Chromatophony: A Potential Application of Living Images in the Pixel Era

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Manuscript Received 27 October 2020

Abstract
Squids can rapidly change their body color using chromatophores that are controlled by electrical signals transmitted through nerves. The authors transform a squid’s skin into an audio visualizer, Chromatophony. This is accomplished by sending an electric tone signal composed as music to the skin. Although the appearance of Chromatophony is similar to computer-generated images, it is based on a natural phenomenon with a colorful mosaic display. By comparing chromatophores with pixels, the authors propose Living Images, to expand the potential of visual expression from the perspective of bio-art theory.

Cephalopods such as squids are known to rapidly change their body color to display patterns for intimidation or camouflage. Using this phenomenon, we created Chromatophony, an artwork in which chromatophores, organelles composed of living cells that allow the squid to change color, are converted into an audio visualizer by electrical stimulation.

In this paper, we use Chromatophony as a means to reconsider bio-art from the perspective of visual art. We report on the significance of an idea called Living Images in the practices of bio-art, for setting a critical perspective into the unit of pixel dominant to contemporary visual display.

First, we describe the idea of Living Images and then discuss the historical background of pixels to compare digital images and Living Images. We explain our work and clarify the significance of Living Images within bio-media art as well as contemporary visual culture.

What is the Living Image?
We define Living Images simply as aesthetic images generated from living cells, exemplified in the history of scientific practices and the recent rise of bio-art: from Alexander Fleming’s microbial paintings [1] to recent trends in bio-art through the experimentation with biological networks in slime mold [2]. Although Chromatophony (Fig. 1) can be placed within this category; notably, our work attempts to embody the idea of Living Images literally, as we explain next.

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The idea of Living Images is derived from the hypothesis, declared recently in the domains of art history and visual culture studies, that images are alive [3,4]. For example, Hans Belting’s *Bild-Anthropologie* describes an image as being nomadic, allowing it to settle in people’s bodies [5]. From ancient burial objects to contemporary digital photography, Belting emphasizes the functions of the image independent from humans and its vitality that enables it to inhabit the human body and technological media.

While Belting describes “living images” from an anthropological perspective, we appropriated this idea and applied it to bio-art. Bio-art is a practice of using the knowledge of biology as an artistic medium, or of advancing the changing nature of life through artistic output [6]. Along with the rise of bio-art, the development of molecular biology and genetic engineering also continued during the latter half of the 20th century. The recent discovery of horizontal gene transfer [7] and the way viruses and pathogens proliferate overlap with the nomadic images proposed by Belting. Therefore, we focus on bio-artworks composed of cells or tissues that are literal living images.

We also discuss the pixel, the elementary unit of digital images, comparing with the context of Living Images. Therefore, we refer to the studies of Alexander Galloway [8], in which he detaches the pixel from its computer context and places it on the historical horizon with reference to neo-impressionist pointillism and 18th-century calculators. From this perspective, we evaluate the analogical functions of chromatophores and pixels as units of living/digital images.

**Genealogy of the pixel and its two functional aspects**

In 1965, the term pixel appeared in a technical report titled “Digital Video Processing at JPL” [9], and was derived from the words “picture element” and “picture cell.” For a while, it was used alongside the word “pel,” also derived from “picture element.” Gradually, the word “pixel” came to mean an element in an image sensor or the smallest unit of a digital image, a light-emitting element composing a digital display [10].

In contrast to the historiography of this invention, Galloway extended the implications of this term epistemologically by focusing on its functions. Initially, he noted two modes of pixels: the Yokokawa et al, *Chromatophony: A Potential Application of Living Images in the Pixel Era*
little square as the smallest geometric point and the numerical value as an algebraic number without substance. Then, he argued that even before the computer, pixels could be found in the technical and aesthetic practices of the modern era, starting in the 18th century. If we understand the pixel as a little square, it is possible to view these geometric points as a descendent of artistic expressions such as De Stijl, color field paintings and neo-impressionist pointillism. Conversely, given that pixels function as a numerical value, they had been incorporated by Jacquard looms as well as Nicholas Saunderson's 18th-century calculator. The latter, a manual calculator, had a procedural algorithm and mechanism that involved the interlocking of a grid of pins to facilitate computations.

Based on these two aspects, Galloway reconsidered the features of a pixel as a given coordinate or luminance value that could be processed mathematically. He states: “The pixel is to the digital image as the frame is to the cinematic image” [11]. In other words, just as a single pixel does not make sense unless it is assembled with other pixels in an image, a frame in a film only has meaning if projected continuously with other frames. Further, pixels divide images spatially, just as frames divide motion temporally.

Galloway is not the only one who traced the genealogy of pixels back to film and neo-impressionism. Among studies in aesthetics and art history, Meredith Hoy states in her book, From point to pixel, “[p]ointillism contains enough digital elements from the beginning to the end of production to warrant consideration as a digital system, but it is not computational” [12]. From this perspective, the little, square pixel can be treated as the descendent of modern paintings, although they exclude its numerical function.

Before Galloway and Hoy, Sean Cubitt stated in his book, Cinema Effect, that the equivalent of the pixel could be found in the pointillism of neo-impressionists such as Pissarro, Seurat and Signac who translated light into pigments. Further, Cubitt extended this relationship to the contemporary products of the Lumière brothers: the cinematograph and Autochrome [13]. Although the emphasis differs from art history to media theory, these discussions are significant when examining the context of Chromatophony, which uses the pigmented colors that are embedded in the skin of a squid to form a visual display. To compare the chromatophores constituting Living Images with the pixels in digital images, we adopted the claims that focus on the visual and spatial as well as the algebraic and temporal aspects of pixels.

**Chromatophores as a pixel of Living Images**

The rapid color change in squids is made possible by a set of organelles called chromatophores, comprising multiple muscle and nerve cells, and pigment-containing pouches [14]. Each chromatophore contains only one type of pigment; during color changes, only the pouches contract or expand, changing them in size [15]. This makes chromatophores an elementary unit of Living Images just as the pixel in digital images.

These “dots” come together to form larger patterns, whose density of colors evokes the impression of pointillist paintings of the Neo-impressionists; zoologist Andrew Parker compares the way these pigment vesicles come together to create colorful images to the pixels on a screen [17].
This analogy is not confined to visual appearance, but extends to function. Each squid has chromatophores whose relative positional relationships are unique [18]. Further, their ability to change color is based on the physical coordinate values of the chromatophores stimulated by nerve impulses. This feature is similar to the algebraic aspects of pixels that represent numerical values, as Galloway have described.

Therefore, we could summarize the correspondence between pixels and chromatophores in the following manner. First, from a geometric viewpoint, both are small dots in a larger pattern. Second, just as pixels in a digital image connect to an electrical circuit to emit light in response to an assigned luminance value, the chromatophores on the body of a cephalopod are connected to neural circuits, resulting in the contraction of muscles in response to an electrophysiological signal.

Given that their visual appearance and their functional system resemble pixels, it might be no coincidence that one of the etymologies of the word “pixel” is picture “cell.” Therefore, if a pixel is a “cell” in a digital image, so too can a chromatophore be a “pixel” in a Living Image. Our aim is not just to appreciate the beauty of chromatophores, but to see a living cell as a medium to compose visual art. The significance of this work is discussed next, where we explain the works we created in detail and discuss the possibilities of expressions created using chromatophores.

**Chromatophony: modulation between human and squid**

In work similar to ours, Backyard Brains (BB), a company that sells educational neuroscience laboratory kits, conducted an experiment wherein music was used as the electrical stimulation to manipulate a squid's chromatophores [19]. In the video, they stimulate chromatophores by connecting electrodes to the fins of a euthanized longfin squid. The video shows the chromatophores opening and closing, responding mainly to the low bass and kick sounds of the song “Insane In The Brain” by Cypress Hill. Greg Gage, co-founder of BB, said that this is because low sounds tend to generate action potentials in motor neurons [20].

In contrast, we created music tailored to the characteristics of the chromatophores, and made them audible to people through speakers to achieve audiovisual unity when observed. To determine the signals most likely to stimulate chromatophores, we selected a sine wave as the electrical stimulus, and investigated the relationship between the response of chromatophores and the signal while adjusting its frequency.

For this project, fresh squid was ordered from Yobuko Port, Saga Pref., near our laboratory. The squid was filleted before the experiment, and a clipped sample was used. The stimulus was applied to the epidermis of the squid through iron electrodes, which were attached to an audio cable. Figure 2 shows the setup used for the experiment. The voltage of the stimulus was increased until the chromatophores exhibited the desired reaction. The distance between the electrodes was 15 mm, and the voltage ranged from 0.4 to 0.8 V. The action potentials of the squid nerve ranged from 5 mV to 10 mV, which differed significantly from the voltages used in the experiments. This difference may have been due to the high resistance of the electrodes and the sample. The results indicated that the squid’s chromatophores responded best to stimuli of Yokokawa et al, *Chromatophony: A Potential Application of Living Images in the Pixel Era*
approximately 90 Hz, and barely responded to stimuli exceeding 800 Hz (Fig. 3). When similar, successive stimuli were given, the response of the chromatophores could be erratic. The time for chromatophores to open in response to the stimuli differed based on their color (Fig. 4).

![Fig. 2. Audio signal applied to squid skin through audio cable to stimulate chromatophores. (© 2020 Juppo Yokokawa)](image)

![Fig. 3. Area of chromatophores at different frequencies. (© 2020 Juppo Yokokawa)](image)
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Fig. 4. Series of images of skin samples. Purple chromatophores responded to the stimulus earlier than the brown chromatophores. The interval between each image is 1/30 s. Scale bars are 1 mm. (© 2020 Juppo Yokokawa)

Based these results, we created music to stimulate the chromatophore by editing a low frequency (around 90 Hz) stimulus as sound material on Ableton Live. Using this, we created the video work, Chromatophony. The reaction of the chromatophores was recorded using a digital microscope (VHX-5000). The result was a computer graphic-like video in which the geometric movements were coordinated with our custom music, although the system used was simple and the responding material was organic (Fig. 5).

Fig. 5. Piece of waveform of the music we produced and the corresponding screen captures of Chromatophony. The video was recorded in full HD and 32-bit (float) audio. The interval between each image is 1/10 s (three frames). The chromatophores are responding to the attack of sound. (© 2020 Juppo Yokokawa)

Considering the chromatophore as a unit of Living Images, the possibilities we can derive from this work should be explored. Although the placement and color (RGB) of each pixel can be specified in advance, stimulating chromatophores using electrodes is less accurate, and we do not have the ability to move individual chromatophores. However, our aim was not to control their movement.

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https://doi.org/10.1162/leon_a_02107
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organs, but an attempt to modulate the audible thresholds as an aesthetic condition between human and squid. In fact, the result becomes apparent through the fluidity and dynamic movement in the images, which achieves a display that cannot be replicated by software. The realization of Chromatophony is not just intended to be a video artwork, but site-specific art considering that we had to acquire fresh squid for each performance. Although, it had to be recorded digitally and shared on a pixel-based screen, the essence of the work is a collaborative performance between humans and squids. We consider these specific features of Chromatophony as an embodiment of Living Images.

Discussion: Chromatophony as Living Images
We discussed Chromatophony by comparing chromatophores and pixels from the perspective of media theory, and demonstrated the unique characteristics of images formed by chromatophores. Our aim for the future is not to replace the squid's chromatophores with pixels, but to show more diverse ways of understanding visual expression. Therefore, we next expand the discussion and compare Living Images with digital images.

Previously, we defined Living Images as aesthetic images generated from living cells. Johanna Rotko's yeast-based photographic project (Fig. 6) [21], Diana Scherer's root-sculpture (Fig. 7), and experiments of natural computation visualized in slime mold (Fig. 8) [22] are examples of recent works. As one of the earliest works, we can mention Alexander Fleming's attempt at microbial painting. Not only are these bio-art, but they were also created in the process of scientific experimentation using living organisms. As these works are also the corporealization of Living Images, we can formulate their features specifically.

First, their textures are not restricted to displays or printing limited by arbitrary signals, RGB or CMYK. Traditional paintings use natural pigments whose colors could not be quantified easily, and printed materials have unique textures resulting from the materials used, including the pigment and pulp. Further, the Autochrome photographic technique used potato starch as a filter to realize vivid color development. Living Images make us aware of the texture possibilities that natural components combined with digital technologies can create. For example, Chromatophony combines complex color texture with computational audio signals. Thus, Living Images can change how we perceive the historical role that living things played in art, such as carmine refined from scale insects.

Moreover, Living Images present unpredictable features we cannot control. Although the cells themselves can be analyzed in chemical and physical terms [23], living materials can also produce spontaneous and unintentional movements. Those reactions sometimes produce novel results in visual images exceeding our intentions and expectations, and this is one of the reasons bio-art is receiving more attention.

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Fig. 6. Johanna Rotko's yeast-based photographic project. (© 2014 Johanna Rotko)

Fig. 7. Diana Scherer, Interwoven #14, 2018, Photography, textile from woven plant roots | 50 × 60 cm | ed. 5 + 2 AP. (© Diana Scherer)
The point here is not to praise the beauty of nature in contrast to artifacts created from it, for the examples we discussed did not use “pure” natural products, but revealed that the living things are inherently hybrids of the natural and the artificial. Therefore, we use the term “aesthetics” to define Living Images, as it concerns works of art as well as implying an attempt to critically examine the senses themselves, which are embodied in specific techno-cultural conditions. Therefore, Chromatophony is not a “re-presentation” of concrete pictures or figures, but an attempt to “present” the dynamic process of a Living Image, which becomes perceivable through cells.

Conclusion
We discussed the idea of Living Images and the historical background of pixels as a prelude to the discussion of their characteristics. Then, we compared chromatophores and pixels in the context of media studies, and proposed Chromatophony as an example of a Living Image. Finally, we discussed the unique characteristics of this work compared to other bio-art and the possibilities of using Living Images as visual expressions. However, the scope of Living Images is still debatable. In other words, it is necessary to discuss whether the smallest unit of Living Images needs to be a cell, and whether the cell needs to be alive. Inevitably, this will lead to discussions regarding the ethical considerations of life and death.

The possibilities of various forms of Living Images that are not mere replications of photographs or paintings can also be discussed. In this respect, it is important to represent images that are recognizable to humans, while focusing on the dynamic process through which images emerge across species; this is the uniqueness of Chromatophony that distinguishes it from other bio-art.

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Images flood social media today, and the number of shares seems to measure their value. In contrast, Living Images cannot be edited or shared as easily. This may seem inconvenient at first; however, in today's world overflowing with images, it gives us an opportunity to reconsider the way we interact with images. By analyzing the units of Living Images and comparing them with pixels in digital images, we can observe their material conditions of their vitality providing us with a fresh perspective on the theory and history of images.

Acknowledgments
This project was supported in part by JSPS KAKENHI (Grant No. JP17H04772, No. JP19H01225, JP20H01203, and JP21H00495).

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