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ART'S HIDDEN TYPOLOGY

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When we look at works of art, our brain reacts to what we see in subconscious ways. Certain aspects of our perceptions can be captured using algebraic methods.

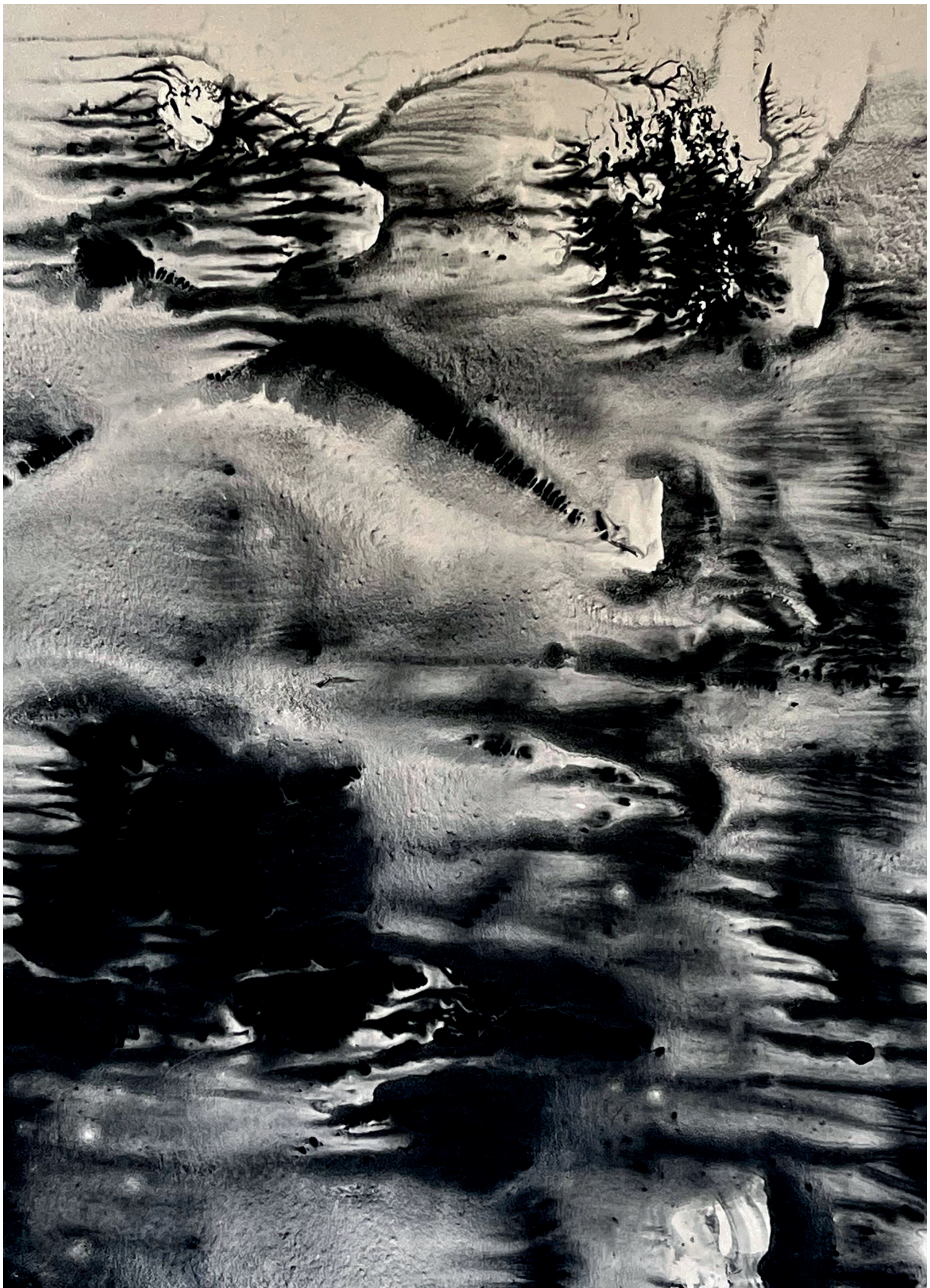

Image painted by Lidia Kot, "Three-Quarters of the Face of Blackness," Wozownia Gallery, Toruń, 19.11–26.12.2021

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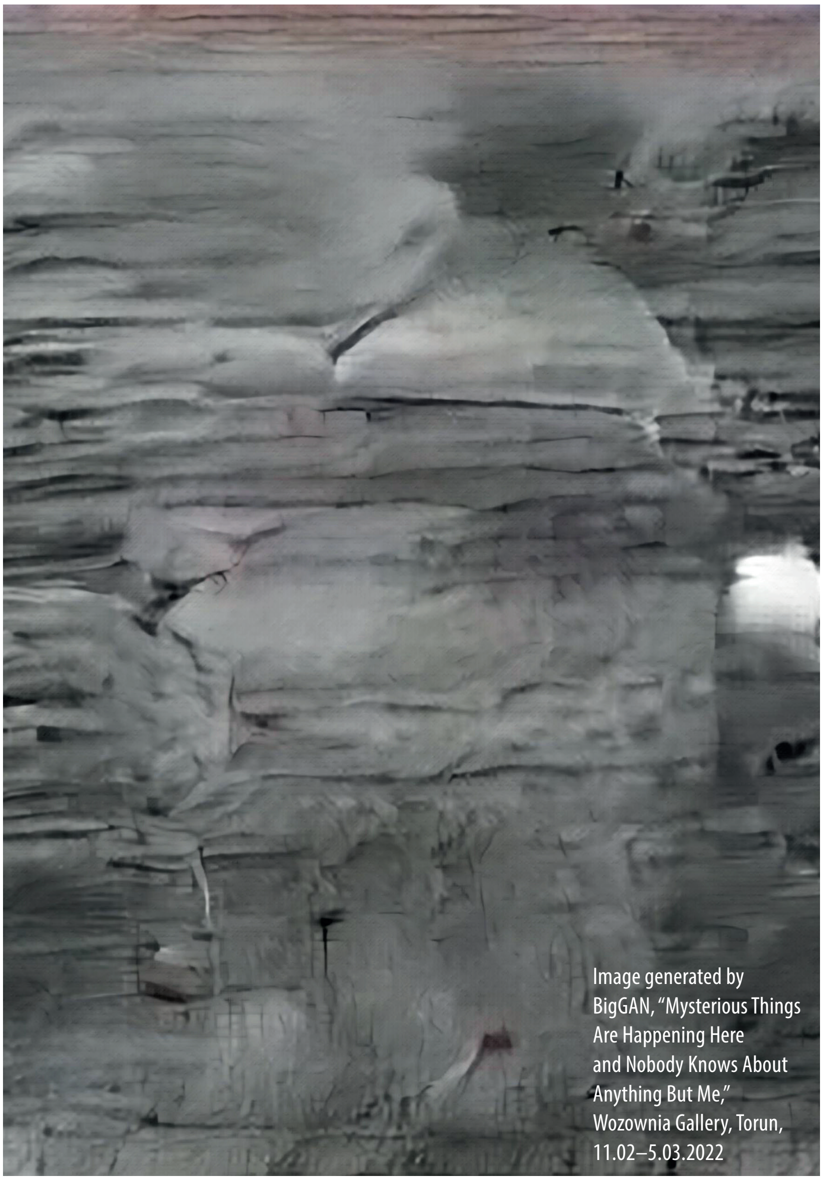

Image generated by BigGAN, "Mysterious Things Are Happening Here and Nobody Knows About Anything But Me," Wozownia Gallery, Torun, 11.02–5.03.2022

When we look at a painting, what is it that we observe? What catches our attention, and why? Do we look for hidden messages in paintings? Is it easy to create a visually intriguing image without being an artist? These are some of the questions we tried to address by carrying out a psychological and neurophysiological experiment, using both human-painted images and images generated by an artificial neural network.

The primary goal of the experiment was to measure people's physiological and psychological reactions to abstract images created by an artist and those generated by a neural network, and to check if those reactions differ. We stipulated at the outset that our goal *was* not to produce "artificial paintings" perfectly imitating "real" art, or to improve methods of doing so (although this might be possible by cleverly applying our findings). Moreover, the imperfect nature of the generated images allowed us to draw interesting conclusions and attempt to answer some of the questions mentioned above.

The experiment

In our experiment, two separate groups of visitors to the Wozownia Art Gallery in Toruń were each presented with a set of images: either 12 human-painted works, or 12 similar works generated by an artificial neural network. The original works by a human painter, displayed at the first exhibition, were the outcome of a continuous creative process, which included the selection of their final form. The second set of images was generated using BigGAN (Big Generative Adversarial Networks), a publicly available artificial neural network trained on millions of images of human surroundings. It can generate photorealistic objects in 1000 categories. We utilized the possibilities offered by its architecture to obtain abstract images based on the real objects on which the network is trained. For this purpose, certain network operations were randomly disrupted. This gave us a set of 4500 objects. To exclude the influence of simple differences resulting from different brightness or color intensity, each of the 4500 images was compared with each of the 12 human-painted works using a function calculating the difference between the parameters (color, intensity) of pixels of the two images. The average values of differences between the images allowed us to select 12 images least deviating from the chosen human-painted works. Randomly assigned titles for each of the computer-generated images and a short description of the exhibition to be published in the gallery's information leaflet were generated using the

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GPT-3 chatbot. This set of images was then put on display at a second exhibition, presented in a randomly chosen order.

The study looked at eye-tracking movements, EEG, and responses to questionnaires asking about the aesthetic and emotional feelings experienced by visitors while viewing images from both groups. The research was conducted during viewings at the gallery and at our lab, to which subjects were invited immediately after visiting the gallery. Here, the human-painted and network-generated images were presented on a computer screen. Data was collected twice, during and immediately after two consecutive gallery visits, one week apart. Study participants, and indeed all viewers of the exhibitions, were not informed about the nature of the study; the exhibitions were arranged and the works presented using methods aiming to avoid any prejudice towards the computer-generated images.

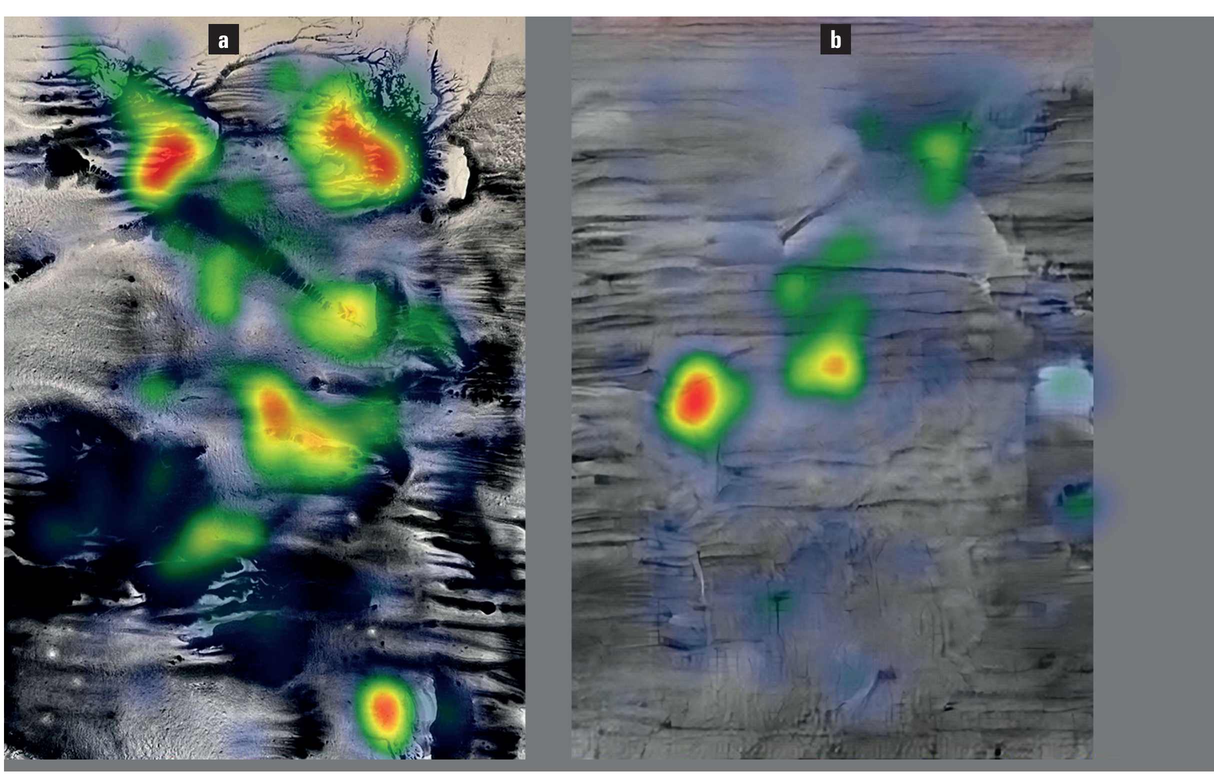
The study embraced a number of diverse experimental methods; in this article we will focus on the analysis of eye movements. In the simplest approximation, such movements consist of *fixations* – relatively stable eye positions focusing on a specific area of vision, lasting 150–600 milliseconds – and *saccades* – sudden eye movements shifting the gaze from one area to another. Fixations are an indicator of perceptual information processing. During saccades, suppression occurs – visual information intake is inhibited. The number and frequency of fixations turned out to be higher during the first visit to the gallery, when observing human artists' works. This effect did not occur for the works generated by the network. The amplitude of the saccades, in turn, is distinctly larger for the latter than for the human-painted works. This indicates that in the case of network-generated works, it is more difficult to find parts of the image that capture one's attention.

Perception

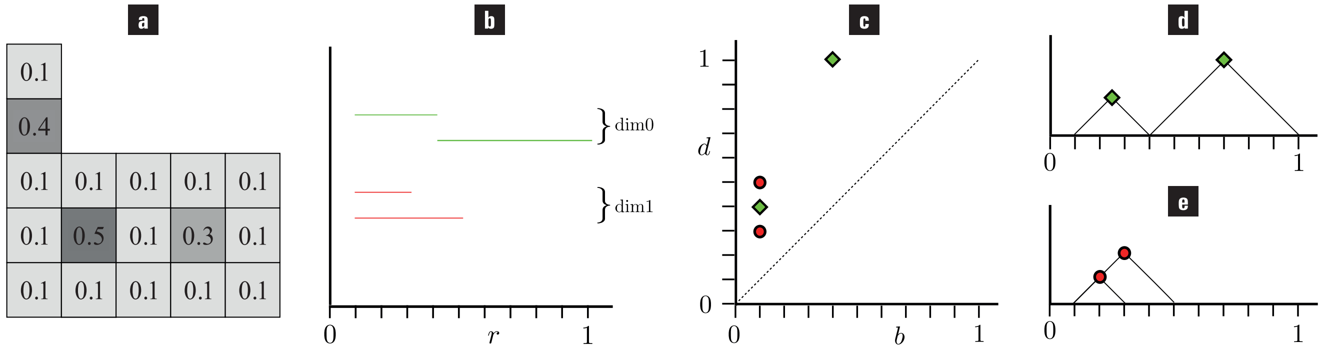
Analysis of eye-tracking data reveals, as expected, that observers focus on specific features of an image. It is reasonable to assume that our attention is primarily drawn to geometric objects. When we look at an image, we perceive entire structures composed of individual points/pixels (especially geometric structures), rather than individual points – in other words, we group discrete elements into larger units.

In perceiving geometric structures, we focus on the simplest patterns, such as distinct areas of a specific color or hue, or areas of one color against another. This places emphasis on topological rather than strictly geometric properties, although topology can be considered the most fundamental form of geometry. The rationale for our interest in topological properties alone is that they are independent of arbitrarily fixed coordinates and metric properties of perceived objects. In addition, topological properties are relatively immune to disturbances such as changes in illumination, visual acuity, or noise.

The basic concepts important for analyzing the topological features of datasets, irrespective of how



"Heat maps" of eyeball fixations, based on eye-tracking data. Averaged number of fixations for all subjects in the experiment for a human-painted image (a) and computer-generated image (b). The number of fixations increases along the color sequence: green – yellow – red



Topology and persistence:
a) an example structure where pixels are presented as squares of varying brightness (gray intensity). Intensity here is a good parameter for filtration, when looking at the image through filters that only allow pixels of sufficiently high brightness. If the most discriminating filter is applied, transparent only for the very brightest pixels (0.1 gray intensity on a scale from 0 to 1), the visible structure will consist of two disjoint pieces separated by an invisible pixel of intensity 0.4. One of these pieces will have two "holes" (invisible pixels of gray 0.3 and 0.5). The Betti numbers (described in the text) thus take values $\beta_0 = 2, \beta_1 = 2$. Using a more transparent filter will make the pixel of gray 0.3 visible and one of the "holes" will disappear, so then $\beta_0 = 2, \beta_1 = 1$. For a filter with even greater transparency, we will see the pixel of gray 0.4, which connects the two separate parts of the structure into one piece, leading to $\beta_0 = 1, \beta_1 = 1$. Finally, with a filter that also shows the darkest pixel of gray 0.5, the second "hole" will disappear – $\beta_0 = 1, \beta_1 = 0$. b) "barcode" representation, corresponding to the structure shown in a): dim0 refers to β_0 (zero-dimensional structures), dim1 to β_1 (one-dimensional structures), c) persistence diagram, d) and e) persistence landscape (see main text)

they are presented (e.g. as an image), are *filtering* and *persistence*. Imagine viewing a black-and-white image consisting of pixels in various shades of gray, through a filter that only allows shades above a certain intensity level to pass through. Clearly, using this filter may cause us to miss certain geometric structures formed by darker pixels. As we adjust the filter's transparency, some structures may appear or disappear. This procedure, whereby certain properties (geometric or topological) depend on a parameter (in this case, the transparency of the filter), is known as *filtering*. As the parameter changes, a specific structure may come into being or disappear. The range of the parameter across which a given structure exists is called its *persistence*. Structures with the longest persistence are the most significant and usually most characteristic of the object under study.

Topology in practice

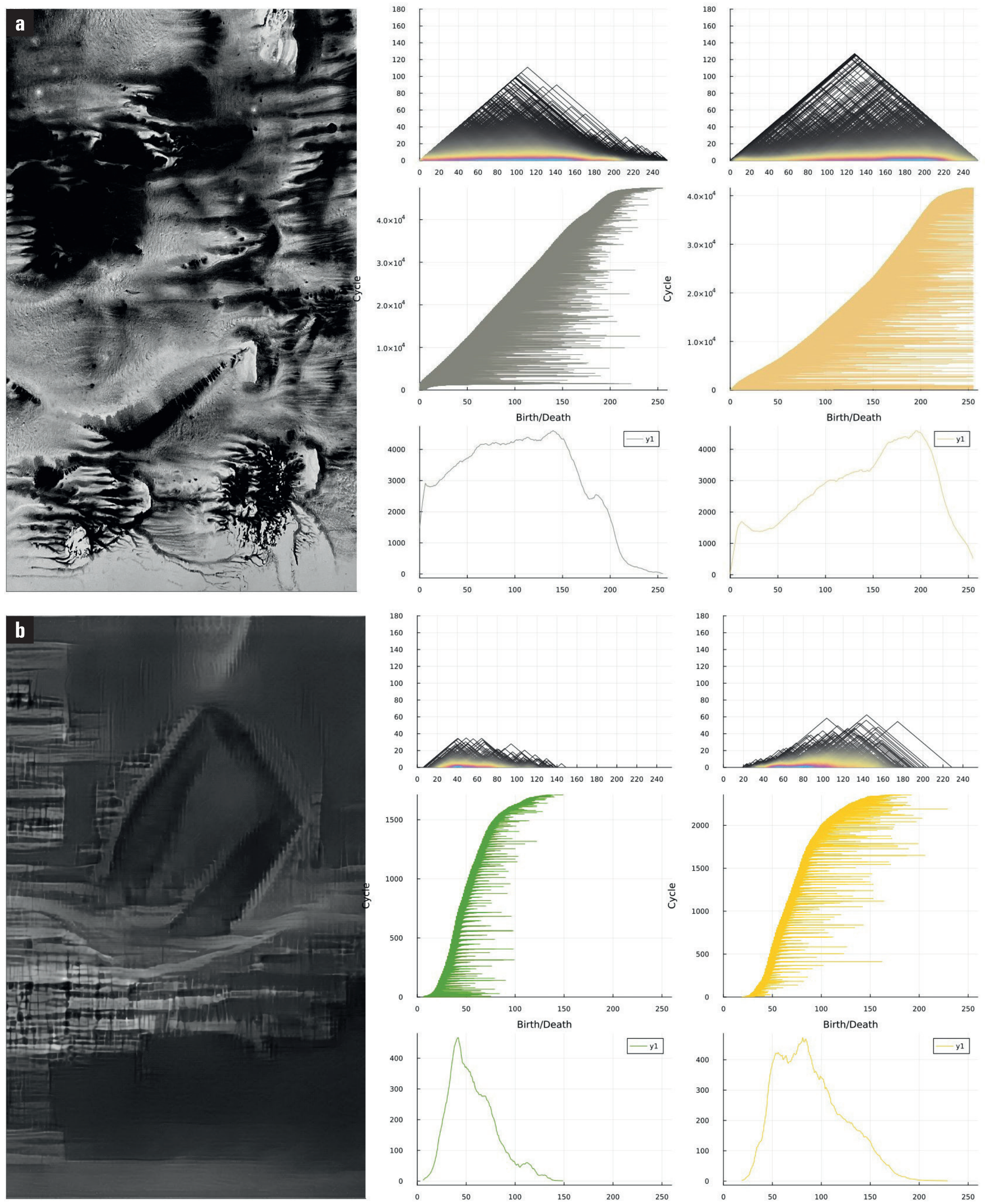
The field of mathematics that deals with the quantitative (essentially: algebraic) analysis and characterization of topological structures of interest and their persistence is known as *algebraic topology*. It tells us that for two-dimensional objects, such as images, two topological characteristics are important. The first is connectivity – the number of disconnected parts of a given structure (e.g., areas of the same color), the second is the number of "holes" in a given area (e.g., the number of areas of a certain color completely surrounded by areas of a different color). In algebraic topology, these numbers are known as Betti numbers, denoted as β_0 and β_1, respectively.

Several methods have been developed to represent the results of filtration. One of the first ideas was to use "barcodes." Each structure corresponds to a segment on a line parallel to the axis of the filtration parameter r, which begins when the structure appears (i.e. at point r_b) and ends when it disappears (at point r_d). Persistence can also be represented on a two-dimensional diagram with coordinates (r_b, r_d), called a persistence diagram. Naturally, points on this diagram occupy only the area above the main diagonal. By connecting each of these points to the diagonal with vertical and horizontal segments, we get a system of "pyramids" – isosceles right triangles. After this diagram is rotated by $\pi/4$, it becomes a *persistence landscape*. A good, global characterization of the variability of the entire topological structure in the filtration process is given the so-called Betti curve, which illustrates the sum of β_0 and β_1 for the entire area (image) depending on the value of the filtration parameter r.

Curiosity

Our analysis of sample images from the two exhibitions showed differences in their topological structure: in terms of both the richness of the persistence landscape and the "barcode." The shape of the Betti curves is also different.

Interesting conclusions can be drawn from analyzing the places where the most persistent topological structures emerge and disappear. Comparing heat maps of eye fixations with diagrams of topological structures indicates that fixations correlate well with areas where, from a topological point of view, there's "something going on" in the images with richer structure.



Topological properties of sample images from the two exhibitions: a work by a human artist (a) and a work generated by BigGAN (b). The second column shows the persistence landscape, the "barcode" representation, and the Betti curve (see main text) for zero-dimensional structures – connected components (dim0). The third column shows the same for one-dimensional structures – or "holes" (dim1). The images were converted to black and white, meaning pixels were assigned a corresponding level of gray depending on the intensity of the color of the original image. Essentially the same results are obtained by applying the color distribution to the R, G, and B components and determining the topological characteristics for each component

Many existing studies in the international literature have aimed to capture the relationship between viewers' aesthetic feelings and certain numerically quantifiable characteristics of artworks. Usually, the quantitative characterization was based on statistical properties, such as correlations of intensity, gradient, etc. In this part of our research, we were not interested in the aesthetic value of the works, and we based their mathematical characterization on topology, not statistics. We seek to capture the hidden information in works of art, which is contained in areas where interesting things happen from the point of view of topology.

Overall, we found that the topological properties of images are indeed related to the neurophysiological reactions of people viewing them. Images with a more complex topological structure reduce the intensity of scanning (the amplitude of saccades), while concentrations (fixations) are associated with areas where the topological structure is more complex.

ACKNOWLEDGMENTS

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Further reading:

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