



HOKKAIDO UNIVERSITY

Title	Animal Glasses Lab Commentary Book
Author(s)	Kasuga, Haruka; Ohashi, Machiko; Konishi, Yusuke et al.
Description	アニマルめがねラボ : VRで生き物の視覚を考えよう. 2018年10月14日. 北海道大学 CoSTEPメディアデザイン実習主催. 札幌市円山動物園. 北海道札幌市.
Issue Date	2020
Doc URL	https://hdl.handle.net/2115/76625
Type	book
File Information	CoSTEP-MD2018_English.pdf





Animal Glasses Lab.

**COMMENTARY
BOOK**

In 2018

**By Hokkaido University CoSTEP Media Design Practice &
Animaware Co., Ltd.**

Introduction



This booklet is a commentary on virtual reality (VR) videos expressing the characteristics of vision in animals. The VR videos were produced as a part of the activities of the CoSTEP (Communication in Science & Technology Education & Research Program) Media Design Practice in Hokkaido University and were used at the Animal Glasses Laboratory held as a part of Sapporo Creative Convention No Maps 2018 held on October 14, 2018 and held during Equimonia 2018 from December 1st to 2nd, 2018, at the Animal Glasses Park, an ICT event, held in the underground walking space near Sapporo Station on December 16, 2018 and at a visiting lecture for a hospital classroom, “Himawari Branch”, of Hokkaido University Hospital on April 23, 2019.

The five senses of humans and other animals differ from each other. The question arises as to how humans can understand the manner in which animals perceive the surrounding world by using their own five senses. Prior researches on the visual characteristics of animals have been conducted using both of anatomical and behavioral methods. Based on these scientific viewpoints, we expressed the vision of non-human animals. To understand how animals actually see the world, we must undergo the experiences of that animal. We attempted to provide opportunities for imagining and considering the structure of the eye and the process of evolution by presenting participants with the differences in vision between that of humans and other animals. We provided VR videos to participants through the use of VR headset, as this type of video is immersive. For these VR videos, we recorded panoramic videos of six different animals: dogs, cats, geckos, frogs, turtles and tortoises. Visual characteristics are then divided into three types (i.e., visual acuity, color vision, and dynamic vision) and tailored for each animal.

(Hokkaido University CoSTEP Media Design Practice: Machiko Ohashi, Haruka Kasuga, Haruna Kitamura, Yusuke Konishi, Masataka Yamamoto, Yuichiro Ikeda; director of Animaware Co., Ltd.) Correspondence to: Takashi Murai (E-mail address: murai@costep.hucc.hokudai.ac.jp)

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Eyesight

Eyesight or visual acuity refers to the limit of sensory abilities or the extent to which you can distinguish small visualized details.

The eyesight of an animal can be measured using black and white stripe patterns, as shown in Figure 1. As the number (density) of stripes is increased, black and white are averaged, eventually making the stripes invisible as if the pattern were even gray. Eyesight is defined by the limit until which these stripes can be seen, and the number of stripes per visual angle is called the spatial frequency [1].

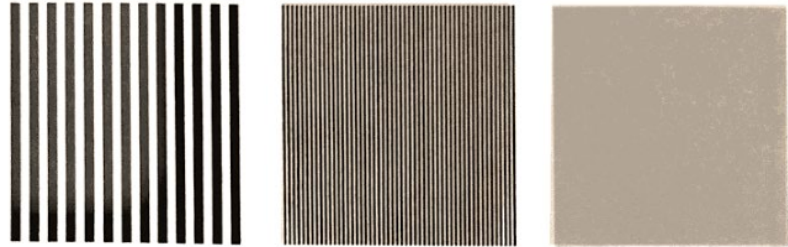


Figure 1. Measurement of eyesight using stripes [1]

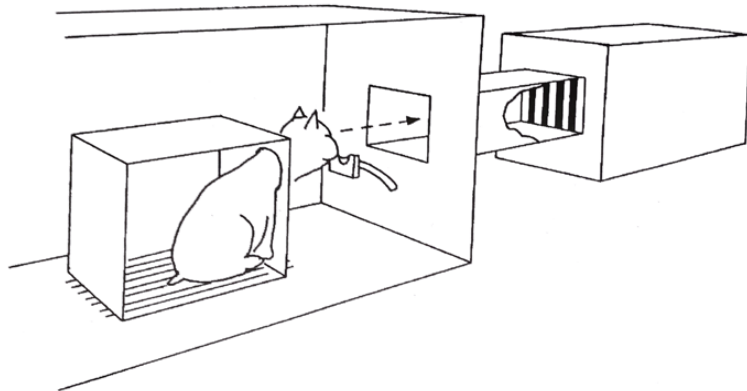


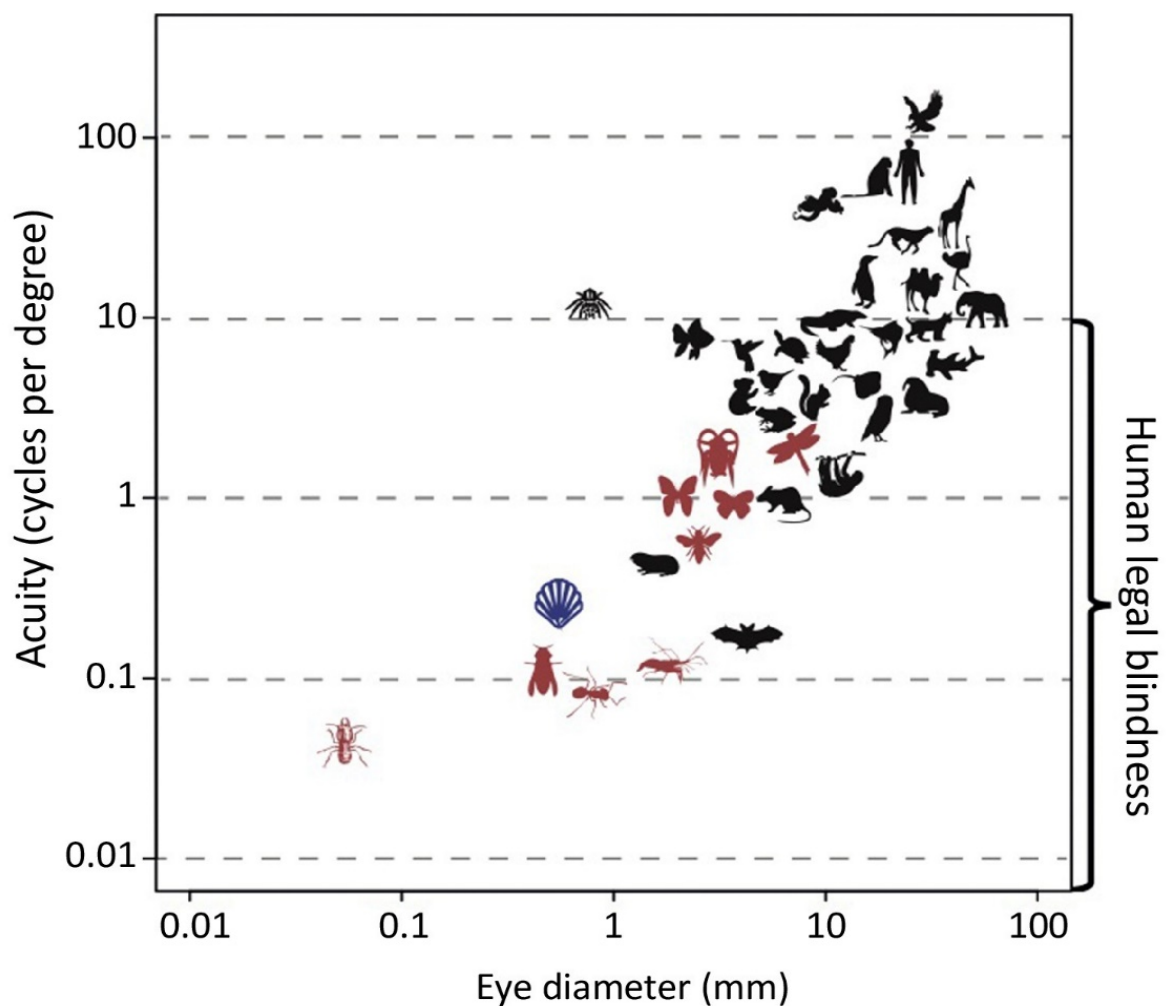
Figure 2. Experiment for measurement of a cat's eyesight [3]

Behavioral experiments are often utilized when measuring eyesight using stripes, as shown in Figure 1. For example, a cat is trained using food to push a lever with its mouth when a striped or gray pattern is identified (Figure 2), whereas a falcon is trained using food in a similar manner to fly when a striped pattern is noted [4]. There are also other methods, such as anatomical calculation and physiological measurement.

Figure 3 shows the results of research summarizing the degrees of eyesight (spatial frequency) for various animals. These values may vary considerably depending on the measurement and calculation methods used. Generally, diurnal animals and humans tend to have good eyesight, compared to that of nocturnal animals. It is also said that there is a close relationship between an animal's

height and its eyesight. From an ecological point of view, as a tall creature's point of view is higher for it to see farther away, it is believed that good eyesight is essential to see long distant objects. From a structural point of view, as the body is larger, the eyes also become larger in proportion to it. Eyesight can be improved when the number of photoreceptor cells is large.

It is noteworthy that many animals do not fit the



Trends in Ecology & Evolution

Figure 3. Relationship between eye diameter and the eyesight of various animals [2]

abovementioned rule. Animals, such as predatory birds, tend to have good eyesight in proportion to their height to find their prey, such as rats on the ground, when they are high up in the sky. On the other hand, animals living in dark places, such as moles and bats, develop a sense other than sight, such as olfaction and hearing, to locate their prey. Bats are known to “see” the world by the use of ultrasonic sounds. The possession of better eyesight does not make one superior, while having a worse eyesight does

not make one inferior. There is diversity in sight, which serves as a clue for understanding the living strategies of creatures.

The eyesight VR videos were focused on chelonian. Some turtles and tortoises are popular as pets, and I had two of my own as a child. When the chelonian approached my finger, I would notice that it would move its mouth. It left me wondering if the chelonian could see my face and fingers.

In this movie, we applied a blurring process by using a Gaussian function while referring to the eyesight of a pond slider measured using a physiological method called the visual evoked potential (VEP) [5]. From the graphical data shown in Figure 3, we note that a turtle's eyesight is about one-tenth times that of humans. Three of my friends with eyesight ranging between 2/20 to 4/20 vision participated in the research on the blurring condition of the world with a visual acuity of 2/20 to 4/20. It is said that when you have poor eyesight, you can see nearby objects clearly, whereas distant objects would appear blurry. Unfortunately, we were unable to reproduce this phenomenon by using this process.

We hope this VR video will enable you to perceive how a turtle may dimly see the face and fingers of a person outside its aquarium.

Furthermore, a question is asked when the VR video ends to



Figure 4. Before shading (left) and after the process (right)

trigger the consideration of the possibility of ecological factors that can influence the eyesight by observing the chelonian habitat of both turtles and tortoises from the chelonian's perspective (Figure 5). To the best of my knowledge, there is no accurate answer with regard to turtles. This is because there has not been any detailed research on the aspect of terrestrial tortoise's eyesight. I suppose there are various ways to understand this: "the eyesight of tortoises is likely to be better because it is easier to see when on land" and "aquatic turtles often come on land so there is hardly any difference in the vision of two different chelonian

species.” We hope you will not only come to understand that the world you see is not common among animals, but also take interest in the fact that the way the world looks and how one feels may differ for different people.



Figure 5. Question shown at the end of the VR video
“How does eyesight vary depending on the living environment?”

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Color Vision

Color is not attached to the objects around us, but rather perceived depending on the wavelength of the light reflected from objects. Color vision is the ability to detect and analyze changes in the wavelength composition of light [1]. As shown in Figure 1, light of different wavelength is perceived as different colors when it is absorbed by cone cells of the eye. Color appearance from a physical description of the stimulus is strongly affected by the context in which it is seen. Humans have three types of cones that are most sensitive to light of short, medium, and long wavelengths, and are called S, M, and L cones. They are also called blue, green, and red cones, respectively. This is so because, for example, we perceive short-wavelength light as blue light when it stimulates S cones of the eye, but not M or L cones. However, not all creatures can perceive color this way. As shown in Table 1, there are creatures with two or fewer types or four or more types of cone cells. Even if the number is the same, the characteristics of the distinguishable wavelengths may differ. It is, therefore, assumed that the different world appears differently to each creature.

The distinctiveness of colors is believed to have

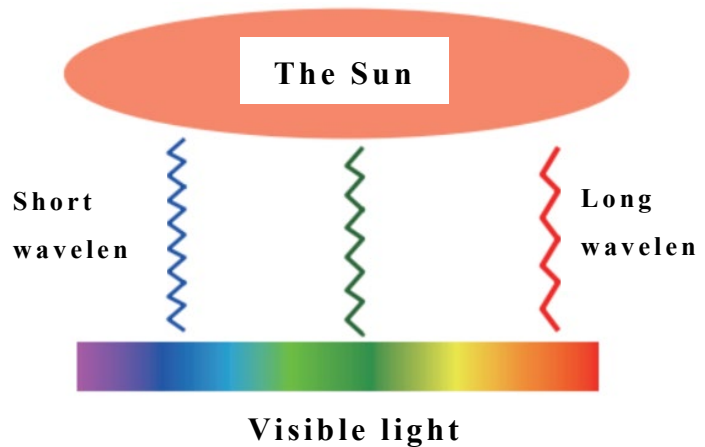


Figure 1. Color perceived according to wavelength length

Table 1. Types of pyramidal cells for other creatures [1,2]

Birds	Swallowtail butterflies	Honeybees	Dogs
Four	Six	Three types (differing from those of humans)	Two

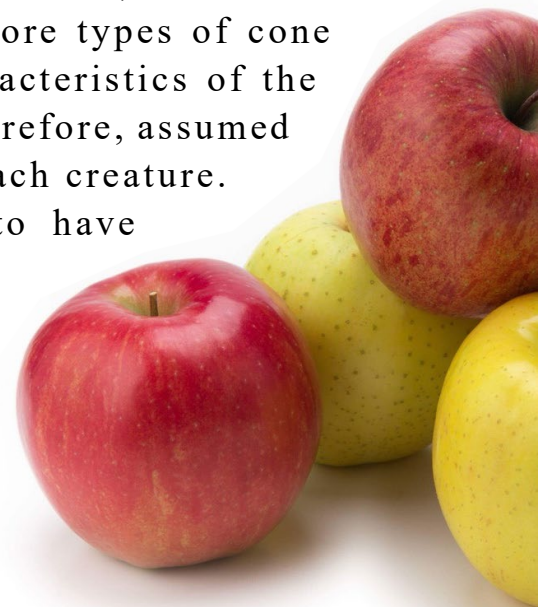




Figure 2. The photo on the right depicts a state in which red and green is difficult to be distinguished from each other while that on the left depicts a state in which they can be distinguished.

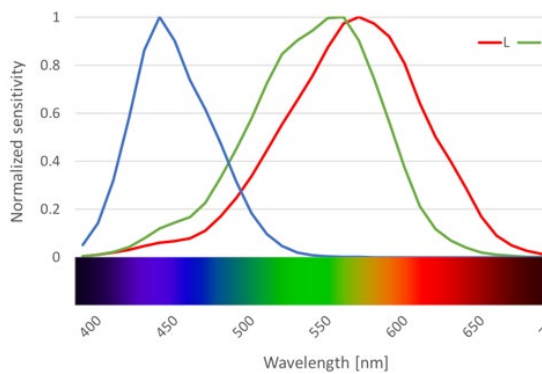


Figure 3. Wavelength characteristics of trichromacy in humans

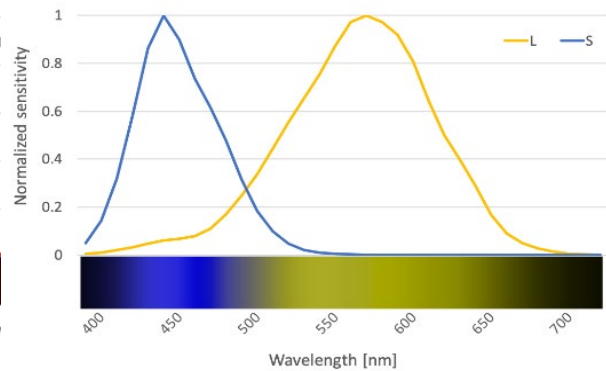


Figure 4. Wavelength characteristics of deuteranopia

evolved based on the life of each creature. For example, there is a well-known assumption that human ancestry has evolved to distinguish the color of leaves from that of fruit to make fruits easier to find like shown in Figure 2 (left) [3]. On the other hand, it is more difficult for dogs and cats to distinguish between red and green objects despite being able to easily distinguish between blue and yellow objects like shown in Figure 2 (right) [4,5]. This could be based on the assumption that dogs and cats may not need to discriminate between green and red objects when it comes to hunting and living. From this prediction, we tried to express the color vision of dogs. Based on the results of previous researches, it can be seen that the color vision of dogs is similar to that of a deuteranope with missing M cones (Figure 4).



As a conversion process from color vision of trichromacy in humans to that of deuteranopia, we utilized the calculation that is summarized on the next page. The color vision of a deuteranope with missing M or L cones is often expressed as blue and yellow. However, the state of the color actually seen can only be understood by people and dogs with deuteranopia. Meanwhile,



Figure 5. The photo on the left depicts trichromacy, while that on the right depicts the color vision of dogs.

although they do not reproduce color vision, these color vision expression attempts can be used for color barrier-free designs that can be easily recognized by all color vision types. In other words, it is considered to be effective as a trigger for understanding the way dogs see the world. We created videos with VR to enhance the immersive feeling and create a deeper understanding of the color vision of dogs. Figure 5 shows a screenshot of the actual VR video. It is observed that the red color of the food bag for cats and the training equipment looks yellow with the color vision of dogs. Additionally, the pink (light purplish red or magenta) color of the bag that the woman is holding in her left hand appears blue. However, in Figure 3 (left), you can see that there is no light wavelength corresponding to magenta color. People with trichromacy perceive the color as magenta when red and blue lights are mixed, that is, when L and S cones are stimulated to the same degree. It is believed that there are cells that compare signals of L cones and M cones and cells that compare signals from S cones and added signals from L and M cones in the color vision model of the human brain

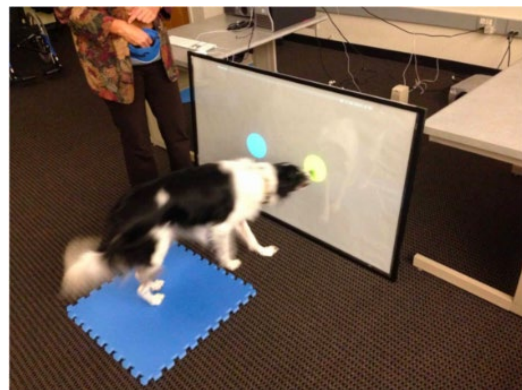


Figure 6. Interface for guide and assistance for dogs [8]

with trichromacy [6]. However, in the case of deuteranopia, M-L opponent cells are less likely to work, and only S-(M+L) opponent cells, that is, blue-yellow opponent cells are considered to be the basis of color vision according to the opponent-process theory. For dogs, magenta objects appear as a color close to blue if the light from that object stimulates S cones more strongly than L cones.

This shows that, when considering the environment for dogs, we should not consider the color element in the same way that we do for humans. When you play with a dog using a red ball on a lawn, it can be difficult for the dog to distinguish the ball from the lawn, as shown in the example consisting of apples and leaves (Figure 2). Of course, you can utilize the aspects of nature for dogs like olfactory training that you make the dog find the treasure (in this case, the ball). On the other hand, there are also situations that it is better for dogs to distinguish objects easily especially for training or working. For examples, tools for dog agility are colored using a combination of blue and yellow, and so on, so that dogs can easily identify those tools visually. Furthermore, interfaces for working dogs have been developed in recent years, and they are designed using a combination of colors such as blue and yellow, as shown in Figure 6, which can be easily distinguished based on the color vision of dogs.

If you like dogs, you may already know that it is difficult for them to distinguish between red and green objects. This kind of problem exists for other creatures as well. If you can simulate the color vision, it may give humans a chance to think about the feelings of dogs and other creatures.

Conversion process

for the color vision of dogs (deuteranopia) [7]

1. After normalizing from 8-bit values (I, J, K), cancel the correction such as gamma correction, etc., and set the (R, G, B) value

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} 0.957237 * (I/255)^{2.2} + 0.0213814 \\ 0.957237 * (J/255)^{2.2} + 0.0213814 \\ 0.957237 * (K/255)^{2.2} + 0.0213814 \end{pmatrix}$$

2. Convert from RGB color space to LMS color space

$$\begin{pmatrix} L \\ M \\ S \end{pmatrix} = \begin{pmatrix} 17.8824 & 43.5161 & 4.11935 \\ 3.45565 & 27.1554 & 3.86714 \\ 0.0299566 & 0.184309 & 1.46709 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

3. Convert to deuteranopia in LMS color space

$$\begin{pmatrix} L_d \\ M_d \\ S_d \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0.494207 & 0 & 1.24827 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} L \\ M \\ S \end{pmatrix}$$

4. Inversely convert deuteranopia from LMS color space to RGB color space

$$\begin{pmatrix} R_d \\ G_d \\ B_d \end{pmatrix} = \begin{pmatrix} 0.80944 & -0.130504 & 0.116721 \\ -0.0102485 & 0.0540194 & -0.113615 \\ -0.000365294 & -0.00412163 & 0.693513 \end{pmatrix} \begin{pmatrix} L_d \\ M_d \\ S_d \end{pmatrix}$$

5. Remove the gamma correction and return to the 8-bit value

$$\begin{pmatrix} I_d \\ J_d \\ K_d \end{pmatrix} = \begin{pmatrix} 255 R_d^{(1/2.2)} \\ 255 * G_d^{(1/2.2)} \\ 255 * B_d^{(1/2.2)} \end{pmatrix}$$

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Dynamic Vision

The ability to see moving things is called dynamic vision. Dynamic vision can be divided into two categories: the visual sense of Kinetic Visual Acuity (KVA) for identifying a broken Landolt ring approaching you from a distance and the visual sense of Dynamic Visual Acuity (DVA) for identifying the broken ring moving in the horizontal direction from left to right. For example, the measurement of dynamic vision at a driver's license lecture for the elderly corresponds to the abovementioned KVA. In these elderly lecture classes, a broken ring approaches at a high speed, and when the direction of the break of the broken ring can be determined, a button is pushed to measure the dynamic vision of the participants [1].

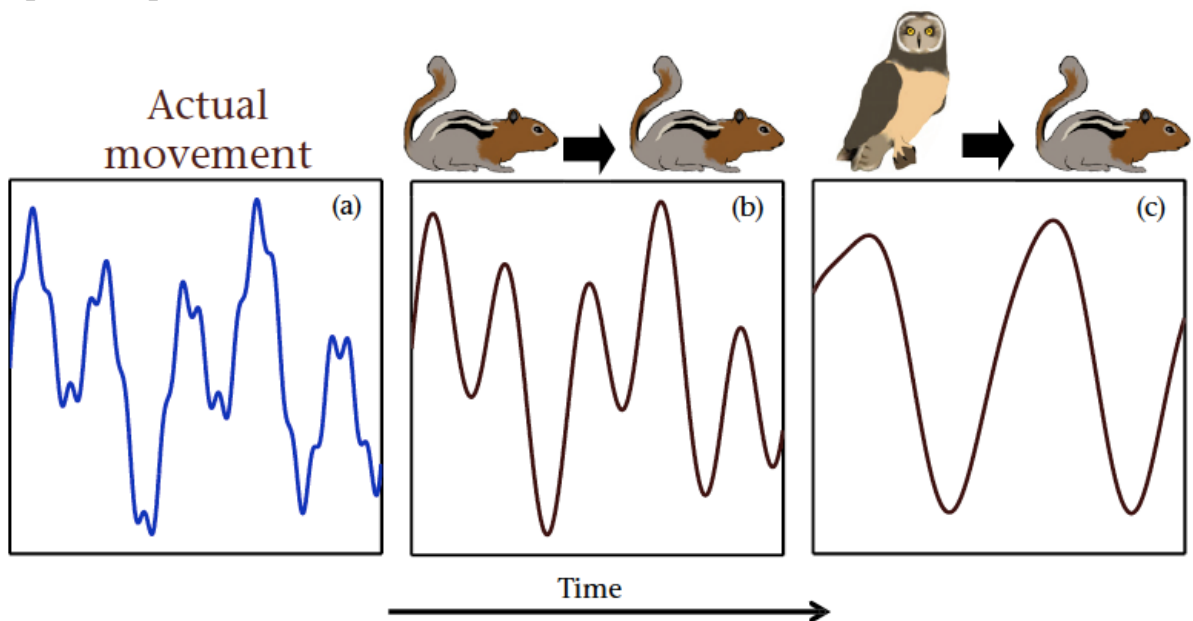


Figure 1. Schematic diagram of resolution per hour of visual perception of animals [2]

Generally, it is said that dynamic vision differs from creature to creature, and by using the technique of measuring the critical flicker-fusion frequency (CFF), we can determine the dynamic vision of different creatures. In simple terms, dynamic vision is examined depending on the number of times you can identify the

flashing of light in one second [5]. For example, in the case of humans, it is said that the CFF is approximately 60 Hz, or the flashing of about 60 lights per second, in an optimal situation [6]. Some scientists proposed that for small animals with a better metabolic rate, the frequency is higher than that of large animals. It can be generally assumed that small animals are able to move quickly because they view large animals as moving more slowly than themselves [2]. In Figure 1, the vertical axis represents the position of the animal while the horizontal axis represents time. When moving quickly, the motion curve becomes complex, as seen in (a). Here, if the curve of (a) is the movement of a squirrel, its movement as seen from the same species of squirrel will be as shown in (b). It can almost catch the movement of the original (a), but this is because the visual resolution of a squirrel per hour is high. On the other hand, when an owl with a low resolution per hour looks at the movement of the squirrel in (a), it can only be regarded as a rough movement like (c).



Figure 2. Traffic light [4]

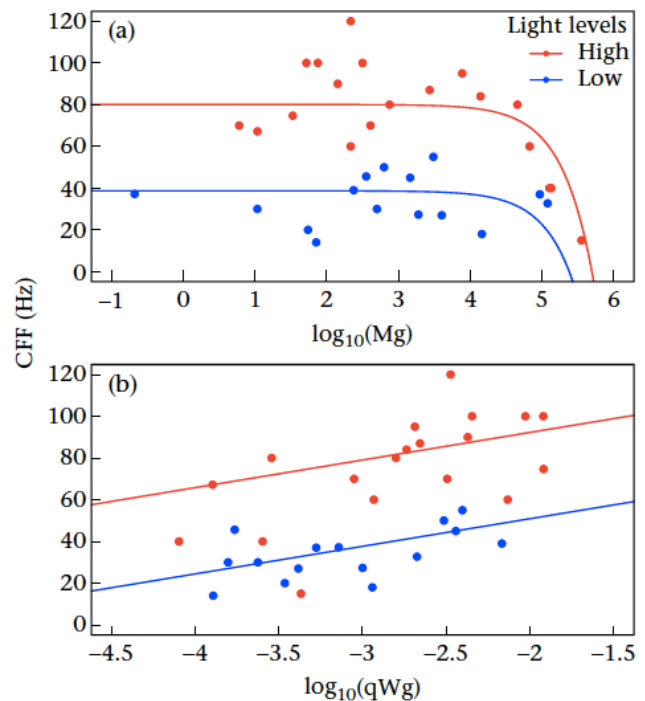


Figure 3. (a) Relationship between body weight and critical flicker-fusion frequency (CFF)

(b) Relationship between metabolism and CFF. Light level refers to the intensity of light in the inhabited environment. [2]

A team at Trinity College Dublin (TCD) in Ireland observed the CFF for more than 30 animals, such as dogs, lizards, pigeons, and chelonian [2]. As the table summarizing the animals that served as observation targets is published in a thesis written by the team at

TCD [2], we recommend taking a look at it. For example, the CFF for dogs was 80 Hz, the CFF for geckos was 20 Hz, the CFF for leatherback sea turtles was 15 Hz, and the CFF for squirrels and pigeons exceeded 100 Hz. Although it might be difficult to interpret these results, it can be understood that LED traffic lights blink for squirrels and pigeons. Although humans with a CFF of approximately 60 Hz generally do not understand it, LED traffic lights flicker approximately 100 times per second [3]. In particular, it is proposed that there is a correlation between metabolism and CFF, as shown in Figure 3(b). In Figure 3(b), the CFF increases as metabolism increases.

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Column – A quick glance at image processing

Although slightly different from dynamic vision, frogs hardly recognize stationary objects and can only see moving objects [7]. This makes it possible for them to sensitively perceive and capture fast-moving insects, such as flies that they eat. However, the question arises as to why frogs do not recognize stationary objects.



(a) Original



(b) Difference image generated



(c) After morphology



(d) Blurring of non-moving

Figure 4. Processing process of a frog's vision in VR videos

We created a VR video based on a frog's vision. In this video, we used a motion detection algorithm based on a method called MOG 2 [8,9] to completely blur non-moving objects. MOG 2 is a type of background subtraction that is used as an approach for detecting a moving object by sequentially constructing a background model from a past frame using mixed normal distribution and taking the difference from the current frame. Creating of sequential background models prevents areas without moving objects from being detected as differences due to illumination changes, the reflection of shadows, and so on. In other words, in order to detect a moving part from a frame in a moving picture as shown in Figure 4 (a), it is only necessary to know the part that is not moving for a specified number of past frames. As a result, Figure 4 (b) shows a difference image in which the portions assumed to be moving are represented in white. As the difference image contains noise due to detailed changes such as lighting, it is necessary to remove noise by open processing of

morphological transformations. Additionally, in the difference generated with MOG 2, only the outline of the moving object is detected, and hence, it is necessary to fill in the undetected parts inside the contour by a closing processing of morphological transformations, etc. As a result, as shown in Figure 4 (c), it is possible to extract the moving area from the moving image, and completely blurring only the unmovable area as shown in the eyesight section of this book. It then becomes possible to express the frog's vision as shown in Figure 4 (d). With regard to the implementation of MOG 2, it is recommended to refer to the background difference section of the image processing library OpenCV commonly used in programming languages such as C++ and Python. There are various other methods also for the background subtraction approach. If you are interested, please try out various methods depending on the video that you want to process. In a similar manner, OpenCV can be used to conduct morphological transformations. Each parameter varies depending on the video that you want to process.

As this video created using the above method lacks accuracy owing to camera resolution and other problems, it does not represent the actual frog vision. However, we can catch a glimpse of the world that frogs experience in terms of seeing only moving objects. Although it seems like a disadvantage to restrict extra information to such an extent, it becomes easier to clearly perceive the insects that they feed on and the natural enemies that may attack them. I believe that VR's strength lies in its ability to make people aware of the fact that the eyesight of each creature has evolved as required based on the requirements of the creature. If you are interested in this video, please examine the vision of your favorite creature and try implementing it while referring to this book.

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Conclusion

As mentioned in the introduction, the VR videos were used at four events.

We were able to hold these events thanks to the tremendous cooperation of the No Maps Committee, Sapporo Maruyama Zoo, the Equimonia 2018 Executive Committee, the Sapporo Information Technology Promotion and Diffusion Council (UNISON), teachers in the Himawari Branch and all participants in those four events. In addition, many people provided us with help in shooting footage of animals, thereby enabling us to successfully create these VR videos. We greatly appreciate Takashi Murai (Specially Appointed Professor of CoSTEP Communication in Science & Technology Education & Research Program, Hokkaido University) for providing us with a great deal of advice on management through these events and Makoto Mizunami (Professor of Behavioral Neuroethology, Department of Biological Sciences, Faculty of Science, Hokkaido University) for supervising the content of the VR videos as well as the commentary for participants and this book.

January 17, 2020



