of auxin, a plant hormone responsible for stem elongation, which is a survival response by the plant to search for light. While the elongation of the cress occurs, Petrič's spine is shortened by standing for so long, in *"'vegetalized' immobility"*, as cleverly observed media art critic Régine Debatty.

Artworks involving biological matter raise complicated ethical issues, usually evaluated by an assigned ethical committee. According to the artist, choosing an uncomfortable position was an attempt to approach an ethical interaction with the plants, although the extreme dissimilarity between the human and the vegetal world provides no moral basis to assure a fair interaction. The logic adopted was that, since the cress faces difficulties under the imposed shadow, the artist, in turn, would self-imposition the difficulty of standing without moving. With a background in biology, Petrič explains that muscles are there to move, making movement an inherently animal characteristic. Thus, standing for so long is a situation that requires a form of resistance (inversely) similar to that required of the field of cress.

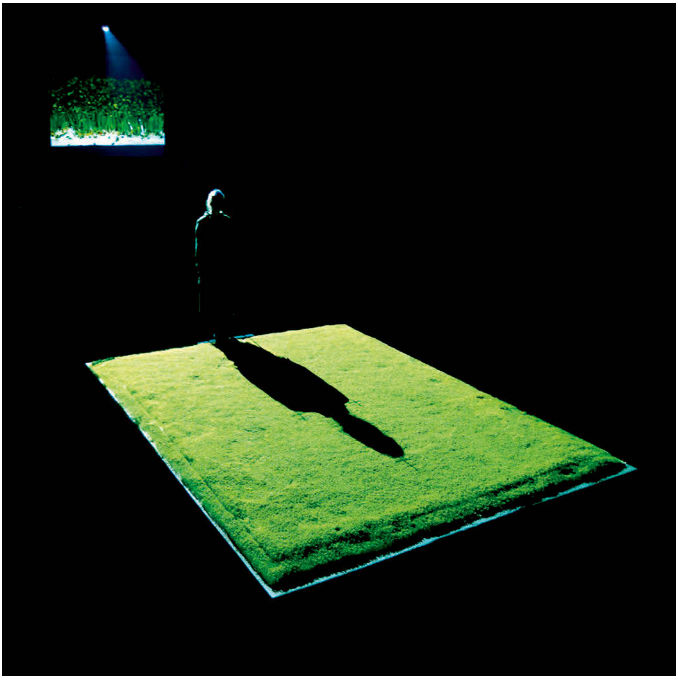
Petrič's performance is a plastic space-time framing of what the artist terms 'plant-human intercognition', *"a process during which the plant and the human exchange physico-chemical signals and hence perturb each other's state."*[156] It draws attention to the materiality of the relations, where physical movement or, rather, the interplay between mobility and immobility is indirectly used as a metaphor for what is alive and

153 Photoreceptors that detect light and regulate a variety of vegetal metabolic processes.

154 Weil 2014: 14-15.

155 The performance title is etymologically formed by the Proto-Indo-European/Greek terms: skótos (σκότος), which correspond to darkness, shadow and poiesis (ποιέω), which refer to making, creating, composing. Etymonline <https://www.etymonline.com/word/*skoto-> and <https://www.etymonline.com/word/poesy> Accessed July 15th 2018.

156 Petrič, Špela. Website of the artist. Available at <http://www.spelapetric.org/> Accessed October 22th 2017.



2.18: Slovenian artist Špela Petrič performing *Confronting vegetal otherness: Skotopoeisis* (2015) at the Click Festival in Helsingor, Denmark, 2017. Photo: Miha Turšič. Courtesy of the artist.

in communication or common-action. However, as the artist herself puts it, the experiment on hybridity cannot be seen only through the lenses of functionality as it comprises "*a conceptual enslavement of particular capacities of plants and humans with the purpose of recognizing the limits of compatibility, empathy and post-anthropocentrism*".[157]

2.2.2 Phototropy: light-sensitive artificial life

Photosensitive principles ruling organisms' lives have also been addressed in artworks by the pioneers in using plants as interfaces[158] Christa Sommerer (1964-) and Laurent Mignonneau (1967-) in the 1990s, when they frequently explore various biological concepts via three-dimensional computer graphics. In one of their classic interactive installations, *Phototropy* (1995), the artists use the biological process for which the artwork is named to discuss light as a metaphor for life and death. The

157 Ibid.

158 The worldwide known installation *Interactive Plant Growing* dates from 1992.

ability of the artists to create metaphors and an interactive design using biological and computational knowledge is a result of their fruitful collaboration. Sommerer is graduated in biology and botany, whereas Laurent Mignonneau holds a PhD in engineering. They have managed to transform their artistic processes and creations into a material and embodied philosophy.

The interactive computer installation is based on the interaction between audience and virtual insect-like organisms, whose lives were influenced by the flashlight held and moved by the participants. The virtual organisms search for the central focus of light in order to get support and energy. The pre-conditions for interaction are set.

2.19: Participant in the installation *Phototropy* (1994-1995) in Moscow.
© Christa Sommerer & Laurent Mignonneau. Courtesy of the artists.

Although this initial description might lead to the impression of a simple reactive artwork, its complexity becomes clearer when its *modus operandi* is revealed and one sees how the metaphors emerge from the experience.

Virtual cocoon-insects' life-cycles are dependent on the concrete light beam provided by the participant and are controlled by algorithms that establish the role of light as simultaneously live-enabling and dangerous. The photosensitive apparatus of the virtual characters is enacted by an artificial system, namely a camera and computer, running computer vision software. The electronic basis of a camera allows uses far beyond what is encompassed by the metaphor of an eye as image forming entity. The artists had the freedom to create the rules of the system, inventing how the photosensitive feature of the ensemble screen/camera/image would lead to a meaningful experience. According to Sommerer and Mignonneau's own description:

> When reaching a certain quantity of light intensity, the insect-like artificial creatures will be able to reproduce, by exchanging their genetic information. Two crea-

tures will then produce an offspring, that carries the genetic code of the parents. The child insect will follow the light source as well.[159]

Thanks to its familiar quotidian form and function, the flashlight is an effective and intuitive interface that easily invites the audience into the game's dynamics. By adjusting the speed that they move the flashlight, the visitors discover different reactions. The creatures need some time under the light beam to be able to reproduce. On the one hand, if the flashlight is turned off, the virtual organisms die and instantly fade away; when it remains so, the system enters an autonomous mode, developing the self-generated growth of new cocoons, ready to be 'awakened' by the next visitors. Here light gains another layer of meaning: it determines the life cycle, represented by the time that the interaction between visitor and system has lasted.[160]

At this point it is worth recalling Rudolf Arnheim's contention that human perceptual differentiation between organic and inorganic forms occurs relatively late in a person's development. According to him, children and those the author called 'primitives' do not distinguish between dead and living things. The same applies to artists, the arts and spontaneous perception.[161] This spontaneous perceptual quality is rescued by the playful atmosphere of media artworks like *Phototropy.* Using dynamic systems that conceptually center around the animation of originally nonliving objects, it explores the principles of life on both conceptual and material levels, as if actualizing the 'breath of life' through the management of energy. It is interesting to note that when the opposite happens – transforming life into things – ethical objections are raised against the outrageous objectification of life.[162]

The interaction dynamics between visitors' flashlights and the installation's system in *Phototropy* make light simultaneously the technical engine and the symbolic

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159 Sommerer, Christa; Mignonneau, Laurent. Documentation of the installation on the website of the artists. Phototropy. 1995. Available at <http://www.interface.ufg.ac.at/christa-laurent/WORKS/CONCEPTS/PhotoConcept.html> Accessed November 12th 2017.

160 According to the words of the artists: *"Life is not only seen as a temporary appearance, it is considered to be an involving mechanisms, that links the artificial life of the insects to the real life of the visitors".* (Sommerer and Mignonneau, 1995)

161 For Arnheim scientific and objective criteria to discriminate animate and inanimate, as intelligent and non-intelligent forms are not valid to spontaneous perception. He offers an interesting example of how amazed an occidental being of the 20th century can be by the behavioural similarities between a simple phototropic robot ant and a living being. He concludes that probably the behavior patterns of observed forces is perceived as more complex when it involves a reciprocal exchange between object and its environment. (Arnheim 1980: 391-393)

162 A rich example is the critique by Chun on the ur-text of modern genetics, which suggests reading Erwin Schrödinger's "*What's life?*" (1944) as "*What's software?*". (Chun 2011: 103)

vehicle of life, growth, reproduction, evolution and movement. The artists managed to coincide the abstraction of meanings with the concreteness of the physical world. When insects reach the epicentre of the light beam and stay there for too long (possible if the visitor does not move it), the light becomes dangerous, burning the virtual insects to death. The analogy of danger is not entirely accurate, however, since the participant clearly distinguishes the virtual otherness of the artificial creatures and their ability to be reanimated at anytime by turning the flashlight on. Nevertheless, in the fictional pact between audience and artwork, "*the visitor has to be careful with his/her lamp.*"[163] While interacting, the visitor learns quickly how the system works and becomes more aware of her responsibility for keeping the interaction with the artificial system alive.

Phototropy's system is programmed so that participants are constantly required to search for an equilibrium or an optimized way of interacting. One needs to adapt by means of improvising with the artificial creatures to keep the interaction going. In this sense, the artwork is also an expressive sample from the 1990s wave of Artificial Intelligence (AI) and generative algorithm applications that incited discussions of hybridity through the concept of artificial life. In *Phototropy,* AI algorithms are the means through which visitors can inhabit an artificial biosphere. Since the meanings evolve from experience, the concept of 'emergence', borrowed from the field of biology and the theory of complexity[164], became a key component of the interpretive lexicon for media artworks based on AI techniques.

Through the careful articulation of concepts, materials and techniques, the artists managed to create an artwork whose hybridity is essentially enabled by the role of photosensitivity in bridging the communication processes between human and non-human actors.[165]

2.2.3 Pulsu(m) Plantae: hacking photosensitivity

Living organisms are often referred to as the most complex "machines" we know, with complex adaptive, regenerative and reproductive properties that are still physically unrealizable in man-made machines. On the software level, however, this becomes more easily feasible, as exemplified by *Phototropy*.

Attempts to implement machinic features with living entities triggered the creation of wetware, a term currently used in computer science, biology and the

163 Sommerer and Mignonneau 1995.

164 Érdi, Péter. *Complexity explained.* Berlin/Heidelberg, Springer: 2008.

165 These terms are direct references to Bruno Latour's Actor-Netwerk Theory (ANT), its matherial-semiotic method and the so-called symmetry principle. Latour, Bruno. *On actor-network theory. A few clarifications plus more than a few complications.* In: *Soziale Welt*, Vol. 47, 1996, pp. 369-381.

arts to refer to devices that blur the borders between organic and machinic elements. In computer science, wetware refers to organic computers built from living neurons, also known as artificial organic brains or neurocomputers. In biology, it refers to the protocols and molecular devices used in the fields of molecular and synthetic biology. In the arts, an elucidative recent example of this technique is the cybernetic neural synthesizer *CellF* (2017), a wetware-based autonomous instrument made of networked biological matter that evolves, created by artist Guy Ben-Ary (1967-).[166]

The popularization of synthetic biology and organic machines fostered the emergence of biotinkering and biohacking communities, in which artists are often members. Given the increasing accessibility of techniques for manipulating biological matter, one now encounters exhibits featuring artworks based on fungi, algae and bacteria more and more frequently.[167] The metabolic activities of living beings are being abstracted into measurements of variations in electric resistance by means of electronic and digital instruments. Although the potential of light sensitive organisms to be used in the context of wetware has been considerably enhanced, the most established examples of the artistic use of photosensitivity are based on hacking organisms' photosensitivity rather than creating new photosensitive wetware and letting the organisms evolve on their own.

Pulsu(m) Plantae (2010)[168], by Leslie Garcia, is a project that emerged within the biohacking context. Its purpose was to empirically analyse the various sensitive mechanisms of plants and discern how their metabolic processes constitute means of communication even though they are imperceptible to the human senses. Technically, *Pulsu(m) Plantae* consisted of different electronic set-ups based on the transduction of plants' metabolic activities into sounds, which Garcia termed sound prostheses.

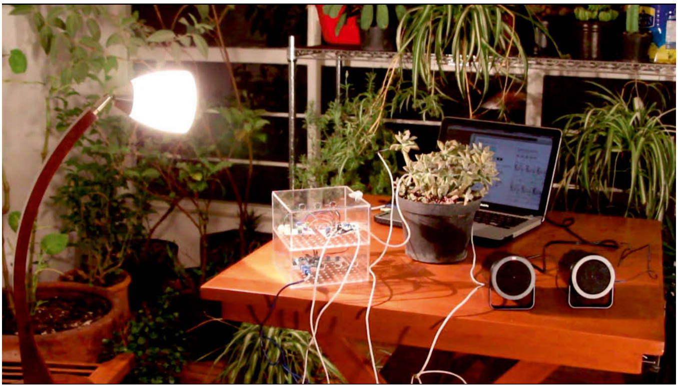
In scientific research, the effect that light has on plants is usually understood as either a signal or an energy source. This, too, is probably a model of understanding based on the functions of man-made devices: photovoltaic cells simply absorb energy, while CCDs generate data. However, in the wetware context, this traditional

166 More information about the project at <http://cdm.link/2017/05/cybernetic-synth-contains-brain-grown-inventors-cells/> Accessed May 9th 2017.

167 To mention few contemporary examples I can there are Pierre Huygue's (1962-) *After ALife Ahead*, at *Skulptur Projekte* 2017 in Münster, Germany; and Philippe Parreno's (1964-) untitled exhibition at Martin Gropius Bau, Berlin, between May and August 2018, in the context of the program *Immersion - Exhibition 4*. Both artworks included bio-reactors as actants in their aesthetic proposals. Furthermore, the Art Laboratory Berlin has focused their programs in non-human subjectivities, which ends to be a trendy topic in the Anthropocene.

168 More information about the project is available at <http://lessnullvoid.cc/pulsum/> Accessed September 6th 2017.

distinction used in media theory loses its significance. Whether using the energetic or the signalling properties of light and light-sensitive matter, what propels the increasing hybridization of media artworks is the common denominator of electric current. Exploring this possibility, Garcia built a series of prototypes that were progressively enhanced during the course of several international workshops and art exhibitions.



2.20: One of the set-ups for *Pulsu(m) Plantae* (2010), by Leslie Garcia: Sonifying the photosensitivity of a suculenta. Courtesy of the artist.

Pulsu(m) Plantae is based on both the implementation of biofeedback principles between plant, machine, artist, and (eventually) visitors, and on the concept of chaosmosis, developed by philosopher Félix Guattari (1930 – 1992) in a book with the same name. By questioning traditional subjectivity's foundations, Guattari's ethico-aesthetic paradigm envisions acknowledging other forms of subjectivity, which involves the redefinition of machines and their influence on subjectivity's composition. His paradigm also includes the hybridization of "*semiologies that produce significations, the common currency of social groups*" with "*a-signifying semiotics, which regardless of the quantities of significations they can convey, handle figures of expression that might be qualified as 'non-human'*.[169]

In this sense, hybridizations present in artworks like *Pulsu(m) Plantae* evince the materiality of communication[170] and demonstrate that every materiality is dis-

169 Guattari, Félix. *Chaosmosis: an ethico-aesthetic paradigm.* Translated by Paul Bain and Julian Pefanis. Bloomington and Indianapolis: Indiana University Press: 1995. p. 36.
170 Gumbrecht 2004: 8.

cursive.[171] Furthermore, as media artist and theoretician Guto Nóbrega precisely formulates:

> More than interactive response to human behaviour these organisms ask for dialogues, requiring a sort of investigation into their own nature in order to unfold the network of meaning to which they belong. If nature is a concept, never achieved objectively, but only subjectively, and if art is one of the most powerful tools to modulate subjectivity, ultimately our consciousness, the hybrid of plants and artificial systems may bring new insights about the world we live in and its ongoing metamorphosis.[172]

Together with Guatarri and Nóbrega's theoretical reflections, Garcia's practice provides the ground for a genuine discussion[173] of otherness and non-human subjectivities.

While Guattari criticizes the attempt of structuralism to put everything related to the psyche under the control of linguistic signifiers as a mistake[174], it also probable that artworks consisting of such hermetic concepts and technologies might not communicate anything to people who do not share a similar vocabulary and skillset. The nature of these media artworks poses artists with a challenging task: How can one communicate the extraordinary experience of discovery they had in the creative process that at the same time enables an intelligible and welcoming means for external observers to join the aesthetic system? How can one keep the system open to further conversation[175] and create the conditions for meaning to emerge through experience for every single participant? Concepts, like materials, can be understood and handled as abstract machines that demand to be articulated to enable a richer process of exchange in any aesthetic system.

2.3 Hybrid matters

As shown throughout the chapter, photosensitivity has been explored in media artwork thorough a variety of forms and approaches using organic and machinic elements. An overview of structural and operational similarities and differences bet-

171 Barad, Karen. *Agentieller Realismus: Über die Bedeutung materiell-diskursiver Praktiken*. Berlin: Suhrkamp, 2012.

172 Nóbrega, Guto. *Equilibrium*. Website of the artist, available at <http://www.gutonobrega.co.uk/Equilibrium> Accessed August 9th 2017.

173 Especially due to the care Garcia has demonstrated by offering an ongoing series of workshops and providing rich documentation on her personal website.

174 Guattari 1995: 5.

175 Eco, Umberto. *Obra aberta: Forma e indeterminação nas poéticas contemporâneas*. São Paulo: Editora Perspectiva, 1991.

ween the photosensitive parts of a human eye and a digital camera enables one to observe how organic and machinic entities are mutually influenced by one another and amenable to hybridization processes. The following sections, in addition to briefly contextualizing the conceptual and historical framework of such processes, discusses the implications of hybridization for the way in which (media) art is conceived and realized.

2.3.1 A brief conceptual-historical contextualization

The hybridization of biological and man-made sensorial apparatuses is hardly new. Although multiple perspectives on the interdependence between nature and culture have been established for quite some time, what such perspectives demonstrate is that this relationship has not always been symbiotic. At the beginning of the industrialization period, for instance, natural and machinic entities were often seen as oppositionally and violently connected.[176] The legacy of this industrial heritage remains, and its deconstruction has been an arduous challenge. Systems theory, bionics, cybernetics and new materialism are just a few of the countless theoretical frameworks that have contributed to the dissolution of the nature-culture dichotomy.

Biologist Ludwig von Bertalanffy (1901-1972), founder of the general system theory during the early twentieth century, was one of the early proponents of an organismic and integrative approach.[177] Bertalanffy was a strong critic of the mechanistic view of man (and its origins in Newtonian physics) inherent to industrial society, holding it responsible for the focus on a hierarchical notion of mankind exercising control over matter. Organicism, as the historian of science Debora Hammond (1951-) has written, was essentially rooted in the search for analogies between living and non-living systems.[178]

While it is true that "*the complex biophysical and biochemical processes underpinning sensors and sensing in living organisms are governed by the same fundamental physical-chemical principles and laws that describe artificial sensors*"[179], it is also true, as shown by organismic models rejecting the atomist and reductionist approaches frequently used in physics and chemistry, that "*the distinction between the organic and the inorganic is not a question of substance but of organization.*"[180] The organismic perspective attempts to clarify why, despite continuous efforts to merge biological and human-

176 Fohler 2003: 124-5.

177 Hammond, Debora. *The Science of Synthesis: Exploring the social implications of General Systems Theory.* Boulde, Colorado: University Press of Colorado, 2003. p. 32.

178 Ibid.

179 Barth, Friedrich G; Humphrey, Joseph A.C.; Secomb, Timothy W. (eds.) *Sensors and sensing in biology and engineering.* Wien/New York: Springer, 2003. p. V.

180 Hammond 2003: 32.

made entities, one today still encounters approaches based on the culturally constructed organic-machinic dichotomy.

One place where the opposition between what has 'naturally evolved' and human artefacts is still frequently found is in partial appropriations of the Darwinian notion of evolution. Contemporary statements such as "*even the living world makes use of certain 'technologies'*"[181] or "*a stunning wealth in the inventions made by millions of years of evolutionary history*"[182] suggest that nature has planned, projected and implemented "solutions". However, the reason that it is difficult to talk about "design" in nature is that, as evolutionary principles demonstrate, movements towards changes in living beings are not based on practical efficiency, but on stability and survival. If efficiency were to be defined through cybernetic principles, namely as better adaptation to circumstantial conditions, the comparison could work. In practice, however, engineering and management circles comprehend it essentially in terms of profit.

There are still other reasons why technical definitions of sensors likewise reflect the distinction between nature and culture. In the *Handbook of Modern Sensors* (2004), the inventor Jacob Fraden distinguished natural from man-made sensors. On the one hand, "*the natural sensors, like those found in living organisms, usually respond with signals, having an electro-chemical character; that is, their physical nature is based on ion transport, like in the nerve fibers*"[183]. On the other hand, "*in man-made devices, information is also transmitted and processed in electrical form – however, through the transport of electrons*"[184]. Aware of this basic difference, scientists pioneering the dissolution of the borders between biological and machinic entities, have taken on the challenge of minimizing it, or at least, learning from it empirically. That was the central move, for instance, behind the emergence of fields such as bionics, which was established at the end of the 1950's and defined as "*a general catchword that covered attempts to analyse biological processes, to formalize them and to implement them on computers*"[185].

The research conducted at the Biological Computer Laboratory (BCL), founded and headed by cyberneticist Heinz von Foerster (1911-2002), also unfolded in the same context. Among the collaborators were Humberto Maturana, Warren McCullough (1898-1969), Ranulph Glanville (1946-2014), Paul Pangaro, and Stuart Umpleby (1944-). They and other collaborators were mainly concerned with topics like the

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181 Meixner 2003: 27.

182 Barth et al 2003: 11.

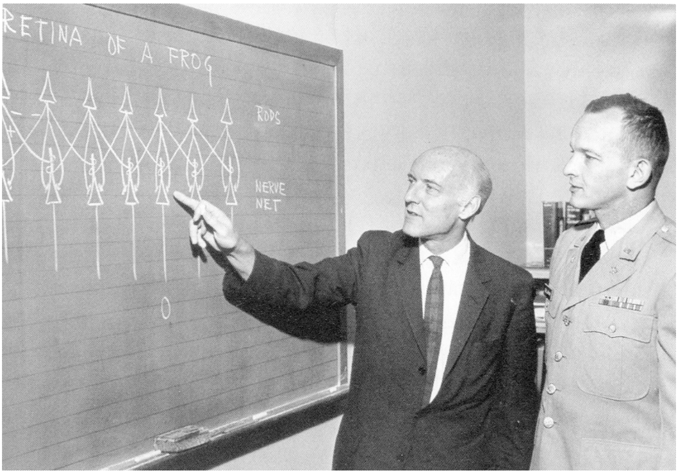
183 Fraden, Jacob. *Handbook of Modern Sensors: Physics, Designs and Applications.* New York, Berlin, Heidelberg: Springer-Verlag, 2004, p. 01.

184 Fraden 2004: 01-02.

185 Müller, Albert. A brief history of the BCL. Heinz von Foerster and the Biological Computer Laboratory. In: Müller, Albert.; Müller, Karl H. *An unfinished revolution? Heinz von Foerster and the Biological Computer Laboratory | BCL 1958-1976.* Vol.3 of the Series: Complexity | Design | Society. Wien: Echoraum, 2007. p. 286.

synthesis and operationality of neurons, the simulation of genetic pre-organization, and the adaptability of the machines to the surroundings. One can consider the aforementioned BCL experiment *Numarete* as an indirect result of the acknowledgement of the closeness between human vision and cognitive faculties; using a common available photosensitive element of the epoch to simulate mathematically the counting phenomenon in machinical terms.

The theoretical framework discussed at that time at the BCL is still relevant today, albeit in a radically different technological context. Moreover, as far as can be gathered from the published documentation, the results of the experiments there did not have a greater impact than that of other laboratories or artists in the same period, or even earlier. The novelty and power was more substantially related to the cross-disciplinary methodology[186] implemented by von Foerster and his collaborators.



2.21: Heinz von Foerster explains the McCullogh-Pitt neuron model using the example of a frog's retina at BCL. Courtesy of the Heinz von Foerster Archive, Institute of Contemporary History, University of Vienna.

Hybrid entities are now much easier to implement, and represent an alternative to the organic-machinic dichotomy, being essentially enabled either by biofeedback principles and/or through the computational assisted synthesis of bio-

186 Foerster, Heinz von. *Cybernetics of Cybernetics: The control of the control and the communication of the communication.* Minneapolis: Minnesota, Future Systems, Inc. 1995. For a more specific perspective on the topic see also: Müller, Karl, H. A period of High-Trans-disciplinarity, 1948-1958. (Müller and Müller 2007: 225-251)

materials, biosensors[187] and biomachines. Subsequent fields of investigation, such as bionics, bioinformatics and bioengineering, are also dedicated to the development of biosensors and other man-made biological machines. According to sensor engineer Hans Meixner, the creation of biosensors is based on the exploration of "*the capability of biological materials (...) to find certain substances, so-called analytes*[188]*, among a multitude of other materials, in accordance with the lock-and-key principle of molecular biology and to react with them*"[189]. While chemically reacting, biological material and analytes are conducive to changes in physical parameters, such as the electric potential, mass, fluorescence or temperature. Here Flusser's theory of the zero-dimensionality of electronic and digital media meets the MIT Media Lab founder Nicholas Negroponte's (1943-) statement that "*bio is the new digital*"[190]: the physical changes from the chemical reaction are converted into measurable signals, to be amplified[191] and made available for use in another desired (or needed?) context.

In the context of visual media history, at least since the advent of photography and the manipulation of silver salts in combination with other organic components, light-sensitive materials have been dealt with fundamentally on the nanoscale. However, the currently available instruments and promising science fiction-like properties of wetware are driving research sponsors to massively invest in cross-disciplinary research in order to identify the molecular components of living systems and to understand the process of their synthesis.[192] In a sort of return to the atomist epistemological credo that "*each molecule or macromolecule is or can be functionalized in order to perform a specific performance*" and in which "*enzymes and proteins are redefined as biological machines*"[193], nanotechnology, according to the historian of chemistry Bernadette Bensaude-Vincent (1949-), has received special attention in the last two decades. In fact, one can approach the development of nano-machines as a sort of scale translation, since nanotechnology scientists are mainly occupied in transferring the operations of machines and devices developed in the twentieth century to the molecular scale. Nanotechnology has triggered epistemic

187 "From combining certain biological building blocks used by organisms to perceiving signals with components of mensuration and analysis engineering, a number of interesting applications are arising. Biosensors can be regarded as a bridge between biology and engineering (especially electrical engineering and electronics)". (Meixner, Hans, 2003: 27)

188 Analyte (or analito) is technical word that refers to a chemical substance that is the subject of chemical analysis.

189 Meixner 2003: 27.

190 Lecture "Why Bio is the New Digital" by Joichi Ito from the MIT Media Lab. Available at <https://www.youtube.com/watch?v=pnHD8gvccpI> Accessed October 13th 2017.

191 Meixner 2003: 27.

192 Bensaude-Vincent, Bernadette. *Materials as machines.* Unpublished manuscript of the lecture held at the opening conference of the research group Science in the Context of Application" in October 2016. p. 7.

193 Ibid.

changes and reintroduced the extensive use of the machine metaphor, which had been temporarily abandoned in favor of metaphors from information theory and technology. Interestingly, the historian of science Lily E. Kay (1947-2000) has described how the opposite happened within the field of molecular biology in the 1950s[194], when the rhetoric of 'biological specificity', highly influenced by mechanical lock-and-key analogies, was largely abandoned in favour of an information-thinking paradigm. Now, it seems that contemporary hybridization processes are being based on the mergence of both.

For Bensaude-Vincent, the convergence of AI (Artificial Intelligence) and MSE (Material Science Engineering) has been a new Renaissance along the lines envisioned by computer scientist Hiroshi Ishii in his "radical atomsäpproach. The use of nanotechnological tools has also been taken up in the arts under the name of Nano Art, whose manifestations are still grounded in a pictorial understanding of the arts, or on the previously known physical scale, even revisiting Guttenberg's era, as demonstrated by the case of the smallest book ever printed: *Teeny Ted from Turnip Town* (2007)[195], by the artist Robert Chaplin (1968-). The potential to program zero-dimensional matter towards self-regulating operations is still more dream than reality. More artworks dealing with the manipulation of materials to achieve hybridity can be found under the umbrella of bio art, which frequently involves forms of reprogramming biological matter through genetic modifications. To this date, the author is unaware of any expressive symbolic and aesthetic use of photosensitive nano hybrid machines, able to coincide material, technical and semantic layers.

In addition to providing a very small overview of the variety of approaches to the hybridization of organisms and machines, recounting the history and aesthetic appropriations of photosensitive elements has elucidated how the emphasis in organic-machinic relationships on differences or similarities, respectively, are influenced by cultural factors that have changed over time.

2.3.2 Hybrid artworks: What is at stake?

Observing the technical and aesthetic appropriations of photosensitive elements calls attention to the intrinsic correlations between discoveries about the human sense of sight and the way optical media, specifically digital cameras, operate. Reducing vision to photosensitivity and its electrical properties leads to three con-

194 Chun 2011:104 apud Kay 2000: xv.

195 The book has been produced in partnership with the Nano Imaging Facility of Simon Fraser University and measures 0.07 x 0.1mm using a focused-gallium-ion beam and electron microscopes; the book consists of 20 microtablets carved on a polished single piece of crystalline silicon. More information at Nanowerk, an electronic magazine for Nanotechnology: Nanotechnology lab produces world's smallest book. Available at <https://www.nanowerk.com/news/newsid=1773.php> Accessed July 15th 2018.

current benefits: (1) it improves our knowledge of a material-based phenomenon and acknowledges its specificities in their respective contexts; (2) it permits the transposition of the photosensitive qualities of the retina (or of an image sensor or other organic element) to other objects and contexts; and (3) it enhances the possibilities of coupling these new objects with other objects with distinct characteristics. These coexisting tendencies have already been analysed by the sociologist and philosopher Bruno Latour (1947-) in his work on the proliferation of hybrids and the confusions in the cultural movement of modernity, which he considers to be based on practices of purification and translation.[196] In Latour's own words:

> the word 'modern' designates two sets of entirely different practices which must remain distinct if they are to remain effective, but have recently begun to be confused. The first set of practices, by 'translation', creates mixtures between entirely new types of beings, hybrids of nature and culture. The second, by 'purification', creates two entirely distinct ontological zones: that of human beings on the one hand; that of nonhumans on the other.[197]

Latour's observation explains the foundation of dichotomous thinking while reconciling its role with existing initiatives to overcome it. The coexistence of purifications (process n.1 above) and translations (processes n. 2 and 3 above) on the material level of media artwork is, therefore, a concretization of Latour's philosophical statement.

As observed in the examples discussed above, media artworks are at liberty to go beyond an anthropocentric perspective and overcome the pre-established opposition between mechanistic and vitalist paradigms,[198] and they demonstrate how hybridization can occur on different levels and to various degrees of intensity. Considering the example of hybrid vision, the prosthetic sight developed in *EyeWriter* resulted from a deepening understanding of eye-brain collaboration through computer vision technology. The new understanding and its material implementation led to the transposition of the ability lost in the artist's hands to his still functioning eyes, and it was achieved by means of a complex physical translation from eye movements into light beam variations.

The hybridizations found in *Skotopoiesis* and *Pulsu(m) Plantae* touch on lesser known terrain, aesthetically speculating on the operational modes of vegetal otherness. In the first case, the artist took for granted that plant behaviour is already known and predictable; whereas in the latter, the artist traces paths for investigation, favouring the deepening of knowledge precisely through the physical translati-

196 Latour, Bruno. *We have never been modern*. Cambridge, MA: Harvard University Press: 1993, p. 10-12.

197 Ibid.

198 Hammond 2003: 32.

on processes, from light (and other types of stimulus) to sound. The hybrid quality of both these examples, however, is still less intense than in scientific attempts to synthetize an organic tissue, such as the 3D printing of photosensitive proteins in the aforementioned organic/artificial retina. Hacking plants and bacteria or any other living body, as Leslie Garcia does in *Pulsu(m) Plantae*, is different from fabricating biomaterials with similar photosensitive properties to those of living beings via computer assisted design. In such cases, purification and translation procedures coincide at the very origin of the creative process, amplifying the confusion that Latour has depicted.

That the implementation of prosthetic elements, biotinkering and bio-synthesis in the arts necessitates intertwining organic materials and machines is clear. However, the main ongoing development has been the convergence of sensing (as input) and actuating (as output) in the same body. The clear and well-defined input-output paradigm long followed by information engineers is being broken. In addition, and for the same reason, the cybernetic appraisal for circularity has never been so explored. The level of hybridity in media artworks is directly related to both the intensity and quality of feedback processes between the parts of the system, as well as the degree to which they push the whole towards self-regulatory and self-organizing situations. In this sense, the creative possibilities of hybrids range from 'design from nature' to 'design with nature'; in other words, from bio-mimicry to bio-synthesis. The first comprehends the transposition of biological mechanisms in terms of other materialities; whereas the second already takes the biological materialities as its point of departure and is, therefore, closer to the possibility of generating self-organizing systems.

These practices suggest that the material turn in the arts is now about fictionalizing[199] directly with matter, and no longer only with its mere representational possibilities. Media artworks are made by recombining the material building blocks of physicochemical phenomena that science has made accessible through processes of abstraction and fragmentation. In this sense, one may also understand the coupling of science and art in media art as a way to implement and merge the purification and translation processes of knowledge construction. This is the context in which the imaginative acts of media artists aim to "*increase the number of choices*"[200] with the goal of realizing "*all possible abstract machines*".[201]

199 Experimenting in the arts has always been directly with matter. The paradigm change implicit with this term refers to the current possibility of using the imagination to create new materials, non-trivial and non-existing combinations. It suggests approaching the idea of invention, creation of new functions and narratives.

200 von Foerster, Heinz. Ethics and second-order cybernetics. In: *SEHR*, Vol. 4, Issue 2: Constructions of the Mind. Updated June 4th 1995. p. 9.

201 A direct reference to William Ross Ashby's (1903-1972) definition of Cybernetics "*as the study of all possible abstract machines*". (EMCSR 2012)

In addition to the technical knowledge needed to execute an artistic conception, media artists need sensitivity and awareness to deal with the limits and potentialities of communication between all kinds of materials. Every living entity and every material and technological object presents its own ongoing historicity and agency, which partake of the stabilising-destabilising dynamics of the world.[202]

Thinking of media art as a field for creating hybrid machines[203] entails approaching contemporary artworks as relational entities and demands constant changes of perspective from all involved agents. This approach requires ignoring the separation between art and science, since both are integrated within a single interlaced field of knowledge and action; it also requires neglecting excesses of objectivity or subjectivity in order to exercise a more empathic post-human paradigm. On the contrary of what many may think, post-human attitudes do not devalue human beings but rather facilitate and create conditions for resituating humans in a less arrogant, less destructive and more balanced position within the planet's dynamics.

Biological diversity and the diversity of media devices enhance the possibilities of recombination in an even broader variety of contexts, where the task of media artists becomes investigating and designing the exchanges of electric and electrochemical signals through the senses and sensitive materials, directing the flux of signals between both carbon- and silicon-based structures. This extreme freedom of matter manipulation is also why ethical committees are needed at art exhibitions featuring biomaterials. These committees face the challenge of constantly having to revisit what the cyberneticist von Foerster formalized as the principle of undecidable questions: "*Only those questions that are in principle undecidable, we can decide*".[204]

In media art and in the creation of hybrid systems, knowledge emerges both from the empirical experience with the materials and the articulation of scientific, logical, symbolic and other abstract mental models potentially corresponding to a certain reality. Intertwined with sensuous and aesthetic layers, the scientific knowledge involved in media art can neither be too hidden nor too emphasized. The task of media artists is far from familarizing the audience with scientific principles that one could get by consulting reference works. Rather, if there is a general challenge, it is to investigate modes of sensitising the audience to perceive and reflect on the complexity of relationships and modes of existence in the world, especially in ways that other traditional art forms are not able to address. In addition, it is important when dealing with hybrid technical ensembles to constantly nurture a critical approach towards scientific methods, expanding the dialogue with the

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202 Barad 2003.

203 In this process, manifold personalised methods can evolve. A methodological starting point can be, for instance, to imagine improbable (or less probable) hybrid combinations through 'what if' questions, either speculating about a better future for humankind and the planet, or reflecting on the past, as is done by media-archaeological artists.

204 von Foerster 1995: 7.

audience. These observations lead to the conclusion that the hybridity of media artworks is a characteristic that radicalizes both the procedural and the contextual aesthetic basis of contemporary art to an even greater degree.

Photosensitive elements have been used here to make the complex relations and conflicts behind organic and machinic entities explicit, as well as to show how contemporary artworks are addressing their own hybridization. We have learned that, rather than assuming a position between conflicting absolute viewpoints, it is more important to observe that the oscillating movement between purifying and translating any sort of materiality in media artworks turns simple matter into symbolic entities, whose meanings are open and moveable, with enough power to trigger reflection and, perhaps, changes in society. While this chapter has mostly looked at media art in relation to purification processes more aligned with objectivist scientific thinking, the following chapter will focus on media devices and artworks based on the translation of materialities, namely between light and sound.