Collaborative crowd games exploring participatory sensing and intelligent artificial life simulation techniques

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Abstract. *Mobile devices have become an indispensable part of modern life. We investigated how such devices could be used to improve audience experience at entertainment events, and as a result, we proposed Cabo DIGuerra, a collaborative mobile game that uses motion sensors and microphones to provide interactivity between the audience and the show through a dispute that digitally simulates a tug-of-war. Bumbometer, an evolution of Cabo DIGuerra, was used in two case studies at large events in northern Brazil, with the results indicating the game's and proposed technologies' suitability. Furthermore, a prototype application was developed based on the findings of case studies with a Boids-based artificial life system, Bumboids.*

Resumo. *Os dispositivos móveis se tornaram uma parte indispensável da vida moderna. Neste trabalho, investigamos como tais dispositivos poderiam ser usados para melhorar a experiência do público e, como resultado, propusemos Cabo DIGuerra, um jogo móvel colaborativo que usa sensores de movimento e microfones para proporcionar interatividade entre o público e o espetáculo através de uma disputa que simula digitalmente um cabo de guerra. O Bumbômetro, uma evolução do Cabo DIGuerra, foi utilizado em dois estudos de caso em grandes eventos no norte do Brasil, com os resultados indicando a adequação do jogo e das tecnologias propostas. Além disso, uma aplicação protótipo foi desenvolvida com base nos resultados de estudos de caso com um sistema de vida artificial baseado em Boids, o Bumboids.*

1. Introduction

Brazil hosts a number of major events throughout the year, including Rock in Rio, Carnival, New Year's Eve, and Folk Festivals. The adoption of smartphones across all social classes and age groups provides a powerful but underutilized computing tool. We proposed some alternatives ways of encouraging audience interaction and engagement in on site or remote events. This paper is the result of previous publications that sought to promote audience engagement before and during the COVID-19 pandemic [Martins et al., 2021a, 2020b,a, 2021b].

The audience is no longer merely a passive observer and is increasingly demanding a prominent role in entertainment events. People are frequently seen using their smartphones to send direct messages, interact on social networks, take pictures, film, and engage in other related activities. Individuals in the audience perceive the combination of technology and interaction between the performer and the audience as

positive. Because of the pandemic, events had to be adapted to virtual mode, limiting interaction between performer and audience to the exchange of messages and emoticons on live streaming platforms, increasing the demand for innovation in these events.

The **main objective** of this research consisted in developing and exploring a collaborative crowd game with effective use of mobile computing technologies and collective computing and sensing techniques. Thus, the following **research questions** were proposed: a) how can we provide greater interactivity, immersion, collaboration and user experience in entertainment events using computational tools? b) how can we better leverage a mobile technological tool (smartphones) in the entertainment industry?

This paper is organized as follows. Section 2 presents some theoretical aspects of this research such as Crowd dynamics, Mobile Crowd Sensing, Collaborative games and an agent based algorithm. Section 3 presents the applications developed, the *Cabo DIGuerra*, Bumbometer, and the Bumboids. Section 4 summarizes the contributions of this research. And, in Section 5 the final considerations are made.

2. Background

In this section we will contextualize the theoretical concepts involved in the development of the applications and the various case studies, expanding the concepts given in Martins et al. [2021a,b].

2.1. Crowd dynamics and Mobile Crowd Sensing

Defined as the study of large groups of individuals in a given space, Crowd Dynamics is an area with a wide variety of applications [Still, 2000]. While research in this area often focuses on aspects of studying behavior in emergencies, work such as that by Baig et al. [2015] addresses issues related to crowd emotion, providing tools for improving the individual's experience.

The use of computational tools developed as a way to obtain accurate data about crowd behavior is a very present trend in recent papers in the area. One proposal in this direction is the use of smartphones as a data source. Mobile Crowd Sensing covers not only technical aspects related to mobile devices but also aspects of human behavior. Collective sensing methods that act in scenarios where the use of cameras is restricted or unfeasible have recently emerged, one proposal in this direction is the use of smartphones as a data source [Guo et al., 2015; Macias et al., 2013]. The growth in numbers of mobile devices, such smartphones, tablets or activity trackers, has made large-scale sensing feasible at a low implementation cost.

2.2. Collaborative games

Collaborative games are those that aim to increase the sociability of the players as a general goal. It not only encourages participants in an elicitation activity to collaborate in developing a shared understanding of a problem or solution, but it also incentivizes a greater sense of participation.

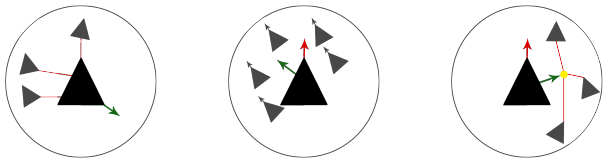
Veerasawmy and Iversen [2012] have built a prototype called BannerBattle in a crowd entertainment environment to examine the usage of technologies to enhance the crowd experience. The study described three crowd behavior features, imitation,

emergence, and self-organization, which were later utilized as analytical methods to evaluate the prototype. The findings of a case study conducted during a football match revealed that using a game as an entertainment tool was effective in engaging the crowd and so improving the overall experience. When employing Bumbometer in a competitive/collaborative situation, we found a resemblance to BannerBattle regarding the use of audience engagement as a data source.

2.3. Artificial Life simulation: boids, behaviours and algorithms

Initially proposed by Reynolds [1987], Boids is a program that simulates the swarming behavior observed in several species in nature such as birds and fish. In his work, Reynolds defined three parameters that each agent in the simulation must obey. The *flocking* behavior emerges from these parameters in an emergent way, that is, the behavior arises from the interaction of each individual with the others, and the whole is the result of the individual interaction. Next, the three main rules that define the behavior of the boids are presented and in the Figure 1 the same rules are represented in a visual form.

- Separation: keeps each boid away from another in order to avoid collisions.
- Cohesion: the tendency of boids to stay in groups, avoiding drifting apart.
- Alignment: the general direction of group movement.



(a) Separation. (b) Alignment. (c) Cohesion.

Figure 1. Boid behavior parameters.

Several variations of the original model have been proposed over the years, and the model has gained popularity in computer science applications. It is the foundation upon which Particle Swarm Optimization was first developed. In a review by Long et al. [2019], several algorithms based on animal behaviors were analyzed, emphasis on techniques using herding, in which a single cell guides the others. Also, the use of parallelization techniques are extremely relevant since the execution time of a classical Boids implementation reaches the order of $O(N^2)$.

3. A mobile-web system as collaborative crowd game versions

Two variants of the proposed system will be presented in this section. The first encounter, called Cabo DIGuerra, was created as a proof-of-concept to examine technology problems and further investigate the concept. A second version, named Bumbometro, was created, this time with a clear research purpose and a case study as a target. Finally, there is the Bumboids, which is a collaborative game prototype based on the Boid algorithm.

3.1. Cabo DIGuerra (Digital Tug of War) and applications

Based on the traditional Tug-of-war game, where two teams compete against each other through force pulling a rope, Cabo DIGuerra (Digital Tug-of-war) is a digital version of the same game, hence the inspiration for the name. The collaborative game consists

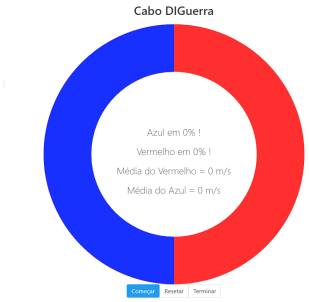


Figure 2. Display screen of Cabo DIGuerra, the lower line of division moves according to percentage for the victory of each team

of two modules, a Mobile Application, used by players, and a web application, seen in Figure 2.

The game works as follows: the participants are divided into two teams, one blue and one red. At a hundred milliseconds a comparison is made between the teams, the one with the greatest ”strength” receives one point while the other has a decreased point. The team whose score reaches one hundred points first wins.

3.1.1. A game tool for balance & blending in a choir

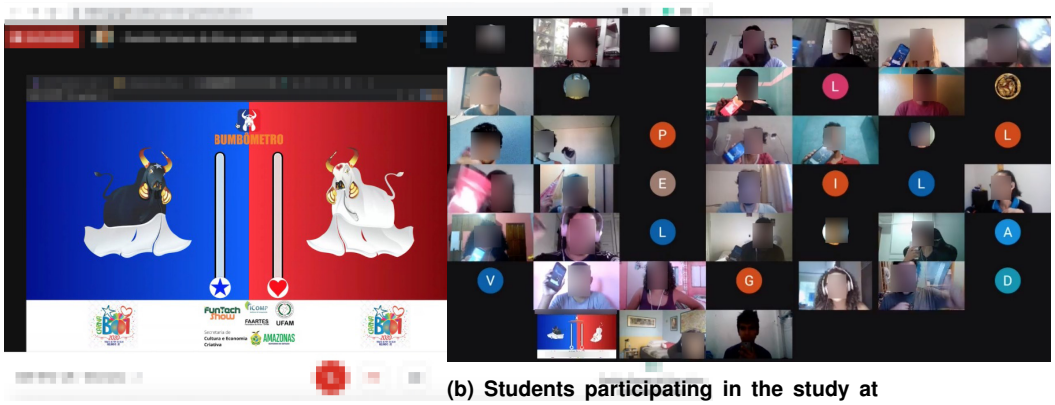
Although initially Cabo DIGuerra was developed as a collaborative crowd game in entertainment events, a musical choir group has expressed interest in the use of the system as a tool to the maestro. In such mode, the goal becomes to balance the voices, that is, the teams must remain balanced in regard to the sound volume.

Figure 3. Some pictures from the experiment with a musical choral group. Mobile devices were utilized in the experiment to measure the level of sound produced.

The experiment ran without any problems, being actively used by the choir, as seen in Figure 3, the system behaved as expected with no connection problems or server overload. A more detailed report can be found in **?**.

3.1.2. A demo game of digital tug of war in a dynamic between students

A experiment was performed via streaming with about fifty students of an EaD (e-learning) course where they played from their homes as seen in Figure 4.



(a) Online interaction feedback screen

(b) Students participating in the study at the time of interaction

Figure 4. Screenshots of a test that was carried with a group of students in a remote manner.

The goal of this experiment was to investigate if using the system in a remote environment was feasible. The volunteers were briefed on the game's mechanics a few days before the experiment. The experiment went off without a hitch, demonstrating the viability of remote use, but a few issues arose. The volunteers complained that the User Interface was not clear enough. It was noted that there was no connection indicator of any kind, making it impossible to know if the players were actually sending any data at all. A more detailed analysis was reported in Martins et al. [2021a].

3.2. The Bumbometer mobile crowd game and applications

The Bumbometer evolved from the Cabo DIGuerra, the application used in this research dealt with a technological action carried out during a special Carnival event, as reported in Martins et al. [2021a]. It was a collaboration between the author and the Amazonas State Government through the State Secretariat of Culture and Creative Economy (SEC-AM).

The galeras, the fans of each folkloric aggregation known as Bois (Garantido and Caprichoso), compete through movement. The application records the device's acceleration and sends it to a cloud database. This data is obtained from the database by the web application, which adds up the individual acceleration of all participants.

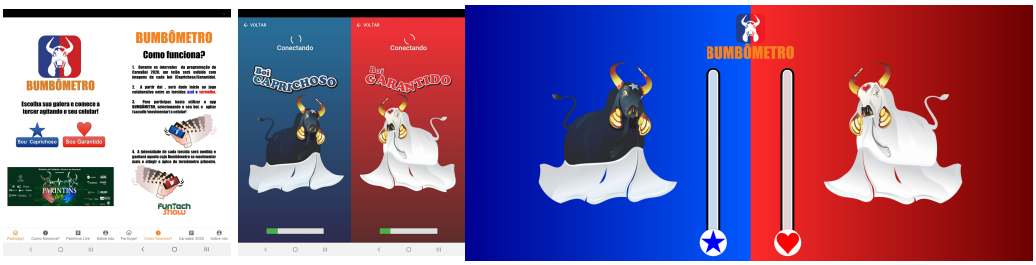


Figure 5. Screenshots of the bumbometer application. On the left, the four main screens of the mobile app, on the right the thermometer screen.

The main function of the mobile application, Figure 5, which is available for Android and iOS operating system devices, is to serve as a platform for capturing motion,

sound, and location data from participants while the web app is running. The design was created to reduce the need for interaction between the user and the device, allowing them to focus on the show. The web app is used to display and control the system. The application architecture is mobile-web serverless. This is a cloud execution model in which a cloud provider dynamically allocates compute and storage resources required to complete a task, as illustrated in Figure 6.

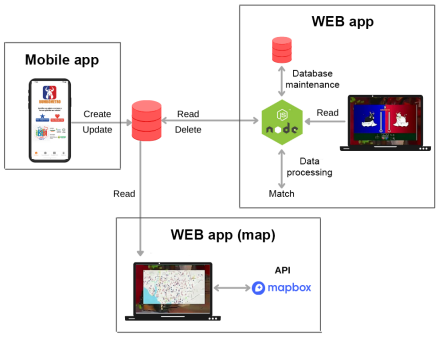


Figure 6. Serverless architecture of the mobile-web system.

3.2.1. CarnaBoi Fest Folk in-person cultural event

Carnaboi is an annual event held during Carnival in the city of Manaus that incorporates folk traditions from the north of Brazil into the Carnival celebrations. The event, held in 2020 as seen in Figure 7, brings together artists who primarily sing and perform Bois Garantido and Caprichoso melodies, as well as other artists and regional rhythms. Introducing new forms of audience engagement at Carnaboi events necessitates careful planning. As a result, a series of meetings were held in collaboration with Amazon's Secretariat for the Cultural and Creative Industries (SEC-AM) to promote the use of the Bumbometer app during the event.

Figure 7. Picture of the Carnaboi 2020 event. Source: SEC-AM.

At each interval between stage shows, the event's presenter invited the audience to participate in an interaction section that represented an engagement dispute with the Bumbometer. Following the game, some members of the event's audience were approached and asked to complete a questionnaire to assess their engagement. The questionnaire, the application logs, as well as the activity logs of the app stores, were analyzed, the results were disclosed in Martins et al. [2021a].

3.2.2. Fest Folk Live remote cultural event in pandemic times

Following the COVID-19 pandemic, several artists began to make live presentations that were broadcast over the Internet from their own homes. The entertainment industry had to adapt to new times and formats by leveraging digital information and communication technologies more effectively. This environment proved to be favourable to the use of the Bumbometer application/game in an remote context, some screenshots of the event can be seen in Figure 8.

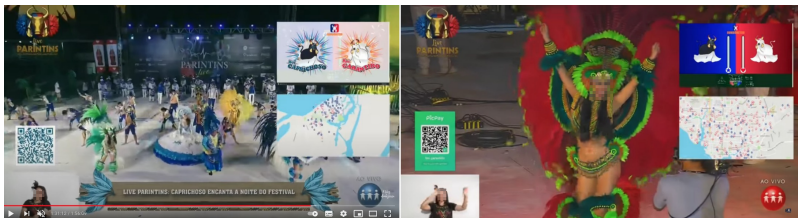


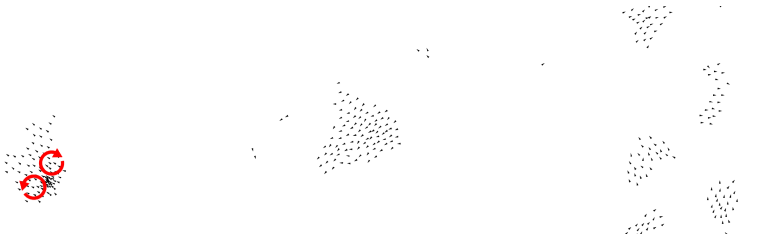
Figure 8. Screenshots the use of Bumbometer application during the Parintins Live 2020. Source: A Crítica

The collaborative-competitive game Bumbometer was used during a live web broadcast as well as a retransmission of a major Brazilian TV station, with an audience from all over Brazil; this was an interaction based on previous case studies, as described in Martins et al. [2020b, 2021a]. It also included an improved version of the technological application used in Carnaboi 2020, this time with crowds interacting remotely via mobile devices, and a map that was updated in real-time with the location of all participants. Meetings with partners were held during the study's preparation to obtain details about the event's broadcasting process. The event was broadcast on two platforms, one of which was the respective television station and the other, YouTube.

3.3. A collaborative game prototype based on Boids

A rotation behavior toward the center of the group was observed in a first implementation of the program (Figure 9.a) when groups larger than ten Boids were used. Once different weights were assigned to each of the parameters it was discovered that varying the weights of each of the parameters significantly changed the behavior of the Boids, which proved to be consistent with previous the work Zhong and Cao [2016]. With 3 for separation, 2 for cohesion, and 1 for alignment, the behavior resembled a school of fish, with rapid trajectory changing movements, as shown in Figures 9.b and 9.c. It was then possible to recreate several different behaviors by changing these values, such as tendencies to maintain larger or smaller groups, more frequent changes of direction, no group formation, and so on.

It was decided to use a two-dimensional representation of the algorithm. Each boid is made up of a cicle, which is used to calculate collisions, and a vector, which is used to calculate motion. The space may or may not have walls on the edges, and the unit of measurement is pixels. Several other behaviors were added later. These behaviors are defined by coefficients, seen in Table 1, which can be changed at any time during the simulation. Furthermore, these coefficients are applied using a normal distribution method, resulting in a more natural behavior of the boids while maintaining the program's intent.



(a) Separation:1 Alignment:1 Cohesion:1 (b) Separation:3 Alignment:2 Cohesion:1 (c) Separation:3 Alignment:1 Cohesion:2

Figure 9. Examples of changes in behavior according to different weights for each parameter.

Table 1. Coefficients of boid behavior and their description.

Coefficient	Description
Introversion	The tendency of the boid to remain close to other boids. The more the boid, the more it seeks to get closer to its fellows
Radius	Boid size. Both visually and for collision detection purposes.
Fear	Determines how much a prey boid seeks to get away from predatory boids.
Courage	Determines how much a predatory boid seeks to collide with prey boids.
Speed	The speed of the bull. This coefficient is affected by the type of the boid (prey are slightly slower than predators). fanged boids get a small boost when in groups and about to be attacked.
Segregation	The tendency of the boid to blend in with boids of other colors..

From the experience of the development of the Bumbometer, **Bumboids** was developed, which combines the infrastructure already developed and tested with a new form of visualization and participation. In this version, boids are employed as a type of competitive visualization. Each team has a single hue of boids, and participants can utilize a photo or image as ”their boid,” which will appear as one of the boids in the battle. The collaborative game mechanics are similar to those used in Bumbômetro, with some slight graphic variations.

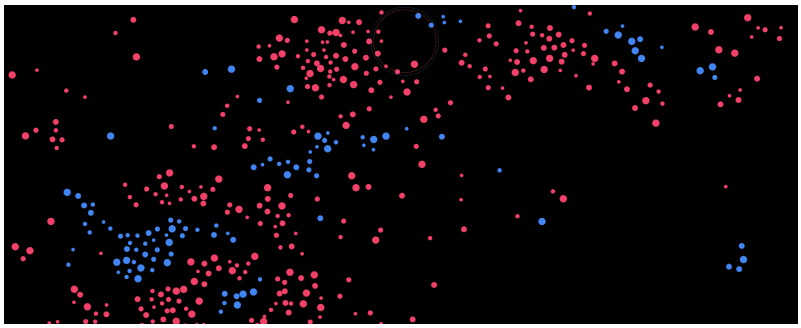


Figure 10. Screenshot of the Bumboids WEB application. Here the photos are shown as dots for better visualization.

The main interface of the program is depicted in Figure 10, which features the boid algorithm display in the center and bars representing the ”strength” of each team on the sides. The boid are represented by colored circles that can be substituted with photographs of the individuals. The boids of the team with the most ”strength” prefer to hit the boids of the opposing team, killing them, as the game goes, and the behavior of each side boids is determined by how the players participate. This impact

affects the boids speed, aggressiveness or proclivity to hit the enemy team's boids, and how they resist the opposing team's boids. The mobile application has undergone modest cosmetic modifications in contrast to the Bumbometer application, however the application infrastructure has remained same.

4. Contributions

Apart from the innovative approach to dealing with a dynamic real-time use case by using a serverless model, the application and infrastructure developed proved to be highly adaptable, having been used in various events and scenarios, praised by the event's organizers, and being the subject of multiple research papers [Martins et al., 2021a, 2020b; **?**, 2021b]. The main contributions can be summarized as follows:

- an literature review regarding the theoretical aspects involving several aspects such as Crowd Dynamics and Mobile Crowd Sensing as well as on the use of collaborative games as crowd entertainment and the boid algorithm.
- design of client-server web application architecture, with simultaneous sending, manipulation, storage, and dynamic visual response, and in reduced response time, large-scale mobile sensor data. Making use of existing assets and a low-cost solution to store data in the cloud. And a prototype utilizing an intelligent-based agent behavior as a visual and interaction stimulant.
- a successful, field-tested application using participatory sensing in crowd events, aiming at increasing audience engagement and providing useful data to the event organizers.
- a case study during a world pandemic, in one of the biggest folkloric festivals of the north region of Brazil, with widespread adoption and data gathering.

5. Concluding Remarks

This research project focused on the development of a collaborative crowd game to encourage immersion and engagement in entertainment events. It is also worth noting that the research was carried out in a theoretical and technologically innovative manner, resulting in the development of a validated application that is now available for usage in app stores, Android, and IOS versions. Gustavo Martins, the undergraduate student in focus in this CTIC-CSBC 2022 contest, was in charge of all the research, development, and outcomes provided. Except for some areas of the application graphics, such as drawings and animations, which were created with the help of a designer and other undergraduate students.

Finally, through the COVID-19 pandemic, the technological innovation solution proposed in this work was pioneered, used via *streaming* and open TV, in a real-time and large audience case study. It was possible to promote greater engagement of the audience during one of the first distance cultural events, in June 2020, enhancing the interactive experience of the spectator, mitigating the impact of social distancing, and providing the student to acquire know-how throughout the scientific research cycle and development with technological innovation.

Acknowledgments

This research is part of scientific initiation projects PIBIC/PAIC 2018/2019 PIB-E/0364/2018 and PIBIC/PAIC 2019/2020 PIB-MULT/0059/2019, UFAM/CNPq, whose

advisee and supervisor belong to the CNPq research group in Optimization, Algorithms and Computational Complexity (ALGOX). The authors were also supported by Brazilian funding agencies: CAPES, CNPq and FAPEAM. Thanks also to the joint work of the FuntechShow/IComp group and the Faculty of Arts (FAARTES) from UFAM, in the application of the game in large real-world crowd events, which in partnership with the Amazonas State Department of Culture (SEC-AM), *Calderaro* Network Communications (TV ACrítica) and *Boi-Bumbá* folk groups *Caprichoso* and *Garantido*.

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