The (Un)Answered Question: A Data Science Powered Music Experiment

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Abstract. This paper describes the intentions, setup, and live performance of a musical experiment that explores the complex intersection of human-technology interactions, music, and data collection. It brings art and data science together through a novel experimental music installation. The interdisciplinary project "The (Un)Answered Question: A Data Science Powered Music Experiment" explored integrating data science and biomedical imaging techniques with theatrical and compositional ideas. This combination leads to the creation of interactive music. Gestural interfaces and sensory input devices translate physiological behavior into music through digital signal processing. Ralph Waldo Emerson's poem "The Sphynx" and Charles Ives' composition "The Unanswered Question" serve as foundational elements to create a live remix of the original music using biometric data from performers and an audience of 180 people. The audience became a powerful instrument of musical expression. Each live performance was experiential and unique, depending on the different people involved.

Keywords: Peroforming Arts · Music · Data Science · Biometrics

1 Introduction

For centuries, arts and sciences have been in fruitful dialogue. The cross-fertilization between art and science is rooted in the exchange of ideas, techniques, and methods between these two fields of science. Leonardo da Vinci and others combined

scrupulous anatomic studies and examination of biological structures with artistic work. The potential of this exchange has reached a whole new level with the emergence of digital technology, which has created new possibilities for artists and scientists to collaborate and create works that bridge the gap between their respective domains.

The theater is a form of performing arts [2] that has been particularly affected by the cross-fertilization of art and science, especially in the digital age. Digital technology has allowed theater to explore new forms of storytelling and push the limits of what is possible on stage. For example, digital projections and interactive technologies can be used to create immersive environments that enhance the audience's experience of a performance. Moreover, advances in computer graphics, animation, and special effects have made it possible to create virtual worlds that can be integrated into live performances. This has opened up new possibilities for theatrical productions, allowing them to incorporate elements of science, such as astronomy, biology, or physics, into their narratives.

Scientific breakthroughs, on the other hand, are also often motivated by technological advancements that enable new experiments and data collection and visualization methods, as well as novel experimental setups. The advances in modern methods and technologies in information and data science have pushed the reachable scientific frontiers tremendously, with the vector space of explorable phenomena constantly expanding.

We are both explorers — artists and scientists. Driven by curiosity, the quest for new ways of approaching the world, by the fascination with a particular structure or phenomena, and by the toying around with new ideas, always in search of new answers, or even more, new questions.

"The (Un)Answered Question: A Data Science Powered Music Experiment" is an interdisciplinary project that aims to artistically make the field of data science accessible to the public.

The basic idea was to create a unique remix of the piece "The Unanswered Question" by the American composer Charles Yves[7]. The remix is based on biometric data recorded from the audience. The goal is to create a new remix every night based on the emotional responses of the audience. Regarding the technical setup, there were two main challenges:

1. How to create music from biometric data?
2. How to distribute the generated score in real-time to the musician?

In this paper, we describe the modes of cooperation, shared methods, technology, and the initial results of the first prototypical work.

2 Technical Setup

The goal of the project was to use gesture interfaces and sensory input devices to translate physiological behavior into music through digital signal processing. The

[7] https://www.youtube.com/watch?v=kkaOz48cq2g

first step was to create an interface between the audience and the technology. Sensors and surveys were used to collect both objective and subjective data from the audience. The second step was to process this data using methods from the field of data science. This data would be used as input to render a unique remix of Charles Yves' "The Unanswered Question" and to develop a visualization of the input data.

2.1 Data acquisition

Nowadays, a wide range of sensors are available to record human physiological behavior [8], such as *Electroencephalography* (EEG), heart rate monitors, or surveys. Therefore, an integral part of the project was to determine which techniques could be used to record humanoid data. The project should be performed live in a theater with an audience of 180 people, therefore some external conditions had to be taken into account.

Due to the substantial size of the audience of 180 participants and the spatial situation of a large theater hall, we decided to conduct a survey, and when selecting suitable sensors, we decided to record *heart rate* frequency using wearable fitness trackers [1] and *emotions* using automatic recognition of facial expressions [14,6].

Emotion — Cameras A pair of cameras is used to capture the emotional expression of each person in the audience. Therefore, two cameras are strategically placed in front of the stage, one to capture the left half and the other to capture the right half of the audience (Figure 1). Each camera acts as an input source for the emotion analysis software. The reason for using two cameras was to get a more frontal view of the faces from the audience for better analysis. One camera was controlled by a Dell Latitude 7400 and the other by a Dell XPS 13 notebook.

To analyze the emotions of the audience, software was developed in Python to identify and categorize facial expressions. The framework Retinaface [16] was one of the components used to recognize the faces of each person. Retinaface uses an edge-based recognition technique that is highly accurate even in large crowds and provides box coordinates and orientation points for each identified face. To analyze the facial emotion, components and models of Deepface [15] are used. Deepface is a framework developed for both face recognition and analysis.

The result is an assignment to each identified face in the audience with the percentage of the emotions anger, disgust, fear, happiness, sadness, surprise, and neutrality. For example, one person could be 60% happy and 40% neutral. The results are summarized in a CSV file containing one line per face identified with the corresponding percentages of the seven emotions. In order to capture possible changes in the audience's emotions during the playing of the original piece, a snapshot of the input stream was recorded and analyzed at regular five-second intervals.

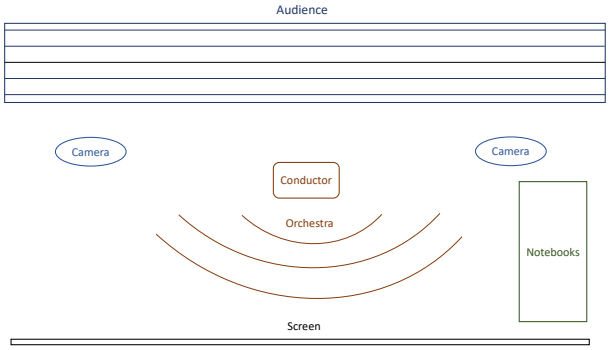


Fig. 1: Set-up of the stage.

Heart frequency — Fitness Tracker The MiBand 5 fitness tracker[8] was used to track the heart rate of the audience, with each MiBand measuring and logging the heart rate locally every minute. Once all data was collected locally, the MiBand logs were collected using a Dell Latitude 7400 and a Dell Latitude E7 notebook. The advantage of using two computers is that each computer can cover half of the audience, speeding up the collection process.

To record the local MiBand protocols using the two computers, Python software was developed. The software is based on the MIBAND 4 Python library [7]. This library requires the bluepy Python package [10] to access the Bluetooth interface of the device. The MIBAND 4 Python Library communicates with the MiBand via this interface and receives its responses. Some outdated functions had to be adapted. For example, the activity log has been migrated to MiBand 5 and replaces outdated dependencies.

The developed software connects to each MiBand, extracts the heart rate data from the MiBand protocol, and disconnects from the MiBand. This step takes some time due to the limitations of Bluetooth. A computer can only connect to seven MiBands at the same time. The MiBands are, therefore, processed using a queue. In the end, all the values from all the MiBands were written to a CSV file. As the heart rate recording, like the emotion recording (Section 2.1), was intended to record the changes in the audience's values during the performance of the original piece, the values from the MiBands were written to the CSV file at one-minute intervals.

Empathy — Questionnaire In addition to the objective data of the audience, such as heart rate and emotions (Section 2.1), subjective data was also collected. For this purpose, we measured individual personality aspects of the visitors based on the global dimensions of personality — the so-called "Big Five" [5,4] — which include neuroticism, extraversion, openness to experience, agreeableness,

[8] https://www.mi.com/global/miband/

and conscientiousness. To reduce the number of questions, we only focused on the *agreeableness* dimension. As the heart plays a central role in our play, we used the agreeableness dimension as a metaphorical measure for magnanimity (the German translation "Großherzigkeit" literally means "big-heartiness"). Our questions were based on the agreeableness dimension of the German NEO-FFI short version [11]. Due to the concerns of the organizers, however, we modified some questions to make them sound more positive to preserve the positive mood at the beginning of the play. Thus, the survey consisted of the following four questions:

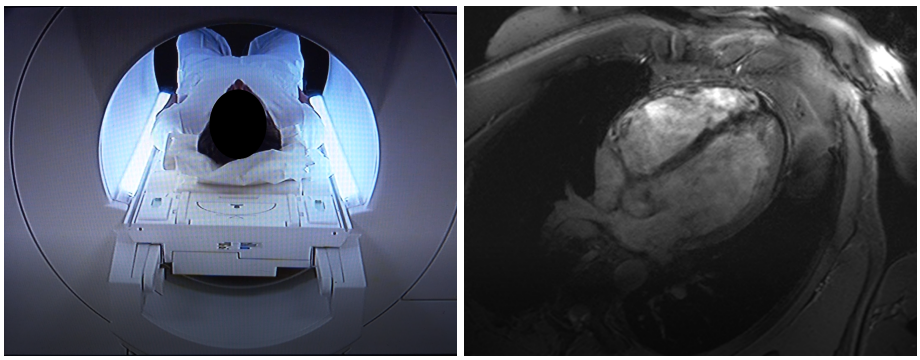
1. I am empathetic and warm-hearted.
2. I have the ability to ignore the idiosyncrasies and mistakes of others.
3. I am helpful and selfless.
4. I am always determined to help others in case of an accident.

Each of these questions could be rated on the following scale: (1) *Disagree at all*, (2) *Rather disagree*, (3) *Partly*, (4) *Tend to agree* and (5) *Totally agree*. The questionnaire included an additional question on the position of the chair (left vs. right). The visitors were instructed to complete the digital questionnaire before the musical performance started. For this, we placed QR codes in the room that the visitors could scan with their phones and then fill out.

Heart frequency — cardiac MRI In addition to the data collected from the audience during the live performance, *cardiac Magnetic resonance imaging* (MRI) data [3] from an actor's heart was collected beforehand while reciting Ralph Waldo Emerson's poem "The Sphynx". The actor without any known history of cardiac disease was included after approval by the local ethical committee[9]. Informed written consent was obtained from the volunteer prior to the study. MRI was conducted on a 7.0 T whole-body MRI scanner [12][10] equipped with an 8 kW RF power amplifier[11] and a gradient system (maximum slew rate=170 mT/m/ms, maximum gradient strength=38 mT/m). For radiofrequency excitation and signal reception a 32 channel self-grounded bow-tie transceiver array was used [9]. 2D CINE FLASH imaging of the heart was performed to obtain short axis (SAX), two-chamber (2CV), three-chamber (3CV), and four-camber views (4CV) of the human heart (spatial resolution = $(1.1 \times 1.1 \times 2.5)$ mm^3, echo time TE = 2.09 ms, repetition time TR = 4.55 ms, parallel imaging acceleration GRAPPA R = 2, views per segment = 10, number of cardiac phases = 30, receiver bandwidth = 446 Hz/Px, nominal flip angle = 22°). For retrospective cardiac gating and prospective cardiac triggering *electrocardiogram* (ECG) electrodes and an MR stethoscope[12] were placed between the

[9] registration number EA1/256/19, Ethikkomission, Ethikausschuss am Campus Charité – Mitte, Berlin, Germany
[10] MAGNETOM, Siemens Healthineers, Erlangen, Germany
[11] RFPA, Stolberg HF-Technik AG, Stolberg-Vicht, Germany
[12] EasyACT, MRI.TOOLS GmbH, Berlin, Germany

transceiver array and the anterior chest wall. An average heart rate of 55 bpm was observed. The overall image quality provided ample blood-myocardium contrast and enabled the visualization of fine subtle anatomic structures including the compact layer of the right ventricular free wall and the remaining trabecular layer. Pericardium, mitral, and tricuspid valves and their associated papillary muscles, and trabeculae are identifiable.



(a) Actor in MRI scanner while reciting the poem and images of his heart are taken.

(b) MRI image of the actor's heart.

Fig. 2: MRI data of the actor's heart was recorded before the performance (Images: Max Delbrück Center for Molecular Medicine in the Helmholtz Association).

2.2 Data processing

After all the data from both the actor and the audience had been recorded, they needed to be processed. The goal was to avoid a linear correlation between the audience and performer data and the music. For example, emotions should not directly influence the strings, and the rhythm should not be synchronized with the audience's heart rate. To prevent this, we used clustering techniques to modify certain aspects of the musical composition. We merged the heart frequency data from the actor's MRI data with the audience's heart frequency data in one CSV file and the facial recognition data with the survey values. We perform a *K-means clustering* [17] for each collected timestamp. The center point of each cluster was then determined, which was used as input to generate a new score.

2.3 Score Remix and Score Distribution

We decided to use Inscore (v1.31)[13] as an environment for the design of interactive, augmented, dynamic musical scores. Inscore is an open-source software that was initiated by Dominique Fober and the Interlude project. It is based on the GUIDO Engine, so it works natively with Guido Music Notation (GMN)[14]. GMN is a formal language designed to create musical scores that are readable by machines and humans.

Our technical setup consists of internal developer software (*ScoreMaker*) and *Inscore*. The ScoreMaker processes the clustered audience data (Section 2.2) and creates a remix, presented as a musical score in GMN-Format. The ScoreMaker was developed in Python and communicates with Inscore via the Open Sound Contol (OSC) protocol [18]. The Center of Music and Film Informatics at Detmold University of Music[15] provided valuable information on several digital score viewing software. However, the combination of ScoreMaker, INScore, and Guido seemed to be most promising, especially in terms of how quickly a music score could be instantly remixed. Moreover, Inscore offers its own script language (*Inscore Script*), which enables dynamic score augmentations.

In a preceding step, we analyzed the original score of Charles Yves and decided to cut the score into semantic pieces (i.e., phrases and motifs), to provide meaningful musical sequences. Based on the provided clustered audience data, ScoreMaker selects semantic musical pieces, rearranges them, and performs several transformations like (Figure 3):

- rhythmic variations
- transpositions
- stretching and shrinking phrases

For musicians, we decided to use Lenovo Chromebook tablets (in total, 35 tablets). We decided to use Chromebooks because the screen dimensions are similar to a sheet of music. Moreover, Chromebook allows one to run Android and Linux simultaneously in containers. For the visualization of the gmn-scores, we used Inscore Viewer. After rendering the full score, it is separated into single-part scores. These are then distributed to the 35 musicians' tablets. The tempo is indicated by a synchronized cursor above the notes (Figure 4). In addition to the new score for the musicians, certain parts of the poem are triggered by cluster data via OSC over a time series into Ableton Live, using a python-based OSC-Player. The cluster controls which verse of the poem is included in the remix on any random day. Important tools proved to be Pythonosc and Guidolib. In addition, the sound of certain sections of the orchestra is manipulated electronically. The woodwinds and trumpet are being picked up by microphones, and their signal is being altered using a video mapping of the MRI-heart to control parameters and faders in Ableton. This was archived by existing max4live devices.

[13] https://inscore.grame.fr/
[14] https://guidodoc.grame.fr/
[15] http://www.cemfi.de/

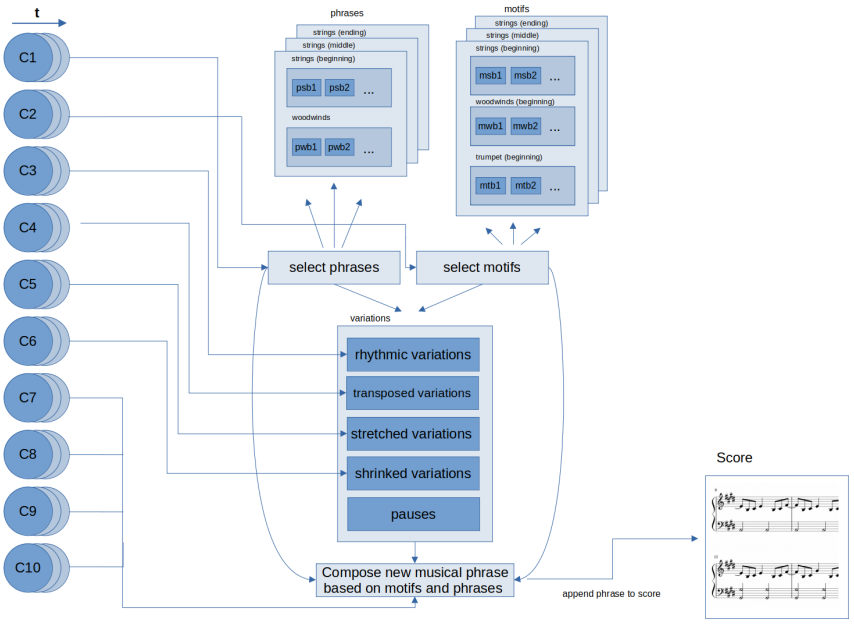


Fig. 3: Workflow to create a new remix based on the cluster files.

2.4 Visualization

The visualization was implemented using Unity 2D and consists of oval-shaped emoticons, the beating MRI image of the heart in the center of the image, and a point for each spectator in the audience (Figure 5). Each dot flashes in rhythm with the measured pulse and moves from emoticon to emoticon. Since it was not possible to assign each person exactly the emotion and pulse rate, this was done randomly. Another reason why an explicit assignment was not possible was the wearing of face masks against COVID-19 in the audience, so that for some people no emotion data could be collected. Another reason was the wiring of people. For a concrete assignment of the pulse, cables would have been better, but it was also a public artistic performance and not a laboratory set-up.

The goal of the visualization is to convey to the audience what data have been recorded, an understanding of the collective and individual influence on the orchestra remix, and to put the poem The Sphynx and the composition The Unanswered Question into a common context. A constantly evolving image with a timeline and constant update represents the process and evolution through simple tools. The blue background color was a suggestion from the organizers, as this color is meant to convey a scientific image [13]. The beating heart is placed in the center of the screen for the connection of the individual elements of conception, the poem “The Sphynx”.

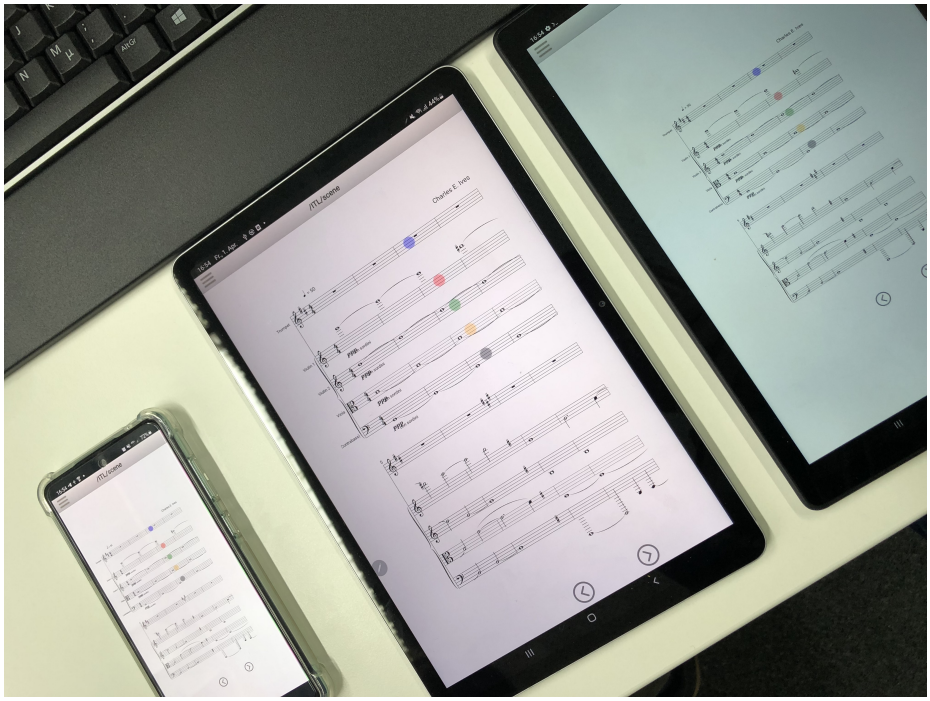


Fig. 4: The new scores were distributed to the orchestra's tablets.

Assuming a faster perception through images, emoticons were used in addition to the text ("neutral", "happy", etc.) to represent the emotions. In addition, emoticons create a more exciting and less static image, so aesthetics also plays a formative role in this decision. The arrangement resulted from different test runs, which resulted in the emotions 'neutral' and 'happy' being particularly frequently accessed. To avoid creating a one-sided moving image, they were arranged (after evaluating the prototype performance) in such a way that the dots move across the entire screen as far as possible. Again, aesthetics and dramaturgy were decisive factors. The color of the emoticons is the matched complementary color to the background color to create a visually pleasing composition.

3 Live Experiment

Based on the composition "*The Unanswered Question*" (1908) by the American composer Charles Ives (1874–1954), a performance was realized at the Saarländisches Staatstheater in which biometric data of the participants (audience and performer) were processed in video projections and live orchestral remix.

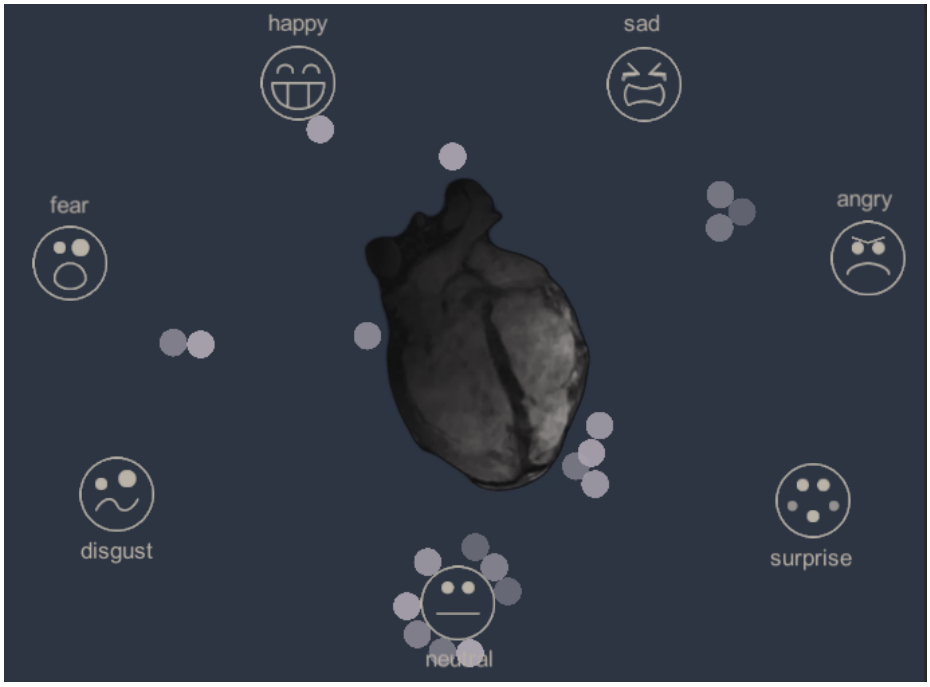


Fig. 5: Visualization of the recorded data of the audience and the actor, heart frequency, emotion and magnanimity.

The composition "The Unanswered Question" refers to the poem "The Sphynx" by Ralph Waldo Emerson[16] and addresses the riddle of the Sphynx from the Oedipus legend. Often described as philosophical "programm music," Ives describes the basic idea of his composition as a debate about the "eternal question of existence". In an increasingly complex world characterized by artificial intelligence and the advancing digitalization of all areas, this question is posed in a new context. The aim of the project was to investigate the relationship between humans and technology, music, and data science, using a musical-digital experimental set-up: Can data science help to turn the "unanswered question" into an "answered question?"

The experience of a concert, the interaction between orchestra and audience, is a unique live artistic experience. With methods and techniques from the field of data science (Section 2), it has been possible to turn every evening into a unique experience that depends on the different people involved in the audience.

The live performance at the Saarländisches Staatstheater, consisted of the following three parts:

[16] https://poets.org/poem/sphinx

Part 1: Recitation In the first part of the live performance, an actor recited the poem "The Sphynx". During recitation, synchronized visualization (Section 2.4) of the heart MRI data (Figure 6), which was previously recorded during the actor's recitation (Section. 2.1).

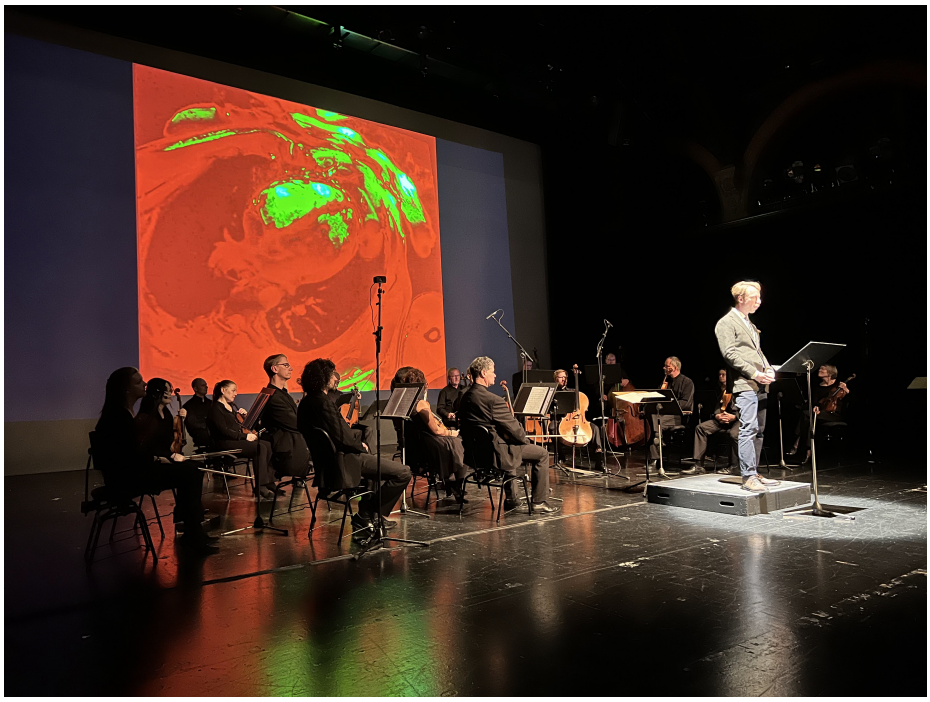


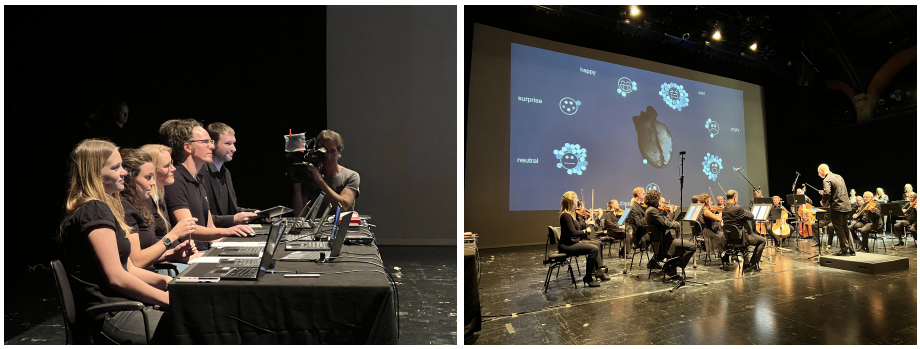
Fig. 6: Visualization of the heart MRI data during the recitation.

Part 2: Orchestra performance In the second part of the live performance, the orchestra played Charles Ives' "The Unanswered Question". Meanwhile, the MiBand fitness tracker track the heart frequency, and the facial recognition tracks the emotions of the audience with 180 members.

Pause During the pause, all the time series data recorded in part two had to be processed and the notes for the remix generated. To do this, the data from the MiBand fitness tracker first had to be transferred to a CSV file (Section 2.1). Then the MRI data was merged with the heart frequency and the survey values with the emotions recognition. The data was clustered (Section 2.2), and the resulting clusters were used to generate the score (Section 2.3). A remix was rendered into a new score for the left half of the audience and one for the right

half of the audience. The new scores were distributed to the 35 tablets of the orchestra.

Part 3: Remix Audition In the third and final part, the remix was performed live by the Saarländisches Staatstheater Saarbrücken in front of the audience (Figure 7). First, the newly generated remix from the left half of the audience was played, followed by the remix from the right half of the audience. Meanwhile, the visualization of the data of the audience and the actor was shown synchronously. This made the recorded data audible and visible to the audience. The result was a unique remix of the original composition based on biometric data reflecting the emotional reactions of the audience. This experiment demonstrated the potential synergy between art and science in the creation of interactive musical experiences.



(a) Data processing during the performance.

(b) Orchestra and visualization.

Fig. 7: Live performance at Saarländisches Staatstheater Saarbrücken. While the orchestra is playing, the biometric data is processed and visualized in the background of the stage.

4 Conclusion

Based on Ralph Waldo Emersons's poem "The Sphynx" and the piece "The Unanswered Question" by the American composer Charles Ives, a prototype live performance was developed in which biometric data of the audience and performer, collected via human-machine interfaces, were processed in video projections and live orchestral remixes. In this way, the interdisciplinary project "The (Un)Answered Question: A Data Science Powered Music Experiment" createed an immersive live experience using tools and techniques from the field of data science.

Various biometric data of the audience and the performer, such as heart frequency or facial expression, recorded by fitness tracker or emotion recognition, are decisive for the respective result. An intelligent algorithm collects these various biometric data and processes them into a visualization and a live orchestral remix of the original composition. This remix becomes a new score that is streamed to the musicians' tablets. The result was an immersive and exclusive live performance.

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