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Learning to See Differently

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Abstract
Visual literacy takes for granted that humans are the main perceivers and decipherers of visual stimuli into meaningful information. The focus of this paper is to introduce the idea of a non-anthropocentric visual literacy and explore how it could help us better understand the myriad species that coexist with humans on Earth, their interactions with one another, and our interactions with them. Our work attempts to visualize the world beyond our vision — in the infrared and the ultraviolet. Using photography, we have imaged our world to translate what is visible to non-humans into the visible for humans. The information contained in these images reveals "hidden stories" about how organisms interact and make decisions, perhaps helping us to envision a more responsible future not only for our own species but also for the tens of millions of other species with whom we share the Earth. In sum, we propose that learning to see the world as other organisms do should be a part of visual literacy study and practice.

Keywords: Anthropocene, cognition, photography, non-visible spectra

Introduction

Visual literacy is "a set of abilities that enables an individual to effectively find, interpret, evaluate, use, and create images and visual media" (Hattwig et al., 2011, p. 1). This standard definition of visual literacy includes two key features. First, it is clearly anthropocentric. The "individuals" who perceive, decipher and interpret visual stimuli and information are assumed to be human beings. Yet, virtually all other organisms—including animals, plants, fungi, and microbes—perceive and respond to visual stimuli in ways that could be categorized or modeled as "interpreting" or "evaluating" their information content.[i] The focus of this paper is to introduce the idea of a nonanthropocentric visual literacy and explore how it could help us better understand the myriad species that coexist with humans on Earth, their interactions with one another, and our interactions with them.

Second, the core actions of visual literacy—the processes of finding, interpreting, evaluating, and using visual information—are like the interactive processes within complex systems leading to emergent phenomena.[ii] Learning how to approach, engage with, and think deeply about complex systems is an emerging frontier in education (e.g., Bolt et al., 2021; Chua et al., 2017; Talanquer et al., 2020; Thomassen & Stentoft, 2020). Our work uses new approaches to thinking and learning about complex systems (Chua et al., 2017) to suggest methods for uncovering and learning the multifarious "hidden stories" behind the images and visual media we are confronted with daily.

Specifically, imagery and visual media are seen and interpreted on several levels. These levels are encapsulated in the three prompts posed in the "Stories" thinking routine of Chua et al. (2017).

1. What is the story that is presented?
2. What is the untold or hidden story?
3. What is your story?

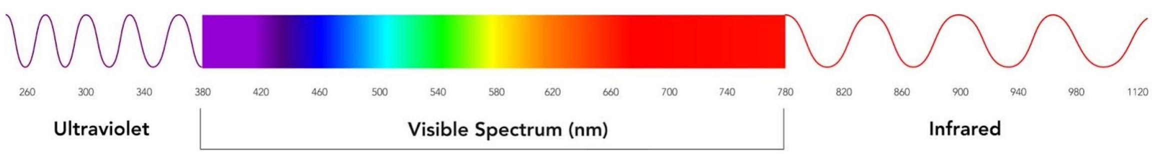
Applied to imagery and visual media, the viewer should first ask: what is the message or idea that is being conveyed? Secondly, the viewer should ask a series of more probing questions, such as: what additional data or other information went into creating the imagery; what ideas, perspectives, or events were emphasized or de-emphasized, and why; what information was left out, and was its omission innocuous or did it contribute to meeting a particular agenda; and who (or more expansively, what other species) is (are) advantaged or disadvantaged by the presentation? Thirdly, viewers should be invited to revise the imagery: How might I re-imagine (or re-image) it?[iii]

Human Vision

The ways in which humans process visual information is a complex process that is not reducible to the digitized systems that we have created to make images of the world. How we perceive the world has more to do with how we process the visual stimuli we receive rather than with how individual photons hitting a sensor through a digital-camera lens are quantified. That is, we are more like a cognitive processing engine,[iv] and the way we construct an image of the world in our minds is a result of the collective evolutionary history that we share with all other organisms.[v]

An example of how humans respond to warning stimuli triggered by visual recognition is by avoiding red-colored objects in the wild, such as those of red baneberry or coral snakes. These responses result from a combination of learned and innate understanding of our perceived threats. Note that we rarely respond to images of coral snakes in the same visceral way as we do to these snakes in real life, and that not all red berries are poisonous and should be avoided; contrast red baneberries with raspberries. The processing depends on the visual stimulus or image and context and additional learned information (Cauchoix et al. 2020).

Figure 1
Ultraviolet, Visible, and Infrared Spectra



Note: The ultraviolet spectrum between 260–380 nanometers (nm) is visible to many organisms. The human visible spectrum is 380–780nm. The near-infrared spectrum that can be detected with the silicon-based camera sensor chips used by almost all digital cameras ranges from 780–1100nm. Graphic by the authors.

Our visible spectrum sets boundaries on what we perceive visually and on our cognitive processing of them. Humans have a three-cone color-vision system that enables us to see colors ranging from violet (380 nm) to red (780 nm) (Figure 1).[vi] For example, when we look at Figure 2, we "see" the green leaves (reflecting light at ~550 nm) and the azure sky (at ~500 nm). These perceived colors and their relationships help inform our understanding of the scene, which we may interpret as a warm sunny day with few predators and as an image that we may consider to be aesthetically pleasing. However, this understanding and interpretation is limited to the wavelengths we perceive and does not represent anything other than a human-based assessment of this environment.

Non-Human Vision

Most other organisms respond to visual stimuli in systematic ways that have meaning for their existence (Holland, 1992; Bräuer et al., 2020; see Footnote ii). For example, blue jays are averse to the warning colors of orange-and-black monarch butterflies (Brower et al., 1968). Another example is vines that move toward relatively bright openings in a forest canopy. Even though these responses are light-based and we can appreciate and understand the visual stimuli and the processing mechanisms of other organisms, their modes of cognition, and associated physiological or environmental constraints are foreign to our typical way of thinking (Bräuer et al., 2020).

But most other organisms have evolved to have different visual receptors that are sensitive to wavelengths that we cannot see. Thus, they see the world in ways that are completely invisible to us but perceptible and meaningful to them. For example, where we see a pink wild geranium (Figure 3, left), a bee whose visual system also perceives ultraviolet radiation (below 380 nm) instead sees a contrasting target that signals

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where nectar is available amid a contrasting inedible background (Figure 3, right).

Figure 2
Saplings, Visible Spectrum

Note: Original digital image © by the authors, 2021.

Visual responses also differ because of evolutionary differences in visual systems and receptors between humans and other organisms. How can we understand and comprehend these differences? In *What is it like to be a bat?* Thomas Nagel (1974) distinguished between asking what it would be like for a person to have the optical system of a bat (and thus see "like a bat") and asking what it would be like for a *bat* to see as a bat itself does. This is a relevant distinction, because to know what it might be like for a bat to be a bat would involve more than looking at a sonar display. Rather, it would require seeing the world through the visual and cognitive processing systems a bat uses to perceive and interpret the world. Bräuer et al. (2020) similarly emphasize the importance of "biocentric" cognition, noting that different organisms have evolved cognitive processing mechanisms through different pathways. They conclude that psychologists and educators are unnecessarily myopic in assuming there is only one type of cognition and that it is restricted to humans.

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Figure 3
Wild Geranium

Note: Image in visible spectrum (left) and ultraviolet spectrum (right). Original digital images © by the authors, 2021.

Recognizing and appreciating differences in cognitive understanding, such as visual literacy, of humans and other organisms requires a general definition of cognition (see Footnote iv and at least the distinction identified by Nagel (1974). First, we must understand the sensory inputs that bats (and other organisms) perceive. Second, we should understand (and replicate, for example via artificial intelligence) their underlying cognitive processing engines. We focus on the former in this article; Bräuer et al. (2020) review progress in the latter, especially in the context of biocentric (as opposed to anthropocentric) cognition.

Capturing imagery outside of the human-visible spectrum

We begin our approach to understanding non-human visual literacy by developing a system for making images of the same environment in multiple spectra, including those spectral ranges where other organisms see and discern useful information invisible in the human visible spectrum. This system gives us a chance to see what imagery is being presented to organisms that "see" different wavelengths of reflected light. These information-rich images then act as the starting point for further investigations of how these organisms might react to or interpret visual stimuli in the context of their environment.

From decades of scientific research, we know that other organisms "see" reflected ultraviolet (wavelengths below 380 nm) or infrared (wavelengths beyond 780 nm) light (Figure 1). Although we cannot directly see reflected light (radiation) in these wavelengths, we can mathematically transform ultraviolet and infrared images into images that reflect light in our own visual spectrum. Such transformed (or "mapped") images can be gray-scaled or artificially colored. We work with the former, which are similar in appearance to desaturated, monochrome photographs. The same image appears very different to us in visible color, desaturated monochrome, and transformed from infrared or ultraviolet images. The infrared version appears to "glow," whereas the ultraviolet version appears "drab and chilly" (Figure 4).

Transforming reflected wavelengths ordinarily invisible to us into digital images creates an artificial representation of the various wavelengths of light reflected by these objects. The images do not represent the world as seen or interpreted by organisms that directly sense ultraviolet or infrared wavelengths. These wavelengths may be interpreted by organisms that sense them as "colors" or they may trigger some other type of stimuli in their processing systems (Bräuer et al., 2020). However, creating remapped images acknowledges that these wavelengths exist and could include information that appears to be beneficial to other organisms. These images also allow us to think about a world beyond our vision that we cannot process or contextually understand. Although these stimuli and interpretations are challenging for us, observations and experiments on how organisms respond to such imagery can provide clues to how they interpret their visual world (Bräuer et al., 2020; Cauchoix et al., 2020).

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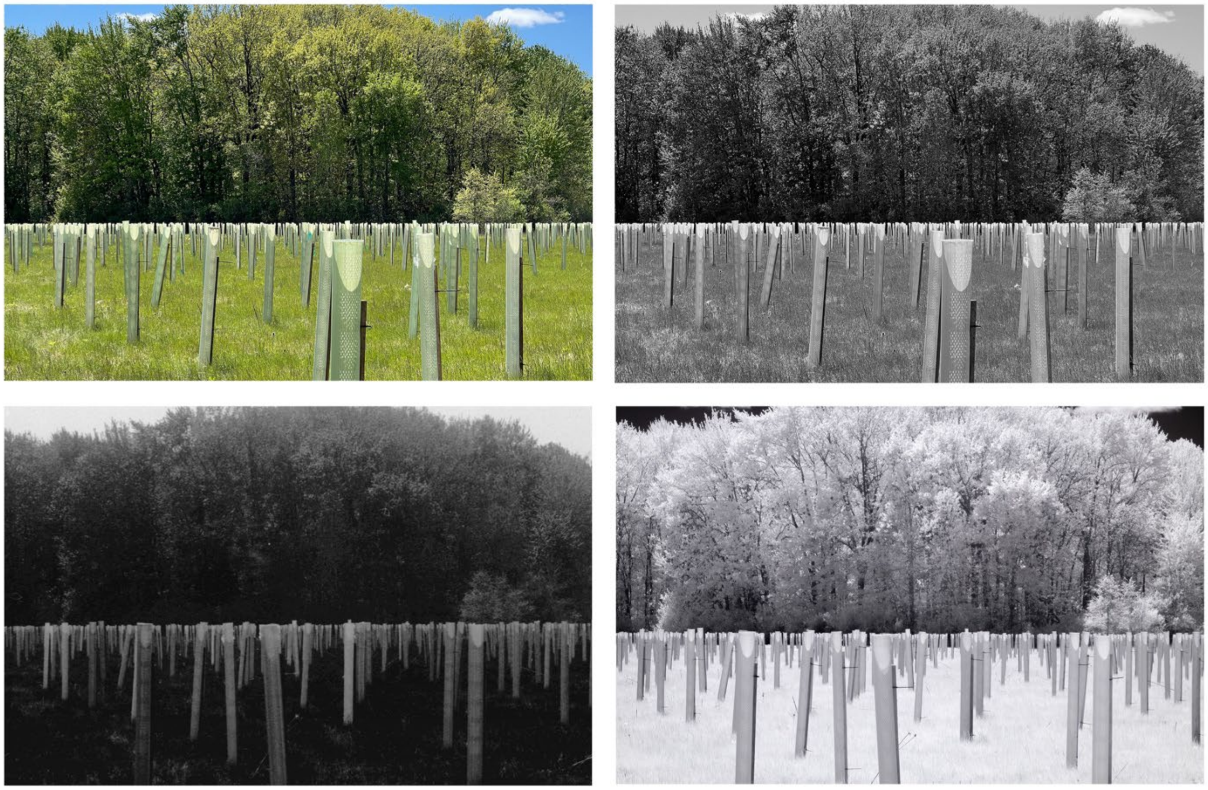
Figure 4
Saplings



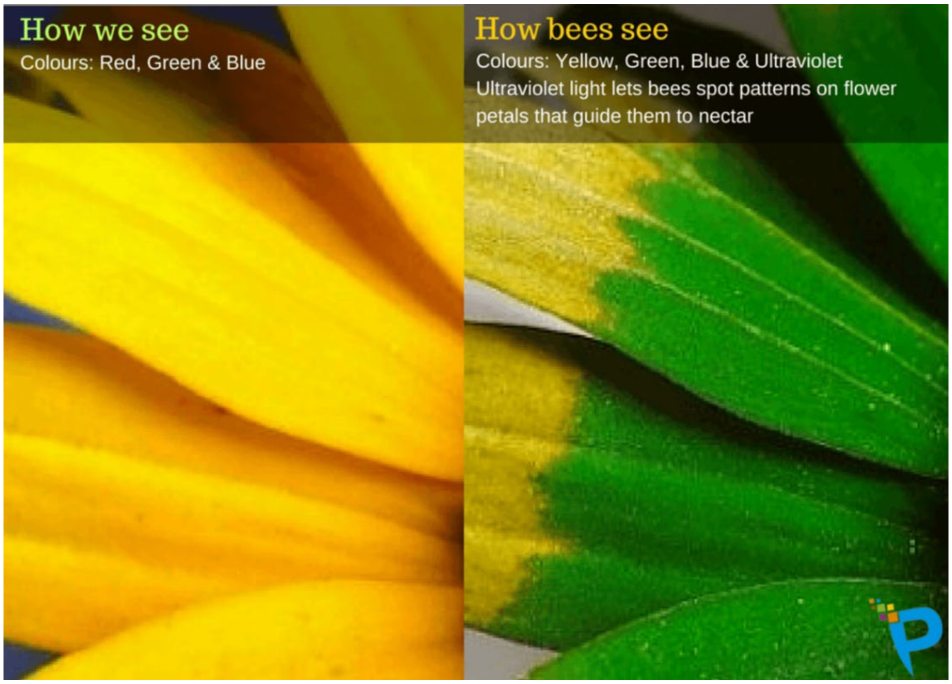
Note: Clockwise from top left: Visible light; Desaturated visible; ; Infrared light (mapped to visible) Ultraviolet light (mapped to visible) light. Original digital images © by the authors, 2021.

For example, bees collect nectar from flowers with targets that are visible to them because they "see" in the ultraviolet (Figure 5). When we use a camera to capture an ultraviolet image of a flower (Figures 3, 5), we collect the first bit of information we need to understand the visual literacy of foraging bees. But a visually literate bee also is collecting and processing other information—not all of which is visual[vii]—that it uses to "decide" whether to go to the target and collect the nectar. This additional information includes the presence of surrounding flowers and potential predators or the distance it will need to fly back to its nest. Although other sensors might collect this (and other) contextual information, it usually is not easily captured by an optical (digital) camera; a purely optical system of understanding perception is inadequate for understanding non-human visual literacy (Bräuer et al., 2020). However, knowing that bees can perceive information that is invisible to us provides the starting point for intuiting their visual literacy.

At the other end of the spectrum, some snakes use their pit organs to sense infrared radiation (a.k.a. heat). More precisely, snakes sense temperature differentials between the background and their usually mobile prey. Thermal imaging technology has revealed the resulting stimulus (the image) and the snake's potential response to it (attacking the prey) (Figure 6). In short, the ability of snakes to collect and cognitively process information contained in infrared imagery allows them to be visually literate about what to us is darkness.

These two examples illustrate the potential for understanding alternate visual literacies of other organisms. Context and other factors also play a role in their visual and cognitive processing systems (Bräuer et al., 2020) and we refer to these factors as "intentionality." However, we recognize that our perception of apparent intention and actual intention (in a human sense) are two very different things (Bräuer et al., 2020; Holland, 1992; and Footnote i).

Figure 5
Human Vision versus Bee Vision



Note: In the right image, the flower is remapped from the full range of wavelengths that a bee can see into false colors used to map ultraviolet wavelengths into the human-visible spectrum. Some of the wavelengths visible to bees overlap our human-visible spectrum (left). The remapped image allows us to see the bees' "target." Image by Dr. Klaus Schmidt reproduced from http://www.punditcafe.com/science/human-vs-animal-vision-cat-bee-snake-shark-dog-vision/ (CC-BY)

Intentionality

Visual literacy is not just a practice of parsing and interpreting an image as presented. Rather, visual literacy requires that we reveal an image's "hidden story" (sensu Chua et al., 2017) by examining its context and further evaluating the intentionality of the image's creator. For example, "fake news" (Figure 7) is faked for a reason. Choosing to accept it as truth or dismiss it as false takes more than just viewing the image or video. The choice we make is a cognitive decision conditioned on our own perspectives or biases and an understanding of the intentionality of the faker.

By extension, there is also cognitive processing from observation to action for organisms (Bräuer et al., 2020). Other organisms rarely intentionally create images, but they do process their visual world, respond cognitively, and make what we view as "decisions"—like bees collecting pollen or the snake attacking its prey—based at least in part on what they "see." There undoubtedly are characteristics of nectar-bearing objects that also occur on other objects that bees do not approach or warm objects that snakes do not attack. Understanding what factors and contexts determine the ultimate "decisions" of other organisms remains an active area of research in many disciplines.[viii]

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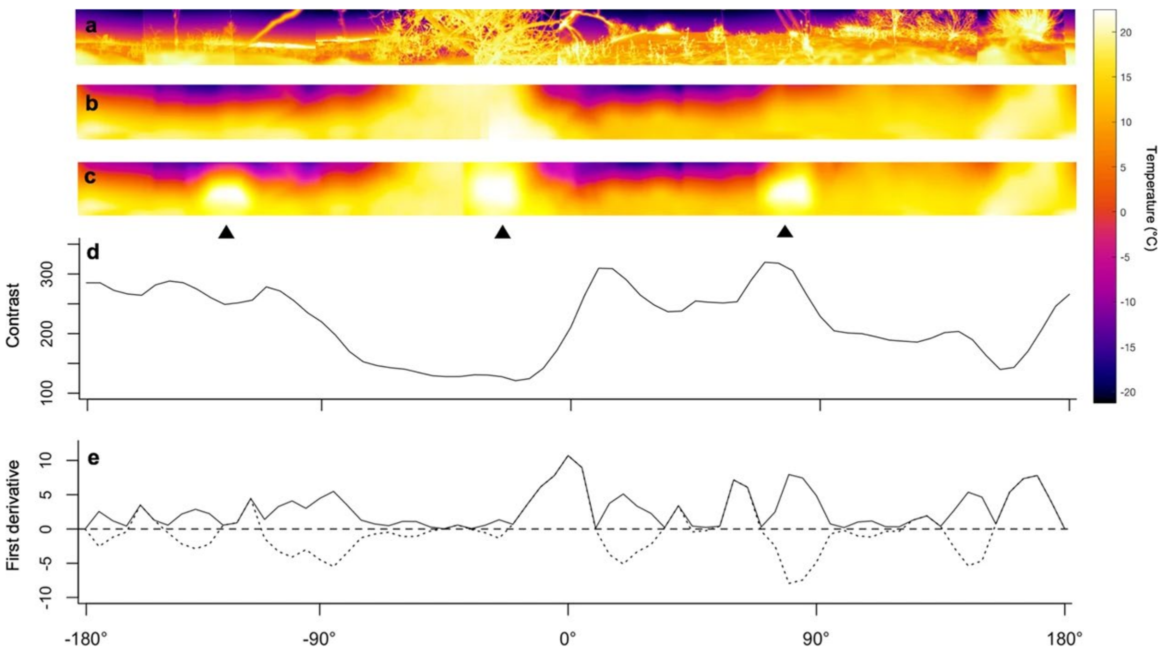
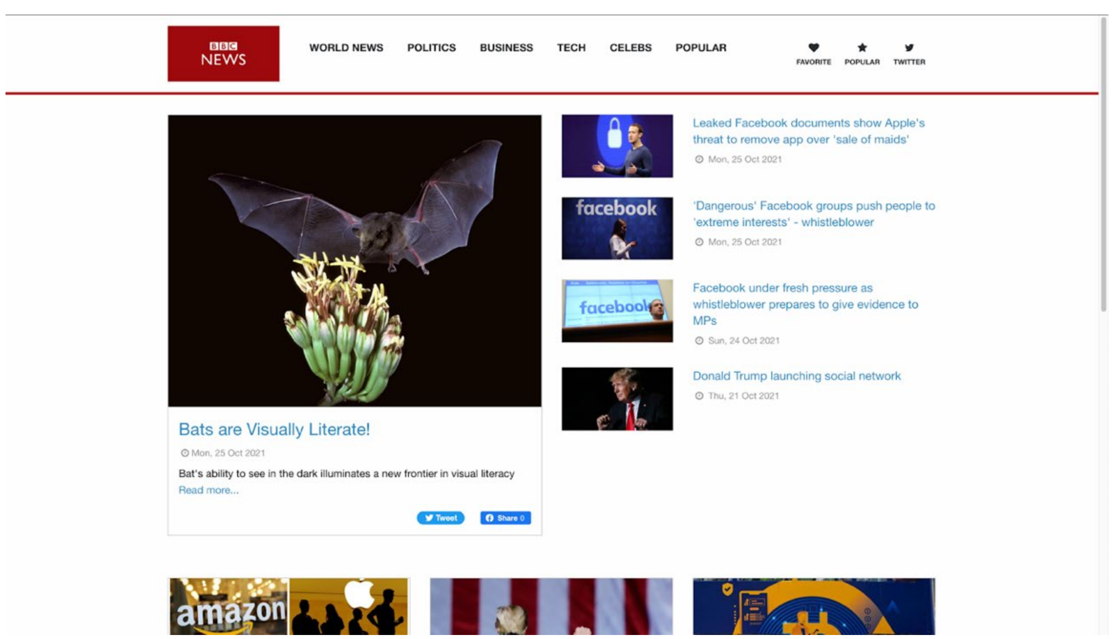
Figure 6
Infrared-sensing Snakes Select Ambush Orientation Based on Thermal Backgrounds



Note: In this figure, thermal imagery illustrates that a sidewinder rattlesnake "sees" a strongly contrasting warm kangaroo rat (bright dot indicated by the triangles in panel **c**) as it moves across and contrasts with a thermally variable landscape. Composite digital image reproduced from Figure 2 of Schraft et al. (2019), CC-BY-4.0.

Figure 7
Fake News Article



Note: Digital image generated 25 October 2021 by the authors.

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Organisms in their own context
Our 80–100-year lifespan is one of the central contexts through which we interpret images and other world phenomena.[ix] But few organisms share our lifespan. What might that mean for their visual literacy?

Like our exploration of saplings and geraniums (Figures 3 and 5), we have examined and imaged the world's longest-living singular organism, the Great Basin bristlecone pine (Figure 8). The oldest of these trees is nearly 5,000 years old. They live in cold, dry, inhospitable-to-us environments on mountains and mountaintops at elevations of 9,500–11,000 feet (3,000–3,500 meters) above sea level (e.g., Ferguson, 1968; Bailey, 1970). The trees are visually distinctive because as they age, encounter threats in their environment, and are damaged, some sectors of the trees may die but others live on. The resulting, contorted trees appear to be barely alive, sculptural objects that nonetheless continue to grow and reproduce for centuries or millennia (Ferguson, 1968).

The set of images shown in Figure 8 depicts the trees in their environmental context—at high elevation on cold, dry mountaintops in Nevada, USA—as they would be seen in the human-visible spectrum and in the ultraviolet and infrared (remapped into our visible spectrum). The images in these spectra alone may not reveal any new information. The ultraviolet and infrared images could be perceived as variations on a standard black-and-white print that uses information from the human-visible spectrum Still, the ability to compare the images across spectra asks a viewer to consider what or who may be perceiving these trees in ways different from us.

From our point of view, the desaturated visible-light image (Figure 8, top left) reveals a scene with tonal relationships that map precisely to the perceived brightness of the full-color visible image (Figure 8, top right). The relationship between colors we perceive as bright and warm (yellow, orange, red) and the lighter gray-to-white values assigned in the desaturated image allows us to make sense of the objects in the scene, even though we cannot discern any exact colors. Rather, we quickly understand (cognitively process) the relationships between tones and imagine the color relationships that represent our experience in the world.

When we look at the remapped ultraviolet (Figure 8, lower left) and infrared (Figure 8, lower right) images, these known relationships between value and color no longer exist. The remapped ultraviolet image shows us a pale sky without a shading gradient. Such a sky appears unearthly because we expect to see a tonal shift from a light gray at the horizon to a darker gray as we look upward. The foliage in the trees also is remapped into a singular gray tone without any of the natural variations we expect to see in the visible spectrum, in which leaves would reflect more than one hue of green. Even the bark of the tree appears to be washed out in the remapped ultraviolet image. Any evidence of variation in the hue of the bark—an indication of a living tree—has been stripped away.

The remapped infrared image has dramatically different relationships in its tonal values and contrasts. We perceive dark skies with less gradation, strongly set back from intense, bright whites of the foliage. These bright whites indicate light that has been scattered and highly reflected from the tree's needles (Knipling, 1970). The bark of the tree, though slightly less varied and brighter than it appears in the desaturated visible-light image, shows a large amount of detail and tonal variation, matching our visual assumptions about a living tree more closely.

Just as we needed additional environmental and hidden contextual information to understand what a bee or snake understands and "sees" in invisible wavelengths, we also need to uncover the deeper story hidden within a tree. The biological and environmental causes of a tree's visible traits rarely are visible—at least to us humans—from exterior inspection. Rather, both the tree's age and clues to its highly variable growth rate and proximate causes are revealed only by looking inside the trees and then analyzing the data using statistical tools and computer models (Figure 9).

Imagery and visual media also can reveal relationships between the images themselves and between the images and topics or issues of broader societal relevance.[x] For example, the photographs of flowers taken in the ultraviolet spectrum (Figures 3 and 5) touch on concepts ranging from aesthetics (e.g., Is it as

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beautiful to me as the photograph taken in the human-visible spectrum?), through biodiversity (e.g., What animals see flowers this way?), or the rapid decline of bees and the pollinator crisis (e.g., How is our world diminished when there are no longer any animals that can see flowers this way?).

Figure 8
Great Basin Bristlecone Pines

Note: Clockwise from top left: Visible light; Desaturated visible; ; Infrared light (mapped to visible) Ultraviolet light (mapped to visible) light. Original digital images © by the authors, 2021.

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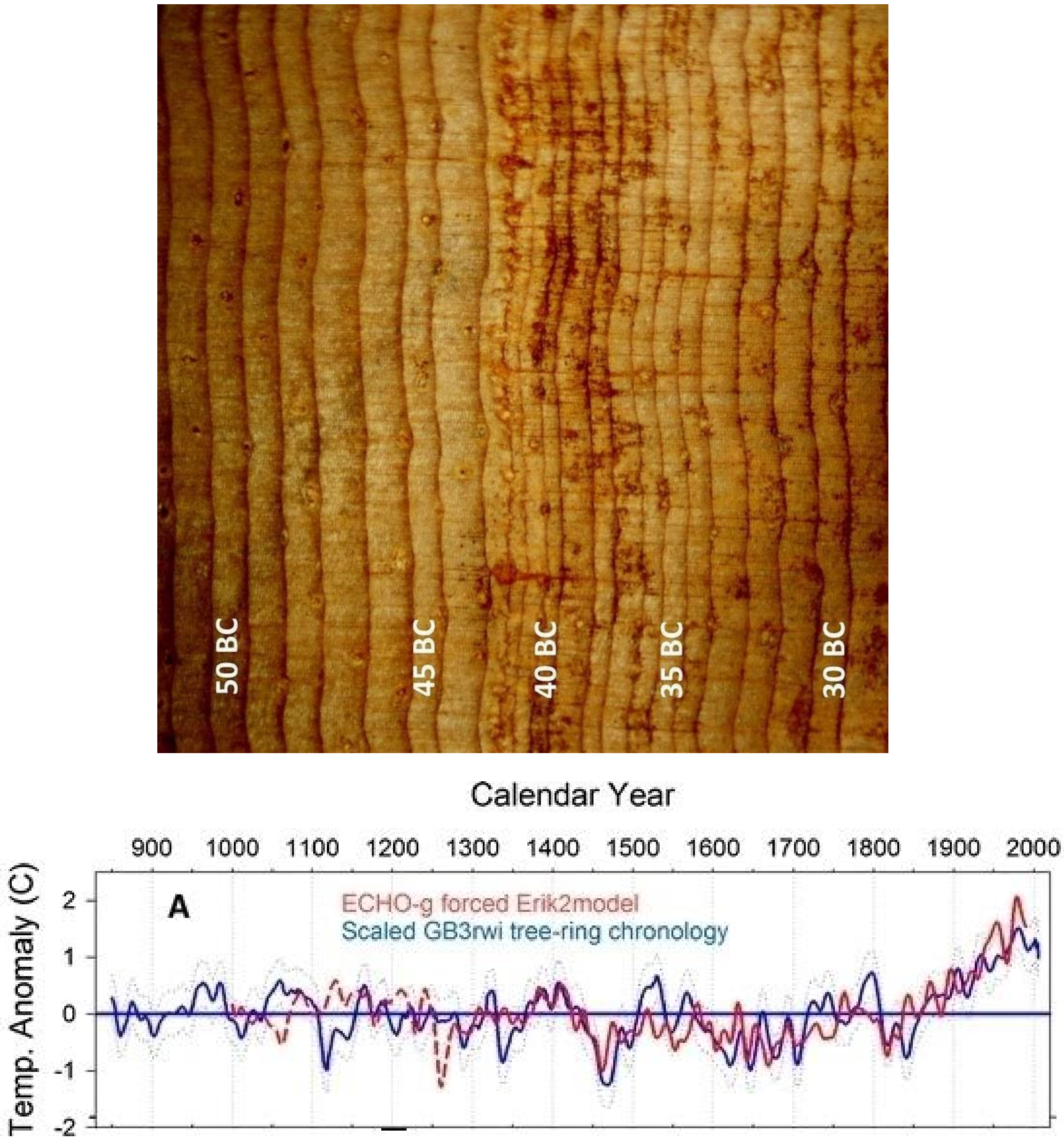
Figure 9

The Long-term Invisible Context of Bristlecone Pines Made Visible



Note: Top: A cross-section through a tree core taken from a bristlecone pine in the Snake Mountains, Nevada, USA. The light areas between the darker lines are annual growth rings—how much the tree grew in diameter each year. Narrower growth rings indicate slower growth than wider ones, and the width is used by dendrochronologists (literally: "tree timers") to infer the climate and growing conditions in each year. The extremely narrow growth rings after 44 BCE are associated with a large volcanic eruption. Photo credit: DRI Science; CC-BY-NC-ND 2.0. Bottom: an approximately 1000-year independent reconstruction (model) of global temperature (red line; values indicate difference ["anomaly"] between the modeled temperature and the long-term [1000–1990] global average) is paralleled almost exactly by the tree-ring widths of bristlecone pines from Nevada and California (blue line). Although the actual bristlecone pine tree-ring record extends more than 4,500 years into the past, this particular climate model only extends back to about 1000 CE. Image reproduced from Figure 5A of Salzer et al. (2014); CC-BY 4.0.

Conclusion: The Value of a Nonanthropocentric Visual Literacy

Why is it important to image and understand the world in ways that reflect how other organisms see, sense, and cognitively process it? On the one hand, understanding nonhuman senses and cognition are of interest (Bräuer et al., 2020). Of more immediate concern, the dual threats of the climate emergency and rapid biodiversity loss (Pörtner et al., 2021) illustrate that we rarely see or understand ourselves and our impacts on the world around us. An expanded visual literacy that includes the other tens of millions of Earth's species could help us envision a sustainable future.

The unattributed adage that "you can't understand someone until you've walked a mile in their shoes" is the foundation for empathy. Similarly, taxonomists—scientists who describe and name new species—often assert that people will be more willing to protect other species (i.e., biodiversity) when we know their names. We would extend this to say that to understand and empathize with other species, we need to see the world through their eyes. Cognitive scientists increasingly agree that only a few ways of thinking differentiate humans from other species (Bräuer et al., 2020). Imagination and abstraction are seen as unique to humans (Egnor, 2015), but it is not clear how we can differentiate the appearance of imagination from its actuality (Holland, 1992). If we cannot distinguish between what a person thinks it is like to see like a bat and what a bat thinks it is like to see like a bat, does it matter in terms of expressing visual literacy? And if we persist in centering cognition in an anthropocentric fashion—that is, cognitive scientists "tend to overrate cognitive skills that are human-like and assume that certain skills cluster together in other animals as they do in our own species" (Bräuer et al., 2020, p. 1)—we will continue to fail to imagine independent evolution of cognitive processing systems.[xi]

In terms of its contribution to visual literacy, the most valuable and successful imagery and visual media that is created or collected and processed by artists, scientists, educators, and media professionals should reveal to the extent possible hidden stories and encourage relational thinking. If we are to better understand how the interactions between organisms on our planet work, we need to be able to see and think in terms outside our own. If we learn to see and understand what a bee or a snake "sees," we can reveal hidden worlds. A tree may initially appear to us as only a source of lumber and shade, but for other organisms, it is a shelter, a source of food, or a connector of fungi, among many other functions. We can be told these facts, but it takes a more impactful approach with images of the world that we can learn to understand to generate a more useful response. We think that response can come from the re-presentation of the real world in accurate but out-of-the-ordinary methods. Although we know that our images cannot reveal the full extent of these hidden worlds, they allow us to begin to imagine the information we are missing and the information we may lose forever as biodiversity declines. At the same time, understanding the processes by which other organisms see, live, and interact with the world de-centers humans as the sole beneficiaries of slowing the dramatic changes to the global climate system that we have caused.

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Footnotes

[i] For example, Holland (1992, pp. 24-25) notes that “we rarely think of anticipation, or prediction, as a characteristic of organisms in general, though we readily ascribe it to humans. Still, a bacterium moves in the direction of a chemical gradient, implicitly predicting that food lies in that direction. The butterfly that mimics the foul-tasting Monarch butterfly survives because it implicitly forecasts that a certain wing pattern discourages predators. A wolf bases its actions on anticipations generated by a mental map that incorporates landmarks and scents.”

[ii] While noting that there are many different definitions and uses of “complex systems,” Ladyman et al. (2013) coalesce these into a tentative definition of a complex system as “an ensemble of many elements which are interacting in a disordered way, resulting in robust organisation and memory” (p. 57), in which memory is “the persistence of internal structure” (Ladyman et al., 2013, p. 59; after Holland, 1992; and Manson 2001, p. 410).

[iii] Editing, revising, and remixing of posted imagery and visual media should always conform to copyright guidelines or options provided through Creative Commons licensing (Creative Commons, n.d.).

[iv] “Cognition” refers to “adaptive information processing in the broadest sense, from gathering information through the senses to making decisions and performing functionally appropriate actions, regardless of the complexity of any internal representational processes that behavior might imply” (Shettleworth, 2000, p. 43). “Engine” is used here in reference to the Middle English definition of *ingine*, a

product of ingenuity, which is separate from the purely mechanical connotations to which the modern term refers.

[v] Lyon (2021) provides an approachable summary of the evolution of cognition. Bräuer et. al. (2020) and Cauchoix et al. (2020) offer more technical reviews of current thinking on the topic.

[vi] This assumes neither enhancement of color vision in humans through tetrachromacy ("Tetrochromacy," 2022) nor color-vision deficiency ("color blindness") caused either by a genetically determined problem in the development of one or more of the sets of the eye's color-sensing cone cells or by damage to the eye, optic nerve, or areas of the brain responsible for processing visual input ("Color blindness," 2021). Additional pre- and post-processing of images and educational materials would be needed to ensure that individuals with color vision deficiency could accurately interpret the content and context of imagery and visual media.

[vii] For example, although it has long been known that honeybees use optically-processed information to track the polarization of sun as a navigational tool, Liang et al. (2016) discovered that bees also can detect the magnetic polarization of the earth and use this additional information to navigate to and from the hive. Similarly, dogs use smell (olfaction) far more than they use vision to "see" their worlds (e.g., Gazit and Terkel, 2003). An even more extreme example is the single-celled, aneural ("brainless") slime mold *Physarum polycephalum,* which uses mechanical sensations to sense the locations of objects in its environment and make "decisions" about which direction it grows based on those locations. Murugan et al. (2021) suggest that this slime mold is using its entire single-celled body as a distributed sensor array and substrate for computation and cognition. Walecki (2021) provides a lay summary of Murugan et al.'s technical paper.

[viii] A recent related example is in Reichert et al. (2021). Vernouillet (2021) provides a readable summary of Reichert et al.'s (2021) technical article.

[ix] For example, our perception of "rapid" climate change and environmental "tipping points" assumes a particular temporal scale (Bestelmeyer et al., 2011).

[x] Extended from the *Thinking with Images: Uncovering Relational Patterns* thinking routine in Chua et al. (2017).

[xi] Ironically, such a failure of imagination is a decidedly nonhuman trait. See Egnor (2015).

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