



Describing and Comparing Co-located Interaction in Interactive Art Using a Relational Model

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Abstract. Co-located interaction in interactive art takes place among two or more co-located audience members and the technical system of an artwork. In this paper, we aim to assess the descriptive and comparative qualities of our previously developed relational model for describing and analysing such forms of interaction. The model focuses on specifying the actions of the interacting elements, such as the audience and art system, and the various forms of communication between them. To assess its significance, we first develop selection criteria and classification dimensions to select eight artworks that are representative of diverse forms of co-located interaction. The relational model is shown to be suitable for describing the selected artworks and comparing their similarities and differences. As outcome, it reveals different types of relationships between the actions of interacting elements that would otherwise not be highlighted. As such, it provides a context for analysing and discussing strategies for co-located interaction and points to opportunities for research and creation in this field.

Keywords: Co-located interaction · interactive art · interaction model · mediated communication · audience-artwork interaction

1 Introduction

Co-located interaction in interactive art takes place when two or more audience members are physically present at the same location, participating simultaneously in an interactive experience. Previously, we developed a relational model with the aim of describing co-located interaction in interactive art [1]. While the interaction between the audience and art system is often viewed as a dialogue [2], in the context of co-located interaction the dialogue model falls short in capturing the diverse relationships between the interacting elements and the unique roles each element plays in the overall interaction. In response to this limitation, our relational model focuses on describing the various forms of communication occurring among the interacting elements and how these elements relate to and influence one another [1].

We believe that the relational model provides a systematic approach to examine and compare different forms of co-located interaction, further enabling us to discover patterns

and identify new research areas. Therefore, there are two main objectives of this study: firstly, to assess the descriptive and comparative capabilities of the relational model with regard to diverse forms of co-located interaction; and secondly, to gain insights into the characteristics and features of such interaction using the relational model.

In the following section, we very shortly introduce the relational model and discuss its features and scope. In Sect. 3, we outline the selection criteria, the classification dimensions and the process of selecting a total of eight artworks that represent the range and diversity of co-located interaction. In Sect. 4, we apply the relational model to describe the co-located interaction in each artwork and compare their similarities and differences. Finally, in Sect. 5, we reflect on the effectiveness of the relational model and discuss our insights into the various forms of co-located interaction.

2 A Relational Model of Interaction

The detailed motivation for, description of, and background of the relational model can be found elsewhere [1]. The model starts by identifying the individual actors participating in the interaction, each of which is described as an element. The type of an element can be ‘audience’, referring to the participating audience, or ‘art system’, referring to the technical system(s) of an artwork. To describe an interaction, the model examines the actions performed by the interacting elements, such as a movement, an update of a display, or pressing of a button. Following an action, a form of communication is created and directed at (an)other element(s). Communications can be either direct, only taking place between two communicating elements, or mediated, taking place between two communicating elements via a third element. And they can be either private, which can only be perceived by the communicating elements, or public, which can also be perceived by other elements. An action can be performed by one element or multiple elements together and it can be directed at one or multiple elements. The same action can also be directed at different elements thus creating different forms of communication. For each action, the model examines what role(s) it plays in the context of the interaction and how it influences other elements.

Although the model was developed for describing co-located interaction, it does not set any requirements for the number and types of elements or the location of interactions. The concepts involved can potentially describe interaction in general and artworks involving non-human actors such as animals or plants. It is important to note that the model focuses on describing the relational exchange between and among the elements. It does not specify the internal processes of the elements such as data processing and cognitive processes. Besides, as the model mainly accounts for actions that are directed at other elements, it does not explicitly indicate the receptive actions, such as sensing and observing. Therefore, it also does not include the audience members who are only spectators of the interaction.

3 Artwork Selection and Classification

To evaluate the descriptive and comparative capabilities of the relational model for analysing different forms of co-located interaction, we develop three selection criteria and seven classification dimensions to select different artworks that are representative

of different forms of co-located interaction. The selection criteria help us to specify and narrow down the type of artworks of our interest. The classification dimensions aim to systematically delineate forms of co-located interaction that share common attributes and show the breadth of the landscape of co-located interaction in interactive art, which can in turn help us position the selected artworks within this landscape.

3.1 Selection Criteria

Our first criterion is that the artworks should involve active audience participation and at least one autonomous art system. Guljajeva distinguishes interactive art from other types of participatory art by highlighting the active engagement of the audience and the presence of an interactive system that is responsive to the audience's input [3] (p. 66). We agree that active, conscious participation of the audience is central to the interactive experience. However, we believe that an interactive system, or what we refer to as an art system in the relational model, does not only respond to the audience but can also trigger or initiate interaction and even mediate interaction between audience members.

Criterion two is that the artworks we consider use computational technologies at the core of the art system. In such cases, the computers are often used for processing data captured by sensors or input devices and programming the responses and behaviour of the art systems [4].

The third and last criterion specifies that specifies that active participation of multiple co-located audience members is required. The interaction takes place not only between the audience and art system, but also between audience members. Therefore, we do not consider interactive artworks that are designed for one audience member, despite the fact that such artworks can sometimes accommodate multiple audience members to observe the interaction.

3.2 Classification Dimensions

Before introducing our classification dimensions, we first review previous works in this area and discuss their similarities and differences compared to our approach. Mubarak proposed a taxonomy to classify co-located interaction in art installations based on factors influencing the audience experience [5]. The first factor *scale* describes the number of participating audience members and is classified as small (≤ 10), medium (11 - 100), and large (> 100). The *interaction modality* refers to the method by which the audience interacts with the artwork, which can be through direct physical manipulation (direct), through individual remote input devices (facilitated), and captured by non-invasive sensing technologies (ambient). The *input and output distribution* indicates the distribution of input and output devices of the art system and is classified as centralized, partially distributed or fully distributed. The ability of the audience to recognize the effect of their actions in the artwork is described as *feedback attributability* ranging from low to medium to high. *Activity type* describes the audience activity solicited by the artwork, which can be collaborative when the audience must work together, competitive when the audience must challenge each other, and solitary when each audience member acts independently. The last factor proposed by Mubarak, *participation symmetry*, is defined by Bell as the "distribution of actions and contributions between participants" [6], which

can be either symmetrical when the audience participates equally, or asymmetrical when audience members play different roles.

Taking Mubarak's taxonomy as a reference, we propose seven classification dimensions that focus on differentiating the various forms of organization and participation, instead of the factors influencing the audience experience discussed by Mubarak. To start, the levels of *scale* are delineated by arbitrary numbers and can hardly be considered a defining factor of an artwork. Instead, we propose *participation style* (PS) to describe the arrangement of the audience. It can be classed as duo, which is for two audience members; group, which takes place among one or more groups of audience members with limited numbers (>2); crowd, which takes place among one or more crowds of audience without any practically imposed limits on audience numbers. Additionally, the audience may have varying levels of commitment, either participating consistently throughout the interaction or having the freedom to join and leave as they wish. To distinguish between these two types, we propose *audience constellation* (AC) with fixed or fluid levels respectively.

Mubarak's *interaction modality* and *input and output distribution* pertain to aspects of the input and output set-up of an art system. For *interaction modality*, we find that it does not significantly impact the ways of participation. For instance, the audience can directly manipulate a virtual object via camera-tracking technologies, which blurs the distinction between direct and ambient modalities. For *input and output distribution*, we find that the technical configuration of an art system cannot sufficiently describe the access the audience has to it. A set of distributed devices can still be accessed by the audience equally and publicly. Instead, we propose the dimension *input and output access* (IA & OA) and distinguish private (accessible to one audience member only), partially public (accessible to more than one but not all audience members), and public (accessible to all audience members). An art system can have multiple private, partially public, public or mixed varieties of inputs and outputs.

As Mubarak's *feedback attributability* of the audience's actions can be highly subjective and contingent on the number of audience members, we do not consider it a defining factor for delineating forms of co-located interaction. Here we adopt the dimensions of *activity type* (AT) and *participation symmetry* (PSy). In many interactive artworks, the audience engages in open, hybrid and/or exploratory social activities that can neither be defined as collaborative nor as competitive. Sometimes the audience can also invent and transition between different types of activities. Therefore, we classify *activity type* as individual, when audience members participate individually and independently; social, when the activities require more than one audience member to perform together; mixed, when both types are supported. For *participation symmetry*, besides symmetrical and asymmetrical, we include varied to indicate when the audience can transition between the two.

Lastly, as mentioned before, the art system can not only respond to the audience but also initiate interaction. We use *initiator* (Ini) to indicate which element initiates the interaction, and it can be the audience, art system, other, and varied when the elements have equal chance to initiate the interaction. All the dimensions and their scale levels are summarized in Table 1.

Table 1. Classification dimensions and their scale levels for co-located interactive artworks.

| Dimensions | | Scale levels | | | |
|------------|------------------------|--------------|------------------|--------|--------|
| PS | Participation style | Duo | Group | Crowd | |
| AC | Audience constellation | Fixed | Fluid | | |
| IA | Input access | Private | Partially public | Public | Mixed |
| OA | Output access | Private | Partially public | Public | Mixed |
| AT | Activity type | Individual | Social | Mixed | |
| PSy | Participation symmetry | Symmetrical | Asymmetrical | Varied | |
| In | Initiator | Art system | Audience | Other | Varied |

3.3 Selecting Artworks

Based on the selection criteria, we can identify a wide variety of artworks. Our seven classification dimensions allow over 3,000 unique combinations, each representing a potential form of co-located interaction. However, these dimensions are not entirely independent from each other, for instance, the *input and output access* cannot be partially public if the *participation style* is duo. It is also reasonable to assume that not each unique combination has been realized. Nonetheless, it is impractical to cover all existing varieties of co-located interaction within the scope of this paper.

To tackle this dilemma, we suggest prioritizing some dimensions and scale levels to narrow down the artwork selection while preserving their potential to show the diversity of co-located interaction. Considering that not all combinations of the dimensions can be realized for each *participation style* and that the group and crowd share quite some similarities, we do not consider each of them independently but aim to cover all the variations in the final selection. The different types of *input and output access* indicate how much freedom each audience member has in the interaction and what kind of information is available to them. They affect the organization of the audience but are less significant than *participation symmetry* when it comes to considering the effects of the audience's action on the art system and the interaction. Therefore, we do not consider the *input and output access* independently when selecting the artworks.

Moreover, for *participation symmetry*, we propose to take the scale level 'varied' as an alternative to either 'symmetrical' or 'asymmetrical'. Given the definition of co-located interaction, the audience is likely to engage in social or mixed instead of individual activities. As co-located interaction mainly concerns the involvement of the audience and the art system, we focus on the audience or the art system as *initiator* of the interaction.

3.4 Selected Artworks

We searched for artworks in online archives such as the Ars Electronica Archives [7] and the Archives of Digital Art [8], and from personal knowledge of existing artworks. We selected eight artworks that satisfy the selection criteria and represent a meaningful distribution within the classification. They encompass a range of interactive experiences,

including participatory performances, games, and interactive installations, and were created between 1997 and 2016. These eight artworks and their corresponding classification scale levels are summarized in Table 2. Below we introduce them individually based on their positions in the classification dimensions.

Table 2. Eight selected artworks and their classification scale levels.

| Artwork | PS | AC | IA | OA | PSy | AT | In |
|---|-------|-------|------------------|---------|--------------|--------|------------|
| Brainball (2003) | Duo | Fixed | Private | Public | Symmetrical | Social | Audience |
| Randomly Generated Social Interactions (2016) | Duo | Fixed | Private | Private | Symmetrical | Social | Art system |
| World Skin (1997) | Group | Fixed | Private | Public | Asymmetrical | Social | Audience |
| Zoom Pavilion (2015) | Crowd | Fluid | Public | Public | Asymmetrical | Mixed | Art system |
| Boundary Functions (1998) | Group | Fluid | Public | Public | Symmetrical | Social | Audience |
| Spatial Sounds (100dB at 100km/h) (2000) | Crowd | Fluid | Public | Public | Varied | Mixed | Art system |
| Lights Contacts (2009) | Crowd | Fluid | Partially public | Public | Asymmetrical | Social | Audience |
| Body Movies (2001) | Crowd | Fluid | Public | Public | Symmetrical | Mixed | Audience |

Brainball (2003) by Smart Studio is a game between two audience members based on brain-computer interface technology [9]. The art system consists of EEG sensors, computers, software programs, a steel ball, a constructed table, and a display. Two players interact via the EEG sensors. Seated on both ends of the table, either one of the players can press a button to start the game. Their brainwaves are measured by the EEG sensors and used to control the movement of the ball on the table. The more relaxed player, as assessed via the brainwaves, scores a point over the other player. Meanwhile, both the brainwave data and game status are shown on the display next to the table.

Brainball requires two audience members to participate in a game, therefore it can be classed as a duo *participation style* in a fixed *audience constellation*. The *input access* to the art system is private as each player uses the sensor individually while the *output access* is public as the ball movement and the display can be seen by all present audience. The *participation symmetry* is symmetrical as both players contribute equally to the interaction. The interaction takes place as a competitive game, therefore the *activity type* is social. An audience member (*initiator*) can initiate the interaction by pressing a button. Brainball demonstrates a form of co-located interaction with a fixed and symmetrical participation style in a social activity initiated by the audience.

Randomly Generated Social Interactions (2016) by Anastasis Germanidis is an interactive performance in which the audience is asked to interact with each other following instructions generated by the art system [10]. The art system consists of headphones, mobile phones, and software programs. Each audience member accesses the art system via a mobile phone and headphones. The art system assigns a fictional identity to each participant and randomly matches them together in pairs. Subsequently, the participants are given computer-generated instructions via the headphones for what to say and do during their interaction with each other.

Although Randomly Generated Social Interactions enables a group of audience members to participate, the interaction is intended for pairs of participants; thus we classify it as duo *participation style* and fixed *audience constellation*. The artwork provides both private *input and output access* to each participant via the use of mobile phones and headphones. Although each participant is assigned a different fictional identity, the *participation symmetry* is symmetrical as their roles in the interaction are equal. The *activity type* is social as the participants are required to interact with each other. The art system initiates the interaction by instructing the audience (*initiator*). Based on the classification scale levels, Randomly Generated Social Interactions is largely similar to Brainball, the key difference being that its art system initiates the interaction instead of the audience. It demonstrates a form of co-located interaction with a fixed and symmetrical participation style in a social activity initiated by the art system.

World Skin (1997) by Maurice Benayoun is an interactive artwork in the form of a photo safari inside an immersive projection of a war zone landscape [11]. The art system consists of a projection room, projectors, a joystick for navigation, sensor-fitted cameras, computers, software programs, and speakers. The audience interacts via the input devices and plays different roles in the interaction. The artwork requires at least two audience members to participate. The exact number of participants depends on the number of input devices used in the exhibition set-up. One audience member plays the role of a ‘driver’ and navigates in the virtual landscape with the joystick while others play the role of ‘photographers’ who can take photos of the landscape with sensor-fitted cameras. The positions and orientations of the cameras are tracked and once a shot is taken, the corresponding surface of the virtual landscape is removed.

Similar to the previous two artworks, in World Skin the *audience constellation* is fixed and the *activity type* is social as the audience must work together to navigate and take photos. The main difference is that more than two audience members participate in the interaction. As the number of participants is limited by the number of input devices, we class it as a group *participation style*. Each participant has private *input access*

via the input devices and public *output access* as the projection can be perceived by everyone present. The audience plays different roles, making the *participation symmetry* asymmetrical, and initiates the interaction (*initiator*). The work demonstrates a form of co-located interaction with a fixed and asymmetrical participation style in a social activity initiated by the audience.

Zoom Pavilion (2015) by **Rafael Lozano Hemmer and Krzysztof Wodiczko** is an interactive installation with an immersive projection of live images of the audience inside the exhibition space [12]. The art system consists of projectors, infrared cameras, infrared illuminators, computers, software programs and speakers. The audience interacts mainly with their bodies. The camera views of the audience are displayed on the left, front, and right walls. The back wall, or 'archive wall', shows a grid of small, coupled face images of the audience. Several recognition algorithms detect the faces and bodies of the audience. When no one is detected, the cameras will zoom-out and show the maximum field of view. When one person is detected, a white rectangle is drawn around their face or body, and the camera will zoom-in until this rectangle fills the screen. When two people are detected, a line is drawn between their bodies and a word describing their relation based on their spatial distance is shown. When two people's faces are shown simultaneously, they are displayed together as a 'couple' and stored on the archive wall.

Unlike the previously mentioned artworks, although with constraints of the physical capacity of the exhibition space, Zoom Pavilion allows for a variable number of audience members with no clear demarcation between those who are observing and those who are participating. We consider its *participation style* as crowd and *audience constellation* fluid. The *input and output access* are both public, as they can be shared and perceived by all audience equally. As the art system selects the faces of some audience members to zoom-in or draw connections between their bodies, there is an asymmetrical *participation symmetry*. The *activity type* is mixed because the audience can participate both individually and collectively. For instance, two audience members can control the line drawn between them together. The art system initiates the interaction by actively selecting and drawing connections between audience members (*initiator*). This artwork demonstrates a form of co-located interaction with a fluid and asymmetrical participation style in mixed types of activities initiated by the art system.

Boundary Functions (1998) by **Scott Snibbe** is an interactive installation that requires the active participation of more than one audience member [13]. The art system consists of a camera, a computer, software programs, a projector, and a retroreflective floor. The audience interacts mainly with their bodies. When there is one person on the floor, nothing happens. With two people present, a single line cuts between them bisecting the floor and dynamically changes as they move. With more than two people participating in the interaction, the floor divides into cellular regions that demarcate the space closest to the person inside—a pattern known as a Voronoi diagram. If two or more audience members touch each other, they are registered as one unit by the art system impacting the Voronoi diagram.

The *participation style* of Boundary Functions is group as the number of participants is limited by the physical set-up of the installation. Like Zoom Pavilion, the *audience constellation* is fluid as people can join and leave the interaction freely. The *input and output access* are both public, as they can be accessed and perceived by all participants.

Since the art system responds to each participant equally, its *participation symmetry* is symmetrical. The art system requires multiple audience members to act together, and therefore the *activity type* is social and the audience is the *initiator* of the interaction. It demonstrates a form of co-located interaction with fluid and symmetrical participation style in a social activity initiated by the audience.

Spatial Sounds (100dB at 100km/h) (2000) by Marnix de Nijs and Edwin van der Heide is an interactive installation that consists of a speaker mounted on a robotic arm, custom developed software for the interaction and real time sound generation, ultrasonic sensors, and an angle sensor [14]. The audience mainly interacts with the position of their bodies in relation to the installation. The robotic arm rotates and scans the space with ultrasonic sensors mounted on the speaker. The artwork has four interaction modes. In mode 1, the arm rotates slowly and scans the space with a low humming sound that changes briefly when a person is detected. Once someone is detected, the art system continues scanning for a while and switches to mode 2, in which the arm makes one full rotation and stores at which angles it detects people. Then it randomly selects one person and attempts to follow them. The sound also changes depending on the arm's rotation speed. If the art system keeps detecting people, it will change to mode 3. If no one was detected, it switches back to mode 1. In mode 3, the arm has a fixed rotation speed but changes direction when someone is detected. The actual speed of the arm is the main parameter for the sound generation and the detection of audience is expressed by a pulse train sound. When the art system detects too many people nearby it moves to mode 4. If this does not happen, it moves back to mode 2. In mode 4, the more people there are and the closer they stand, the faster the arm rotates, while it will slow down when they move away from the arm. The sound is powerful and influenced by the rotational speed. After a fixed duration it will switch back to mode 3.

Similar to Zoom Pavilion, the *participation style* of *Spatial Sounds (100dB at 100km/h)* is 'crowd' as it allows for a variable number of audience members only limited by the exhibition space. Like the previous two artworks, the audience can join and leave the interaction freely in a fluid *audience constellation*. Unlike all previous artworks, here the art system has different modes of behaviour, which results in a varied *participation symmetry* and a mixed *activity type*. For instance, in mode 2 only one audience member is selected by the art system while in mode 3 all members have equal chance to engage in a social activity by 'passing' the art system to each other. The *input and output access* to the art system are both public and the art system initiates the interaction (*initiator*). It demonstrates several forms of co-located interaction with a fluid and varied participation style in mixed types of activities initiated by the art system. It also shows that different forms of co-located interaction can be combined to enrich the interactive experience.

Lights Contacts (2009) by Scenocosme is an interactive installation that responds to physical contact among the audience with varying sounds and lights in a public setting [15]. The art system consists of a sensor ball, a computer, software programs, LED lights, and a speaker. The audience mainly interacts with their bodies and has different functions in the interaction. A first individual is required to put their hand on the sensor ball. In doing so, the audience activates the art system and becomes an extension of its sensing unit. If that person remains alone, nothing else happens. Due to conductivity of the human body, when another person touches their skin, the art system detects changes

in the electrostatic charge, then generates sounds and alters the light accordingly. The more people touch each other the more sound sources are generated.

The *participation style* in Lights Contacts is crowd as there can be an unlimited number of participants. Like the previous three artworks, people can join and leave the interaction at any time in a fluid *audience constellation*. As the sensor ball is only available to a limited number of people, the *input access* is partially public, while the *output access* is public as the generated lights and sounds are displayed publicly. Similar to World Skin, the *participation symmetry* is asymmetrical as some people must touch the sensor ball. The participants rely on each other in a social *activity type* and initiate the interaction (*initiator*). It demonstrates a form of co-located interaction with fluid and asymmetrical participation style in a social activity initiated by the audience.

Body Movies (2001) by Rafael Lozano-Hemmer is an interactive projection installation for public spaces [16]. The art system consists of projectors, robotic controllers, portraits, a public surface, Xenon lights, a screen, a camera, computers, software programs, and speakers. The audience mainly interacts with their bodies. A set of portraits is projected on a surface and washed out by lights positioned at a distance on the floor. The audience enter the space and their shadows are thrown onto the projection surface so that portraits are revealed. The artwork tracks the edges of the shadows and once they overlap with a portrait, a hotspot is activated for a few seconds and an audio track is played. When all portraits are revealed, the artwork blacks out the projection and displays a new set of portraits at different locations on the projection surface. Meanwhile, the tracking interface is displayed in real-time on a display next to the projection.

Similar to Lights Contacts and Zoom Pavilion, the *participation style* of Body Movies is crowd as there is no practically imposed limit on the number of participants, and the audience has the freedom to join and leave the interaction in a fluid *audience constellation*. The *input and output access* are both public, as they can be accessed and perceived by all audience members equally. The *participation symmetry* is symmetrical as all people participate equally. The audience can interact both individually and with each other to reveal portraits or perform together in a mixed *activity type*. The audience initiates the interaction by casting shadows on the projection surface (*initiator*). It demonstrates a form of co-located interaction with fluid and symmetrical participation style in mixed types of activities initiated by the audience.

4 Application of the Relational Model

In this section, we apply the relational model to describe the forms of co-located interaction in the selected artworks¹. Based on these descriptions, we further compare them and identify their similarities and differences.

¹ Visualisations of co-located interaction in the selected artworks are available online: https://github.com/danxxu/co-located_interaction.

4.1 Describing the Selected Artworks Using the Relational Model

Brainball (2003) by Smart Studio

Here the interaction takes place among one art system and two audience members. There are two forms of direct private one-to-one communication from the audience to the art system. Firstly, either audience member can press the button to start the game and initiate the interaction. Secondly, both audience members share their brainwaves with the art system to compete in the game and participate in the interaction.

There are two forms of direct public one-to-many communication from the art system to the audience. The art system calculates the difference between the audience's states of relaxation based on their brainwave data and uses this information to move the steel ball as a response. This also informs the audience of their relative states of relaxation and provides a game for them to compete in. Meanwhile, the brainwave data and game status are displayed on a screen, which informs and provides feedback about the audience's states of relaxation. However, such information can also distract them and disrupt their performance.

As the ball movement and screen display reveal the mental states of the audience, it creates a form of mediated public one-to-one communication between them via the art system. The audience can also converse with each other through speech and body language in a form of direct public one-to-one communication, allowing them to exchange information, influence and disrupt each other's performance.

Randomly Generated Social Interactions (2016) by Anastasis Germanidis

Here the interaction takes place among one art system and two audience members and multiple instances of the interaction can take place simultaneously. There are two forms of direct private one-to-one communication from the art system to the audience. Firstly, the art system generates a fictional identity for each audience member to provide background for the interaction. Secondly, it instructs the audience to initiate the interaction and directs their performance. As an audience member enacts the instructions, they also communicate the information from the art system to the receiving audience member. This creates a form of mediated public one-to-one communication from the art system to the receiving audience member via the enacting audience member.

The audience can also converse with each other through speech and body language in a form of direct public one-to-one communication, allowing them to respond to the instructions and participate in interaction. Meanwhile, this form of communication provides channels for them to exchange information and coordinate actions that are not prescribed by the art system.

World Skin (1997) by Maurice Benayoun

Here the interaction takes place among one art system and at least two audience members. There are two forms of direct public one-to-one communication from the audience to the art system that depend on the role of the audience. If an audience member is the 'driver', they navigate the landscape to initiate and participate in the interaction and facilitate the 'photographers'. If an audience member is one of the 'photographers', they take photos of the landscape to express themselves, initiate and participate in the interaction. Multiple instances of such communications can take place.

There are two forms of direct public one-to-one communication from the art system to the audience. Firstly, the art system updates the virtual landscape as a response to the 'driver' and provides content for interaction. Secondly, the art system removes the pixels of taken shots in the landscape as a response to the 'photographers' and provides means for expression. Multiple instances of such communication can take place. Meanwhile, the art system plays audio to enhance the interactive experience in a form of direct public one-to-many communication to the audience.

Among the audience members, there are two forms of public communication and multiple instances of such communications can take place. Firstly, they can express themselves by changing the landscape either through navigation or taking photos in a form of mediated one-to-many communication via the art system. Secondly, they can converse with each other through speech and body language in a form of direct many-to-many communication to exchange information and coordinate actions.

Zoom Pavilion (2015) by Rafael Lozano-Hemmer and Krzysztof Wodiczko

Here the interaction takes place among one art system and one or more audience members. There are two forms of direct public communication from the audience to the art system and multiple instances of both forms of communication can take place. Firstly, the audience members enter the exhibition space to participate and perform in the interaction in a form of many-to-one communication. Secondly, once selected as a pair, the audience members can move to vary the line drawn between them to participate in the interaction and express themselves in a form of many-to-one communication.

There are five forms of direct public communication from the art system to the audience and multiple instances of such communications can take place. Firstly, the art system displays live camera images on the walls to provide content for interaction and a means for expression in a form of one-to-many communication. Secondly, the art system can zoom-in on the face of a chosen audience member to initiate interaction, isolate them, and provide a means for expression in a form of one-to-one communication. Thirdly, the art system can draw a line between two chosen audience members and label their spatial relations to initiate interaction, provide shared control of its visual response and a means for expression in a form of one-to-many communication. Fourthly, the art system stores and displays paired images of the audience to draw connections between them and provide a visual history of the interaction in a form of one-to-many communication. Lastly, the art system plays audio to enhance the perception of its actions in a form one-to-many communication.

Among the audience members, there are three forms of public communication and multiple instances of such communications can take place. Firstly, once an audience member's face is magnified by the art system, they can make facial expressions to participate in the interaction and express themselves in a form of mediate one-to-many communication via the art system. Secondly, pairs of audience members can move to vary the line between them to communicate and perform with each other in a form of mediated one-to-one communication via the art system. Lastly, the audience can also converse with each other through speech and body language in a form of direct many-to-many communication, which allows them to exchange information and coordinate actions.

Boundary Functions (1998) by Scott Snibbe

Here the interaction takes place among one art system and at least two audience members. There are two forms of direct public communication from the audience to the art system and multiple instances of such communications can take place. Firstly, the audience can move across the floor to initiate and participate in the interaction, and express themselves in a form of one-to-one communication. Secondly, the audience can touch each other to trigger a different response from the art system in a form of many-to-one communication.

There are two forms of direct public one-to-many communication from the art system to the audience. Firstly, the art system projects a Voronoi diagram based on the positions of the audience as a response to their actions and provides shared control and a means for expression. Secondly, when audience members touch each other, the art system reconfigures the Voronoi diagram as a response and to create connections between the audience. Multiple instances of such communication can take place.

There are two forms of public many-to-many communications among the audience and multiple instances of such communications can take place. Firstly, the audience can move towards or away from each other to shape the Voronoi diagram in a form of mediated communication via the art system. Secondly, the audience can converse with each other through speech and body language in a form of direct communication, allowing them to exchange information and coordinate actions.

Spatial Sounds (100 dB at 100 km/h) (2000) by Marnix de Nijs and Edwin van der Heide

Here the interaction takes place among one art system and at least one audience member. As there are different interaction modes, we describe each separately. In mode 1, there are two forms of direct public one-to-many communication from the art system to the audience. Firstly, the art system rotates to inform the audience the current interaction mode and gather inputs for interaction. Secondly, the art system plays audio to enhance the perception of its movement. Once it detects an audience member, it changes the audio to inform them of the detection and initiates the interaction in a form of direct public one-to-one communication. Multiple instances of such communication can take place. When the audience approaches the art system, they are registered by the art system which allows them to participate in the interaction and trigger a switch of interaction mode. This creates a form of direct public one-to-one communication to the art system, while multiple instances of such communication can take place.

If the art system keeps detecting audience, it switches to mode 2. In this mode, it first makes a full rotation and scans the space to gather inputs for the interaction and inform the audience the current interaction mode in a form of direct public one-to-many communication to the audience. Then it selects one audience member for two forms of direct public one-to-one communication. Firstly, the art system follows the selected audience member to initiate interaction and isolate them. Secondly, it generates audio based on its rotation speed to enhance the perception of its movement. The chosen audience member can move to direct the art system and participate in the interaction in a form of direct public one-to-one communication to the art system. During this interaction, other audience members can approach the art system while their presence is registered to trigger a switch of interaction mode, effectively in a form of direct public one-to-one communication to the art system. Multiple instances of such communication can take

place. Note that although the art system attempts to follow one specific audience member, it may lose track of them if they move away or if another person appears between them and the art system. If no person can be detected for some time, the art system reverts to mode 1. If the art system keeps on detecting audience members, it switches to mode 3.

In mode 3, there are two forms of direct public one-to-many communication from the art system to the audience. Firstly, the art system rotates at a fixed speed to indicate the current interaction mode. Secondly, it generates audio based on its rotation speed to enhance the perception of its movement. Once an audience member is detected, there are two forms of direct public one-to-one communication from the art system to the audience and multiple instances of such communication can take place. Firstly, the art system changes direction to initiate the interaction and provide a game for the audience. Secondly, it plays audio upon detecting an audience member to inform and enhance the perception of its action. Meanwhile, the audience can move to direct the art system, participate in the game and trigger a switch of interaction mode. This creates a form of direct public one-to-one communication to the art system and a form of mediated public one-to-one communication between the audience members via the art system as they can 'pass' it around to express themselves. Multiple instances of both communications can take place. If the audience moves away, the art system reverts to mode 2. If the audience remains in front of the art system, it switches to mode 4.

In mode 4, there are three forms of direct public one-to-many communication from the art system to the audience. Firstly, the art system speeds up to indicate its behaviour change and urge the audience to move away. Secondly, once the audience moves away, the art system slows down as a response and to indicate its behaviour change. Lastly, the art system generates audio based on its rotational speed to enhance the perception of its movement. The audience can move away as a response and to comply with the art system. This creates a form of direct public one-to-one communication to the art system and multiple instances of such communication can take place. After some time, the art system reverts to mode 3.

In all modes, the audience can converse with each other through speech and body language to exchange information and coordinate actions. This creates a form of direct public many-to-many communication and multiple instances of such communication can take place.

Lights Contacts (2009) by Scenocosme

Here the interaction takes place among one art system and at least two audience members. There are four forms of public many-to-one communication from the audience to the art system that depend on the actions they take. Firstly, one or more audience members can touch the sensor ball in a form of direct communication to activate the art system and serve as a prerequisite for the interaction. Subsequently, other audience members can touch the 'activating' audience, or the other way around, to trigger the response of the art system, initiate and participate in the interaction and express themselves. This creates both a form of mediated communication from the subsequent audience to the art system via the 'activating' audience and a form of mediated communication from the 'activating' audience to the art system via the subsequent audience. Lastly, once the art system is activated, the activities of both groups of audience are registered by art system.

This creates a form of direct public many-to-one communication from all audience to the art system.

There are two forms of direct public one-to-many communication from the art system to the audience. Firstly, the art system generates audio based on the audience's contact with each other as a response and to provide feedback about their touch intensity and a means for expression. Secondly, the art system alters the colours and behaviours of the lights in line with the audio to enhance the audience's perception of it.

There are two forms of public many-to-many communication between the audience. Firstly, as the lights and audio directly reflect their contact with each other, they can communicate with each other via the light and audio by altering their touch in a form of mediated communication via the art system. Secondly, the audience members can converse with each other through speech and body language to exchange information and coordinate actions in a form of direct communication. Multiple instances of such communication can take place.

Body Movies (2001) by Rafael Lozano-Hemmer

Here the interaction takes place among one art system and one or more audience members. There is a form of direct public many-to-one communication from the audience to the art system and multiple instances of such communication can take place. The audience cast their shadows on the projection and the camera captures and tracks the shadow contours, allowing them to initiate and participate in the interaction.

There are four forms of direct public one-to-many communication from the art system to the audience. Firstly, the art system displays the shadows of the audience to provide feedback about their movements and a means for expression. Multiple instances of such communication can take place. Secondly, the art system displays the tracking interface to provide feedback and inform the audience of their performance and the status of interaction. Thirdly, when a shadow overlaps with a portrait, the art system activates a hotspot and plays an audio clip in response to provide feedback about the achievement. Multiple instances of such communication can take place. Lastly, once all hotspots are activated, the art system blacks out the projection and updates the portraits as a response and initiates a new session of interaction.

There are two forms of public communication between the audience and multiple instances of such communications can take place. Firstly, the audience can communicate with each other through their shadows to express themselves and perform in the interaction. This creates a form of mediated many-to-many communication via the art system. Secondly, the audience members can also converse with each other through speech and body language to exchange information and coordinate actions in a form of direct many-to-many communication.

4.2 Comparing the Selected Artworks

The relational model provides a systematic framework for describing the various forms of co-located interaction in the selected artworks. It breaks down interactions by examining the actions performed by interacting elements and the various forms of communication resulting from these actions. This approach not only helps us describe interactions but also allows for consistent comparisons between them. In total, we identify five common

themes from the similarities and differences between the selected artworks and discuss them individually below.

Types of Reactions

In all selected artworks, some actions of the elements serve as responses to other elements' actions. We can say that the elements can act and react to each other. This is the case primarily between the art system and the audience. Upon examination, we observe several different types of reactions.

To start, reactions performed by the art system can provide feedback about the effects of audience actions on the art system and the interaction. For instance, in *World Skin*, the art system changes the display of the landscape according to the actions of the audience. In *Brainball*, *Body Movies*, and *Spatial Sounds* (100dB at 100km/h), the art system uses visual or auditory displays to inform the audience of the status of interaction or its recognition of them. Besides that, reactions of the art system can provide continuous sensory cues on the actions of the audience. This is most obvious in *Zoom Pavilion*, *Boundary Functions*, and *Lights Contacts*, in which the art systems translate information such as the audience's mutual distances and touch intensity into visual and/or audio cues. Lastly, the reactions of an art system can in turn trigger or initiate the interaction. For instance, in *Zoom Pavilion* and *Spatial Sounds* (100dB at 100km/h) the art system reacts to the presence of the audience with visual and/or audio and physical responses to initiate interaction.

Conversely, reactions of the audience are mainly to comply with or perform actions demanded by the art system. For instance, in *Randomly Generated Social Interactions* and modes 2 and 4 of *Spatial Sounds* (100dB at 100km/h), the audience follows instructions or prompts from the art system to engage in specific actions. It is important to note that reactions are not isolated events but rather part of a continuous process of exchange between actions and reactions. As a result, a reaction to one element can trigger further reactions or influence subsequent actions of that element.

Influences Between Actions

Besides action-reaction relationships, the actions performed by elements can also influence each other in other ways. Firstly, an action can act as a prerequisite for subsequent actions, necessitating the element to execute the action prior to or concurrently with other actions. As in *Brainball*, a participant must press a button to start the game. In *Lights Contacts*, the audience must first touch and maintain contact with the sensor ball to activate the art system. Furthermore, an action can disrupt the execution of other actions. In *Brainball*, the display of real-time brainwave data and direct communication between the audience can hinder the performance of individual players in the game. Lastly, an action can facilitate or enhance other actions, often in parallel to each other. For instance, in *World Skins* an audience member navigates the landscape to facilitate others taking photos, and the art system plays audio to enhance their experience. The use of audio to enhance the perception of other actions is also seen in *Zoom Pavilion* and *Spatial Sounds* (100 dB at 100 km/h), while in *Lights Contacts* it is light that enhances the perception of the audio.

Roles of Direct Communication between the Audience

As a characteristic of co-located interaction, the audience can communicate with each other directly. This communication can take the form of verbal exchanges and non-verbal means, such as gestures, facial expressions, and touch. Direct communication among audience members enables them to exchange information and coordinate their actions. By sharing their experiences and knowledge of the interaction's mechanics, the audience can propose new ideas, insights, and comments on each other's performance. Here direct communication can facilitate the audience to take action. This dynamic is present in all artworks but *Brainball*, where direct communication can actually disrupt the players' composure, potentially affecting their ability to succeed in the game.

Moreover, direct communication among the audience can also become part of the interaction. Notably, in *Randomly Generated Social Interactions*, the art system instructs the audience to communicate directly with one another, making this form of communication a central aspect of the interaction. Similarly, in *Boundary Functions* and *Lights Contacts*, physical touch of audience members triggers responses from the art system, making direct communication a key mechanism driving the interaction.

Creating Connections among the Audience

A recurring theme in all selected artworks is the art system's active role in establishing or enabling connections among the audience during the interaction. We observe several distinct approaches to achieve this.

Firstly, connections can be created in an arbitrary manner. For instance, in *Randomly Generated Social Interactions*, the art system instructs the audience to engage and converse with one another. Similarly, in *Zoom Pavilion*, the art system randomly pairs the faces or bodies of audience members, facilitating chance encounters.

Secondly, in some instances the art system creates interdependencies among the actions of the audience: the actions of one audience member may affect or depend on the actions of others. There are different ways in which art systems utilize this approach. The art system can draw upon the differences in people's behaviours. In *Brainball*, the movement of the ball is determined by the relative states of relaxation of two audience members, rather than being controlled by a single individual. Alternatively, an art system may react to actions that require multiple persons to perform together. For instance, the audience must touch each other to trigger responses from the art system in *Lights Contacts* and *Boundary Functions*. Yet another manifestation is when the art system enables shared control over its responses among the audience, as in *Zoom Pavilion*, where the art system draws a line between two audience members that varies as they move closer and further apart. Similarly, in *Boundary Functions* the Voronoi diagram depends on the positions of all audience members.

Another strategy employed by art systems to foster connection is by encouraging collaborations among the audience. As demonstrated in *World Skin* and *Lights Contacts*, the audience members play different roles and have different functions, requiring them to work together in the interaction.

A final approach observed is seemingly counterintuitive: the art system creates connections between audience members by isolating an individual from the rest. In such instances, the art system deliberately focuses on a single person, placing them under a spotlight. By doing so, it amplifies the selected individual's actions, triggering them

to express and connect with others. This effect is evident in Zoom Pavilion, where the art system randomly selects and magnifies the face image of an audience member. Similarly, in mode 2 of Spatial Sounds (100dB at 100km/h), the art system randomly chooses an audience member to follow. This deliberate ‘isolation’ also evokes an emotional connection among the audience, as the possibility of being chosen looms over all its members.

Forms of Mediated Communication

In all works, there is at least one form of mediated communication, where one element communicates with another element through a third element. Most prevalent is the audience’s mutual communication via the art system. In works such as World Skin, Body Movies and Zoom Pavilion, the art system provides a stage and means for expression to the audience. Alternatively, it can translate information about audience actions into additional sensory cues to be used by the audience to communicate with each other—as in Zoom Pavilion, Boundary Functions, and Lights Contacts, the distances between the audience members are translated into (audio-)visual cues.

Alternatively, audience members can communicate to the art system via another audience member. As shown in Lights Contacts, the art system only responds when two groups of audience members touch each other.

A third intriguing form of mediated communication is observed in Randomly Generated Social Interactions, where the art system generates content and instructs audience members to act it out, thereby conveying the information to others. In this scenario, the art system communicates to the receiving audience members via the acting audience member who becomes in effect a ‘tool’ for expression.

5 Discussion and Conclusion

As shown in the previous section, the relational model enables us to provide detailed descriptions of a diverse range of co-located interactions. We carefully selected eight artworks that represent different forms of co-located interaction based on different combinations of *audience constellation*, *participation symmetry*, *activity type*, and *initiator*. Using the relational model we described their co-located interactions following the actions of the audience and art system in terms of various forms of communication. This allows us to specify the role each element plays in the interaction and how they influence and relate to each other. The main concepts used in the model—the identification of elements, their actions and forms of communications to each other—were shown to be universal and applicable to all artworks. More importantly, the model’s approach provides a frame for analysis that can be adapted to examine and compare different forms of co-located interaction.

A key aspect of the relational model is identifying the roles of the actions performed by the elements. In doing so, we observe different ways in which the audience and the art system can act and react to each other, revealing patterns in these relationships. Additionally, it highlights the influences between actions of the elements that are necessary for the interaction and establishing various mutual relationships. We can envision creating new forms of interaction by composing different types of action-reactions and influences

between actions for different elements. An intriguing avenue for future investigation is a comprehensive exploration of existing relationship typologies and their prevalence across different elements in interactive artworks.

The relational model not only enables us to dissect and examine interaction in terms of various forms of communication but also provides a template for conceiving and creating new relationships among the elements. It shows that an element can both influence other elements directly and mediate the communications between other elements. One related insight of co-located interaction that was revealed by our analyses pertains to its inherently social nature. By definition, a co-located interaction requires multiple co-located audience members to participate simultaneously and the interplay between them becomes central to the overall interactive experience. To achieve this, an art system can employ diverse strategies to foster connections between audience members, draw upon the direct communication between co-located audience members, and devise novel forms of mediated communication.

The relational model does not make prior assumptions about behaviours of an art system and the audience, and attempts to describe them in equal terms. This perspective opens up possibilities to conceive new ways of participation. For instance, the audience can be 'used' as a tool for expression and communication. Nevertheless, we also notice the differences between the behaviours of art systems and audiences. For the art system, its actions are usually concrete and definable as they are often programmed and scripted. While for audiences, their actions are more open and diverse, and variable on an individual basis. As a result, we often use general terms to describe the actions of the audience. However, we also see opportunities here to create art systems that are more 'human' and can surprise or even make mistakes; such as in *Spatial Sounds* (100dB at 100km/h), where the art system may misidentify the audience.

Meanwhile, when speaking of the audience, we only consider those who are actively participating in the interaction and not those who are merely observing. In some artworks, there is no clear distinction between participating and observing audience members, as in *Zoom Pavilion*, *Spatial Sounds* (100 dB at 100 km/h), and *Body Movies*. While in other works, there is a clear distinction between participating and observing audience. This is the case for both fluid and fixed *audience constellation*, as shown in *Brainball*, *Randomly Generated Social Interactions*, *World Skin*, and *Boundary Functions*. In these works, the presence of spectators can potentially influence the participating audience. It may be valuable to include this influence in the model too.

We have selected artworks that were mainly developed in the Western cultural context, created between 1997 and 2016 and with documentation available. Our classification dimensions focused on parameters defining audience participation. In the future, it would be interesting to apply the relational model to more recent artworks, use different classification methods, such as aspects defining audience experience and include different cultural contexts.

To conclude, we demonstrated the effectiveness of the relational model in describing and comparing different forms of co-located interaction in interactive art. The model provides a systematic approach to examine co-located interaction and uncover the various relationships and influences between interacting elements. Moreover, it allows us to compare different artworks and reveal patterns of co-located interaction. Through the

analysis, we have identified insights about co-located interaction and opportunities for creating new forms of communication and interaction. While our focus has been on co-located interaction, the same process can be applied to study other types of interaction and audience participation. The relational model shows a concrete step forward from the dialogue model to further understand interaction in interactive art.

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