Integrating Computational Creativity and Climate Data for Environmental Awareness: Design and Analysis of an Ongoing Project

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Abstract

Climate change is often understood through scientific data, but how can digital technologies be used to make climate change more accessible to non-expert publics? This article presents a project that explores the intersection of computational creativity and environmental awareness through a web platform that transforms real-time climate data into interactive audiovisual art. By collecting live climate data from satellites and processing it into unique visual and musical compositions, the platform translates global environmental phenomena into local, personal aesthetic experiences. Using generative algorithms, data-driven creativity and interactive design, the platform aims to bridge the vast scale of climate change with the intimate scale of individual perception. Based on observation of users engaging with the platform and qualitative feedback, we analyse the potential of digital art for environmental education, the challenges of representing environmental data in non-figurative ways, and the technical challenges of adapting scientific data infrastructure for artistic exploration. We conclude by suggesting that art can play an important role in climate communication and that computational creativity can significantly contribute to this by connecting objective data with subjective representations.

Introduction

Throughout history, humans have observed and recorded weather to predict its outcomes. Long before the advent of electronic technologies, artists drew inspiration from their observations of the weather to create works of art. Leonardo da Vinci, using black chalk on paper, created the drawing A Deluge (1517-1518), illustrated in Figure 1, which depicts the dynamic flow of clouds and water (Randerson et al., 2015; Randerson, 2018).

In recent years, climate change has become an increasingly significant issue, prompting the integration of scientific data into artistic practices to create a bridge between science, art, and public awareness. While art has long used the climate as a source of inspiration, today's urgent climate issues demand new approaches that move beyond inspiration and into active engagement. Artists have begun using digital and interactive tools to transform complex climate data into immersive and engaging experiences, aiming to raise awareness and inspire action.

Many recent new media artworks merge science and engineering elements with artistic and creative practices. In the sonic domain, the sonification of climate data has been used to transform data into sound and music, illustrating the impact of climate change (Quinn, 2001; Perera, 2015; Chafe, 2018; Barth et al., 2021). In (Chopra, Hessels, and Black, 2022), various artistic approaches are presented that combine science, engineering, and creativity to reflect on climate change and its implications. Many of these works are participatory, prompting the viewer to become an active agent, someone who experiences our ever-evolving society rather than remaining a passive observer. And art approach is now important part of scientific and political discussions about climate change, as the inclusion of the Art x Climate gallery into the USA's 5th National Climate Assessment makes clear[1].

Figure 1 - Bequeathed to Francesco Melzi; from whose heirs purchased by Pompeo Leoni, c.1582-90; Thomas Howard, 2nd Earl of Arundel, by 1630; Probably acquired by Charles II; Royal Collection by 1690.

[1] https://nca2023.globalchange.gov/art-climate/e

Academics, too, are increasingly focused on acting in response to climate issues. Recognizing their responsibility to act, they not only lead by example by reducing their carbon footprints but also leverage their creative thinking to contribute to climate solutions, raise awareness of the devastating impacts, and help catalyse cultural change (Pease and Pease, 2023; Utz and DiPaola, 2023; Jääskeläinen and Biørn-Hansen, 2024)

Computers and computational systems have been fundamental in these early explorations. Whether using computer systems to create new media art that explores climate change or employing scientific data about the environment as material for artwork, artists addressing climate change have embraced computers as interactive and inspirational tools. Through various engagements with these digital materials, the abstract, statistical, and global language of climate change—such as "global mean temperature," "carbon budget," and "planetary tipping points"—is transformed into a language of emotional engagement that aligns with the spatial and temporal scale of human perceptual capacities (Andrade and Moroni, 2023). As an artistic movement, climate art is growing. However, in the field of computational creativity, climate change remains a rarely addressed topic. Recent work, such as the CreaVisions platform (Rafner et al., 2023), demonstrates the emergence of a growing community of practice cantered on computational co-creativity for sustainability.

Nevertheless, computational creativity undoubtedly holds the potential to contribute significantly and play a pivotal role. Data visualizations driven by computational creativity, along with decision-making, scenario planning, problem-solving, and the enhancement of both human and scientific creativity, can all play a significant role (Pease and Pease, 2023).

In this paper, we present and discuss the GaiaSenses project, an art-science initiative aimed at making climate change more tangible for non-expert audiences. GaiaSenses is a web platform that presents users with audiovisual compositions based on their geolocation and local weather conditions. These audiovisual compositions are driven by weather and climate data, such as temperature and humidity, to create a real-time experience.

The audiovisual compositions can be shared on social media. The goal is to evoke a sense of empathy for the planet, starting with attention and care for the local area, potentially triggering actions. As Haraway (2016) argues, the way environmental changes are communicated must be reconsidered, and projects like GaiaSenses aim to address this transformation through ideas, projects, actions, and attitudes. We cannot change the climate directly, but we can influence people's attitudes—particularly their awareness, emotional engagement, and sense of agency. These are fostered throughout the project's lifecycle: from design and development to student engagement and experiential learning with climate phenomena, through reflective practices on representation, and into public dissemination and user interaction. The goal is to cultivate a deeper personal and collective response to environmental challenges.

This article is composed of the following sections. The first section presents a technical description of the platform

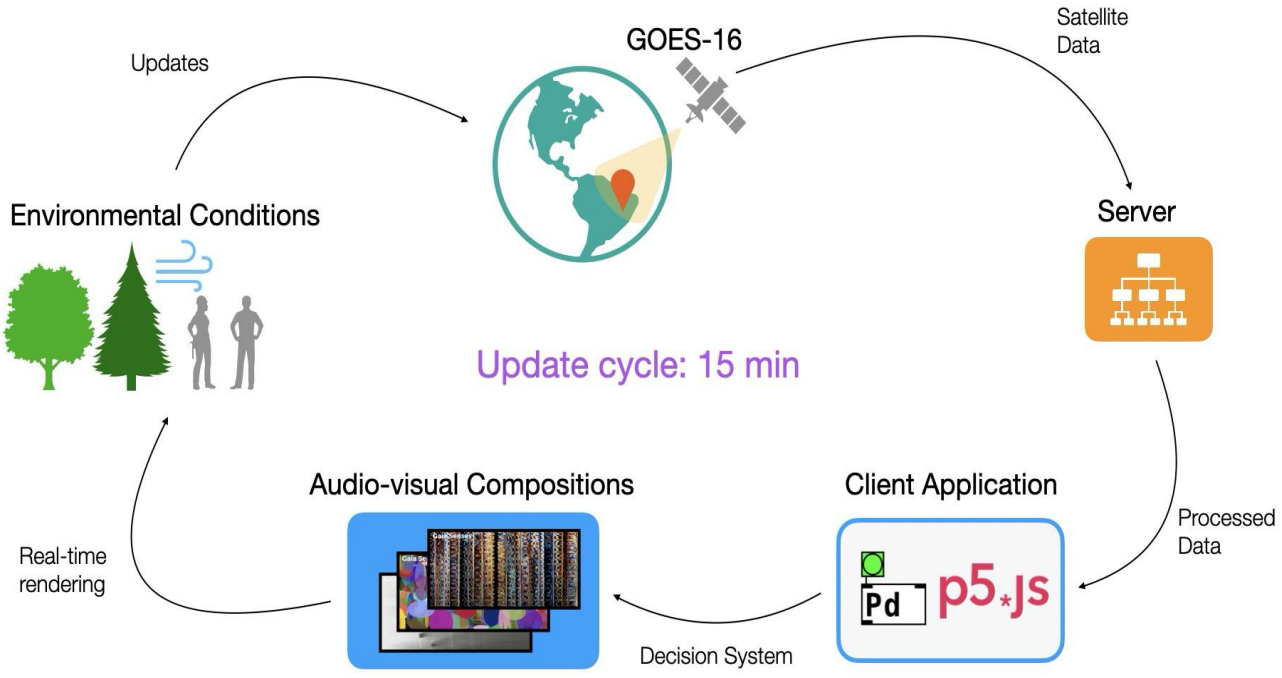

Figure 2 - The GaiaSenses Platform Architecture.

focusing on how local weather data is acquired, processed, transformed into animated and sonified compositions, and presented to the user. The second section describes what users see and hear when interacting with the platform, the audiovisual compositions, and discusses their aesthetic aspects. Following, the Visual Compositions and the Multiparadigm Sound Generation System are described. Then, we present a discussion regarding initial public response about the project and its intended evaluation. And finally, a conclusion.

The GaiaSenses Project

Many of the main topics regarding climate change are data that makes little sense for the human sensorium scale: global mean temperature and atmospheric CO_2 concentration for example, are phenomenon that are usually invisible and not perceptible in the local scale but are crucial to the understanding of climate change. The GaiaSenses project bridges this gap by combining scientific knowledge and art-based methods to create non-figurative audiovisual compositions that are powered by patterns present in the data. It is an attempt to make these patterns that are usually meaningful only for climate scientists, able to be experienced aesthetically by non-expert audiences. Practically, this is done by transforming weather and climate data into audiovisual compositions.

For that, the project deploys a specific pipeline responsible for collecting, processing, transforming and delivering data to its users, as shown in Figure 2. It broadly works as: 1) as the users access the GaiaSenses Web Platform, the geolocation data (latitude and longitude) from the accessed device is collected and sent to our servers; 2) The geolocation data is then used as input to get weather data from the GOES 16 and 19 Satellites data archive stored in an Amazon S3 Server or another meteorological platform. This data is then processed and cropped to the specific time and area of interest of the user, resulting in a small dataset containing information like temperature, humidity, precipitation, wind and lightning occurrence, that is sent back to the user's device. 3) In the device, this weather data is used as parameters to animate a specific P5.js sketch depending on the data characteristics. At the same time, the weather data is sent to a specific Pure Data patch to be used as input for a generative audio composition. 4) Finally, the animation and the sonification are combined in a single stream and rendered in real time in the user's device, presenting an audiovisual composition based on the weather conditions of his location. 5) The user application requests new weather data from the server every 15 minutes to check if there is new satellite data, as this is the period that the satellite takes to update its data, and if positive, uses this new data to update the composition, following the steps described above. This whole process means that each user will receive a composition that is particular about the environmental conditions they are in.

The GaiaSenses Web Platform is developed using open technologies appropriate for each layer of its technical infrastructure. The GaiaSenses Platform itself is an Open Source, and all its repositories can be found at its Github Organization Page[2]. For the Web portion[3], it uses JavaScript and the react.js framework to handle basic user interactions. The compositions are developed using the P5.JS library for creative programming and the audio is interfaced with Pure Data through the WebPd project. The API responsible for acquiring and processing satellite data[4] is developed in Python and uses Numpy for operations. The API is deployed via a Docker Container on a serverless infrastructure on AWS Lambda. The Open distribution of the project's code intends to both create a community around digital and data artists interested in working with weather and satellite resources and to provide practical examples on how to do it.

The data products that GaiaSenses currently uses are the usual data products derived from weather systems: temperature, precipitation, wind (speed and direction), humidity, radiation, cloud coverage, lightning (location of occurrence and count), fire (location of occurrence and count). These data come from different data sources, depending on data availability for the region where the user is accessing the web platform. Basic weather data (temperature, humidity, cloud coverage and win) is acquired by the OpenWeather API, a service that provides near real-time weather data based on a given geolocated point. So, for weather data, the user's geolocation is used as input. Despite the ease of access that the OpenWeather API provides, we insist on accessing more primary data sources, like satellites, so that the compositions can work not only with the values for weather conditions, but also with the errors, uncertainties, and inaccuracies that remote sensing systems are subjected to. We believe that access to satellite data can enrich the climate representations of GaiaSenses, providing a deeper and more comprehensive understanding of climate change, aiming not only to represent data but also to reflect its uncertainties and limitations.

For lightning data (place of occurrence and count), we access data directly from the National Oceanic and Atmospheric Administration (NOAA) Geostationary Operational Environmental Satellite 16 (GOES-16) satellite data archive hosted on an Amazon AWS S3 Bucket. In the S3 Bucket, the satellite data is organized in netCDF4 file with filenames that express a specific pattern that contains the name of the sensor used for capturing the data, the time period that the data was collected, and from where the data is.

The lightning sensor (GLM-L2-LCFA) at GOES-16 has a spatial resolution of $4km^2$, which means that the data is not available by geolocated points, but by a grid of pixels where each element represents a $4km^2$ area of the planet. To get the data, first it is necessary to find the grid element that contains the point of interest. As lightning usually happens in a large area, and not in a single point, the input for this data is a 20 km round wide buffer with the user's location as its center. At our servers this area is transformed into the correspondent grid elements and all lightning data is returned to the user's device.

GOES-16 is a geostationary satellite that covers most of America, which means that, currently, we are only able to

[2] https://github.com/GaiaSenses
[3] https://github.com/fmammoli/Gaiasenses-web
[4] https://github.com/GaiaSenses/satellite-fetcher-aws

collect lighting data for users accessing the platform from within this region. It is our plan to expand our data access capabilities by developing additional integrations with other satellite systems. Fire data is acquired from the Brazilian platform BDQueimadas through its Geoserver.

BDQueimadas is the main platform for fire monitoring in South America and is maintained by the Brazilian National Institute for Space Research (INPE). Much like acquiring data for lightning, we capture fires that are happening in an area around where the user is located, and not only if the user's location is on fire. For that, we create a 10km buffer with the user's location at the center and use this area as the input for the BDQueimadas API. Data is acquired as a list of fires happening in the area, their location, their intensity and a total count. The data on BDQueimadas is available in near real-time, being updated every 10 minutes.

Visual Compositions

The visual compositions in the GaiaSenses Platform are produced using the P5.JS library; a JavaScript library for creative programming that focuses on accessibility and education. The library was chosen due to its capability in portraying complex graphics, its wide-spread use and for being a web-based library, which allows the project to run directly in the Browser, with no need for special environments.

The main approach in the project for creating compositions is to collect already existing P5.JS sketches at the OpenProcessing Platform and use the weather data to modify its intended behaviour. The process of modifying the behaviour of a sketch entails the study of its inner workings and the extractions of parameters from the code that control behaviour such as color, rendering speed, placement of lines, etc. Once extracted, these parameters are turned into variables that are connected to the weather data through a proportion function. The result is that the change in a weather condition, such as temperature, can control the behaviour of a sketch, such as color.

An example is the GenerativeStrings composition, which displays a box with bouncing particles inside and 7 strings tuned to the G major scale. The basic mechanism of the composition is that a sound is produced when particles collide with the string. During our modification process, we connected the agitation of the particles to the temperature value, such as an increase in temperature makes the particles move more rapidly, producing more collisions and, consequently, producing unexpected melodies that are qualitatively different from the melodies produced when they are less agitated.

This approach of modifying existing sketches mirrors the way in which climate change not only creates new environmental conditions but creates them by profoundly modifying environmental characteristics that we once took for granted. A forest might turn into a savannah depending on the increase in temperature and a lake can dry out depending on the change in the precipitation regime. The use of existing sketches, thus, is an aesthetic choice to remind us that when accounting for the environment, creation is co-creation.

GaiaSenses Multiparadigm Sound Generation System

The sound generation system of the GaiaSenses platform operates as a multiparadigm environment, enabling the conversion of environmental data collected by remote sensing platforms into multiple sonic interpretations.

Development Environment Choice

In the initial phase of the project, Pure Data (Pd) was selected as the primary tool for sound development (Puckette, 1997). Pd, a visual programming language for sound creation and interactive multimedia, was chosen for its flexibility and accessibility, facilitating collaboration with a broader network of composers and sound artists that are geographically near to us.

Practical Examples of This Approach

ShockWind: A patch that artistically simulates the interior of a thunderstorm cloud. The composition employs subpatches and dynamic filters that manipulate noise to create sonic textures. Thunder sounds are generated through modulated low-frequency signals, while ambient noise simulates the internal movement of clouds. External reverberation enhances spatial depth.

Drops: A patch that generates sounds of droplets falling on a liquid surface. Rainfall data directly influence the frequency and intensity of the generated droplets, forming an auditory landscape that ranges from light drizzles to intense storms.

Zigzag and Zigzag 2: These compositions utilize dynamic patching techniques to represent visual movements and satellite data through fluid and responsive sounds. Zigzag employs the [clone][5] to create multiple instances of a patch simulating zigzag movements, with timbres modulated by LFOs[6]. Zigzag 2 explores phase modulation and uses continuous sonic flows that evolve in response to environmental data)

Each of these patches exemplifies different strategies for sound mapping, ranging from free artistic interpretations to more direct sonifications of environmental data (D´Incao, 2023).

Explorations Beyond Pure Data

Beyond Pure Data, other systems have been explored for sound generation within browser-based environments. A relevant example is an implementation based on a tutorial for Brian Eno's Music for Airports, adapted in Tone.js[7]. This adaptation served as an initial test for integrating compositional structures within the system. The layered nature of Music for Airports, which does not rely on rapid

[5] https://pd.iem.sh/objects/clone/

[6] https://forum.pdpatchrepo.info/topic/10577/creating-anlfo

[7] https://www.youtube.com/watch?v=36ZggCL4pBo&ab_channel=danbuzzo

rhythmic changes or time-critical processing, made it a suitable model for evaluating the system's capabilities.

Technical and Artistic Characteristics

The patches in GaiaSenses employ various sound synthesis and signal processing techniques. The use of Pure Data allows for the creation of generative and interactive sonic environments, where environmental data directly influence parameters such as frequency, amplitude, and spatialization. Artistically, the project seeks to balance descriptive sonic representations of environmental phenomena with more abstract and interpretative compositions, constructing an immersive auditory experience that fosters a perceptual connection between the listener and the natural environment.

Sonic Horizon

The development of GaiaSenses is ongoing, with plans to integrate additional sound generation systems such as Max-RNBO, SuperCollider, and other computational music frameworks. Building upon these initial explorations, the project aims to establish a systematic methodology for data representation, serving as a foundation for future generative compositions.

Climate Compositions

When interacting with GaiaSenses Platform, the user is presented with a global map with their location at the center, alongside a window with basic weather information of the place they are in, and a button that prompts the user to click it. When clicked, the map fades out to reveal an animation with an accompanying sound, both powered by the data displayed before. Figure 3 shows the composition named Attractor in two different states, when it starts and after 20 seconds. The animation uses lightning data around the users and maps its occurrences to the screen size, so the user location is in the center and the lightning is happening around them. In the animation canvas, the lightning locations act as attractors, exerting a pull force. Then, a semirandom number of particles are dropped in the canvas, these particles are attracted by lightning attractors and each particle leaves a trail. After some time, particles start to concentrate near the attracts, making the canvas region brighter, revealing the spatial pattern of the lightning occurrence.

The sonification of the Attractor composition plays synthesized thunder sounds through a dynamic panning algorithm implemented in Pure Data so the thunder sounds appear to happen in different directions and distances, mirroring the space distribution of lightning occurrence in the data.

Figure 4 depicts how the same composition can look different depending on different weather conditions. It shows the composition named StormEye, which consists of lines that rotate around a center. In the composition, the line colors are connected to temperature data so cold temperatures make the lines more blue and hot temperatures make them redder, the line scattering are connected to wind direction and wind speed. The sound is implemented in Pure Data and presents the user with synthesized sounds of wind gusts that get stronger as wind speed increases at the user's location. The user can have a feel for the wind change patterns by observing the scattering of the lines and see the temperature by observing the mixture of colours.

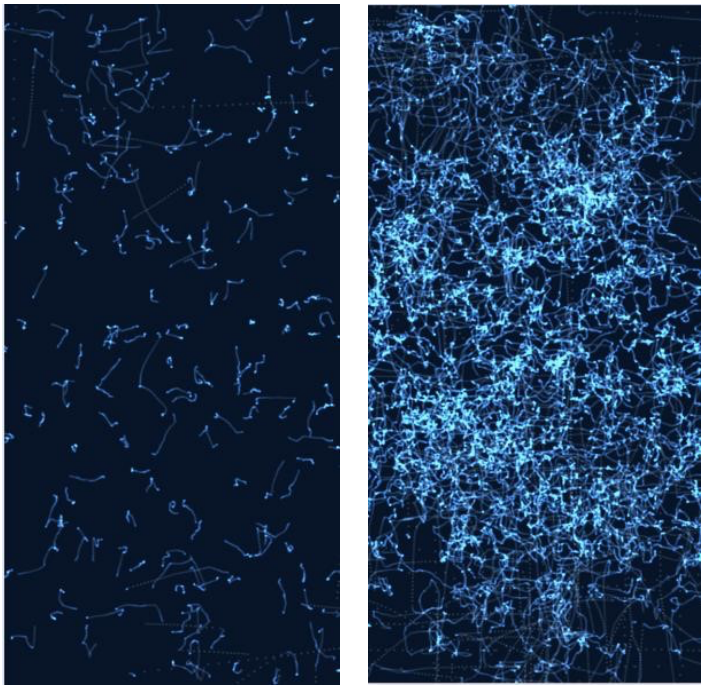

Figure 3 - Different frames of the Attractor composition: left) The composition at its start; right) The composition after 20s of animation.

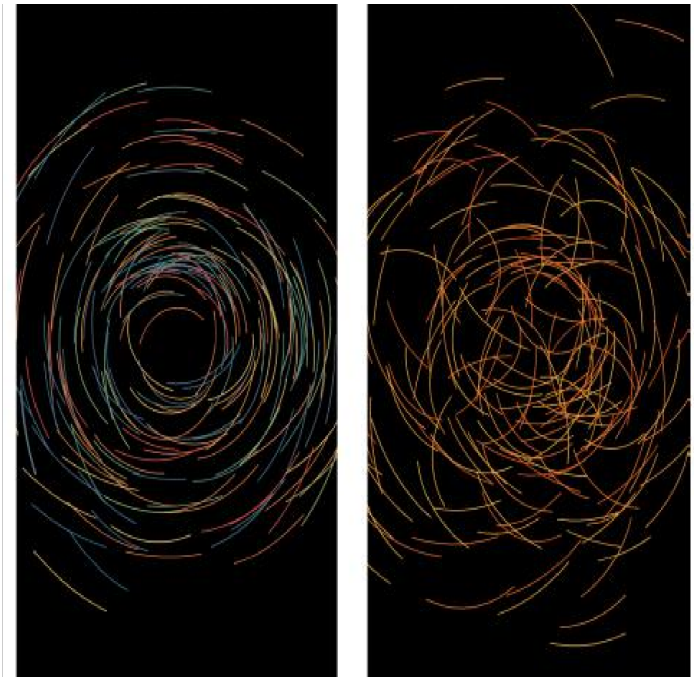

Figure 4 - The StormEye composition in two different weather conditions: left) temperature: 24°C, wind speed: 4m/s, wind direction 20°; right) temperature: 32°C, wind speed: 14.2m/s, wind direction 271°.

A prototype of the GaiaSenses Platform[8] is accessible online with a selected list of compositions to be viewed and listened to.

Discussion

The GaiaSenses Platform aims to make the changing aspects of our shared environment more present in the daily life of publics that are not climate experts. It does so by presenting patterns inherent in climate data in an artful form - audiovisual compositions - instead of the usual scientific graph. An aesthetic form of presenting that is designed to appeal to the user's subjective sensory and emotional experience. This approach is based on research that shows how art can be relevant in communicating climate change (Rice, Rebich, Hespanha and Zhu, 2019) and that information alone is not enough to provoke action (Sommer and Kløckner, 2021). Political causes depend deeply on emotional and personal connection.

The GaiaSenses Platform was presented in three different settings composed of different types of publics. Two were scientific conferences and one was an undergraduate class. Despite the good general impressions of the users, each group interacted differently with the platform. In the conferences, people were expected to interact with digital art experiments and were open to learning how the system worked. Although the platform was made to showcase weather information about the user's current location, and compositions based on that data, users were continuously interested in seeing how their hometown would be depicted in the system. An unexpected response that depicts how the global scale of climate change can be localized in personal experiences, making climate change more tangible (Rosing and Eliason, 2015). Since then, the GaiaSenses Platform also allows users to explore the weather conditions and see compositions of other parts of the planet, not only their current location.

The third presentation happened in an undergrad class where the GaiaSenses project coordinator was presenting a seminar for the class. From the class interaction, one specific comment was particularly interesting: one of the students commented that he was not seeing climate change on the platform. Although the compositions are mostly non-figurative, they are open to interpretation on how any specific sound or image relates to any natural phenomena, the student's comment shed light on the persistence of already existing forms of representing climate and weather data. These data are usually presented on top of maps, as weather predictions, or as rising lines, like the increase in CO_2 emissions over the decades (Mann, 2012).

Representations that non-experts are so used to that create interpretational challenges when they are not present. To overcome these visual affordances of how weather and climate data are often represented has become a central issue in the GaiaSenses project and a source of aesthetic inquiry, confirming that climate change is not only a matter of nature, but also a matter of aesthetics, as suggested by Davis and Turpin (2015).

Evaluation Plan

As the project is still ongoing, it has not gone through a structured evaluation process against a diverse public. As it gains conceptual maturity and technical stability, we plan to conduct an evaluation based on Klöckner and Sommer (2021) proposal of evaluating public response artworks inspired by climate change and Hahn and Berkers (2024) evaluation of artists' intended effect through climate change art. The purpose of the evaluation is to further research how specific aesthetic choices affect the public perception of climate change. As evaluation points, we have three main areas: evaluating interaction (ease of use etc, technical); evaluating aesthetics (does the compositions make people think of any natural phenomena, what emotions it conveys?); and the social aspect.

The interaction evaluation comprises a technical evaluation to understand the ease of use, how intuitive it is to navigate the system, how accessible it is and how is the overall user experience. The aesthetic evaluation consists of a more subjective evaluation and its purpose is to trace how people associate specific graphic and sound design to particular natural phenomena, how this relation is supported by personal history and if it meets their expectation on how climate change should be represented. The social aspect involved evaluating what socio-environmental debates the platform raises and at what scale does it inspire reflexivity among its users and the researchers working on the platform.

To address these points, we plan on a twofold approach: 1) an automated evaluation based on analytics gathered from each access to the web application. This will mostly inform the interactive evaluation and part of the aesthetic evaluation. It is important to note that privacy matters will still be discussed to understand to what extent we should keep the user's data, since we are accessing their location; 2) a qualitative evaluation based on questionnaires with users in controlled spaces and focal groups with users that interacted with the platform in art exhibition contexts. This qualitative approach will provide important data for the three evaluation points (interaction, aesthetic and social) so we can understand the effectiveness of the platform in promoting dialogue about environmental issues and climate change.

GaiaSenses and the Generative IAs

More recently, the field of generative computing has gained significant momentum, driven by advances in hardware, software, and artificial intelligence. This possibility is being considered and evaluated. Incorporating an intelligent layer for the automatic production of creative outputs in GaiaSenses can effectively optimize and expand the process, providing real time personalization. This can be achieved through artificial intelligence (AI), generative algorithms, and machine learning techniques that automatically map climate data to visual and sound representations.

In the current version, since each audiovisual composition is created with a clear artistic intention, the nuances and intentions of the artist are more effectively conveyed. On the other hand, automating the process allows the system to

[8] https://gaiasenses-web.vercel.app

handle large volumes of data, generating outputs in a scalable, real-time, and much faster manner. However, this introduces a new challenge in creative control, as artistic decisions are largely delegated to the machine. New questions arise: To what extent should we detach ourselves from the creative process? How much of the creative process should we entrust to the machine? Another important consideration when addressing climate change and sustainability is the computational cost of generative AI art systems, both in industry and academia. This includes not only the monetary costs associated with training but also the environmental impact during inference (Utz and DiPaola, 2023).

Next Steps

At this stage, we have begun presenting GaiaSenses to various audiences and examining their reactions. Analytical indices are being developed to track its dissemination. An aesthetic framework is also being created. The parameters used in generating the compositions will be stored in a database, which can be used in various ways for aesthetic evaluation.

Here, we propose the possibility of developing a grammar through the definition of parameters and vocabulary for generating compositions or representations. It is desirable for each phenomenon to have more than one representation to provide variety, potentially leading to new algorithms. The combination of climate data, artificial intelligence, and interactivity creates a new aesthetic that challenges traditional artistic conventions. It is important to note that the field of Aesthetics is highly complex (Fishwick, 2008), and this is a statistical study aimed at providing insights for evaluating the algorithms used. Additionally, the aesthetic database may serve as the foundation for predicting future accesses and compositions based on machine learning and artificial intelligence methods, potentially leading to a significant contribution to the field (Franceschelli & Musolesi, 2021; Toivonen & Gross, 2015).

Conclusion

Art plays an essential role in amplifying and complementing the communication of climate change science. The magnitude of the challenges we face no longer fits within the scope of everyday human experience. Rather than grappling with a lack of information, we are now tasked with expressing the hopes, conflicts, fears, and contradictions arising from a crisis that often seems too vast to fully represent. By aligning with the sciences through shared methodologies, tools, localized community platforms, and global digital networks, art focused on climate change can help build coalitions for collective action. Innovative thinking is crucial in tackling climate change, and fields as diverse and interdisciplinary as computational creativity hold great promise for making meaningful contributions.

GaiaSenses operates as a creativity laboratory that delves into the potential of generative algorithms to represent and communicate climate phenomena. By harnessing these challenging visual and sound algorithms, the project transforms complex climate data into dynamic audiovisual representations, allowing for a deeper understanding of the environmental challenges we face. The process not only aims to inform but also to engage and inspire action, using art and science as tools for raising awareness. Through their involvement in the project, students and researchers are not only contributing to the development of these creative outputs but are also becoming active advocates for the climate cause. Their engagement goes beyond academic inquiry, as they embrace the role of climate activists. By combining scientific knowledge with artistic expression, they help bridge the gap between technical data and emotional, human-cantered experiences, by connecting objective data with subjective representations.

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References

Andrade, F., & Moroni, A. (2023, November). Bridging Computational Art and Climate Change: An Analysis of a Mobile Application for Raising Awareness About Climate Change Through Art. In International Conference on ArtsIT, Interactivity and Game Creation (pp. 149-165). Cham: Springer Nature Switzerland.

Barth, A., Karlstrom, L., Holtzman, B. K., Paté, A., Nayak, A. 2021. Sonification and Animation of Multivariate Data to Illuminate Dynamics of Geyser Eruptions. Computer Music Journal, 44:1, pp. 35–50, Spring 2020, Massachusetts Institute of Technology.

Chafe, C. 2018. 1.200 Years of Earth's Climate. https://www.kqed.org/science/1918660/listen-1200-yearsof-earths-climate-transformed-into-sound

Chopra, S., Hessels, S., & Black, K. C. 2022. Artistic Interpretation of Scientific Data on Extreme Weather to Raise Public Awareness for Urban Resilience. In *Data Art for Climate Action (DACA 2022): a dual-hub conference on interactive sonification and visualisation for climate science communication*.

Davis, H., & Turpin, E. 2015. Art in the Anthropocene: Encounters among aesthetics, politics, environments and epistemologies (p. 416). Open Humanities Press.

D´Incao, G. C. E. O., & Moroni, A. (2023). *Composição musical com dados de satélite: Desafios ao 'musicar' números*. In JICC2023 – Jornada de Iniciação Científica do CTI Renato Archer (Campinas, Brasil).

Fishwick, P.A. (Ed.), 2008. *Aesthetic Computing*. MIT Press.

Franceschelli, G., & Musolesi, M. (2024). Creativity and machine learning: A survey. *ACM Computing Surveys,* 56(11), 1-41.

Haraway, D. 2016. Antropoceno, capitaloceno, plantationoceno, chthuluceno: fazendo parentes. *ClimaCom Cultura Científica*, 3(5), 139-146.

Hahn, U., & Berkers, P. (2024). Artists on Climate Change: Their Intended Impact and Audiences. Empirical Studies of the Arts, 43(1), 188-208. https://doi.org/10.1177/02762374241258632

Ikeshiro, R., Simon, L., & Gui, R. 2022. DAT/ACT Data Art for Climate Action Gallery. In Data Art for Climate Action (DACA 2022): a dual-hub conference on interactive sonification and visualisation for climate science communication.

Jääskeläinen, P., & Biørn-Hansen, A. 2024. Critical Questions for Sustainability Research in Computational Creativity. In ICCC'24 will take place June 17–June 21, 2024, at the University of Jönköping, in Sweden.

Klöckner CA, Sommer LK (2021) Visual art inspired by climate change—An analysis of audience reactions to 37 artworks presented during 21st UN climate summit in Paris. PLoS ONE 16(2): e0247331. https://doi.org/10.1371/journal.pone.0247331

Mann, M. E. 2012. The hockey stick and the climate wars: Dispatches from the front lines. Columbia University Press.

Minik Rosing and Olafur Eliasson, "Ice, Art, and Being Human". 2015. Studio Olafur Eliasson.

Pease, A., & Pease, A. 2023. Computational creativity and the climate crisis. In *14th International Conference on Computational Creativity* (pp. 293-297). Association for Computational Creativity.

Pereira, P. T. F. (2023). *Aprimoramento da infraestrutura do aplicativo GaiaSenses para acesso às bases planetárias* [Trabalho de iniciação científica, Centro de Tecnologia da Informação Renato Archer]. Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq).

Perera, J. 2015. Climate Symphony. https://www.jamieperera.com/climatesymphony#ClimateSymphonyLabs.

Puckette, M. 1997. Pure Data: another integrated computer music environment. Proceedings, Second Intercollege Computer Music Concerts, Tachikawa, p. 37-41.

Quinn, M. 2001. Research set to music: The climate symphony and other sonifications of ice core, radar, DNA, seismic and solar wind data. In *Proceedings of the 2001 International Conference on Auditory Display*, Espoo, Finland, July 29-August 1.

Rafner, J., Zana, B., Beolet, T., Buyukguzel, S., Michel, E., Maiden, N., Risi, S., & Sherson, J. (2023). Crea.visions: A platform for casual co-creation with a purpose – Envisioning the future through human-AI collaboration with multiple stakeholders. In Proceedings of the 14th International Conference on Computational Creativity (ICCC '23) (pp. 474–481).

Randerson, J. (2018). Weather as medium: Toward a meteorological art. MIT Press.

Randerson, J., Salmond, J., & Manford, C. 2015. Weather as medium: Art and meteorological science. Leonardo, 48(1), 16-24.

Rice, R.E., Rebich-Hespanha, S. and Zhu, H. 2019, "Communicating about Climate Change Through Art and Science", Pinto, J., Gutsche, R.E. and Prado, P. (Ed.) Climate Change, Media & Culture: Critical Issues in Global Environmental Communication, Emerald Publishing Limited, Leeds, pp. 129-154.

Sommer, L. K., and Kløckner, C. A. 2021. Does activist art have the capacity to raise awareness in audiences?—a study on climate change art at the art COP21 event in paris. Psychology of Aesthetics, Creativity, and the Arts 15(1):60–75.

Toivonen, H., & Gross, O. (2015). Data mining and machine learning in computational creativity. *Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery*, *5*(6), 265-275.

Utz, V., & DiPaola, S. 2023. Climate implications of diffusion-based generative visual ai systems and their mass adoption. In *Proceedings of the 14th International Conference on Computational Creativity*.