A relational approach to understanding interactions in interactive art

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A Relational Approach to Understanding Interactions in Interactive Art

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Contents

Chapter 1

Introduction

This thesis presents a study on modelling interactions in interactive art. In this chapter, we begin by introducing the background of interactive art and the significance of modelling interactions within this field. The main aims and research questions addressed in the thesis are then outlined. This is followed by a summary of the approaches and methods employed to investigate these questions. Finally, the chapter concludes by presenting the overall structure of the thesis and its main contributions.

1.1 What is Interactive Art?

Interactive art is often characterised by active audience participation and the creation of dynamic art systems employing digital technologies. Unlike static artworks such as paintings, interactive art involves a two-way influence between the artwork and its audience, prompting both parties to respond to and shape each other's actions. However, the concept of audience participation is not exclusive to the realm of digital interactive art. Under the umbrella of participatory art, Fluxus artists in the 1960s pioneered performances or "happenings" that actively involved spectators as participants and collaborators (Holdar, 2017). Around the same time, Brazilian artist Lygia Clark developed "relational objects" designed to heighten the audience's awareness of their own bodies through actions with these objects proposed by the artist (Bourriaud, 2002). In both cases, the role of the audience shifted from passive spectatorship to a more engaged, creative one.

The integration of computers into art practices further revolutionised the development of interactive art, exemplified by the 1968 exhibition *Cybernetic Serendipity* at the Institute of Contemporary Arts in London (Usselmann, 2003). This exhibition showcased cybernetic art based on the principle of feedback and control, employing electronic or computer technologies to respond dynamically to external stimuli such as environmental changes or audience actions. These explorations of computer-based interactivity gave rise to a new form of interactive art, opening up opportunities to create dynamic systems capable of engaging with audiences in new ways that were not possible before.

Recognising the transformative impact of computers on artistic practice, Cornock and Edmonds propose a taxonomy of art systems involving computer technologies in a 1973 paper, examining the relationships between artworks, participants, and the environment(Cornock & Edmonds, 1973). It is worth noting that Cornock and Edmonds use the term "system" to describe both the total system, including the artwork and the influencing elements (e.g., participant, environment, time), and the artwork as a system. This taxonomy classifies the total system and includes:

- The static system: The artwork remains unchanging, similar to traditional art objects.
- The dynamic-passive system: The artwork changes over time or responds to environmental factors without participant intervention.
- The dynamic-interactive system: Extends the dynamic-passive system by incorporating participant input, creating a feedback loop between artwork and audience.
- The dynamic-interactive system (varying): A special case in which the artist modifies the system or process in ways not covered by its original definition.

Cornock and Edmonds also introduce the concept of "the matrix" to describe the overarching system within which both the art system and participants operate. Within this matrix, participants play an integral role, at least partially determining the artwork's outcome. Consequently, the traditional role of the artist is challenged: although the artist conceives and initiates the work, they cannot fully control every aspect of its outcome, and furthermore, they often must collaborate with other artists or technical specialists to realise a complex, dynamic art system. As a result, there is no fixed outcome and the artwork becomes non-deterministic.

At the core of interactive art lies the relationship between the artwork and the audience. When analysing computer-driven participatory art, Bell distinguishes interactive art systems from other types of participatory art by emphasising the mutual exchange between humans and machines—or artwork—in a manner similar to a conversation between two human beings (Bell, 1991). This conversational analogy is further advanced by Schraffenberger and van der Heide, who propose a dialogue model for audience–artwork interaction, highlighting that both artwork and audience can not only respond to each other but also have the freedom to act independently—much like two human interlocutors (Schraffenberger & van der Heide, 2012, 2015).

However, such interactive dialogues are not restricted to exchanges between a single audience member and one artwork. As we will elucidate in Chapter 4 and Chapter 5, many interactive artworks involve multiple participants, and in some cases, these may even be nonhuman life forms. In these scenarios, the interaction takes place not only between the artwork and the audience but also among the participants themselves, resulting in complex relational dynamics (Ahmed, 2018). Furthermore, as Kwastek observes in her analysis of digital interactive art, these artworks are frequently presented in public settings with an intentionally positioned performative area, which allows other spectators—or potential participants—to observe the interaction (Kwastek, 2013).

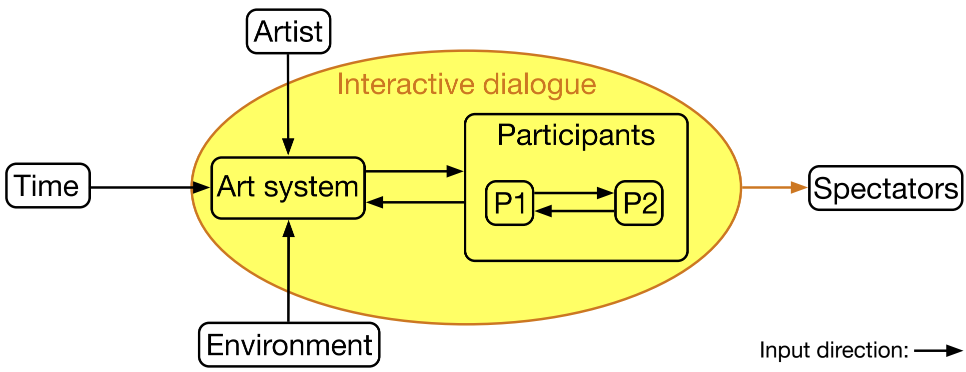

Figure 1.1: Diagram illustrating the primary factors influencing an interactive artwork, with the arrows indicate the main input flows, adapted and modified from Cornock and Edmond's classification diagram. The area highlighted in yellow background indicates where the interactive dialogue takes place.

Taking these perspectives into account, we can sketch out the key factors and various influences shaping an interactive artwork in Figure 1.1[1]. Furthermore, we consider the interactive dialogue an essential component of an interactive artwork. Therefore, we use the term "art system" to indicate the technical body of the artwork for greater clarity.

In this thesis, we are primarily interested in investigating how interactive dialogues manifest in interactive art and understanding the various interactive dynamics at play, particularly in artworks involving multiple participants, as illustrated in Figure 1.1. An in-depth study of these dialogues would not only yield insights into existing practices but also reveal new op-

[1]Here, we only consider the major input flows. It is reasonable to assume that the presence of spectators can also influence the performance of participants, and that the behaviours of participants may affect the decision-making process of the artist.

portunities for future research and artistic creation. To achieve this, we need a systematic and effective approach for dissecting and analysing interactions in interactive art.

1.2 Why Modelling Interaction?

In science, a model is commonly understood as a representation of a target—be it an object, phenomenon, process, concept, or system—designed to explore, explain, or predict that target's behaviour (Oh & Oh, 2011). Models serve as intermediaries between theory and the natural world, allowing researchers to develop theories based on empirical data while also guiding the practical application of established theories. Moreover, scientific models typically employ visual resources, analogies, and simulations to describe, explain, and predict real-world phenomena, facilitating the communication of complex scientific ideas. Importantly, a model does not aim to reproduce reality in its entirety; rather, it offers a simplified version of the target, emphasising selected aspects deemed significant for a specific purpose.

Specifically, a model provides a formal vocabulary and language to specify the target system's properties and behaviours. Edmonds, drawing an analogy to painters who describe colours in terms of hue, texture, and other qualities, advocates for a critical language to articulate, compare, and discuss interactive digital art (Edmonds, 2010). Such a language would enable us to systematically analyse and communicate the defining factors that shape an interactive dialogue. Consequently, in this thesis, we define a model of interaction as: a theoretical and conceptual tool that describes how interactions occur from a specific perspective, outlining key concepts, relationships, and principles governing interactive dynamics.

Meanwhile, modelling interaction refers to the practical process of applying an interaction model to represent, describe, or analyse real or hypothetical interactions. This process entails translating theoretical constructs of the model into concrete representations such as diagrams, formal descriptions, or simulations, either by hand or using specially designed tools. By doing so, researchers and practitioners can systematically examine, compare, refine, or implement complex and diverse interactions. Much like scientific models, developing and applying an interaction model enables a deeper understanding of interactive dialogues. Here, we further elaborate on the practical and theoretical benefits of modelling interactions in interactive art.

Firstly, modelling interactions can produce standardised visual descriptions that enhance communication among artists, collaborators, and audiences. For artists and designers, such representations are valuable for sharing concepts with technical team members during development or with curators and producers as part of proposals or setup plans. Externalising abstract ideas into visual or textual formats also provides tangible materials for reflection, adaptation, and experimentation, supporting ideation and conceptual development. For audiences, the modelling practice offer a vocabulary to articulate their experiences, enabling artists to gather meaningful feedback.

Meanwhile, standardised descriptions also facilitate systematic comparisons between different artworks or the same artwork at various stages of development. These descriptions not only capture the essence of an artwork for archival purposes but also serve as valuable resources for future recreations, adaptations, or academic analyses. Moreover, systematic comparisons of large collections of artworks enable the identification of common patterns and unique characteristics across interactive artworks, contributing to the establishment of benchmarks and best practices that refine methodologies for creating and studying interactive art. These insights can also inspire the creation of new forms of interaction by questioning and challenging existing patterns.

Furthermore, structured interaction models also allow for the simulation and prediction of an interactive system's behaviour. Through simulation, artists can explore how art systems respond to various inputs, including audience behaviours, before physical realisation. This predictive capability enables testing and refining interaction dynamics, identifying potential issues, and exploring alternative scenarios. Simulations also benefit curators and technicians by providing insights into the intricacies of an artwork, aiding in setup, maintenance, and troubleshooting.

Lastly, a systematic study of interactive art also contributes to other areas of Human-Computer Interaction (HCI). The unconventional thinking and creative efforts exhibited in the creation of interactive art can inspire new forms of interaction applicable to other domains of interaction design (Duarte & Baranauskas, 2018)(Duarte et al., 2019). Moreover, interactive artworks can be seen as experiments with emerging technologies, sometimes repurposing them beyond their conventional usage, which stimulates the development of novel interactive systems and technologies (Jeon et al., 2019). Beyond these practical benefits, interactive art frequently adopts a critical perspective on technological development, challenging established norms and inherent assumptions regarding the design of interactive technologies and our relationship with them.

1.3 Aims and Questions

There exist a wide variety of approaches attempting to describe, classify, and evaluate interactive artworks (Schraffenberger & van der Heide, 2012, 2015). However, most of these methods offer a limited, one-sided perspective, focusing either on the experience of the participants or the behaviours of the art system. As a result, they often fail to account for the relational exchange between the two and recognise interaction as a continuous, bidirectional process, overlooking critical factors defining an interactive artwork. Recognising this gap, the central question driving this thesis is:

> **Q1:** How can we model interactions in interactive art in a way that effectively and structurally captures the relational exchanges between the art system and its participants?

A relational approach to describing interaction considers both the individual behaviours of the art system and the participants, as well as how they influence and condition each other through their actions and reactions. Since interaction is inherently a relational process, this perspective provides a deeper understanding of the dynamics and roles of the interacting elements. Therefore, the first objective of this thesis is to develop a relational model of interaction that offers a consistent analytical template and vocabulary for dissecting and describing interactions in interactive art.

Building on this theoretical model, we also aim to operationalise it by developing a modelling tool with an accessible interface and functionalities that facilitate the description process and visualise the described outcomes. In doing so, we seek not only to communicate the relational interaction model more effectively, but also to provide researchers and practitioners in interactive art with a practical tool that can benefit their workflows.

Using the relational model and the tool as the primary analytical lens, we will apply them to describe a diverse selection of interactive artworks. This process serves a dual purpose: first, to evaluate the modelling capabilities of both the model and the tool, and second, to discover patterns and insights into interactions in existing interactive artworks by systematically comparing the descriptions. This exploration leads to the second key research question:

> **Q2:** What insights into interactions in interactive art can be gained from a relational modelling approach?

Although the relational model is designed to be applicable to a wide range of interaction forms, this thesis focuses specifically on exploring variations in *co-located interaction* and *more-than-human interaction*. Co-located interaction occurs when multiple audience members interact simultaneously with an interactive artwork within a shared physical space, where the presence and interactions among audience members are not merely incidental but are integral to the artwork itself. This form of interaction extends beyond a dyadic audience-artwork relationship to encompass a more complex relational scenario, involving interactions both between the audience and the artwork and among the audience members. We argue that co-located interaction presents a compelling case study to evaluate the flexibility and adaptability of the relational modelling approach. Consequently, research question Q2 can be further refined into the following sub-question:

Q2a: What insights into co-located interaction can be gained from a relational modelling approach?

On the other hand, more-than-human interaction represents an emerging trend in interactive art, involving nonhuman organisms as participants to the interaction. This perspective challenges anthropocentric worldviews by recognising the agency and influence of nonhuman entities. As such, artworks within this domain must account for the significant role of nonhuman participants in shaping the interactive experience. Despite increasing interest in such practices, there remains a notable lack of critical studies examining the interactive and relational dynamics within more-than-human interactive art. Therefore, this thesis seeks to test the capabilities of the relational modelling approach in analysing such artworks and uncover insights and limitations inherent to them. This leads to the second sub-question of Q2:

Q2b: What insights into more-than-human interaction can be gained from a relational modelling approach?

In addition to modelling and visualising interactions, we argue that the relational model and its accompanying tool can also support the exploration of new forms of interaction that do not yet exist. By identifying patterns related to the roles of different types of elements in existing interactive artworks, this approach can inform the discovery and creation of novel interactive dialogues. Therefore, the next question we would like to address in this thesis is:

Q3: Can a relational modelling approach support the discovery and creation of new interactive dialogues?

Through the development, application, and evaluation of the relational model and its accompanying tool, we can explore how this approach benefits the research and creation of interactive artworks, while uncovering opportunities and potential avenues for its future evolution. However, since no model can fully encapsulate the complexity of reality, we also critically examine the limitations of this approach, clearly defining its scope and intended applications scenarios. These reflections are encapsulated in the following two research questions:

Q4: What benefits and opportunities does a relational modelling approach provide for understanding and creating interactive art?

Q5: What are the limitations of a relational modelling approach for understanding and creating interactive art?

1.4 Approaches and Process

To address the aims and questions of this thesis, we adopt three complementary approaches. The first approach focuses on theoretical exploration. We begin by reviewing existing interaction models for interactive art, critically examining their strengths and limitations. This analysis allows us to situate our relational interaction model within the broader landscape of interaction models. Building on this foundation, we define the core concepts and descriptors necessary to capture the relational exchanges among elements within an interaction, informed by relevant theoretical discussions. The result of this process is the initial version of our relational model of interaction.

We would like to emphasis here that our theoretical exploration was intentionally constrained within specific interaction models and related tools, and that the concepts and definitions of the relational model were developed with relative independence. While we acknowledge the broader theoretical discourses on interactivity and relationality in philosophy and art theory, these are not the primary focus of this thesis. Nevertheless, we recognise that our work intersects with these discourses in meaningful ways and could both contribute to and benefit from them in future developments.

Our second approach combines practical experimentation with reflective inquiry, adopting a *Research-through-Design* methodology where the development and evaluation of designed artefacts serve as a primary means of generating and communicating new knowledge (Zimmerman & Forlizzi, 2014). Building on the theoretical foundation of the relational model, we design and develop the Relational Modelling Tool (RMT) to describe, visualise, and generate interactions. By translating theoretical constructs into a tangible format with a formal structure, we critically examine the relational model, identify missing components, and uncover potential refinements. This process not only strengthens the model but also reveals opportunities to introduce new features and functionalities that were previously unanticipated.

The third approach centres on the empirical study of the application of RMT, both through our own use and by engaging a wider user group. Throughout its development, we routinely test the modelling capability of RMT by applying it to describe diverse interactive artworks. Here, we do not aim to provide an exhaustive list of artworks–as this would also be practically impossible–but instead carefully select a set of works representative of different forms of co-located interaction (Chapter 4) and more-than-human interaction (Chapter 5), based on developed taxonomies and preliminary analyses. These practical applications generate concrete data for evaluating its effectiveness and provide valuable insights into the described interactive dialogues. Additionally, we organised a workshop with external participants, where RMT is used to model and generate new interactive dialogues. This allows us to gather feedback on

RMT's usability and functionality while collectively reflecting on its strengths, potentials, and limitations.

Finally, we would like to emphasise that our research process is inherently nonlinear and highly iterative. This is particularly evident in the development of RMT. As mentioned before, the outcomes from the empirical evaluations of RMT have been instrumental in shaping its successive updates, leading up to the present version. At the same time, these findings have informed the ongoing refinement of the underlying relational model and contributed to our broader reflections on the strengths and limitations of a relational modelling approach for interactive art. As we expand and enhance the features of RMT, we continue to deepen our understanding of its capabilities and potential. This is only possible as the research and development processes are tightly integrated, where the outcomes from one process continuously provide input and inspiration for the other.

1.5 Thesis Structure

In addition to this introductory chapter, the thesis comprises seven further chapters.

Chapter 2 reviews existing interaction models and tools for describing and analysing interaction in interactive art, discussing their strengths and limitations. Drawing on this analysis, we outline the key considerations for developing an interaction model that can capture a wide range of interactions. We then introduce our relational model of interaction, defining its key concepts and descriptors for dissecting and analysing interactive dialogues.

Chapter 3 focuses on the design and development of the Relational Modelling Tool (RMT) based on the relational model. Here, we elaborate on the key components of RMT for describing and visualising interactive dialogues, compare its functionalities with the original relational model, and discuss its potential benefits and future applications.

Chapters 4, 5, 6 demonstrate the modelling capabilities of RMT in describing and visualising diverse forms of interaction and beyond. Each chapter explores a distinctive form of interactive or participatory art, providing selected artwork examples and descriptions of the respective interactions or participatory processes using RMT. We then discuss the insights gained into the different forms of interaction, the effectiveness of RMT's modelling approach, and its limitations and potential improvements. Specifically:

- Chapter 4 analyses eight carefully selected interactive artworks exploring co-located interaction-when two or more audience members are physically present at the same location, participating simultaneously in the interactive experience.
- Chapter 5 explores the emergence of more-than-human interaction and the significance

of nonhuman participants in interactive art. It analyses five interspecies interactive artworks involving both human and nonhuman organisms.

- Chapter 6 extends RMT’ s application scope beyond interactive art by examining two participatory artworks that illustrate distinct audience engagement mechanisms, yet are not categorised as interactive art.

Chapter 7 presents the results from the workshop we organised to evaluate the capabilities of RMT in modelling, visualising, and generating interactive dialogues with a wider user group. To support the workshop, we also developed a generative component for RMT to support the discovery of new forms of interaction. We report on the workshop outcomes, including the interactions participants modelled and discussion insights on potential interface improvements, various application scenarios, and future development opportunities for RMT. Based on the feedback received, we iteratively refined RMT and reflected on lessons related to designing intuitive interfaces, involving users in the development process, understanding RMT’ s benefits and limitations, as well as clarifying its scope and positioning.

Chapter 8 concludes the thesis by summarising the research carried out in this thesis and our main findings. Specifically, we provide our overarching reflections based on the research questions, discuss remaining challenges and considerations in our approach, explore the broader implications of this study, and propose directions for future work.

Furthermore, it is important to note that each chapter within this thesis has been designed to also function as a standalone article. As a result, certain contents are reiterated to maintain coherence and comprehensibility for readers who may engage with individual chapters independently.

1.6 Contributions

Our key research insights are presented and disseminated through five peer-reviewed publications in international conference proceedings and a journal, which form the foundation of this thesis. These publications were developed in close collaboration with Edwin van der Heide, who acted as an unofficial supervisor throughout the PhD project. The publications detail the development, application and evaluation of the relational model and RMT for describing, visualising, and generating interactive dialogues in interactive art:

- Xu, D., van der Heide, E., Lamers, M.H. and Verbeek F.J. (in print). “Reflections on Using the Relational Modelling Tool for Describing, Visualising and Generating Interactive Dialogues”. Submitted to *International Conference on ArtsIT, Interactivity and Game Creation 2025* and is accepted for publication.

- Xu, D., Lamers, M.H., van der Heide, E. (2025). "A Novel Web-Based Tool for Modelling, Visualising, and Generating Interactions in Interactive Art". In: Brooks, A.L. (eds) *ArtsIT, Interactivity and Game Creation*. ArtsIT 2025. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol 650, pp. 3–19. Springer, Cham. Doi: 10.1007/978-3-031-97254-6_1.

- Xu, D., Lamers, M.H., van der Heide, E. and Verbeek F.J. (2025). "A Relational Look at Interactions between Humans and Nonhuman Organisms in Interactive Art". In: *Leonardo*, vol 58(2), pp. 220–228. Doi: 10.1162/leon_a_02660.

- Xu, D., Lamers, M.H., van der Heide, E. (2024). "Describing and Comparing Co-located Interaction in Interactive Art Using a Relational Model". In: Brooks, A.L. (eds) *ArtsIT, Interactivity and Game Creation*. ArtsIT 2023. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol 565, pp. 198–217. Springer, Cham. Doi: 10.1007/978-3-031-55312-7_15.

- Xu, D., Lamers, M.H., van der Heide, E. (2023). "Towards a Relational Model of Co-located Interaction in Interactive Art". In: Mahé, E. (eds) *Proceedings of the 28th International Symposium on Electronic Art*, pp. 723–732. Doi: 10.69564/ISEA2023-92-full-Xu-et-al-Co-located-Interaction.

In addition, we have made RMT both publicly accessible and open-source [2]. In doing so, we ensure that artists and researchers can easily adopt, adapt, and build upon the software for their own projects. This open-source approach not only promotes reproducibility and transparency, but also encourages collaboration across disciplines and ongoing refinement of RMT in the study and development of interactive art.

Lastly, we contributed to the program of the 13th EAI ArtsIT conference at New York University Abu Dhabi Campus by organising and hosting a workshop titled "Modelling and Creating New Interactive Dialogues in Interactive Art"[3]. During the workshop, participants were introduced to RMT, guided through hands-on modelling exercises, and engaged in group discussions reflecting on their experiences and potential applications of RMT.

[2]The latest version of RMT can be accessed via: https://modeltool.liacs.nl. An instructional video about its application can be viewed here: https://youtu.be/HeniTtbI1SI. Its source code can be found in GitHub via: https://github.com/danxxxu/relational-model.

[3]Official event page for the workshop: https://artsit.eai-conferences.org/2024/workshop-session-modelling-and-creating-new-interactive-dialogues-in-interactive-art

Chapter 2

A Relational Model of Interaction

2.1 Introduction

In Chapter 1, we outline the importance of a structured interaction model in facilitating our capacity to understand, compare, evaluate, and create interactive artworks. Additionally, we highlight the necessity for developing a comprehensive interaction model capable of adequately capturing the relational exchanges between the art system and its participant(s), especially in complex scenarios involving multiple participants. Building on this foundation, this chapter begins with a critical review of existing interaction models and analytical tools for describing interactions in interactive art. We evaluate the strengths and limitations of these approaches, distilling key insights and considerations that inform the development of our relational model of interaction. This model forms the cornerstone of our research and the theoretical underpinning of this thesis.

Following this analysis, we introduce the relational model, defining its core concepts—element, action, and communication—along with the various descriptors used to specify each concept. We argue that the relational model offers a consistent and versatile tool for dissecting and analysing diverse forms of interactive dialogue. While this chapter focuses on providing a comprehensive introduction to the relational model and situating it within the broader landscape of modelling approaches in interactive art, its practical applications in modelling various forms of interaction—and beyond—are demonstrated in Chapters 4, 5, 6.

This chapter builds extensively on our previous work presented at the 28th International Symposium on Electronic Art (Xu, Lamers, & van der Heide, 2023). Initially, the relational model was conceived to describe co-located interaction, which is the central topic of Chapter 4, as detailed in our publication. However, as the model evolved, it became evident that its core concepts, descriptors, and analytical method could be readily adapted to address a wider range of interactive and participatory processes. This adaptability is exemplified in later chapters, which demonstrate its applications in modelling diverse interactions and beyond. Consequently, in this chapter, we recontextualise the relational model as a general interaction model, positioning it alongside and in comparison with comparable models and tools.

2.2 Existing Interaction Models in Interactive Art

A comprehensive review of existing taxonomies and models for classifying interactive art is provided by (Schraffenberger & van der Heide, 2015). In this section, we examine a selection of interaction models and tools with a focus on describing and dissecting the interactive dialogues in interactive art. These include both conceptual frameworks and practical tools or languages designed to analyse interaction dynamics.

As this examination focuses specifically on modelling interactions in interactive art, we do not include modelling approaches from other domains, such as the Unified Modeling Language (UML) commonly used in software engineering. While we identify significant overlaps between our approach and UML sequence diagrams, a detailed comparison and discussion of these relationships can be consulted in Chapter 7.

2.2.1 The feedback loop model and variations

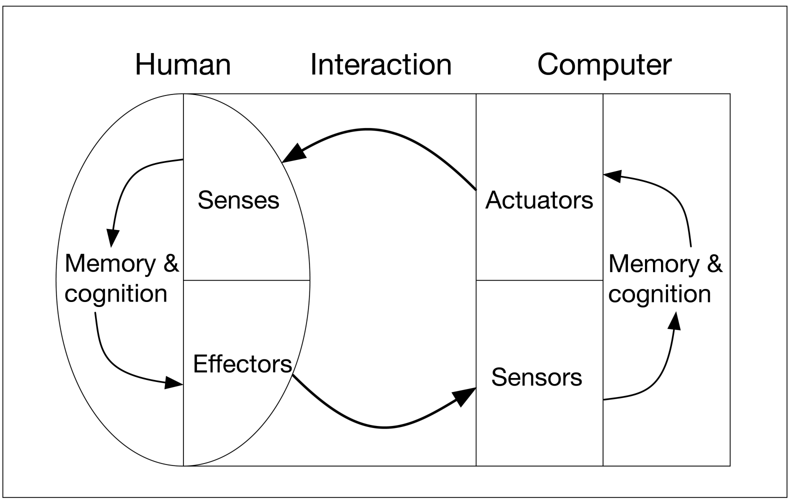

Figure 2.1: Diagram illustrating the feedback loop model. Reproduced from (Bongers, 2000)

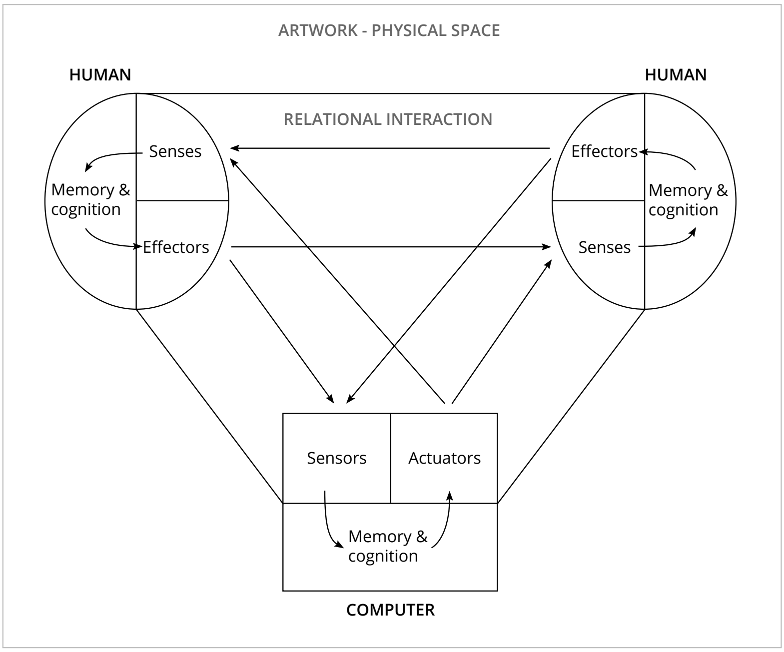

Figure 2.2: Diagram illustrating the model of relational interactive art. Reproduced from (Cabrita & Bernardes, 2016)

Drawing on the principles of cybernetics, Bongers introduces a feedback loop model to describe the physical interactions between individuals and electronic systems in multimedia art (Bongers, 2000) (see Figure 2.1). At the core of this model are the concepts of feedback and control: the system provides feedback to assist the user in articulating control, or delivers feedforward messages to actively guide the user. Bongers has demonstrated that the feedback loop model can be applied to understand the interaction between a performer or an audience member and a digital art system, such as an electronic instrument. Additionally, Bongers also extend the feedback loop model to describe a triadic scenario where the interaction takes place between a performer and an audience member through the art system. However, focusing on the human-machine interaction, the model does not account for the interaction between the performer and the audience member directly if they were to be present in the same physical location, leaving a gap in its applicability to more complex, multi-user contexts.

Building on the feedback loop model, Cabrita and Bernardes propose an interaction model specifically tailored for analysing interactive artworks aiming to foster and strength social connections between audience members, which are coined as “relational interactive art” (Cabrita & Bernardes, 2016). As illustrated in Figure 2.2, this model incorporates another human participant who interacts both with the human and the computer in similar feedback loops. Cabrita and Bernardes further specify that the human-human interaction and human-machine interaction are of equal significance and consistently present throughout the interaction. Additionally, the authors emphasise the interdependence of audience members' actions, with the computer interpreting these actions as collaborative behaviours that "guide its response and shape the next instance of human action." However, while the model offers a promising theoretical foundation, Cabrita and Bernardes do not provide practical examples or applications to demonstrate its utility in real-world scenarios.

2.2.2 The dialogue model of audience-artwork interaction

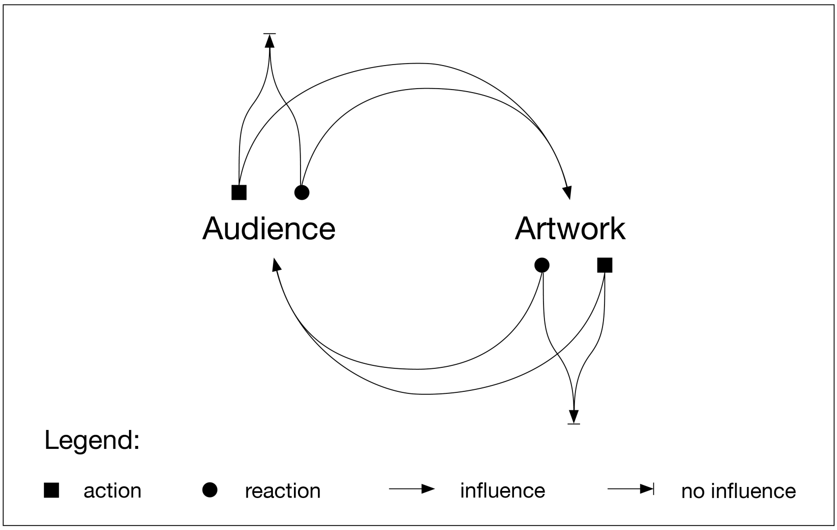

Figure 2.3: Diagram illustrating the dialogue model. Reproduced from (Schraffenberger & van der Heide, 2015)

In an extensive study of audience-artwork interaction within interactive arts, Schraffenberger and van der Heide review existing models and frameworks that aim to capture the diverse characteristics and types of interaction between the artwork and the audience (Schraffenberger & van der Heide, 2012, 2015). Although they acknowledge the usefulness of the feedback loop model, they highlight that its focus on control overlooks other significant dimensions of interaction in the context of interactive art.

In response, they introduce a dialogue model (see Figure 2.3) to describe audience-artwork interaction. Similar to a dialogue between two individuals—where both parties not only respond to each other' s propositions but also have the freedom to switch topics or interrupt—the dialogue model portrays audience–artwork interaction as a dynamic process in which both the audience and the artwork retain the autonomy to respond to each other in various ways and initiate independent actions. Consequently, neither acts randomly nor exercises complete control over the other.

2.2.3 A scoring system for describing interaction

Another significant contribution to modelling audience-artwork interaction is found in Bell' s doctoral dissertation (Bell, 1991). In his thesis, Bell identifies key characteristics of participatory artworks that utilise computer technology and proposes a novel scoring system designed to track changes in the degree of participant control over time, analogous to a musical score. This system is structured around two axes: the horizontal axis documents the actions performed by the participant, while the vertical axis represents the sensory and motor modalities engaged in performing these actions and receiving reactions from the art system. By mapping interactions in this way, the system allows users to identify, at various stages of the interaction, which sensory aspects of the participant are controlled by themselves and which remain under the artist' s direction (through the artwork). Additionally, the scoring system is designed to accommodate complex interaction scenarios; multiple *scores* can be layered or extended to represent branching pathways of options within the interaction.

2.2.4 A graphical language for modelling co-located interaction

Finally, we examine the modelling approaches proposed by Oussama Mubarak in his doctoral research (Mubarak, 2018). While Mubarak's research primarily focuses on modelling co-located interaction, we believe that his approaches are applicable to other forms of interaction and offer valuable insights for interaction modelling more broadly.

The first approach Mubarak introduces focuses on visualising the system layout of art installations. In this model, the key components are interfaces, which may be shared or individual, and are categorised as input, output, or both. The number of interfaces is documented, and their organisation is classified into one of three structures: 1) free, where interfaces can be accessed in any order; 2) queued, where interfaces are accessed sequentially; or 3) looped, where the installation cycles through all interfaces in a continuous sequence. The data flow between individual and shared interfaces is described as unidirectional, bidirectional, or symmetrical correspondence, the latter indicating that all interfaces share the same information. While this approach offers a concise representation of the technical configuration of artworks, it provides limited insights into the functional roles of individual interfaces within the interaction or their relationship to the audience. Additionally, it does not account for interactions between audience members, which are often a critical aspect of co-located experiences.

To address some of these limitations, Mubarak proposes a second approach based on Petri nets, a mathematical modelling language often used to describe information flow in systems with concurrent and asynchronous events. This approach results in a set of graphical elements representing different participant activities and components of the art installation, while indicating the transitions between these elements. Mubarak notes that it "can be used to model co-located human-human, human-machine, as well as human-machine-human interactions around art installations." Compared to the first approach, this method is more comprehensive and expressive, capturing a broader range of activities in co-located interactions. However, as this approach is still in its early stages of development, it often produces highly intricate and specialised descriptions that can be challenging to comprehend.

2.3 Considerations

The abovementioned interaction models in interactive art exhibit both strengths and limitations. The feedback loop model, for instance, is widely adopted by interactive artists and has been influential in conceptualising and understanding interactions within interactive art and other domains of Human-Computer Interaction(Bongers, 2000; Schraffenberger & van der Heide, 2015). Furthermore, as demonstrated by Cabrita and Bernardes, the feedback loop model can be extended and adapted to analyse more complex forms of interaction. However, as previously noted, the focus of the model on user control and system feedback is limited in capturing the nuanced dynamics specific to diverse artistic practices.

In contrast, the dialogue model proposed by Schraffenberger and van der Heide addresses some of the limitations inherent in the feedback loop model by proposing a more diverse and open framework to understand the dynamics between the artwork and the audience. Unlike the feedback loop model, which positions audience as the primary agent and art system as a (passive) tool, the dialogue model acknowledges the mutual responsiveness between audience and artwork. It considers both as potential agents capable of initiating independent actions and influencing one another. Nevertheless, both the feedback loop and dialogue models remain predominantly conceptual models, offering limited practical guidance for dissecting and analysing the specific interactive dynamics within individual artworks.

On the other hand, Bell' s scoring system and Mubarak' s graphical language present more practical approaches for modelling specific forms of interaction. However, these methods also have their constraints. Bell' s scoring system focuses primarily on human-machine interactions within interactive art, which is insufficient for capturing the complexity of interactions involving multiple participants, such as co-located interaction. Moreover, while Bell's model conceptualises the interaction between audience and artwork in terms of the level of control each exerts over the other—a perspective akin to the feedback loop model—it expands on this by acknowledging that the artwork can also exert control over the audience. This introduces a more nuanced bidirectional understanding of mutual influences within an interaction.

Meanwhile, Mubarak's graphical language employs a predefined set of graphical symbols to represent audience activities and the transitions between them over the course of an interaction. This approach is adaptable and scalable, enabling the description of more complex interactive scenarios and allowing for computational analysis of interactions. However, as Mubarak himself acknowledges, the system's abstract notations and lack of a user-friendly interface hinder its usabilities and functionalities, particularly for users unfamiliar with the framework. Furthermore, it does not provide any coherent, systematic guideline to facilitate the adoption of the language and in-depth analysis. Additionally, we argue that Mubarak's focus on activity transitions fails to sufficiently account for how the audience's actions influence the artwork and each other, as well as how the artwork's actions impact the audience.

Taken together, existing modelling approaches tend to be either too generic or too specific, lacking a balanced and comprehensive consideration of the behaviours of both the art system and its participants. A useful interaction model should be *descriptive*, providing sufficient structural information to describe the individual system or situation being modelled; *comparative*, containing metrics for comparing different systems or situations; and *generative*, guiding the creation of new systems or situations (Beaudouin-Lafon, 2000).

Furthermore, although interaction is inherently a relational process, existing models do not sufficiently describe the relationships between the audience and the artwork, or between audience members. As Ahmed notes in discussing forms of interaction in the context of interactive art installations, there is a distinction between interaction and communication: "in communication, the receiver may or may not respond, whereas in interaction, there is a requirement of a response for it to be an 'inter' action" (Ahmed, 2018). This aligns with our understanding of interactivity as a form of mutual responsiveness. In scenarios where multiple audience members are involved, this does not necessarily mean that each interacting partner should be mutually responsive to each other. However, the overall dynamics among them should enable certain forms of mutual responsiveness. If the interaction between an artwork and an audience can be seen as a dialogue of actions and reactions, we can begin to understand complex forms of interaction by examining the actions (and reactions) of all interacting elements. By tracing the directions of these actions, we can identify the different forms of communication at play and specify a network of influences between the audience members and the artwork, forming the foundation for understanding the overall interactive dynamics.

Moreover, the same action performed by an interacting element can yield different outcomes in different interactive artworks. For instance, an audience member waving their arm may change the colour of a visual display in one artwork, while in another, the same gesture may cause the artwork to move away. Therefore, it is crucial to also consider how an action affects other elements and its functions within the specific context of an interaction. We argue that specifying the roles of the various actions performed by the elements is essential for identifying their roles in the interaction and understanding the overall interactive dynamics. This not only aids in distinguishing and comparing different artworks but also reveals patterns that can inspire the creation of novel forms of interaction.

In summary, we argue that an effective model for adequately describing interactions in interactive art should provide a robust template and vocabulary capable of capturing the different relational dynamics occurring within an interaction. Such a model must account for the diverse relationships among the audience, the artwork, and, if present, other participants, enabling a clear understanding of how each element’s actions affect and relate to one another. Furthermore, we contend that this model should treat both the artwork and participants as equally agentic, a perspective that not only opens up new creative possibilities but also challenges conventional assumptions regarding the roles of humans and technological systems in interactive contexts. Finally, the model should be adaptable to accommodate various forms of interaction and scalable, allowing users to customise the level of detail necessary for modelling specific interactive scenarios.

2.4 Key Concepts of the Relational Model

In this section, we present our relational model for describing interactions in interactive art, building upon the theoretical considerations outlined in the previous section. A visual representation of this relational model is provided in Figure 2.4. The model starts by identifying the individual actors participating in the interaction, each of which is described as an *element*. 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). For each action, the model examines what *role(s)* it plays in the context of the interaction and how it influences other elements. In the following subsections, we further elaborate on each key concept and introduce the various descriptors for specifying them.

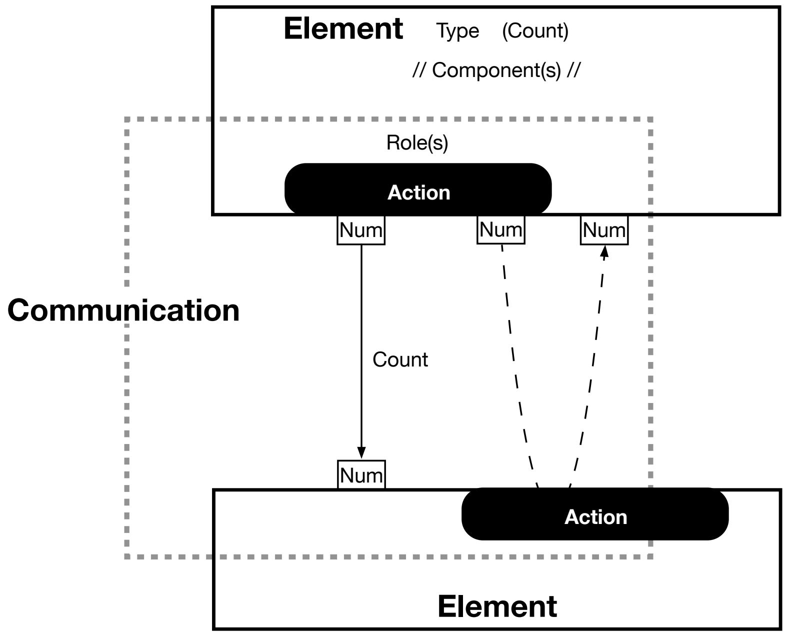

Figure 2.4: Diagram illustrating the relational model.

2.4.1 Element

Type: The categorical description helps to differentiate the elements. Within the context of interactive art, two primary types of elements are commonly identified: the audience and the art system. Cabrita and Bernardes, in their model of relational interactive art, conceptualise the interactive system of an artwork merely as a "computer" (Cabrita & Bernardes, 2016). However, we find this term misleading, as an interactive artwork often involves more than just a computer; other components of the artwork can be equally, if not more, significant in shaping the interaction. Furthermore, we argue that an interactive artwork encompasses both the technical art system—which does not necessarily rely on computers—and the requisite audience behaviour to complete the interaction. Therefore, we propose the term *art system* to describe an autonomous functional unit within an interactive artwork. An art system may comprise input units, output units, and processing units, similar to the computer element in Cabrita and Bernardes' model, or it may be made of physical materials that react to the environment and are manipulated by the audience. An interactive artwork may include a single art system or several art systems, each exhibiting distinct behaviours and capable of establishing dynamic connections with the audience. In the latter scenario, each must be analysed individually to account for their unique contributions to the interaction.

The audience element refers to individual participants engaging with the artwork. In many interactive art contexts, some audience members actively interact with the artwork, while others remain passive observers. These roles are not fixed; participants may transition between these two modes. However, as our model focuses on the dynamics of interaction, it specifically includes those audience members who are directly participating in the artwork and whose actions influence the art system or other participants. Similar to the case of the art system, when distinct behaviours or roles are observed among audience members, each must be explicitly specified using the relational model.

Besides audience members, an interactive artwork may involve nonhuman organisms as participants. In such cases, these organisms can also be described as participating elements using the model. Furthermore, certain interactive artworks are influenced not only by the audience but also by environmental factors (Cornock & Edmonds, 1973). For instance, an art system may adapt its behaviour in response to fluctuations in ambient temperature or real-time internet traffic data. When such factors play a significant role, they can be categorised as environmental elements within the model.

Components: The devices, materials, and apparatus comprised of or used by an element during interaction. In the case of a computer-based art system, these typically include hardware components—sensors, computers, actuators, or displays—to sense the environment and execute actions, as well as software components such as tracking or control programs for processing data and generating commands. For audience, their participation often involves using their bodies to perceive, act, express, and communicate with both the art system and one another. Additionally, they may also utilise additional objects or personal devices. The components of an element define its material basis and help distinguish it from other elements.

Count: The number of elements of the same type that can simultaneously participate in the interaction. In some cases of interactive art, the interaction may involve a fixed number of elements, while in others, the elements may join and leave at any time. Moreover, some interactive artworks may specify a minimum number of audience participants. In this scenario, we can denote the minimal required number of elements with a '+' sign to indicate potential additions.

2.4.2 Action

An action refers to something that is done or performed by the element to participate in the interaction. It is a concrete step taken by an element or multiple elements that alters either themselves or their surrounding environment. Examples range from physical movements (e.g., walking, pressing a button) to updates in display modes (e.g., showing data on a screen or generating audio). Within the relational model, actions are the fundamental units through which elements connect with and influence one another, and thus every action described is directed towards other elements, or an 'outward' action. Activities that involve receiving information —such as sensing or observing—are not explicitly listed as actions. The direction of an action can manifest in two ways: first, the acting element intentionally performs an action directed at the receiving element; second, the receiving element actively captures aspects of the action performed by the acting element, even if the action is not initially intended for the interaction. The latter often occurs when an art system detects and responds to specific actions of the audience.

In a taxonomy of interactive artworks developed in the context of the Prix Ars Electronica, Kwastek identifies a series of key actions potentially performed by the audience as "observe, explore, activate, control, select, participate, navigate, leave traces, co-author, collaborate, exchange information and create" and the corresponding actions made by the art system are "monitor, serve as an instrument, document, enhance perception, offer a game, enable communication, visualize, sonify, transform, store, immerse, process, mediate and tell/narrate" (Kwastek, 2008). While these terms effectively capture the function of an action, they do not necessarily describe the concrete actions carried out by each element. When it comes to describe the interaction in a specific artwork, we first need to identify the individual, concrete actions performed by the elements.

Action role(s): For every action performed by an element, it is essential to define its role(s) within the interaction. These roles reflect the action's functions and its relationships to other actions performed by the same element or by different ones. An action can be *self-initiated* by an element or triggered by another element's actions as a *reaction*. As we discussed before, the terms identified by Kwastek provide a rich vocabulary for expressing these roles. However, in Kwastek's description, the actions of the audience tend to be more active, such as explore, activate, control, while the artwork tends to be at the service of the audience. By contrast, we do not impose any strict distinction between the roles of the audience and those of the artwork; both can assume the same roles. This more flexible perspective opens up opportunities to create new forms of interaction.

2.4.3 Communication

When an element performs an action directed at another element(s), a form of communication is established. In the relational model, communications are regarded as the concrete mechanisms through which elements influence one another via their actions. To describe a form of communication, we specify the arrangement of the elements involved, and the information flows among them. In doing so, we hope to depict a comprehensive picture of the network of influences among the elements. Specifically:

To: The element(s) at which the action is directed. These elements may be of the same type as the acting element or of a different type. The same action can also be directed at different elements, generating multiple forms of communication.

Means: The means by which the action reaches the receiving element. We identify two different types:

- Direct: The action is directly targeted at the receiving element, without the involvement of any intermediate elements.
- Via (intermediate element): The action is targeted at an intermediate element, which then transmits it, via its own action, to the receiving element. This is commonly referred to as a *mediated communication*.

Configuration: The numbers of elements at both ends of the communication. An action can be performed by one or multiple elements, and it can be directed at one or multiple recipients. We distinguish four configurations:

- One to One: From one element to one element only.
- One to Many: From one element to one or more elements.
- Many to One: from one or more elements to one element.
- Many to Many: From one or more elements to one or more elements.

Besides the number of elements, we also identify two settings in which the communication takes place:

- Private: Only the communicating elements can perceive the communication.
- Public: The communication can also be perceived by other elements and observers.

Count: The number of communication of the same form that can occur simultaneously. This does not necessarily require strict temporal synchrony; rather, it concerns more of the element’ s capacity to perform the action, hence the resulted communications, repeatedly. For example, an art system might detect one audience member at a time and emit an audio response. However, it aims to inform all audience members of its capacity to detect their presence. In this case, we consider there to be multiple instances of such communications occurring in parallel.

2.5 Discussion

In this chapter, we reviewed existing models and tools used to capture interactive dynamics in interactive art. Building on the strengths and limitations of these approaches, we propose the relational model as a tool for describing interaction, with a focus on capturing the relational exchanges among the elements. Unlike the feedback loop model and the dialogue model, the relational model provides a practical structure and vocabulary that can be applied to dissect and analyse specific interactions. This not only enables systematic comparisons across different artworks but also opens up the possibility of integrating computational methods into such analysis. Drawing on lessons from the scoring system proposed by Bell and the graphical modelling language proposed by Mubarak, the next step for the relational model involves developing a more intuitive and accessible interface to facilitate the modelling process, which is the central topic of Chapter 3.

The relational model does not impose predefined categories for the types of elements it can describe, and treats all elements—whether audience members, art systems, nonhuman organisms, or environmental factors—using the same analytical frame of reference. By adopting this inclusive and flexible approach, the model is highly adaptable, capable of describing a diverse range of interactive forms and enabling the analysis of interactions from the different perspectives of the various elements involved.

Central to the relational model is its focus on the dynamics of interaction, which it examines through the actions performed by each element and the resulting forms of communication between them. This approach provides a detailed understanding of how elements influence one another through their actions (and reactions), while also allowing us to clarify the roles each element plays within the interaction. Additionally, the open-ended structure of the relational model allows users to tailor the level of detail in their descriptions to meet the specific needs of their analysis, ensuring flexibility and precision.

Beyond analysis, the relational model can also serve as a template for conceptualising new forms of interaction. For instance, users can experiment by combining different forms of communication or redefining the roles of actions performed by elements to create new interactive dialogues. The model further encourages the exploration of unconventional forms of communication. For example, rather than interacting directly with the art system, audience members might influence it indirectly through the actions of another audience member, illustrating a form of audience-mediated communication. Additionally, the model invites speculation on how various forms of communication might interact—whether by disrupting, complementing, or otherwise influencing one another—opening up possibilities for crafting more complex interactive dynamics.

Despite these advantages, the relational model has certain limitations. While it describes element behaviours based on their actions, it does not explicitly account for reactions, which are reflected in the role(s) of actions. Therefore, it does not readily indicate the degree of responsiveness or autonomy exhibited by elements. Additionally, the model captures a snapshot of key interactive dynamics at a given moment, but does not fully account for the temporal evolution of interactions. For instance, the audience may be more exploratory at the onset, as they discover and master the interaction mechanism they may act and react differently. For analyses requiring these temporal or responsive aspects, the relational model can be complemented by other frameworks and taxonomies to provide a more comprehensive account of interaction dynamics.

Chapter 3

The Development of the Relational Modelling Tool (RMT)

3.1 Introduction

In Chapter 2, we introduce a relational model designed to capture the characteristics of diverse forms of interaction in interactive art. This model analyses the actions performed by the interacting elements, be they audience members or art systems, and examines the various forms of communication between them. An intriguing aspect of the relational model lies in its equal treatment of the different types of participants—whether human, nonhuman organisms, or technical systems. This perspective not only enables us to better understand an interactive artwork from the viewpoints of different participants, but also opens creative possibilities for developing novel interactive dialogues where the participating elements take on unconventional roles.

The relational model, when applied manually, demands a strong familiarity with the model and can be both inefficient and prone to errors. To make the model more accessible and streamline the application process to some extent, we decided to translate the model into a web-based tool that can be easily learned and used by a broader group of users, including artists, researchers, and practitioners in the field of interactive art and beyond. Moreover, we also aim to implement features that allow us to explore and generate new forms of interaction using algorithmic techniques. The outcome of this process is the development of a web-based application, referred to as the Relational Modelling Tool (RMT).

RMT offers a structured and formal input area that guides users in describing an interaction using the concepts from the relational model. Given the formal description of an artwork, it automatically generates a visual graph that provides a direct overview of the interaction. The resulting descriptions can be stored in a database for later retrieval, contributing to an expanding collection of interactive dialogues. The formal structure of RMT enforces rigorous reasoning about the relationships between the actions of the elements, thereby making the description more precise. It also generates data with consistent types and structures that allow us not only to easily compare different interactions, but also to generate new interacting elements and behaviours based on the collection of interactive dialogues and draw new connections between them using different combinatorial and randomisation algorithms.

As such, we believe that RMT can not only benefit the analysis of interactive art but also facilitate the discovery and creation of new interactions. It is interesting to note that we did not initially foresee all the benefits and potential of RMT, rather, we discovered, and are still discovering, its benefits alongside its continued development.

This chapter largely builds on our earlier publication presented at the 13th EAI ArtsIT conference (Xu, Lamers, & van der Heide, 2025), which introduces the version 0.1.0 of RMT. Here, we present RMT[1]' s description and visualisation components, detailing its design and development while highlighting modifications made to the original relational model. In this chapter, we focus on sharing RMT' s development process and reflecting on its benefits. In doing so, we aim to highlight how this approach can advance both the research and creation of interactive art, while also inspiring the development of similar tools and applications across interactive art and other domains. The practical application of RMT in describing and visualising diverse forms of interaction in interactive art is demonstrated with concrete artwork examples in Chapter 4 and Chapter 5. Furthermore, since the initial release, we have made several key improvements to RMT based on feedback from other users during an evaluation workshop. The details of the workshop and the improvements are presented in Chapter 7.

3.2 Key Components

In this section, we focus on discussing the design and features of RMT, including some challenges encountered during its development and the adjustments made in relation to the model. RMT' s development has been an iterative process. From the early stages, we have been testing the prototype to model a wide range of interactive artworks, continuously improving upon identified problems and limitations.

RMT is developed using HTML and JavaScript language, allowing easy access via a pub-

[1] In the remaining of this chapter, RMT refers to the version 0.1.0.

lic webpage [2]. The webpage contains what we call a *worksheet* that provides an interface to RMT and allows users to describe an interaction within it. Upon opening it, users can click on the *About* button to view a brief introduction to the relational model and guidance on using the tool. RMT consists of two main components: a set of formal input fields for describing an interaction, and a visualisation component that automatically generates a visual graph of the interaction based on the description. Typically, a worksheet includes a detailed description of an interactive artwork. However, if an artwork contains multiple different modes of interaction, each mode can be described on a separate worksheet.

Furthermore, RMT is connected to a cloud-hosted database using Google's Cloud Firestore service (Google, 2024). The database enables users to save a worksheet with all entered data, allowing them to revisit later or share their work for communication and collaboration. Users can also browse the artwork collection in the database to familiarise themselves with RMT or seek inspirations. A worksheet can be locked for viewing only, with all input fields disabled. Users can click on the *Unlock* button to create an editable copy. Once an unlocked worksheet is loaded, users can directly edit the existing data to refine the description or create new interactions. Additionally, the collection data[3] can be used to facilitate modelling and comparing existing interactions, as well as generating new interactions, as we will elaborate later. Below, we introduce the main features of RMT in detail.

3.2.1 The description component

The description component consists of input fields that are structured based on the key concepts—element, action, and communication—and their descriptors developed in the relational model. To describe an interaction, the model specifies the types and counts of the interacting elements with shared properties and behaviours, the actions they perform, and the forms of communication resulting from each action within one element profile. We group the descriptors for each concept using different outlines or background colours and arrange them in a nested structure to highlight their hierarchical relationships. As illustrated in Figure 3.1, one element profile, indicated with a dotted outline, can contain multiple actions, shown as grey rectangles, each of which can result in multiple forms of communication, depicted as white rectangles. The input fields are either text fields or selection menus. To facilitate the modelling process, a brief explanation is displayed when users hover over a concept or descriptor text. Initially, only the input fields for an element, an action, and a communication are shown. Users can expand the input fields by adding more elements, actions, and communications.

[2] The latest version of RMT can be accessed via this URL: https://modeltool.liacs.nl.

[3] Currently, the database contains the descriptions of a collection of interactive artworks focusing on co-located interaction and more-than-human interaction, which are presented in Chapter 4 and Chapter 5, respectively.

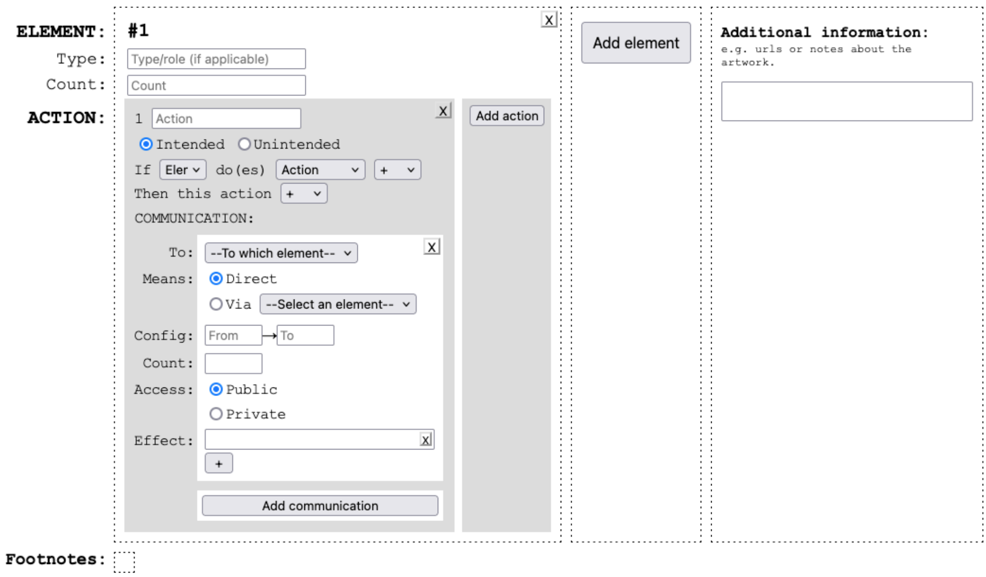

Figure 3.1: Screenshot of the input fields upon opening an empty worksheet.

The input fields largely adhere to the original model described in Chapter 2; however, several important adjustments and additions were made in RMT. Firstly, in the relational model, we previously specified the *components* for each element, which refer to the devices or apparatus constituting the element. However, this descriptor is not always effective or informative when describing human participants when they participate using their bodies. Additionally, in some artworks, elements of the same type and components may exhibit different behaviours and play distinct roles in the interaction, which requires separate analysis. Therefore, we decided to remove the descriptor component and instead ask users to indicate the role of elements after specifying their type, if such distinction is required.

Moreover, in the description of a communication, we have added the descriptor *access* to indicate the degree to which a communication is perceivable by other elements and audience, classifying it as either private or public. This distinction was first made as part of the *configuration* of a communication (see Chapter 2).

We also made some adjustments to enhance the description of an action. In the relational model, we indicated that an action can be either intended or unintended for interaction, but we did not create an explicit descriptor for this distinction. In the application of the model, this information is sometimes mentioned but not always present (Xu, Lamers, & van der Heide, 2023). During the development of RMT, we initially created only a text input field for describing what an action is. Following the strict formal structure of RMT, we soon noticed the omission of the intention of an action. Consequently, we added a radio button after an action that requires users to indicate whether it is intended or unintended for interaction.

Another key adjustment is the replacement of the descriptor *role* for an action in the relational model with the descriptor *effect* for a communication in RMT. Originally, we use the role(s) of an action to describe “the function(s) it serves and how it relates to other actions performed by the same or different elements in the interaction”. Following the nested structure of RMT, we observed that the role(s) of an action can be further broken down into the effect(s) of the various forms of communication it creates in relation to the receiving element(s). To enhance the precision of description, we decided to use the effect of communication to specify the functions and consequences of a communication, and its impact on and relation to the receiving element. When a communication has multiple effects, users can add additional input fields to describe each effect.

The last adjustment we would like to highlight is the addition of condition for an action in the form of *If [Element] does [Actions]*. This addition allows users to specify which prior actions are required for the described action to occur, thereby clarifying the relationships between the actions. Previously, such information was implied in the role(s) of an action. However, as RMT took shape, we realised that a clear indication of the relationships among actions is necessary for users to grasp the dynamic exchange between elements. Moreover, when multiple triggering actions are involved, specifying their roles alone is insufficient to capture the connections among them.

RMT provides several options to describe the condition of an action. Users can select “self-initiated” if an action is initiated by the element itself. If an action is triggered by another action, users can specify the triggering action by selecting the corresponding element and action. In this case, the described action is designated as a reaction. An action can serve as both a triggering action and a reaction to the same or different actions. If an action is triggered by the interplay between two actions, users need to specify both actions and indicate whether they need to occur simultaneously (an *AND* relationship) or only one at a time (an *OR* relationship). With its current structure, RMT can only specify the relationships among triggering actions linearly. When there are more than two triggering actions, their interplay may be more complex. In such cases, users can add a footnote to specify such relationships. The condition primarily aims to capture the formal or logical relationships among actions. For more nuanced influences between them, users can indicate them in the effects of the resulted communications.

Furthermore, when multiple reactions are triggered by the same conditions, RMT provides options to specify the relationships between the reactions[4]. In such instances, users can

[4]This feature was not implemented in RMT v0.1.0 and was identified as a limitation in the original publication

indicate whether the current reaction should occur concurrently with other reactions (an *AND* relationship) or whether only one reaction should be activated at a time (an *OR* relationship) by selecting the appropriate option from the dropdown menu following the “Then this action” prompt. Upon selection, input fields for specifying the associated reactions will be made available. The implementation of this feature is symmetrical to the condition specification process, thereby adhering to the same logic and constraints.

Lastly, to make the description process easier, all input fields are connected to a dropdown list of possible options. For the selection menus related to the condition of an action and describing the recipient or mediator of a communication, the options are based on present information within the worksheet and updates as more data is entered by users. For the text input fields associated with element type, action, and communication effect, the options are collected from all existing descriptions within the worksheets stored in the database. Users can click on the input field to view the attached list and type in letters or words to narrow down the suggestions. If none of the options suits the interaction under description, users can enter new descriptions that will be added to the list once they are stored in the database. We believe this feature not only eases the workload of the modelling process by reducing the need for repeated data entry but also helps users in phrasing these descriptions in a more consistent manner. Besides describing the interaction, users can also supplement additional information, such as the URL to the artwork documentation or other notes.

3.2.2 The visualisation component

The visualisation component of RMT was developed using the D3 JavaScript library (Observable, 2024). Thanks to the formal structure of the input fields, we can represent the concepts and their descriptors in the relational model using a set of visual symbols as shown in Figure 3.2 (left), and code instructions for automatically generating graphs to illustrate a described interaction. These graphs can also be downloaded as PDF files for separate usage. This feature is useful for complex descriptions where the various interplays between individually described elements are not easily perceptible. While modelling such an interaction, users can utilise the visualisation to inspect the description. Furthermore, visualising a described interaction provides users with a direct overview without necessitating a review of all the details in the input fields. As a result, users can easily compare multiple interactions and identify their similarities and differences with direct visual access.

As shown in Figure 3.2 (right), elements represented as rectangles with rounded corners are arranged horizontally in a visualisation, while their actions are depicted as standard rectangles positioned vertically along the central axis of each element. The intention of an action is

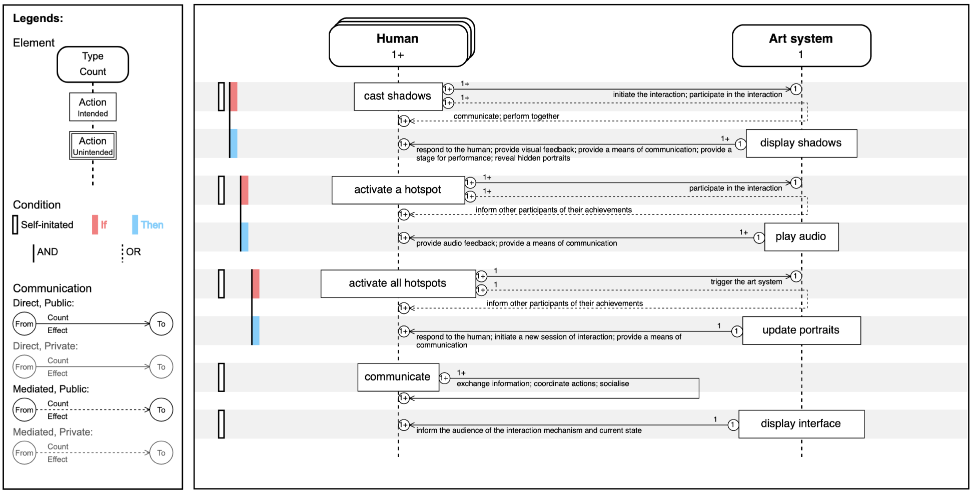

Figure 3.2: (Left) The legend describing the visual symbols representing the concepts and their descriptors for the visualisation. (Right) An example visualisation of described interaction in the artwork ***Body Movies***.

indicated with different stroke styles of the rectangle. When an element count is two, two element squares are drawn on top of each other with a slight offset. If an element count exceeds two or is simply indicated as more than one, only three element squares are drawn in the same stacked and offset manner. This feature aims to provide visual cues regarding the number of elements, rather than displaying precise information. Communications are always depicted as arrows extending horizontally from an action to an element. A solid arrow line represents direct communication, while a dashed line signifies mediated communication. Configurations are registered in small circles at both ends of an arrow. The access level of a communication is indicated by different opacities: complete opacity signifies public access, while partial opacity indicates private access. Moreover, all textual information is displayed on top of the symbols.

These constructions provide a clear overview of the elements, their actions, and the resulting communications in a described interaction. Additionally, a sorting algorithm determines the display order of actions based on their conditions, ensuring that triggering actions are placed before reactions. Aside from this, the order in which the elements, actions, and communications appear follows the sequence specified in the input fields. However, because an action can be present in the conditions of multiple actions and can function both as a triggering action and as a reaction, we faced challenges in visualising the conditions without creating overlaps or messy indicators on top of the main graph.

To address this, we decided to show this information separately on the side using bars with different colours and styles (see Figure 3.2 right). Each action-condition combination is drawn along the same vertical axis and placed next to each other on the left side of the main graph. Triggering actions are indicated using red bars, drawn at the same vertical positions as the actions, while reactions are indicated with blue bars. This solution not only effectively communicates the relationships between actions without overlaying excessive visual distractions on the main graph, but also provides a system that allows for easy compositions of these relationships on its own.

3.3 Benefits of RMT

The formal structure of RMT exhibits numerous advantages over the narrative approach of the relational model when it comes to modelling and visualising interactive dialogues. Additionally, it opens up opportunities for developing features that facilitate the exploration and comparison of large collections of artworks, as well as the generation of new interactive dialogues. Below, we elaborate on these benefits of RMT in greater detail.

3.3.1 Enhance precision and practicality

Compared with the relational model, RMT significantly enhances the precision of the modelling process and the interaction description. Previously, using only the relational model, we could generate a textual description based solely on our understanding of the model. This process was more subjective and prone to errors, often resulting in descriptions that were ambiguous and incomplete. For instance, the intentions and conditions for actions were easily overlooked. In contrast, RMT provides a comprehensive and consistent scheme for each element, along with suggestions for each descriptor. These features not only guide users through the modelling process, but also aid them in formulating detailed descriptions, ensuring that all aspects of the relational model are thoroughly addressed.

In addition to generating datasets with consistent structure, the formal structure of the input fields allows us to define a visual language for depicting an interaction and automate such process. The visualisation can not only facilitate modelling and comparing different interactions by providing a direct visual impression of the descriptions, but also create easily identifiable visual patterns showing some characteristics of an interaction. Moreover, the visual language itself offers a concise and straightforward method for users to configure relationships and draw connections between elements, for instance, using the visual codes for describing conditions of actions. Its simplicity also enables users to quickly sketch interaction ideas, both digitally and by hand. Furthermore, we can implement features that allow users to directly manipulate the visualisation, with corresponding updates made to the input fields. This integration can potentially enhance the usability of RMT, making the modelling process more intuitive.

3.3.2 Explore and compare artwork collections

Datasets of interactive dialogues generated with the formal input fields of RMT create opportunities for developing new approaches for analysis and comparison. The unified data structure not only enables straightforward comparison and robust analysis across diverse forms of interaction but also supports the application of statistical and visualisation methods to derive insights from large sets of interactive artworks, which are not always possible to achieve manually.

Specifically, we can experiment with techniques to visualise the artwork collection to create an overview of the stored interactions and the distributions of the data points across the descriptors. With a sufficiently large collection of artworks, this approach can potentially reveal patterns and trends in the evolution of interactive art. In addition, we propose the implementation of a feature that enables users to select and visualise specific artworks or custom collections, facilitating the comparison of similarities and differences between them.

Furthermore, one could imagine the construction of a *distance measure* between two artworks: a numerical expression based on similarities and differences between their interactive dialogues captured by RMT. Such a numeric construction would allow for interesting distributional analyses of a collection of artworks. For example, clusters of works could be identified based on the relative similarity of their interaction structures using standard data analysis techniques. Alternatively, multidimensional scaling techniques could then be easily applied to map a collection of works onto a multidimensional space, revealing underlying patterns of similarity, similar to the use of principal component analysis in multidimensional data analysis. At an application level, these techniques would enable automated curation of artwork collections, as well as other forms of computational and visual analysis of larger collections.

Currently, users can only access the collection by selecting an artwork's title and viewing the described interaction. We also envision implementing features that allow users to browse the data directly. Such features would allow users to select specific data points and view all artworks containing the same data points. By doing so, they can facilitate users to discover connections between artworks that might otherwise go unnoticed. Such features could also supplement the visualisation of the collection as described above.

3.3.3 Generate new forms of interaction

Beyond analytical applications, the collection of existing interactive dialogues serves as a valuable resource for imagining new interactions. Similar to the *Dadaist* cut-up technique in which a written text is cut up and randomly rearranged to create a new text (Burroughs, 1961), we can apply random and systematic generation and permutation features to explore new combinations of element types and behaviours as well as draw new connections between them[5].

More specifically, we can leverage the existing data about elements from the artwork collections to generate new ones by randomly combining their types, actions, and communications. This feature can be particularly useful for initiating exploration and providing inspiration at the onset of the creative process. Besides generating elements from scratch, we can also provide users with partial control in this process. For example, they can specify certain aspects of an element, such as its type, and then use RMT to generate new actions and communications. Given the diversities of elements in the collection, including human, nonhuman organisms and technical systems, we believe that this feature can stimulate the discovery and imagination of new interactive behaviours and unconventional roles of elements.

Furthermore, we also envision to take advantage of RMT' s formal structure to create new configurations using computational techniques. Once elements are specified, we can draw new connections between them using different combinatorial or randomisation algorithms. These connections can be realised by generating new forms of communication, such as randomly assigning the receiving elements and selecting the means, configurations, counts, and access of communications. Additionally, we can generate new combinations of triggering actions and reactions to configure new relationships between actions. Beyond randomisation, we also plan to apply algorithms that allow users to systematically explore all possible combinations and configurations. These manipulations are possible because these descriptors are confined to limited options, and we believe they can help us discover and create relationships between elements that do not yet exist.

Additionally, the standardisation of data collection allows us to leverage machine intelligence even further. For instance, we can apply data mining and machine learning algorithms to explore relations and patterns within the artwork collection and generate new forms of interaction based on these insights.

[5]The generative functions are realised in the later version of RMT, the detailed description about this is presented in Chapter 7

3.4 Current Limitations

There are a few limitations of RMT we wish to address here. One pertains to the description of action conditions. Currently, users must add footnotes to describe complex relationships involving more than two triggering actions. While this approach is effective for a human user to view a description, it is limited in processing such information using computational means, such as randomising the relationships among the triggering actions to generate new conditions. A potential solution is to use a tree-like structure that allows users to nest triggering actions within different branches and specify the orders of the branches. However, this could potentially increase the complexity of the interface and make RMT harder to use.

Balancing the level of generalisation and specification in a description remains a key challenge in the development of RMT. Presently, it has limited capacity to show information about an interaction that is not captured by the generalised formal structure of RMT. Since interactive art often seeks to create unconventional interactions, such information may be essential for understanding an artwork. For future development, we plan to implement features that allow for more open-ended entries in the input fields. However, it remains a challenge to preserve the benefits of a generalised formal structure while creating room for accommodating individual characteristics. We believe that systematic evaluations with professional users will provide valuable insights for making informed decisions regarding these concerns.

3.5 Discussion

In this chapter, we introduce a novel web-based tool-RMT-built upon our previously developed relational model, designed for modelling and visualising interactions in interactive art. The formal structure of RMT enhances the precision of the modelling process, facilitates the analysis and comparisons of different forms of interaction, and can potentially inspire the creation of new forms of interaction with data-driven approaches that were previously unattainable. Compared with the relational model, our findings highlight RMT' s capacity to emphasise the relational exchange between elements as well as identify and contextualise other known interaction models [6]. RMT not only supports the research and creation of interactive art but can also be used as an educational resource in this field. While our focus remains on interactive art, we believe that RMT can also be applied in other domains of interaction design and research, and the development process can also inspire the creation and development of similar tools and applications across different fields.

Lastly, we wish to emphasise again that the development of RMT is an iterative process,

[6] This insight is shown in the practical application of RMT in Chapter 4 and 5.

with its benefits emerging organically rather than being pre-planned. Since the creation of the first prototype, we have been continually testing the modelling capability of RMT with diverse interactive artworks. As each example emphasises on different aspects about interactions, this process has allowed us to identify limitations and further refine RMT' s features, as well as resolve ambiguities inherent in the relational model. Moreover, we have also been learning about what RMT can do as we develop and enrich its features. For instance, we discovered the potential of the artwork collection and implemented the related features only after the database was implemented, despite originally only intended for storage. This is only possible as the research and development processes are integrated, the outcomes from one process continuously provide inputs and inspirations for the other.

Chapter 4

Describing and Comparing Co-located Interaction

4.1 Introduction

In Chapter 2 and 3, we introduce the relational model and its accompanying web-based tool, the Relational Modelling Tool (RMT), designed to describe and visualise interactions in interactive art[1]. However, until now, we have not demonstrated the practical application of RMT. This chapter addresses this gap by illustrating how RMT can be employed to describe and analyse various forms of co-located interaction. co-located interaction refers to scenarios in which two or more audience members engage simultaneously with an interactive artwork within a shared physical space. In such contexts, the presence of and interactions among audience members are not merely incidental, but are integral to the artwork itself.

While much of the existing research focuses on audience-artwork interaction, co-located interaction introduces an additional layer of complexity by incorporating interactions among audience members. We consider this an instructive case for demonstrating the capabilities of RMT in capturing the multifaceted dynamics among multiple interacting elements. By applying RMT to a curated selection of interactive artworks designed for co-located interaction, we aim to evaluate its effectiveness in describing and comparing diverse forms of co-located interaction. Additionally, we seek to derive insights into the defining characteristics of such interactions based on the analysis yielded by RMT.

The content of this chapter largely builds on our earlier publication presented at the 12$^{\text{th}}$

[1] The latest version of RMT is accessible via: https://modeltool.liacs.nl

EAI ArtsIT conference(Xu et al., 2024). However, at the time of that publication, RMT had not yet been developed, and the analysis was conducted solely using the relational model. Here, we revisit the selected artworks, re-analysing them with RMT to demonstrate the enhancements in description and analysis afforded by its functionalities.

The chapter is structured as follows: First, we provide a detailed explanation of the seven classification dimensions we developed to categorise a diverse range of co-located interactions, which further inform our selection of representative artworks, which we then describe; Next, we introduce eight selected artworks, providing individual descriptions followed by descriptions of their co-located interactions using RMT; In the subsequent section, we present a comprehensive discussion of the insights gained about co-located interaction, drawing on the similarities and differences identified across the artworks; Finally, we evaluate the effectiveness of RMT in supporting this analytical process, reflecting on its strengths and potential areas for improvement.

4.2 Classifying Co-located Interaction

To demonstrate the capability of RMT in capturing and describing diverse forms of co-located interaction, we develop a set of classification dimensions to select different artworks that are representative of different forms of co-located interaction. The classification dimensions aim to systematically delineate co-located interactions sharing 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.

4.2.1 Previous classification

Mubarak proposed a taxonomy to classify co-located interaction in art installations based on factors influencing the audience experience (Mubarak, 2018). The first dimension *scale* describes the number of participating audience members and is classified as small (less than 10), medium (11 to 100), large (more than 100). The *interaction modality* refers to the method by which the audience interact with the artwork, which can be: through direct physical manipulation (direct); through individual remote input devices (facilitated); 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 classed as centralised, partially distributed and fully distributed. The ability of the audience to recognise the effect of their actions in the artwork is described as *feedback attributability* ranging from low to medium to high. The *activity type* describes the audience activity solicited by the artwork, which can be: collaborative when the audience has to work together; competitive when the audience has to challenge each other; solitary when each audience acts independently. Finally, the last dimension proposed by Mubarak, *participation symmetry*, is first defined by Bell as the "distribution of actions and contributions between participants" (Bell, 1991), which can be either symmetrical when the audience participate equally, or asymmetrical when the audience plays different roles.

4.2.2 Defining classification dimensions

While Mubarak defines factors that influence the audience experience of co-located interaction, here we are interested in how such interactions manifest. Taking Mubarak’s taxonomy as a reference, we propose our classification dimensions that focus on delineating the various forms of organisation and participation. 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* to describe the arrangement of the audience. And it can be classed as duo, which is for two audience members; group, which takes place among one or more groups of audience with limited numbers (larger than 2); crowd, which takes place among one or more crowds of audiences 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* with fixed or fluid scale levels, respectively.

Both *interaction modality* and *input and output distribution* pertain to aspects of the input and output set-up of the art system. For *interaction modality*, we find it difficult to draw meaningful distinctions among its different types. 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 think that the technical configuration of the 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* 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.

The *feedback attributability* impacts the individual experience of participants, but is less of a defining factor differentiating different forms of interaction. Instead, we would like to adopt the dimensions of *activity type* and *participation symmetry*. Moreover, 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 class *activity type* as individual, which means the audience participate individually and independently; social, which means the activities require more than one audience member to perform together; and mixed, which means both types are supported. For *participation symmetry*, besides symmetrical and asymmetrical, we include varied to indicate when participants can transition between the two.

Lastly, as mentioned before, the art system can not only respond to the audience but also initiate the interaction. We propose *initiator* 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 respective scale levels are presented in table 4.1.

Table 4.1: Classification dimensions and their scale levels for co-located interactive artworks.

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

4.3 Artwork Selection

The classification dimensions define a 7-dimensional space with over 3,000 different combinations that represent potential forms of co-located interaction. However, these dimensions are not entirely independent of 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 all combinations have been realised. Nonetheless, it is impractical to cover all existing varieties of co-located interaction within the scope of this chapter.

To tackle this dilemma, we suggest prioritising some dimensions and scale levels to narrow down the selection while still preserving the potential to show the diversity of co-located interaction. Considering that not all combinations of the dimensions can be realised in each *participation style* and that the group and crowd share quite some similarities, we do not consider each scale levels independently but aim to cover all the variations in the final selection.

In addition, the different types of *input and output access* indicate how much freedom each audience has in the interaction and what kind of information is available to them. They affect the organisation of the audience, however, they 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 decide to not consider the varieties of *input and output access* when selecting the final artworks.

Furthermore, 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 are 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 the *initiator*. These considerations significantly reduce the space from which artworks can be selected, making the selection process more practical.

We searched for artworks in online archives such as the Ars Electronica Archives ("Ars Electronica Archives", 2023) and the Archives of Digital Art ("Archives of Digital Art", 2023), and from personal knowledge of existing artworks. We selected eight artworks that satisfy the selection criteria and occupy a meaningful position in the classification. These chosen artworks encompass a range of interactive experiences, including performances, games, and interactive installations, and were created between 1997 and 2016. All artworks and their corresponding classification scale levels are summarised in table 4.2.

Table 4.2: 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	Public	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 (100 dB at 100 km/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

4.4 Modelling Diverse Co-located Interaction

In this section, we introduce the artworks individually based on their positions in the classification dimensions and present the description of the co-located interaction within each artwork using RMT.

4.4.1 *Brainball* (2003) by Smart Studio

Figure 4.1: Smart Studio, *Brainball*, 2003. (©photo by paulbetterner)

Brainball is a game that utilises a brain-computer interface between two participants (Hjelm, 2003) (see Figure 4.1). The brain activity of each participant is measured using an EEG sensor, which controls the movement of a steel ball on a table. The more relaxed player, as detected by the sensors, scores a goal over the other player. Since ***Brainball*** requires the simultaneous participation of two players, it can be classified as a duo *participation style* within a fixed *audience constellation*. The *input access* is private as each player uses the sensor individually, while the *output access* is public as the ball movement and a screen displaying gathered brainwave data visible to all present. The *participation symmetry* is symmetrical, as both players contribute equally to the interaction. Given that the interaction takes the form of a competitive game, the *activity type* is social. The interaction is initiated by one player (*initiator*) pressing a button. ***Brainball*** exemplifies a form of co-located interaction with a fixed and symmetrical participation style in a social activity initiated by the audience.

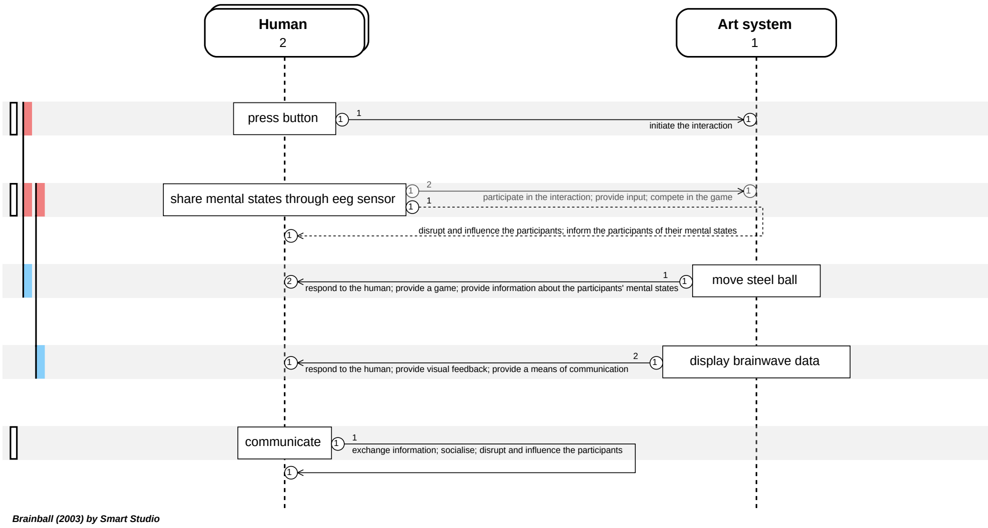

Figure 4.2: Visualisation of described interaction in ***Brainball*** using RMT.

The detailed description of ***Brainball*** can be accessed in this worksheet[2] and the visualisation is shown in Figure 4.2. Using RMT, we identify two element profiles: two participants and an art system. All actions of the elements are intended for participating in the interaction. The interaction begins with either player pressing a button to initiate a direct public communication with the art system. Following this, both players connect to the EEG sensor, sharing their mental states through a direct private communication with the art system. This step enables them to provide inputs to the art system, actively participate in the interaction, and compete in the game.

In response to these inputs, the art system moves the steel ball towards the player who is less relaxed, thereby creating a game dynamic and conveying information about their relative mental states. This action results in a form of direct public communication to both players. Simultaneously, the art system displays real-time brainwave data on a screen, offering visual feedback in a direct public communication to the players. This feedback further informs the

[2]https://modeltool.liacs.nl/?artwork=brainball

players about their mental activities, resulting in a mediated public communication between them, distracting them from relaxation and disrupting their performance.

Throughout the interaction, the players can engage in a direct public communication with each other, exchanging information, socialising, and attempting to disrupt or influence each other's performance.

4.4.2 *Randomly Generated Social Interactions* (2016) by Anastasis Germanidis

Randomly Generated Social Interactions is an interactive performance in which the audience is instructed by the art system to interact with one another (Germanidis, 2016). While the artwork accommodates a group of participants, the interaction is primarily designed for pairs, therefore we classify it as a duo *participation style* within a fixed *audience constellation*. The artwork provides both private *input and output access* to each audience member through the use of mobile phones and headphones. Despite being assigned different fictional identities, the *participation symmetry* remains symmetrical, as all participants have equal roles in the interaction. The *activity type* is social, as the performance requires the audience to engage with each other. Unlike ***Brainball***, where the audience initiates the interaction, here the art system acts as the *initiator* by delivering instructions to participants. In summary, ***Randomly Generated Social Interactions*** demonstrates a form of co-located interaction with a fixed and symmetrical participation style in a social activity initiated by the art system.

The detailed description of ***Randomly Generated Social Interactions*** can be accessed in this worksheet[3] and the visualisation is shown in Figure 4.3. Using RMT, we identify two element profiles: two or more participants and an art system. All actions of the elements are intended for participating in the interaction. First, the art system assigns fictional identities to each participant through a direct private communication. This step provides background information and prepares participants for the upcoming interaction. Next, it delivers instructions to each participant, again via a direct private communication, to initiate the interaction, direct their actions, and stimulate social interactions.

In response to both actions performed by the art system, the participants enact these instructions, engaging in a direct public communication with one another as they participate in the interaction and comply with the command of the art system. By responding to these instructions, the enacting participants also transmit the instructions from the art system to the receiving participants through a mediated public communication.

Additionally, the participants communicate directly and publicly to each other to exchange

[3] https://modeltool.liacs.nl/?artwork=randomly

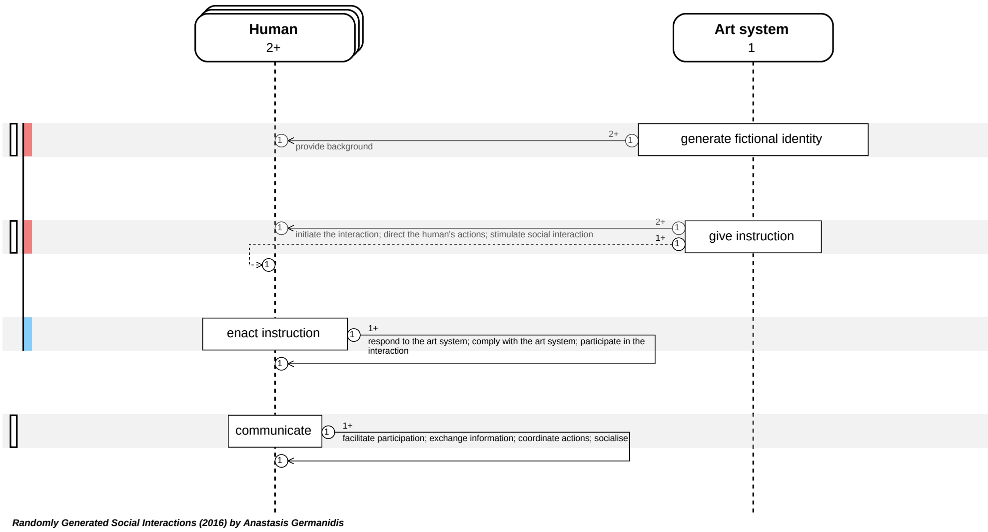

Figure 4.3: Visualisation of described interaction in ***Randomly Generated Social Interactions*** using RMT.

information, coordinate actions and socialise. This direct communication further supports their participation in the interaction.

4.4.3 *World Skin* (1997) by Maurice Benayoun

World Skin an interactive artwork that takes the form of a photo safari within an immersive projection of a war zone landscape (Benayoun, 1997) (see Figure 4.4). One participant plays the role of a 'driver' and navigates in the virtual landscape, while others take on the role of a 'photographer' , capturing photos of the landscape with sensor-fitted cameras. Like the previous two artworks, ***World Skin*** features a fixed *audience constellation* and a social *activity type*, as participants must collaborate to navigate the environment and take photos. However, unlike the other works, this piece requires more than two participants and the number of participants is limited by the available input devices, leading us to classify it as a group *participation style*. Each participant has private *input access* using their respective devices and public *output access* as the projection is visible to all present. The participants initiate the interaction and play different roles, resulting in an asymmetrical participation. Overall, this artwork exemplifies a form of co-located interaction with a fixed and asymmetrical participation style in a social activity initiated by the audience.

Figure 4.4: Maurice Benayoun, *World Skin*, 1997. (©photo by MoBen)

The detailed description of ***World Skin*** can be accessed in this worksheet[4] and the visualisation is shown in Figure 4.5. Using RMT, we identify three element profiles: one participant as the driver, one or more participants as the photographers and an art system. All actions of the elements are intended for participating in the interaction. To start, the driver initiates the interaction by moving the joystick in a direct private communication to the art system, which allows them to participate in the interaction and navigate the virtual landscape.

In response, the art system updates the landscape in a direct public communication to all participants. This response provides visual feedback about the actions of the driver, as well as content for interaction and a means of communication among participants. Additionally, the driver can also communicate to the photographers via the responses of the art system to express their points of view and collaborate with them in a mediated public communication.

The photographers, in turn, take photos of the landscape to initiate and participate in the interaction in a direct public communication to the art system. In response, the art system

[4] https://modeltool.liacs.nl/?artwork=worldskin

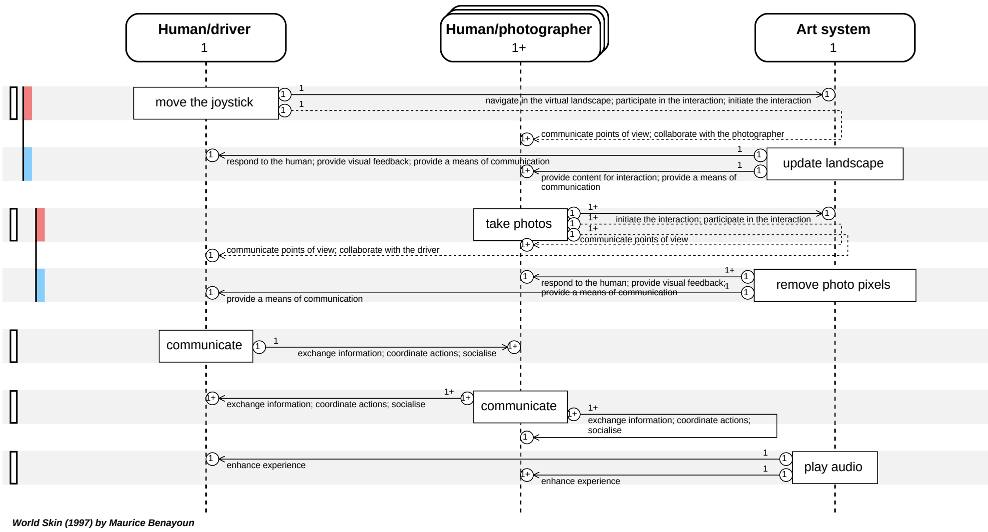

Figure 4.5: Visualisation of described interaction in ***World Skin*** using RMT.

removes the pixels of photographed portions of the landscape in a direct public communication to all participants, providing visual feedback about the actions of the photographers and a means of communication among all participants. The photographers can also communicate both within themselves and to the driver via the responses of the art system in a mediated communication, allowing them to express points of view and collaborate with the driver and each other. As multiple photographers can take photos simultaneously, multiple instances of these communications can occur concurrently.

Throughout the interaction, the art system also plays audio in a direct public communication to all participants to enhance their experience. Meanwhile, all participants can communicate directly and publicly to each other to exchange information, coordinate actions and socialise.

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

Zoom Pavilion is an interactive installation that immerses the audience in a live projection of their own images, captured through surveillance technologies (Lozano-Hemmer, 2015) (see Figure 4.6). Utilising recognition algorithms, the installation detects the faces and bodies of participants, establishing various relational dynamics within the exhibition space. Unlike the previous mentioned artworks, ***Zoom Pavilion*** accommodates a growing number of audience

Figure 4.6: Rafael Lozano-Hemmer and Krzysztof Wodiczko, *Zoom Pavilion*, 2015. (©Antimodular Research)

and there is no clear demarcation between observers and participants. We consider its *participation style* as crowd and *audience constellation* fluid, although the number of participants is ultimately constrained by the physical capacity of the exhibition space. Both of its *input and output access* are public, allowing all participants to share and perceive the experience equally. However, as the system selectively zooms in on certain individuals and draws connections between their bodies, it creates an asymmetrical participation dynamic. The *activity type* is mixed, enabling both individual and collective participation. The art system initiates the interaction by actively selecting and connecting participants. This artwork exemplifies a form of co-located interaction with a fluid and asymmetrical participation style in mixed types of activities initiated by the art system.

The detailed description of ***Zoom Pavilion*** can be accessed in this worksheet[5] and the visualisation is shown in Figure 4.7. Using RMT, we identify two element profiles: one or more participants and an art system. At the outset, one or more audience members enter the exhibition space, not necessarily intending to participate in the interaction. Nevertheless, their presence and actions are detected by the art system, initiating a direct public communication

[5] https://modeltool.liacs.nl/?artwork=zoom

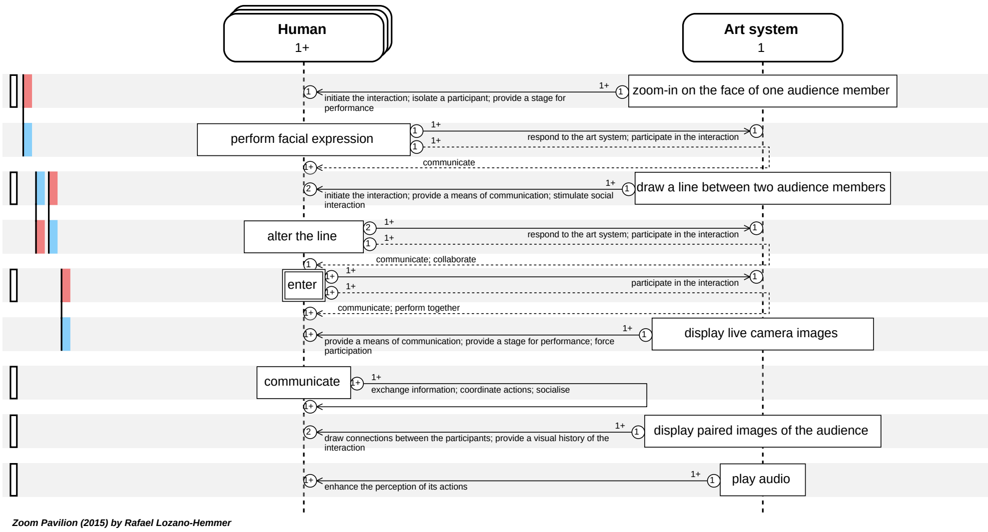

Figure 4.7: Visualisation of described interaction in ***Zoom Pavilion*** using RMT.

from the audience to the art system. In response, the art system displays live camera images of the audience, creating a direct public communication to all present. This feedback compels the audience to engage with the artwork and provides a medium for communication among them. Once participants become aware of the responses of the art system, they may choose to actively participate, further interacting with both the art system and each other through its feedback.

The art system also independently initiates interaction by selecting and zooming in on the face of an individual audience member in a direct public communication. This action isolates the participant, placing them in a performative role. The selected individual may respond by making facial expressions in a direct communication to the art system, thereby also indirectly communicating with other audience members via the responses of the art system. Additionally, the art system dynamically connects two participants by drawing a line between them, establishing a form of direct public communication directed at those involved. This action not only initiates engagement of the audience but also stimulates social interactions between them. The selected participants can respond by moving in a direct communication to the art system, which alters the line, enabling them to collaborate and communicate via the responses of the art system.

Finally, the art system pairs and projects images of the audience members' faces onto a wall, creating a direct public communication visible to all present. This action actively establishes connections between audience members and provides a visual record of the interaction.

Throughout the interaction, the art system plays audio that accompanies its actions in a direct communication to all audience members, enhancing their perceptions of its activities. And the audience can also communicate directly and publicly with one another, exchanging information, coordinating actions, and socialising.

4.4.5 *Boundary Functions* (1998) by Scott Snibbe

Figure 4.8: Scott Snibbe, *Boundary Functions*, 1998. (©Scott Snibbe)

Boundary Functions is an interactive installation designed for multiple participants simultaneously (Snibbe, 1998) (see Figure 4.8). The installation remains inactive when only one participant is present. When two or more people enter the space, the floor divides into cellular regions, each corresponding to the area closest to a participant—a pattern known as a Voronoi diagram. The *participation style* is group, as the number of participants is constrained by the physical set-up of the installation. Similar to ***Zoom Pavilion***, participants can freely join and leave the interaction in a fluid *audience constellation*. Both *input and output access* are public, as they can be shared and perceived by all participants. The *participation symmetry* is symmetrical, as the art system treats each participant equally. Since the art system also reacts to the social behaviours of the participants, the *activity type* is social, with the audience acting as the *initiator* of the interaction. It exemplifies a form of co-located interaction with fluid and symmetrical participation style in a social activity initiated by the audience.

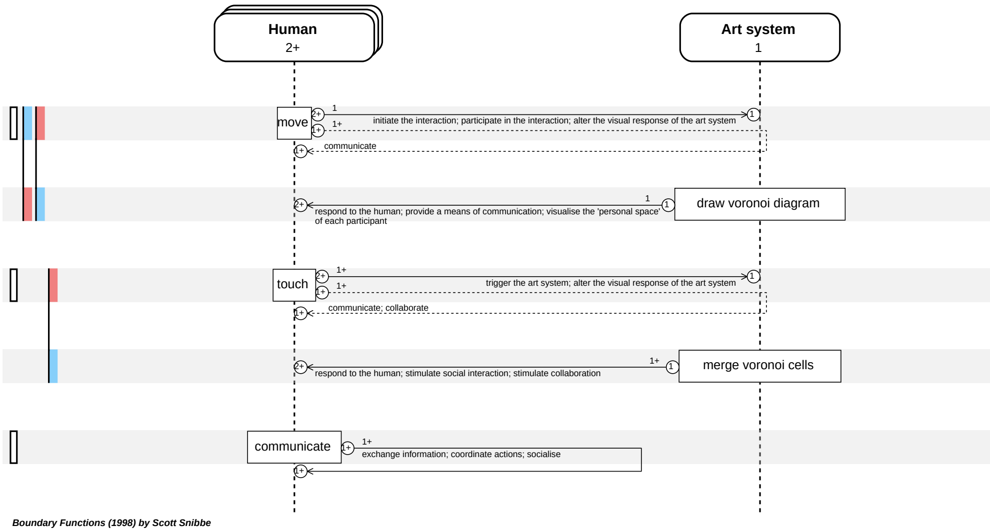

Figure 4.9: Visualisation of described interaction in ***Boundary Functions*** using RMT.

The detailed description of ***Boundary Functions*** can be accessed in this worksheet[6] and the visualisation is shown in Figure 4.9. Using RMT, we identify two element profiles: two or more participants and an art system. All actions of the elements are intended for participating in the interaction. The interaction begins when two or more participants enter and move within the installation space. Their movements are captured by the art system, establishing a direct public communication from the participants to the art system. This enables them to initiate and actively engage in the interaction.

In response, the art system generates a Voronoi diagram based on the positions of the participants in a direct public communication to all participants. This action visualises the ‘personal space’ of each participant, creates a visual connection among them, and provides a means of communication. Consequently, the participants can communicate with each other via the response of the art system by moving around to alter the Voronoi pattern.

Additionally, when two or more participants touch one another, the art system detects this action, resulting in a direct public communication from the participants to the art system. This

[6] https://modeltool.liacs.nl/?artwork=boundary

action allows the participants to trigger a distinct response from the art system. Specifically, the art system merges the Voronoi cells of the participants in contact in a direct public communication. This response further encourages social interactions and collaborations among the participants.

Throughout the interaction, participants can also communicate directly and publicly with one another, exchanging information, coordinating actions, and socialising.

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

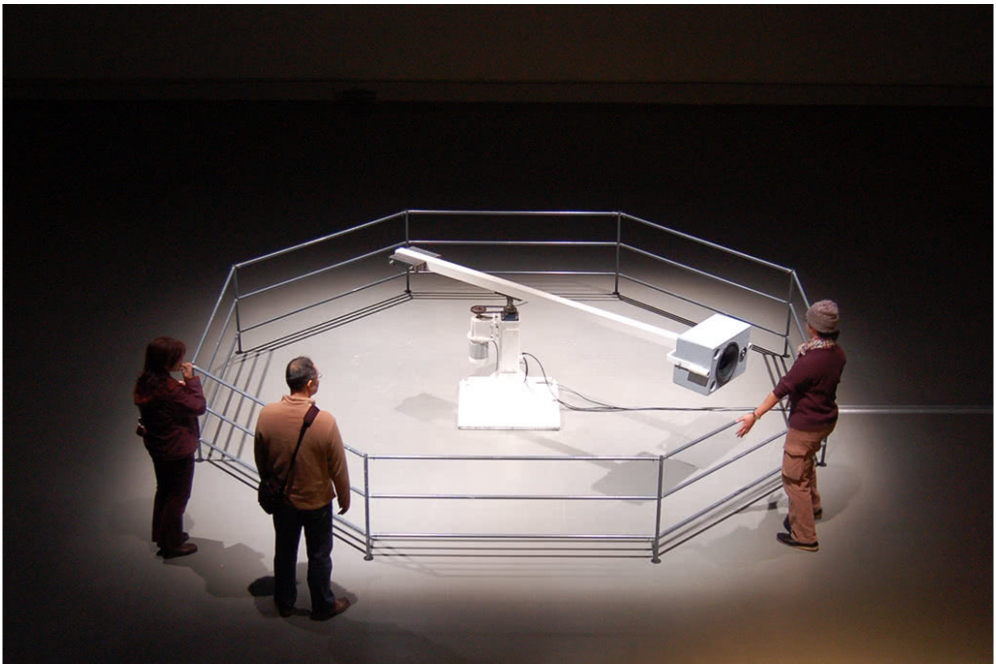

Figure 4.10: Marnix de Nijs and Edwin van der Heide, *Spatial Sounds (100 dB at 100 km/h)*, 2000. (©Edwin van der Heide)

Spatial Sounds (100 dB at 100 km/h) is an interactive installation that features a speaker mounted on a robotic arm, equipped with various sensors that detect both the actions of the audience and its own movements (van der Heide, 2011) (see Figure 4.10). The installation operates across four distinct interaction modes, which are determined by the behaviour of the audience and predefined parameters. The *participation style* is group, as the number of audience is limited by the sensing resolution of the art system. Similar to the previous two artworks, the audience can join and leave the interaction freely in a fluid *audience constellation*. Unlike all previous artworks, the art system has different modes of behaviour and 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 audience members have equal chance to engage in a social activity solicited by the art system. The *input and output access* to the art system are public, and the art system initiates the interaction. This artwork exemplifies multiple forms of co-located interaction, characterised by a fluid and varied participation style across mixed activity types, all initiated by the art system. It also illustrates how different forms of co-located interaction can be combined to enrich the interactive experience. Below, we present the descriptions of each interaction mode separately.

Interaction mode 1

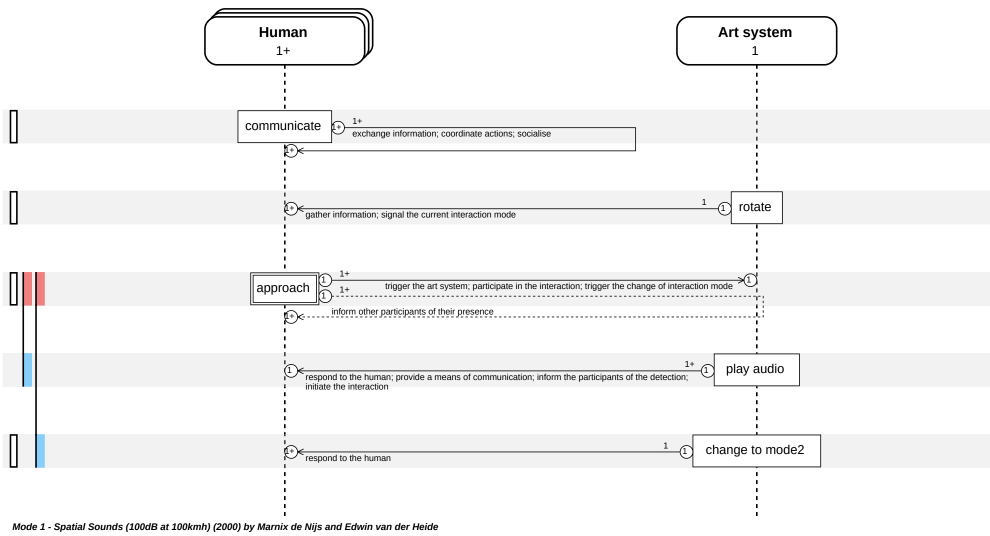

Figure 4.11: Visualisation of described interaction mode 1 in ***Spatial Sounds (100 dB at 100 km/h)*** using RMT.

The detailed description of the interaction mode 1 of ***Spatial Sounds (100 dB at 100 km/h)*** can be accessed in this worksheet[7] and the visualisation is shown in Figure 4.11. Using RMT, we identify two element profiles: one or more participants and an art system. In this mode, the robotic arm begins by rotating slowly, scanning the space while emitting a low humming sound. This action establishes a direct public communication to all audience members, allow-

[7]https://modeltool.liacs.nl/?artwork=spatialsounds1

ing the art system to gather information about their presence and signal the current interaction mode. During this phase, audience members may approach the system without necessarily intending to participate. However, once their presence is detected, a direct public communication is established from the audience to the art system, enabling them to engage in the interaction and potentially trigger a transition to a different interaction mode.

Upon detecting an audience member, the art system responds with an audio signal in a direct public communication to all present. This feedback informs the audience of the detection and initiates the interaction, while also serving as a means for communication among them. As multiple audience members can be detected simultaneously, several instances of this communication may occur concurrently. Consequently, participants can use these auditory cues to signal their presence to one another in a mediated public communication.

Throughout the interaction, the audience can also communicate directly and publicly with each other, exchanging information, coordinating actions, and socialising. After detecting an individual, the art system continues scanning for a predetermined period before transitioning to interaction mode 2. This shift is signalled through a direct public communication to all participants.

Interaction mode 2

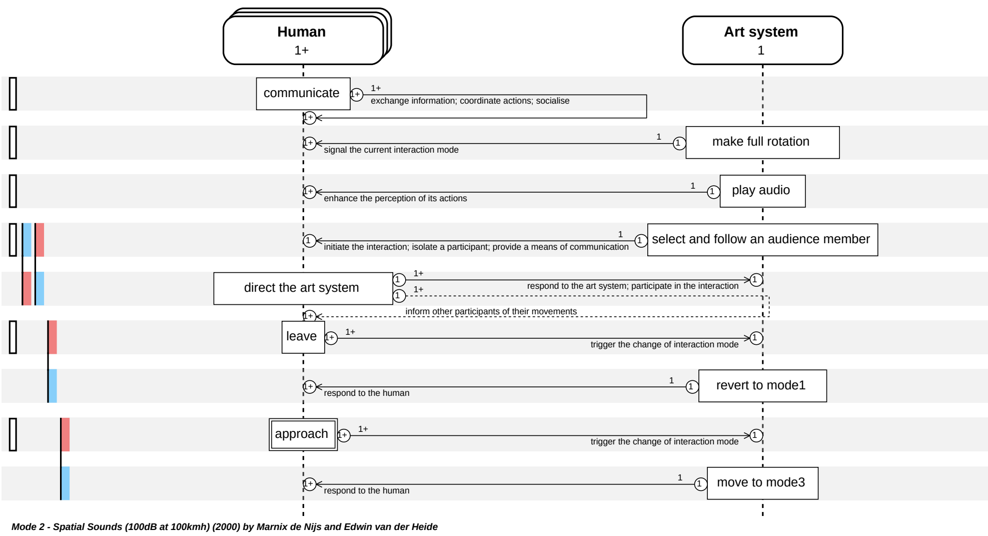

Figure 4.12: Visualisation of described interaction mode 2 in ***Spatial Sounds (100 dB at 100 km/h)*** using RMT.

The detailed description of the interaction mode 2 of ***Spatial Sounds (100 dB at 100 km/h)*** can be accessed in this worksheet[8] and the visualisation is shown in Figure 4.12. In this mode, we similarly identify two element profiles: one or more participants and an art system. At the onset, the art system performs a complete rotation to scan the surrounding space in a direct public communication to the audience, gathering inputs and signal the current interaction mode through direct. Following this, the art system selects and tracks a single participant in a direct public communication to initiate the interaction. By isolating the chosen individual from the broader audience, the art system also provides them with a means of communication. In response, the selected participant can move to influence the art system's position in a direct public communication to participate in the interaction. Furthermore, the participant can also convey their movements to the wider audience via the art system's responses.

Throughout the interaction, participants can also communicate with each other directly and publicly to exchange information, coordinate actions and socialise. Meanwhile, other audience members can still approach the art system, and their presence is detected by the system, establishing a direct public communication from the audience to the system. This detection triggers the art system to switch to interaction mode 3. It is important to note that although the art system attempts to follow a specific participant, it may lose track if the individual moves away or if another participant intervenes between them and the system. Additionally, when participants move away from the art system, this action is detected, prompting the art system to revert to interaction mode 1.

Interaction mode 3

The detailed description of the interaction mode 3 of ***Spatial Sounds (100 dB at 100 km/h)*** can be accessed in this worksheet[9] and the visualisation is shown in Figure 4.13. Here, we identify two element profiles: one or more participants and an art system. In this mode, the art system first rotates at a fixed speed to signal the current interaction mode and generates an audio based on the rotation speed to enhance the perception of its movement. These actions establish a direct public communication to all participants. Meanwhile, one or more participants can approach the art system without necessary intending to participate, establishing a direct public communication to the art system. Upon detecting a participant, the art system immediately changes its rotation direction and generates an audio response in direct public communication, thereby initiating the interaction and introducing a game-like experience for the participants. In turn, the participants can communicate with each other via these responses of the art system, allowing them to engage in a playful activity by passing the system around.

[8] https://modeltool.liacs.nl/?artwork=spatialsounds2
[9] https://modeltool.liacs.nl/?artwork=spatialsounds3

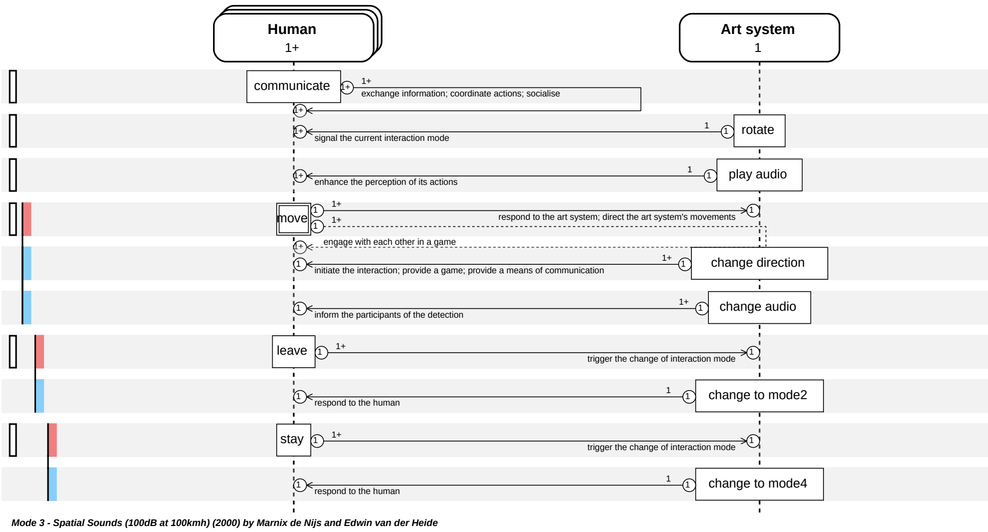

Figure 4.13: Visualisation of described interaction mode 3 in ***Spatial Sounds (100 dB at 100 km/h)*** using RMT.

Throughout the interaction, participants can also communicate with each other directly and publicly to exchange information, coordinate actions and socialise. If participants stay in front of the art system, they trigger it to switch to interaction mode 4. Conversely, if they move away, the art system reverts to interaction mode 2.

Interaction mode 4

The detailed description of the interaction mode 4 of ***Spatial Sounds (100 dB at 100 km/h)*** can be accessed in this worksheet[10] and the visualisation is shown in Figure 4.14. In this mode, two element profiles are identified: one or more participants and the art system. Initially, the art system speeds up its movement in direct public communication to all present to signal the current interaction mode and urge participants to move away. Once the participants do so, the art system slows down in a direct public communication as a response, indicating a change in its behaviour. Meanwhile, the art system also generates audio based on its rotational speed in direct public communication to all audience members to enhance their perceptions of its movement. The audience can then choose to move away as a response in a direct public communication to comply with the art system.

After a predetermined period, the art system automatically reverts to interaction mode 3.

[10] https://modeltool.liacs.nl/?artwork=spatialsounds4

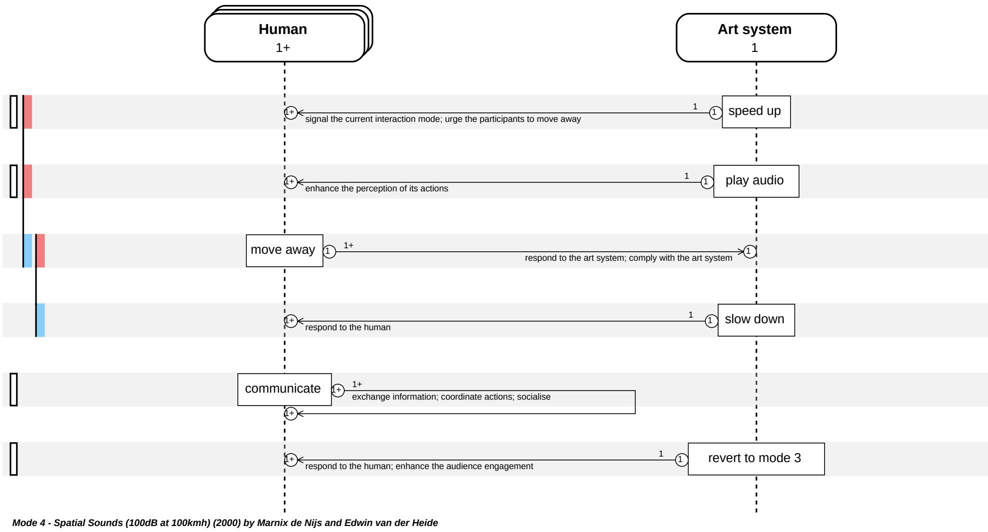

Figure 4.14: Visualisation of described interaction mode 4 in ***Spatial Sounds (100 dB at 100 km/h)*** using RMT.

Throughout the interaction, participants can also communicate with each other directly and publicly to exchange information, coordinate actions and socialise.

4.4.7 *Lights Contacts* (2009) by Scenocosme

Lights Contacts is an interactive installation that responds to physical contact between participants by generating varying sounds and lights in a public setting (Scenocosme, 2009) (see Figure 4.15). To activate the system, a participant must first place their hand on a sensor ball, effectively becoming an extension of the art system's sensing unit. When another participant touches the skin of the first participant, the art system detects changes in electrostatic charge, generating corresponding sounds and altering the lighting. The *participation style* here is crowd, as an unlimited number of participants can engage with the installation. Similar to the previous three artworks, the *audience constellation* is fluid, allowing participants to join and leave the interaction at any time. However, since the sensor ball is available to only a limited number of participants, the *input access* is partially public. In contrast, the *output access* is fully public, as the sounds and lights are displayed openly to all. Similar to ***World Skin***, the *participation symmetry* here is asymmetrical, as only some participants are required to touch the sensor ball. The *activity type* is social, with the audience relying on each other to initiate and sustain the interaction. ***Lights Contacts*** exemplifies a form of co-located interaction with

Figure 4.15: Scenocosme, *Lights Contacts*, 2009. (©Scenocosme)

fluid and asymmetrical participation style in a social activity initiated by the audience.

The detailed description of ***Lights Contacts*** can be accessed in this worksheet[11] and the visualisation is shown in Figure 4.16. Using RMT, we identify three element profiles: one participant as a sensor, one or more participants and an art system. All actions of the elements are intended for participating in the interaction. To start, one participant must touch the sensor ball of the art system in a direct private communication to activate it, thereby becoming part of its sensing unit. Subsequently, this participant must touch other participants in a direct public communication, or vice versa, to initiate the interaction, as well as influence the response of the art system. Additionally, when other participants come into contact with the participant who is in contact with the sensor ball, they too become part of the sensing unit due to the conductive properties of human bodies.

In response, the art system plays and alters the audio based on the proximity and touch intensity of the participants in a direct public communication to all participants. This action provides feedback about the actions of the participants, as well as a means of communication among them. Additionally, it also adjusts the light in accordance with the audio in a direct public communication to all participants to enhance their experiences. Via these responses of the art system, the audience can communicate with each other to collaborative play and performance.

[11] https://modeltool.liacs.nl/?artwork=lights

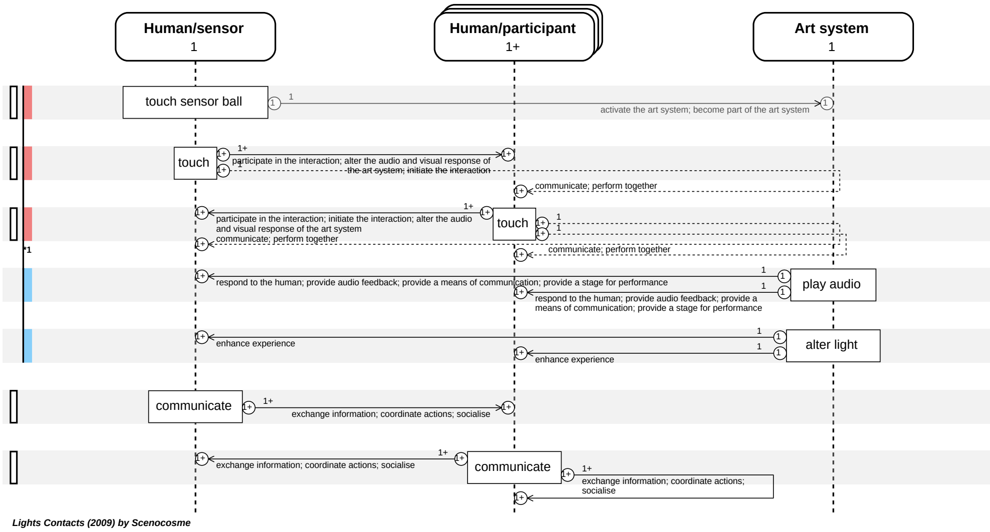

Figure 4.16: Visualisation of described interaction in ***Lights Contacts*** using RMT. *1: (If human/sensor touches sensor ball AND If human/sensor touches human/participant) OR (If human/sensor touches sensor ball AND If human/participant touches human/sensor)

Throughout the interaction, participants can also communicate with each other directly and publicly to exchange information, coordinate actions and socialise.

4.4.8 *Body Movies* (2001) by Rafael Lozano-Hemmer

Body Movies is an interactive projection installation for public spaces (Lozano-Hemmer, 2001) (see Figure 4.17). The audience members can participate by casting their shadows on a large projection screen to reveal hidden portraits and perform with one another. Similar to ***Lights Contacts*** and ***Zoom Pavilion***, the *participation style* is crowd, as there is no practically imposed limit on the number of participants, and they have the freedom to join and leave the interaction in a fluid *audience constellation*. The *input and output access* are both public, as they are shared and perceived by all audience equally. The *participation symmetry* is symmetrical, because there is no separately designated roles for the participants. They can interact both individually and with each other to reveal portraits or perform together in a mixed *activity type*. The audience initiate the interaction by casting shadows on the projection surface. Overall, ***Body Movies*** exemplifies a form of co-located interaction with fluid and symmetrical participation style in mixed types of activities initiated by the audience.

Figure 4.17: Rafael Lozano-Hemmer, *Body Movies*, 2001. (©Antimodular Research)

The detailed description of ***Body Movies*** can be accessed in this worksheet[12] and the visualisation is shown in Figure 4.18. Using RMT, we identify two element profiles: one or more human participants and an art system. All actions of the elements are intended for participating in the interaction. To start, one or more human participants cast their shadows on the projection wall in a direct public communication to the art system. This action allows them to participate in the interaction and communicate with each other. In response, the art system projects these shadows onto the wall in a direct public communication to all participants. This display reveals hidden portraits, offers visual feedback on their movements, and creates a platform for communication and performance. Via the response of the art system, participants can also publicly communicate and perform with each other.

Next, one or more participants can activate a hotspot in a direct public communication to the art system to participate in the interaction. This action triggers the art system to play back an audio response in a direct public communication to inform the participants of their achievements and provide another means of communication. As multiple participants can interact simultaneously, multiple instances of all above communications can occur concurrently.

[12] https://modeltool.liacs.nl/?artwork=bodymovies

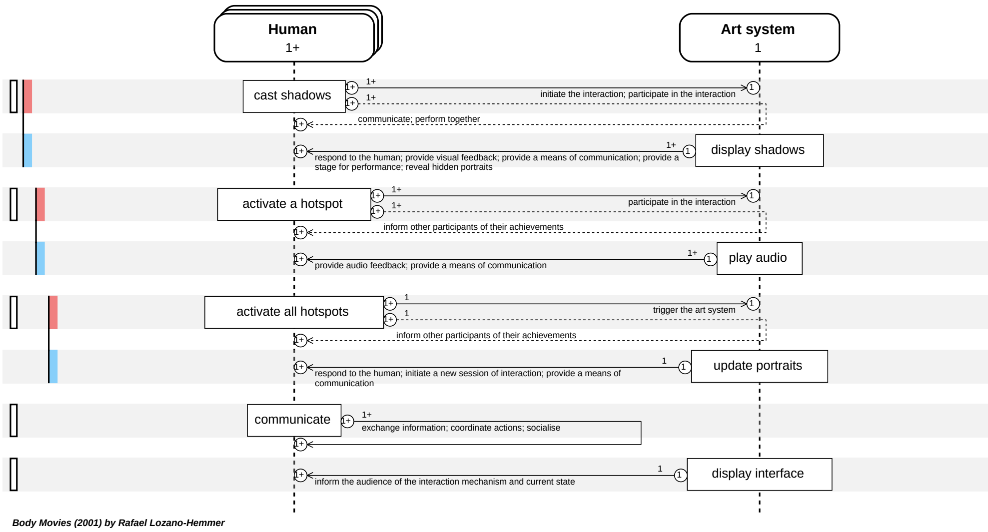

Figure 4.18: Visualisation of described interaction in ***Body Movies*** using RMT.

Moreover, one or more participants can also activate all hotspots in a direct public communication to the art system to trigger the update of the portraits. In response, the art system updates the portraits to inform the participants of this achievement and initiate a new session of interaction in a direct public communication. The participants can also inform each other of activating the hotspots via the responses of the art system.

Finally, the participants can communicate directly and publicly with each other to exchange information, coordinate actions and socialise. Throughout the interaction, the art system also displays its interface to inform the participants of the interaction mechanism and the current interaction state in direct public communication.

In our previous descriptions of ***Body Movies*** using only the relational model (Xu, Lamers, & van der Heide, 2023)(Xu et al., 2024), we specified only the action of casting a shadow performed by the human participants, as this is their primary method of participation and considered activating hotspots only as part of the roles of this action. However, when modelling the same interaction using RMT, it became evident that certain actions of the art system, namely “play audio” and “update portraits”, occur only under specific conditions and are reactions to the audience’ s actions. Therefore, we included the actions “activate a hotspot” and “activate all hotspots” so that the relationships between the actions of the human participants and the art system can be properly described.

4.5 Insights into Co-located Interaction

Based on the descriptions of the various forms of co-located interaction in the selected artworks, we identify five common themes from their similarities and differences and discuss them individually below.

4.5.1 Different types of reactions

In all selected artworks, there are actions performed by elements that serve as responses to other elements. We can say that the elements act and react to each other. This dynamic is particularly evident between art system and audience. Furthermore, upon closer analysis, we can identify several distinct types of reactions within these interactions.

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 example, in ***World Skin***, the art system updates the landscape display in response to audience navigating in the virtual landscape. Similarly, in ***Brainball***, ***Body Movies***, and ***Spatial Sounds (100 dB at 100 km/h)***, the art systems employ visual or auditory displays to inform the audience of the status of the interaction or its recognition of their presence. Additionally, the art system can provide supplementary sensory feedback on the actions of the audience, as seen in ***Zoom Pavilion***, ***Boundary Functions***, and ***Lights Contacts***, where information such as the distance between audience members and the intensity of their touch is translated into visual and/or auditory cues. Finally, the art system can also initiate or trigger interaction through its reaction. For instance, in both ***Zoom Pavilion*** and ***Spatial Sounds (100 dB at 100 km/h)***, the art system reacts to the presence of the audience with visual and/or audio responses to initiate the interaction.

Conversely, reactions performed by the audience primarily involve complying with or performing actions dictated by the art systems. For instance, in ***Randomly Generated Social Interactions*** and in interaction modes 2 and mode 4 of ***Spatial Sounds (100 dB at 100 km/h)***, the audience follows instructions or prompts from the art system to engage in specific actions. It is important to emphasise that these reactions are not isolated events but form part of a continuous exchange between actions and reactions. As a result, a reaction to one element can further trigger reactions or influence subsequent actions of the element.

4.5.2 Influences between actions

Besides this action-reaction relationship, actions performed by the elements can also influence each other in various 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***, an audience member is required to press a button to start the game. And in ***Lights Contacts***, one audience member 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. This is demonstrated in ***Brainball***, the display of real-time brainwave data and direct communication between the players can hinder their performance in the game. Lastly, an action can facilitate or enhance other actions, often taking place in parallel to each other. For instance, in ***World Skin*** the driver navigates the landscape to facilitate the photographers taking photos, and the art system plays audio to enhance their experience. The use of audio to enhance the perception of its other actions is also observed in ***Zoom Pavilion*** and ***Spatial Sounds (100 dB at 100 km/h)***, while in ***Lights Contacts*** it is the use of light that enhances the perception of the audio generated by the art system.

4.5.3 Roles of direct communication between audience

A distinct characteristic of co-located interaction is the ability of the audience to communicate directly with each other due to their co-location. This communication can occur through verbal exchanges as well as non-verbal means, such as gestures, facial expressions, and touch. Since it often takes place in parallel to other actions of the audience, direct communication can either facilitate or disrupt these processes. Such communication enables the audience to exchange information and coordinate their actions. By sharing their experiences and understanding of the interaction mechanisms, audience members can introduce new ideas, insights, and feedback on each other's performances. This dynamic is evident in all the artworks except ***Brainball***, where direct communication may actually interfere with the ability of the audience to remain composed, potentially impacting their success 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 participants to communicate directly with one another, making this form of communication a central aspect of the interaction. Meanwhile, in ***Boundary Functions*** and ***Lights Contacts***, the physical contact of the audience with each other triggers responses from the art system, making direct communication a key mechanism driving the interaction.

4.5.4 Creating connections among audience

A recurring theme across all the selected artworks is the active role of the art system in establishing or facilitating connections among audience members during the interaction. Several distinct approaches are observed in how the art system achieves this.

Firstly, connections can be established arbitrarily. 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 system randomly pairs the faces or bodies of two audience members, facilitating chance encounters.

Secondly, in some instances the art system necessitates interdependencies among actions of the audience, which means the actions of one audience member may affect or depend on the actions of others. Within this context, various methods are employed by the art system. To start, the art system can draw upon differences in the audience’ s behaviours. For example, in ***Brainball***, the movement of the steel ball is determined by the relative states of relaxation between the two players. Alternatively, the art system can react to actions that require multiple audience members to perform together, as seen in ***Lights Contacts*** and ***Boundary Functions***, where the physical touch between participants is necessary to trigger the art system. Yet another manifestation is where the art system enables shared control over its responses among the audience. In ***Zoom Pavilion***, for instance, a line is drawn between two audience members that adjusts as they move closer or further apart. Similarly, in ***Boundary Functions***, the generated Voronoi diagram is determined by the positions of all audience members.

Another strategy employed by the art system to foster connections is to encourage collaborations among the audience members. This is evident in ***World Skin*** and ***Lights Contacts***, the audience members play different roles and have different functions, so they must work together to achieve a shared goal.

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 audience member, placing them under the spotlight. This emphasis amplifies the actions of the chosen individual, triggering them to express and connect with others. This effect is evident in ***Zoom Pavilion***, where the system randomly selects and magnifies the face of an audience member. Similarly, in mode 2 of ***Spatial Sounds (100 dB at 100 km/h)***, the 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 audience members.

4.5.5 Differing forms of mediated communication

In all selected artworks, at least one form of mediated communication is present, where one element communicates with another via a third element. The most common example of this is audience members communicating with each other via the art system. In artworks such as ***World Skin***, ***Body Movies***, and ***Zoom Pavilion***, the art system provides a platform for the audience to express themselves and perform. Additionally, the art system can translate information about audience actions into sensory cues to be used by the audience to communicate with each other. This is evident in ***Zoom Pavilion***, ***Boundary Functions***, and ***Lights Contacts***, where the distance between the audience are translated into audio-visual cues.

Another form of mediated communication occurs when the audience communicates with the art system through another audience member. In ***Lights Contacts***, for instance, the audience member who is in contact with the sensor ball becomes part of the art system, allowing other audience members to interact with the system through them.

A third intriguing form of mediated communication is demonstrated in ***Randomly Generated Social Interactions***. Here, the art system generates content and instructs one audience member to act it out, thereby conveying the information to the other audience member. In this scenario, the art system communicates to the receiving audience member via the acting audience member, who effectively becomes a "tool" for expression.

4.6 Reflection on the Modelling Capability of RMT

As demonstrated in Section 4.4, RMT enables us to provide detailed descriptions of a wide variety of co-located interactions. To illustrate this, we carefully selected eight artworks that represent different forms of co-located interaction, primarily based on varying combinations of their *audience constellation*, *participation symmetry*, *activity type*, and *initiator*. RMT characterises co-located interaction by focusing on the actions of both the audience and the art system and the resulting different forms of communication. This approach allows us to specify the role each element plays in the interaction, as well as how they influence and relate to one another. The main concepts used in the model —the identification of elements, their actions and forms of communications to each other —were shown to be applicable to all artworks. Importantly, RMT offers a flexible analytical tool that can be adapted to examine and compare diverse forms of co-located interaction.

A notable strength of RMT's modelling capabilities lies in its emphasis on the relational exchange between actions. This is particularly evident in the case of ***Body Movies***. When using the relational model alone, the description of the behaviours of the audience were less detailed. However, as RMT requires a clear specification of triggering actions for the reactions in an interaction, the relationships between the actions of the audience and the art system are clearly articulated through their conditional links. As a result, RMT not only produces a more comprehensive description, but also aids in making decisions during the modelling process.

RMT does not presuppose inherent differences between the behaviours of the art system and the audience; instead, it seeks to describe both on equal terms. This perspective opens new possibilities for conceptualising interactive dialogues, such as leveraging the audience as a medium for expression and communication. This idea is particularly relevant in light of advancements in artificial intelligence, which have led to the development of increasingly sophisticated technical systems capable of performing tasks traditionally associated with human agency. Nevertheless, we also notice the differences between the behaviours of art systems and audiences. The actions of art systems are often concrete and well-defined, as they are typically programmed and scripted, whereas audience actions tend to be more open-ended, diverse, and individually variable. Consequently, general terms are often employed to describe audience actions. 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 (100 dB at 100 km/h)***, where the art system may misidentify the audience, resulting in a more unpredictable and engaging interactive experience.

When considering the audience, the relational model focuses mainly on those who actively participate in the interaction, excluding those who are merely observing. In some artworks with fluid *audience constellation*, the distinction between participating and observing audiences is blurred, as in ***Zoom Pavilion***, ***Spatial Sounds (100 dB at 100 km/h)***, and ***Body Movies***. In contrast, other artworks clearly distinguish between these roles, regardless of whether the *audience constellation* is fluid or fixed, as demonstrated in ***Brainball***, ***Randomly Generated Social Interactions***, ***World Skin***, and ***Boundary Functions***. In the latter cases, the presence of observing audiences can also influence those who are actively participating, and it may be valuable to incorporate this influence into RMT and the relational model.

4.7 Discussion

In this chapter, we have demonstrated the effectiveness of describing and comparing different forms of co-located interaction in interactive art using RMT. The tool provides a systematic approach to examining co-located interaction, enabling us to analyse such interactions in concrete terms and uncover the various relationships and influences between the interacting elements. Additionally, it highlights opportunities for creating new forms of communication and interaction. Although we have focused on co-located interaction here, the same methodology can be applied to study other types of interaction and audience participation. We believe that RMT demonstrates potentials in advancing our understandings of interaction in interactive art.

Based on the outcomes derived from applying RMT, it becomes evident that co-located interaction expands the concept of an interactive dialogue into a network of intertwined actions and reactions among multiple elements. The interacting elements not only can act and react to one another in various ways, but their actions also influence each other in ways that are essential to the interactive dynamics and for establishing complex relationships among the elements.

This opens up possibilities for envisioning new forms of interaction by composing different types of action-reaction sequences and influences between actions. For example, rather than the art system providing feedback to the audience as demonstrated in the selected artworks, the reverse could occur. A promising direction for future research would be to conduct a comprehensive exploration of existing relationship typologies and examine their prevalence across the actions of different elements in interactive art.

One aspect of co-located interaction that was highlighted in our analysis of the selected artworks pertains to its inherently social nature. By definition, co-located interaction requires the simultaneous participation of multiple audience members in the same physical space, making their interplay central to the overall interactive experience. To facilitate this, art systems can employ various strategies to foster connections between audience members, drawing upon their ability to communicate directly in different ways, and devising novel forms of mediated communication. The examples from the selected artworks provide a foundation for further exploration in these directions. This insight underscores the capacity of interaction to leverage and incorporate existing social dynamics among participants, while also hinting at the potential effects these dynamics may have on the interaction itself.

Finally, in developing classification dimensions and artwork selection criteria, we aim to select a diverse range of artworks with minimal bias. However, due to the availability and accessibility of documentations, the selected artworks primarily originate from a Western cultural context and were created between 1997 and 2016. Moreover, due to practical concerns, we could not cover all varieties of co-located interaction, but focus on some aspects we deemed most significant. Considering the focus of our classification dimensions on parameters that define audience participation, it would be worthwhile to model and analyse more recent artworks and explore different classification methods, such as those focused on audience experience or varying cultural contexts.

Chapter 5

Describing and Comparing More-than-Human Interaction

5.1 Introduction

Traditional interactive art has predominantly focused on the dynamic interaction between human participants and the technical systems within artworks, referred to as art systems. Alongside the development of human-computer interaction, there has been growing interest in developing interactive technologies to engage animals and other nonhuman organisms (Mancini, 2011)(McGrath, 2009)(van Eck & Lamers, 2013). These explorations not only signify the evolving landscape of interaction design but also suggest the potential benefits of enhancing interspecies relationships through playful interactions mediated by computational technologies (Fava et al., 2019a, 2019b).

Within the field of interactive art, artist researcher Alinta Krauth introduced the term *multispecies interactive art* to characterise a form of interactive art practice that involves both human and animal participants, with a specific focus on enrichment for the latter (Krauth, 2022b). The overarching goal is to actively contribute to alternative ways of relating to our nonhuman companions, thus expanding the field of interactive art in favour of a more-than-human turn. Building upon this idea of multispecies interactive art, here we introduce the term *more-than-human interactive art* to describe the interactive art practice that extends beyond traditional audience-artwork interaction by involving other nonhuman elements as participants.

Grounded in post-humanist philosophy, the more-than-human perspective challenges the anthropocentric worldview by acknowledging the agency and influence of nonhuman entities, spanning animals, plants, ecosystems, and even technological systems (Forlano, 2017)(Giaccardi & Redström, 2020). Consequently, more-than-human interactive art must recognise the significance of nonhuman participants in shaping the interactive experience. While these artworks may not always require human participation, our focus here is on those involving both human and nonhuman organisms. Despite the growing interest in such artworks and practices, there is a notable scarcity of studies that critically examine how interspecies interactions are shaped within instances of more-than-human interactive art. A thorough investigation of such relationships not only allows us to uncover fresh insights, but also to identify gaps or limitations in this field and point to directions for future research and creation.

In Chapter 2 and 3, we introduce the relational model and its accompanying web-based tool, the Relational Modelling Tool (RMT), designed to describe and visualise interactions in interactive art[1]. In Chapter 4, we show that RMT is capable of modelling and analysing diverse forms of co-located interaction. An intriguing aspect of RMT and its underpinning relational model lies in their impartial treatment of various elements—whether human, nonhuman organism, or technical system. Therefore, we believe that it can also provide a valuable theoretical and practical tool for examining different forms of more-than-human interaction and interspecies relationships. By testing the effectiveness of RMT in describing and comparing more-than-human interactive artworks, we also aim to contribute to the methodological tools available to researchers interested in this field.

This chapter builds extensively on our prior publication in the Leonardo Journal (Xu, Lamers, van der Heide, & Verbeek, 2025). Here, we expand on the concept of more-than-human interaction by contextualising it within the wider domains of Animal-Computer Interaction (ACI), biotic games, and other related fields in interaction design.

The chapter is structured as follows: First, we provide a brief overview of the broader context of more-than-human interaction within relevant academic and practical discourses; Next, we introduce five selected artworks that exemplify diverse forms of more-than-human interaction between humans and nonhuman organisms—each artwork is described in detail, followed by a description developed using RMT; Building on these analyses, we present a comprehensive discussion of the insights gained into more-than-human interaction, given the similarities and differences observed across the selected artworks; Finally, we evaluate the effectiveness of RMT's modelling capabilities in this context, reflecting on its strengths and identifying potential areas for improvement.

[1] The latest version of RMT is accessible via: https://modeltool.liacs.nl/

5.2 Situating More-than-Human Interactive Art

Besides interactive art, there have been many attempts to extend the scope of interaction design beyond focusing solely on human users. ACI has underscored the importance of designing interactive technologies tailored to animals, whether as users or participants, with the aim of enhancing their well-being and enrichment (Mancini, 2011)(McGrath, 2009)(Fava et al., 2019a, 2019b). Examples of such applications include interactive installations for captive parrots (Gupfinger & Kaltenbrunner, 2019), video games designed for pets and their owners (Tan et al., 2008)(Noz & An, 2011), and video conferencing systems for domesticated parrots (Kleinberger et al., 2023). Beyond the focus on animal users, Kobayashi et al. have introduced the concept of Human-Computer-Biosphere Interaction (HCBI), which encompasses computer-mediated interactions between humans and elements of the biosphere, such as wild species and biological systems (Kobayashi et al., 2015)(Kobayashi et al., 2009).

Meanwhile, in the context of artistic and entertainment computing, there has always been explorations of incorporating biological systems—ranging from cells to plants, animals, and even entire ecosystems—into digital systems to generate behaviours, leading to the creation of hybrid biological-digital systems (van Eck & Lamers, 2013). Such hybrid systems have also been applied in the development of biotic games, which combines biological organisms or systems with video gaming to raise awareness and understanding of biological concepts in a playful, interactive way (Riedel-Kruse et al., 2011). However, we argue that a key distinction between more-than-human interaction and these hybrid systems and games lies in the role of nonhuman life forms. Instead of merely "incorporate" nonhuman organisms into digital systems or use them as components of game mechanisms, more-than-human interaction treats nonhuman organisms as significant, if not equal, participants in the interactive experience alongside humans.

By shifting the focus away from developing human-centred interactive technologies and systems, the developments in more-than-human interaction have opened up new possibilities for redefining the boundaries of interaction design, fostering more inclusive and equitable relationships between humans and nonhuman entities, and challenging anthropocentric biases in technology and art. This shift not only broadens the scope of interaction design to encompass a wider range of participants but also encourages a deeper consideration of the ethical, ecological, and social implications of creating interactive systems that engage with the more-than-human world.

Similarly, more-than-human interaction broadens the focus of audience-artwork interaction to include nonhuman elements—such as animals, plants, microorganisms, and biological systems—as (active) participants in the interaction. These interactions may occur between nonhuman participants and art systems, between humans and nonhuman participants mediated by art systems, or between different nonhuman participants mediated by art systems. In this study, we focus specifically on more-than-human interactive art that involves both human and nonhuman organisms. By doing so, we aim to investigate how interspecies relationships are created and mediated within these artworks, as well as to identify potential biases in the ways the roles of humans and nonhumans are understood within these interactions.

5.3 Modelling Diverse More-than-Human Interaction

We selected five interactive artworks involving both human and nonhuman organisms for analysis. These artworks, ranging from interactive installations to interspecies games, were chosen for their intention to engage both groups as participants in the interactions. Each piece employs distinct approaches to shape interspecies relationships. We introduce each work individually in reverse chronological order by creation date and describe the more-than-human interaction within them using RMT.

5.3.1 *Mouse Coach* (2023) by Jiabao Li

Mouse Coach is a speculative artwork that lets the artist's pet mouse control her exercise routine (Li, 2023, 2024) (see Figure 5.1). Each time the mouse runs on the training wheel, the artist receives a notification prompting her to run herself. When she matches the mouse's running distance, the artwork rewards both participants with different prizes. In conventional owner-pet relationships, humans are typically responsible for setting exercise routines of their pets. However, ***Mouse Coach*** subverts these dynamics by empowering the mouse to control their owner's exercise routine. This alteration challenges the normative dynamics between humans and their pets, making the work an intriguing case for more-than-human interaction.

The detailed description of ***Mouse Coach*** can be accessed in this worksheet[2] and the visualisation is shown in Figure 5.2. Using RMT, we identify three element profiles: a pet mouse, a human, an art system. For the mouse, the key action it performs in the interaction is to run without any intention of participating. This action is captured by the art system, creating a direct public communication from the mouse to the art system and triggering it to send a notification to the human via a direct private communication. This reaction of the art system initiates the interaction and informs the human of the mouse's activity. Consequently, it also generates a mediated private communication from the mouse to the human via the art system. After receiving the private communication, the human participates in the interaction by also

[2] https://modeltool.liacs.nl/?artwork=mouse

Figure 5.1: Jiabao Li, *Mouse Coach*, 2023. Installation exhibition at IDFA Doclab 2024. (©Jiabao Li)

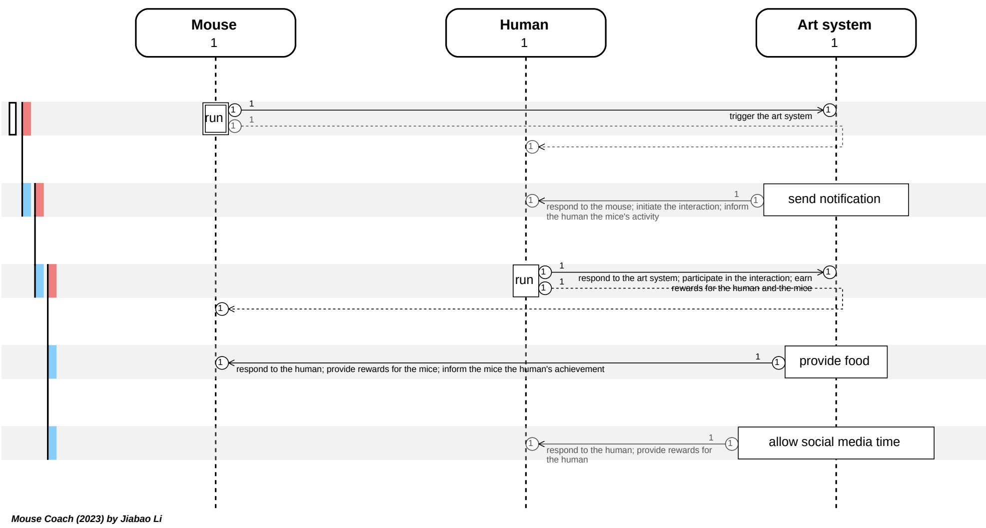

Figure 5.2: Visualisation of described interaction in ***Mouse Coach*** using RMT.

running. This action targets at the art system through a direct public communication, which triggers the art system to reward the human with time on social media and the mouse with food, while also informing the mouse of the human's achievement. As a result, the successful interaction also generates a mediated public communication from the human to the mouse via the art system's reward.

5.3.2 *IntraFacing* (2022) by Alinta Krauth

IntraFacing is a multispecies art game designed for humans and their companion dogs using a pair of mobile phones (Krauth, 2022a). One of the mobile phones detects the movement of the dog and sends a corresponding task to the human that instructs them to engage with the dog in playful ways, such as imitating the dog's actions and expressions. Like ***Mouse Coach***, the human and nonhuman participants share an existing owner-pet relationship. But unlike it, ***IntraFacing*** aims to enhance and enrich this relationship, rather than subvert its dynamics. Moreover, the pet owner and dog share the same physical space with direct access to each other. According to the artist, ***IntraFacing*** explicitly positions her pet dog as a co-contributor in the creative process, highlighting its significance in fostering more-than-human interaction (Krauth, 2020).

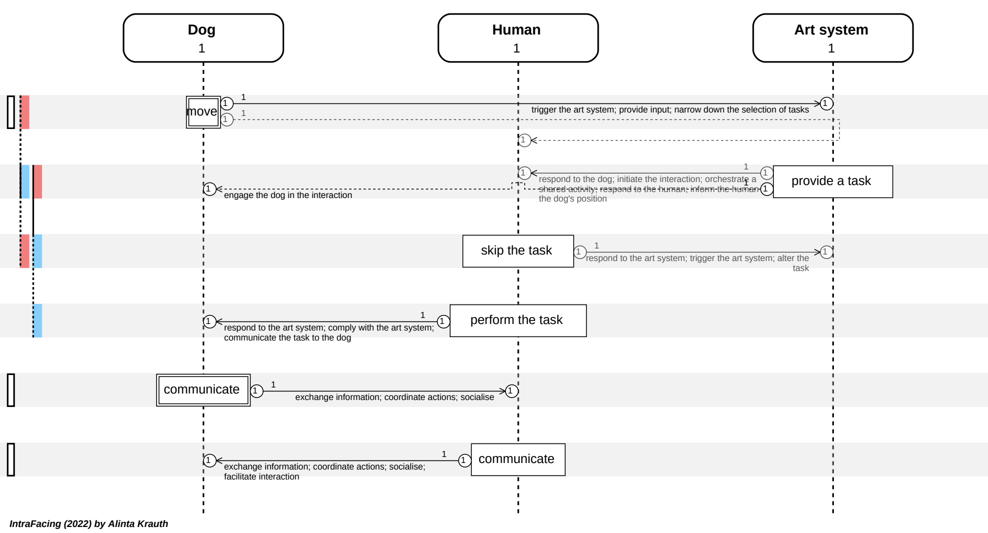

Figure 5.3: Visualisation of described interaction in ***IntraFacing*** using RMT.

The detailed description of ***IntraFacing*** can be accessed in this worksheet[3] and the vi-

[3] https://modeltool.liacs.nl/?artwork=intrafacing

sualisation is shown in Figure 5.3. Using RMT, we identify three element profiles: a dog, a human, an art system. The key actions performed by the dog are moving and communicating to the human directly. We would argue that both are unintended for the interaction. When the dog moves, its body position is detected by the art system, resulting in a direct public communication that triggers the art system to provide a task to the human via a direct private communication. As the task is selected based on the detected position, it also provides input to the art system and narrows down the task selection.

By providing the task to the human, the art system initiates the interaction, informs the human of the dog's position, and orchestrates a shared activity for both participants. As a result, the art system also enables a mediated private communication from the dog to the human via this response.

In response, the human can either skip the task via a direct private communication to the art system, triggering it to provide another task and altering the task selection, or perform the task via a direct public communication to the dog, thereby complying with the art system and communicating the task to the dog. By performing the task, the human also enables a mediated public communication from the art system to the dog via their performance, thus allowing the art system to engage the dog in the interaction.

Finally, the dog and the human can communicate with each other directly and publicly as they share the same physical space. It allows them to exchange information, coordinate actions, and socialise. Note that for the human, this direct communication also facilitates their engagement with the dog in the interaction.

5.3.3 *Playful Rocksalt System* (2015) by Hiroki Kobayashi, et al.

Playful Rocksalt System enables real-time interaction between a human participant and wild deer in a remote forest through a sensing unit that detects a deer's presence, a rotating rock salt platform that attracts the deer, and a rotating camera (Kobayashi et al., 2015). Both the platform and the camera can be controlled remotely via a digital mobile device. Live video feed captured by the rotating camera is displayed on the same device. Although the work is not strictly created in an artistic context, we discuss it in this context because it aims to facilitate new forms of interspecies interaction. Unlike the above two artworks, it focuses on fostering new connections and relationships between humans and nonhuman organisms rather than altering preexisting ones.

The detailed description of ***Playful Rocksalt System*** can be accessed in this worksheet[4] and the visualisation is shown in Figure 5.4. Using RMT, we identify three element profiles: a

[4] https://modeltool.liacs.nl/?artwork=rocksalt

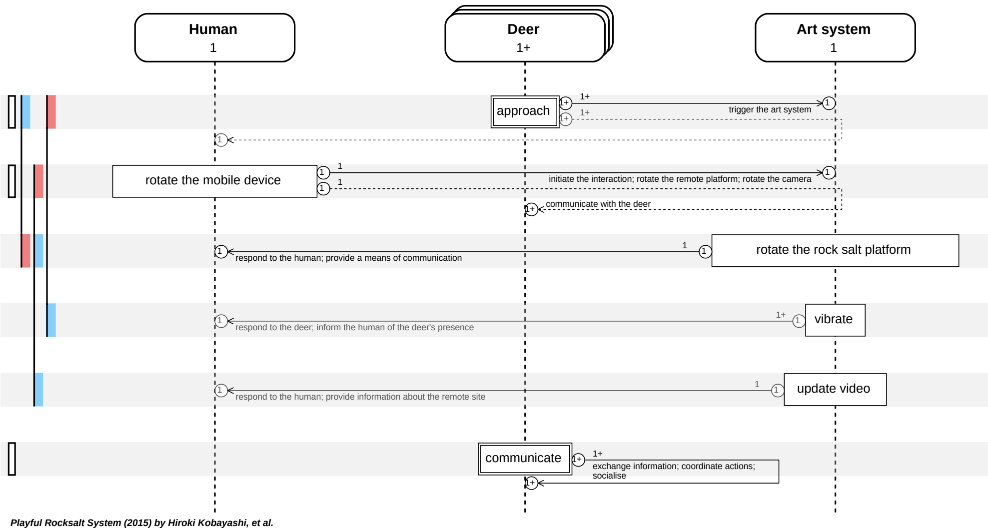

Figure 5.4: Visualisation of described interaction in ***Playful Rocksalt System*** using RMT.

human, one or more deer, an art system. The main action performed by the human is to rotate the mobile device, creating a direct public communication to the art system that allows them to initiate the interaction and control the rotation of the camera and the rock salt platform. In response, the art system updates the video to provide information about the remote site via a direct private communication to the human and rotates the rock salt platform to inform the deer of the human' s action via a direct public communication to the deer. The movement of the platform also enables a mediated public communication from the human to the deer via the art system, allowing the human to attract and respond to the deer.

Meanwhile, one or more deer might approach the sensing unit and the rock salt platform, either voluntarily or being attracted by the rock salt, without any intention of interaction. However, their action is captured by the art system, resulting in a direct public communication that triggers the art system to send a vibratory notification to the human with the mobile device via a direct private communication. As a result, the art system also enables a mediated private communication from the deer to the human via this response. Furthermore, the deer can also communicate among themselves in a direct public communication to exchange information, coordinate actions, and socialise without intending to interact or contributing to the interaction.

5.3.4 *Encounters of a Domestic Nature* (2013) by Amy M. Youngs

Encounters of a Domestic Nature is an installation that facilitates interaction between crickets housed in a living bubble and humans in the same exhibition space through mediated visual access to each other (Youngs, 2013) (see Figure 5.5). As with ***Playful Rocksalt System***, there are no preexisting relationships between the human and nonhuman participants. Like ***IntraFacing***, both types of participants—humans and crickets—are located in the same physical space, allowing them to interact directly. While human and nonhuman participants in the previously discussed cases played distinctively asymmetrical roles and had different degrees of access to the art system, the art system here provides a symmetrical setup for both humans and crickets, potentially allowing for equal participation from both groups.

Figure 5.5: (left) The installation provides symmetrical setups for humans and crickets tailored to their respective scales. (right) Projection of miniaturized humans inside the crickets' living unit. (©Amy M. Youngs)

The detailed description of ***Encounters of a Domestic Nature*** can be accessed in this worksheet[5] and the visualisation is shown in Figure 5.6. Using RMT, we identify three element profiles: one or more humans, one or more crickets, and an art system. The key actions of the crickets in the interaction are chirping and moving, which are unintended for the interaction but are captured by the art system. Each chirp generates a direct public communication to the art system that triggers it to update the landscape projected into the living bubble. This reaction of the art system generates a direct public communication to both the crickets and the humans, providing a visual background to the humans and a potential means of communication for the crickets. As this reaction is triggered by the crickets, it also enables a mediated public communication from the crickets to the humans via the art system.

[5] https://modeltool.liacs.nl/?artwork=encounters

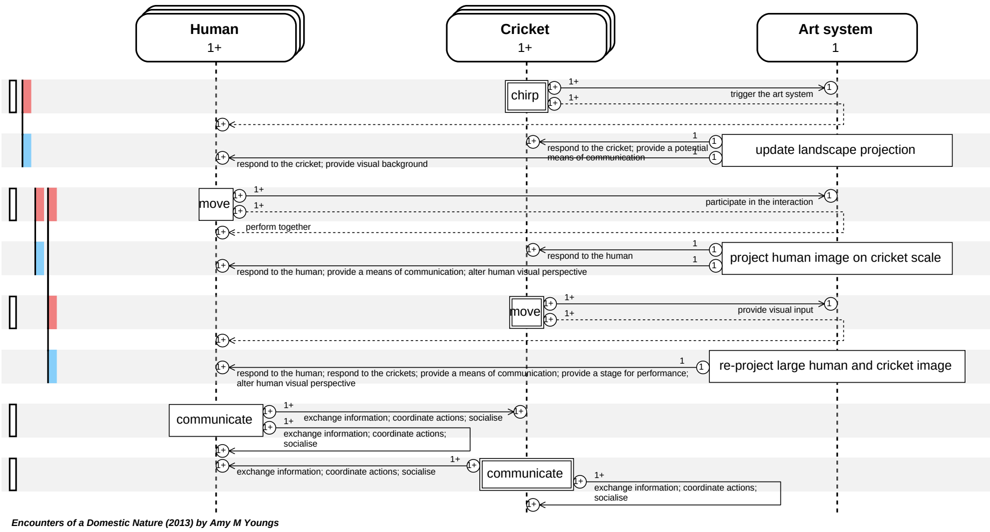

Figure 5.6: Visualisation of described interaction in ***Encounters of a Domestic Nature*** using RMT.

Meanwhile, the humans can move, which is captured by the art system via a direct public communication, allowing them to participate in the interaction. In response, the art system first projects a miniaturised human image into the crickets' living bubble. This action generates a direct public communication to both the crickets, although they may not be able to perceive or interpret the image, and the humans, altering their visual perspective and providing a means of communication for themselves and hypothetically to the crickets.

Moreover, the scenes within the living bubble, including the crickets, are captured by the art system in a direct public communication. The art system then re-projects the image of the crickets with the human projection at a larger scale into the exhibition space. This action generates both a direct public communication to the humans and a mediated public communication from the crickets to the humans, altering the human's visual perspective again and providing a means of communication and a public stage for the humans. Both reactions of the art system can help the humans communicate with each other and perform together through mediated public communication.

Being in the same physical space, the humans can communicate directly with each other and the crickets to exchange information, coordinate actions, and socialise. Similarly, the crickets can also communicate directly with each other and with the humans through actions like chirping and moving. Although these actions may contribute to the interaction, they may not be intended for participation.

5.3.5 *Myconnect* (2013) by Saša Spačal, Mirjan Švagelj and Anil Podgornik

Myconnect is an immersive installation that establishes a biofeedback loop between a human participant and a mycelium network by passing a human's heartbeat signal through the mycelium, translating the modulated signal into various kinds of sensory feedback, and delivering the translated signal back to the human (Spačal, 2013) (see Figure 5.7). In contrast to previous artworks involving animals and insects as participants, which are closer to humans in the animal kingdom, ***Myconnect*** introduces mycelium from the more distant fungi kingdom. The artists aim to establish a symbolic, symbiotic relationship between humans and mycelium that does not occur naturally, creating new interspecies dynamics with a more evolutionarily distinct nonhuman organism in an unusual context.

Figure 5.7: Saša Spačal, Mirjan Švagelj and Anil Podgornik, *Myconnect*, 2013. A human participant lies inside the installation. (©Saša Spačal)

The detailed description of ***Myconnect*** can be accessed in this worksheet[6] and the visualisation is shown in Figure 5.8. Using RMT, we identify three element profiles: a human, a mycelium network, an art system. To initiate the interaction, the human connects to the heart-

[6] https://modeltool.liacs.nl/?artwork=myconnect

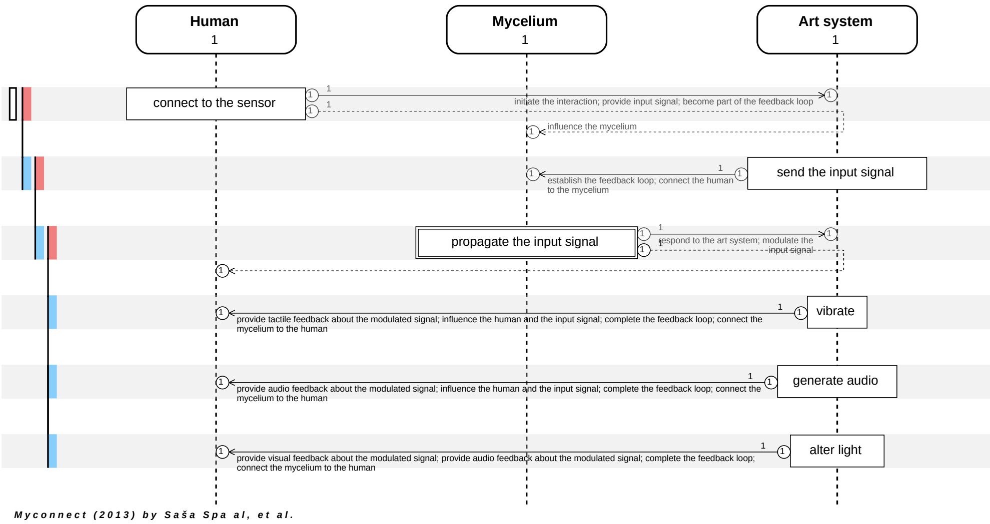

Figure 5.8: Visualisation of described interaction in ***Myconnect*** using RMT.

beat sensor to establish a direct private communication to the art system. This action allows them to provide an input signal and become part of a feedback loop with the mycelium.

The art system then sends the input signal to the mycelium via a direct private communication, connecting the human to the mycelium. Because of this reaction, a mediated private communication from the human to the mycelium is established, allowing the human to influence the mycelium. The mycelium then propagates and modulates the received signal back to the art system via a direct private communication as a natural response unintended for the interaction.

Upon receiving the modulated signal, the art system translates it into vibrations, audio, and changes in lighting that are communicated to the human; the modulated signal in the form of sensory feedback influences the human' s physiological processes, including their heartbeat, to complete the feedback loop. Each of these actions generates a direct public communication to the human. Through these responses of the art system, a mediated public communication from the mycelium to the human is realised.

5.4 Insights into More-than-Human Interaction

Based on the similarities and differences of the selected artworks, we have identified three themes that provide insights into the described more-than-human interactions.

5.4.1 Active versus passive participation

In the selected artworks, we observe a general trend in which humans take on an active role in the interaction, while nonhuman organisms play a passive one. When discussing the role of the audience in participatory art, Guljajeva (Guljajeva, 2018) discerns *active participation*, where the audience voluntarily interacts and is consciously aware of how their actions shape the artwork's output, from *passive participation*, wherein the audience may not intend to interact with and are unaware of their influence on the artwork. In the latter case, the art system often captures and selects audience input without explicit consent. Moreover, passive participation can become active when participants become aware of their impact and willingly choose to interact.

In all the described artworks, humans are aware of how their actions impact the interaction and participate voluntarily. In ***Mouse Coach*** and ***IntraFacing***, while it seems that the art system directs the human participant, they can still choose whether to comply with the art system and determine how to carry out the interaction. In ***Playful Rocksalt System*** and ***Encounters of a Domestic Nature***, humans can directly perceive the effects of their actions on the art system and consciously decide whether to participate.

Meanwhile, although the nonhuman participants in these cases often trigger the art system to initiate interaction, we would argue that these actions are not intended for participation, and they may not be aware of how they affect the interaction. Although they receive feedback about their actions either directly from the art system or indirectly via the humans' actions, it remains unclear whether they could eventually learn about the interaction mechanisms and become active participants.

On the other hand, ***Myconnect*** enrols both the human and mycelium as passive participants with little control over their actions in the interaction. Although the human participant voluntarily connects to the art system, they do not have full control over their heartbeat under the influence of the sensory feedback provided by the art system. Meanwhile, the mycelium reacts to the art system based on their natural responses. Both participants become components of a bigger system—a biofeedback loop—realised through the art system.

For future inquiries, it may be interesting to explore ways to engage nonhuman organisms as active participants and consider scenarios where they interact with humans who participate passively. By shifting the dynamics of agency, we not only propose to explore new possibilities for interaction but also question the prevailing human-centric view of interaction. Achieving this requires effectively communicating the consequences and broader implications of the actions of nonhuman organisms and providing them options for participation, thus enabling them to make informed decisions about whether to participate and how.

It is worth noting that the selected artworks do not aim to educate the nonhuman organisms about the implications of their actions. Instead, they prompt the humans to consider the implications of the nonhumans' involvement. Moreover, since we lack direct access to the cognition of nonhuman organisms, assessing whether they have understood such implications remains speculative from a human standpoint. Clearly, such a proposal requires careful ethical consideration, as it inevitably necessitates humans interpreting the actions and responses of nonhuman organisms, especially those of plants and microorganisms.

5.4.2 Differing forms of mediated communication

In all described interactions, we observe various forms of mediated communication among the elements. Most prevalent is the communication from nonhuman organisms to humans via art systems: In ***Mouse Coach***, ***IntraFacing*** and ***Playful Rocksalt System***, the art systems detect the actions of the nonhuman organisms and inform the human participants with textual or vibratory notifications; in ***Myconnect***, the art system translates the activities of the mycelium network into various sensory cues perceivable by the human; and in ***Encounters of a Domestic Nature***, the art system presents live images of the crickets and humans to each respective group. Although these images are tailored to human visual modalities and therefore cannot be interpreted by crickets in the same manner as by humans, they nonetheless have an impact on the perceptual systems of the crickets. This artwork also allows human participants to communicate with each other via the live displays. In all these cases, the art systems actively relay information from the nonhumans to the humans without the former intending to do so.

The art systems also mediate another form of communication from humans to nonhuman organisms. This can take the form of food-based communication facilitated by the art system, as demonstrated by ***Mouse Coach*** and ***Playful Rocksalt System***. Alternatively, the art system can translate human activities into physical stimuli that affect the nonhuman organisms, as is the case in ***Myconnect***.

Additionally, an art system has the potential to serve as a medium for communication between nonhuman organisms. This is shown in ***Encounters of a Domestic Nature***, where the art system responds to the chirping of crickets by updating the landscape projection that the crickets might use to communicate with each other. Although the projection is tailored to the human visual system, we speculate that the crickets could potentially learn and use this response as a signal for communication.

Although we use the term communication to describe the information flow from and to nonhuman organisms, we cannot infer their intention to communicate or their ability to interpret information as intended by other elements. In all the reviewed artworks, communications with nonhuman organisms primarily rely on basic stimuli-response mechanisms orchestrated by art systems—with or without human involvement. We do believe that researching the different sense-making processes of nonhuman organisms and exploring alternative means of communication with them would benefit the development of more-than-human interaction.

One example of an alternative means of communicating with nonhumans is shown in ***IntraFacing***: The art system communicates to the dog via the human's actions. Here, the human acts as an "interpreter" to convey the rules and contents of the game provided by the art system to the dog. They must engage in a dynamic and continuous exchange with the dog to ensure successful communication. This highlights the potential for harnessing human abilities and skills to communicate with nonhuman participants and for developing artificial systems that recognise communication as a contextual and ongoing exchange between two perceptive, dynamic entities.

Based on these discussions, we can envision new forms of communication by switching the roles of the elements. One distinctive form could be nonhuman organism-mediated communication, where humans and art systems use nonhuman organisms to communicate with each other. For instance, humans could train their companion animals to perform certain actions that are recognised by art systems, or art systems could influence the behaviours of nonhumans to convey information to humans. However, it is crucial to consider the consent of nonhuman organisms in these cases and avoid reducing them to mere tools—an ethical pitfall associated with utilitarianism.

5.4.3 Reconfiguring interspecies relationships

Art systems not only facilitate interspecies communication, but also reconfigure relationships between humans and nonhumans in various ways. First, they can create a collaborative context for both participants. As shown in ***Mouse Coach*** and ***IntraFacing***, the art systems establish interdependence between both participants in accomplishing certain tasks. While in ***Encounters of a Domestic Nature***, the art system provides a shared stage for humans and crickets, although the performance is primarily carried out by and presented to humans.

Alternatively, art systems can establish and mediate connections between humans and nonhumans. In ***Playful Rocksalt System***, a deer's presence is translated into vibrations felt by the human, and the human remotely moves the rock salt presented to the deer. This mechanism allows both participants to engage in open-ended play and conversation. However, the human can also see the deer's reactions via the live display, while the deer's access to the human is restricted to the movement of the rock salt. In ***Myconnect***, the human's heartbeat is transmitted to the mycelium network as electrical signals, and the activity of the mycelium network is translated into multisensory cues presented to the human. The art system forcefully alters the physiological responses of both participants, restricting their agency to influence the process.

Art systems typically serve to facilitate communication and shape relationships between humans and nonhuman organisms because their focus has primarily centred on enrolling them as participants in interactive artworks. To further embrace the more-than-human perspective, we propose that art systems may also be considered participants themselves. This perspective unlocks new opportunities for creating interactions and prompts questions regarding the potential roles artificial systems might play in these scenarios: What forms of participation can they manifest? How might other elements, including humans and nonhumans, mediate and configure their communications and relationships with these systems?

5.5 Reflection on the Modelling Capability of RMT

As demonstrated in this chapter, RMT allows us to dissect the various forms of more-than-human interaction into the actions performed by the elements and the resulting various forms of communication among them. These terms provide concrete steps to specify how the elements influence and relate to each other, allowing for meaningful and systematic comparisons between interactions that might otherwise appear disparate.

As RMT treats humans, nonhuman organisms and art systems with equal terms, it allows us to view an interaction from the perspectives of all elements involved, including the nonhuman ones. In doing so, it becomes possible to identify the distinct roles played by each element on an equal footing and discern the interactive dynamics between them, for instance, whether an element is an active or passive participant. Furthermore, we can also envision new forms of interaction based on the terms specified by RMT and switching the roles of the elements.

Additionally, RMT enables easy identification and contextualisation of known interaction models within specific interactions. For instance, in ***IntraFacing***, the art system first provides a task to the human participant, who can choose to skip the task which in turn triggers the art system to provide another one. This sequence can be identified as a feedback loop, which is a common interaction model in both interactive art and human-computer interaction (Bongers, 2000). The feedback loop is also easily identifiable in the visualisation, shown as the reverse symmetry of the blue and red bars in the conditions of both actions in Figure 5.3. Furthermore, the description using RMT situates such model within the broader context of the interaction, providing a more complete picture of how it relates to other actions and impact the elements.

5.6 Discussion

In this chapter, we apply RMT to systematically examine interactions in artworks involving both humans and nonhuman organisms. Our analysis reveals a recurring tendency to cast nonhuman organisms as passive participants and humans as active. Additionally, we identify various ways art systems mediate communications and (re)configure relationships between them. Taking a more-than-human perspective, we challenge these conceptions of element roles and propose directions for new forms of interaction that highlight the agency of nonhuman elements, including art systems.

The insights into more-than-human interaction discussed in this chapter hold significant potential for application in the development of other interactive systems beyond interactive art that aim to involve both human and nonhuman participants, particularly in fields such as ACI and related domains. Moreover, by demonstrating the capacity of RMT to analyse the behaviours of nonhuman participants and dissect the interactive dynamics within diverse forms of more-than-human interaction, we argue that it can serve as a valuable tool for evaluating the participation of nonhuman elements and identifying potential ethical pitfalls in the design and development of such systems. While this study focused on a limited selection of interspecies interactive artworks, we believe that RMT—and the analytical process it enables—can also be applied to study other forms of more-than-human interaction, such as interactive artworks involving exclusively nonhuman participants or non-organismic elements.

Through this study, we not only demonstrate the capability of RMT to model diverse interspecies interactive artworks, but also aim to provoke discussions on advancing interactive art beyond human-centric approaches. We hope this exploration inspires researchers and practitioners to consider alternative ways of interacting with and relating to the nonhuman world. At the same time, we encourage reflection on the broader implications of such endeavours, particularly in terms of ethical, ecological, and philosophical considerations.

Chapter 6

Modelling Applications beyond Interactive Art

6.1 Introduction

In Chapter 2 and 3, we introduce the relational model and its accompanying web-based tool, the Relational Modelling Tool (RMT), designed to describe and visualise interactions in interactive art[1]. In Chapter 4 and 5, we show that RMT is capable of modelling and analysing diverse forms of co-located interaction and more-than-human interaction involving both human and nonhuman participants, respectively. These analyses not only yielded valuable insights into diverse forms of interaction but also underscored the capacity of RMT to systematically dissect and visualise complex relational dynamics in interactive art. Building on these findings, we propose that the concepts and descriptors of RMT—alongside its underpinning relational model—can be adapted to describe participatory processes beyond the realm of interactive art.

As we emphasised in Chapter 1, the core of interactive artworks lies in the dynamice exchange–or dialogue–between the audience and the artwork, distinguishing it from other types of participatory art. In this chapter, we examine two participatory artworks that incorporate audience input without fostering an interactive dialogue. These works exemplify distinct forms of audience engagement, neither of which is strictly classified as interactive. Using RMT, we describe the participatory processes within these works and analyse the relationships among the key participating elements. The first example, ***Vibe Check*** (2020) by Lauren Lee McCarthy and Kyle McDonald, is also discussed in our previous publication (Xu,

[1]The latest version of RMT is accessible via: https://modeltool.liacs.nl/

Lamers, & van der Heide, 2025). Drawing on the resulting descriptions, we reflect on the broader modelling capabilities of RMT beyond interactive art, while also identifying its limitations and potential areas for improvement. Through this exploration, we not only highlight the analytical potential of RMT across a wider range of artistic and performative contexts, but also consider how insights from these practices can inspire and inform the development of interactive art.

6.2 Modelling Participatory Processes

Here, we select two participatory artworks that exemplify two distinct forms of audience participation: *post-participation* and *hybrid-participation*. In the following subsections, we define these forms of participation, introduce the selected artworks, and present descriptions of their participatory processes using RMT.

6.2.1 Post Participation: *Vibe Check* (2020) by Lauren Lee McCarthy and Kyle McDonald

Vibe Check is an installation that employs surveillance technologies to capture and display live images of gallery visitors along with their "vibes" detected by the artwork (Lee McCarthy & McDonald, 2020). ***Vibe Check*** does not qualify as a conventional interactive artwork, as the artwork does not intend to establish a direct dynamic exchange with the visitors. Instead, it exemplifies a direct post-participative artwork as defined by Guljajeva (Guljajeva, 2018). This term describes artworks that actively capture and select inputs from the audience or other sources for artistic outputs, often without their consent. By applying RMT to describe the post participation in ***Vibe Check***, we aim to evaluate whether RMT can effectively account for the behaviours of a proactive and autonomous art system.

The detailed description of ***Vibe Check*** can be accessed in this worksheet[2] and the visualisation is shown in Figure 6.1. Here, we describe two element profiles: one or more human visitors and an art system. The experience begins when one or more human visitors enter the gallery space. Although their participation in the artwork may be unintentional, their presence provides input to the art system, triggering its subsequent actions. This initial interaction is modelled as private communication between the visitors and the art system. According to the installation setup, up to six such interactions can occur simultaneously.

In response to the visitors, the art system selects one of them for emotional analysis. As this is a crucial step for the art system to gather information and provide inputs for its subsequent

[2] https://modeltool.liacs.nl/?artwork=vibecheck

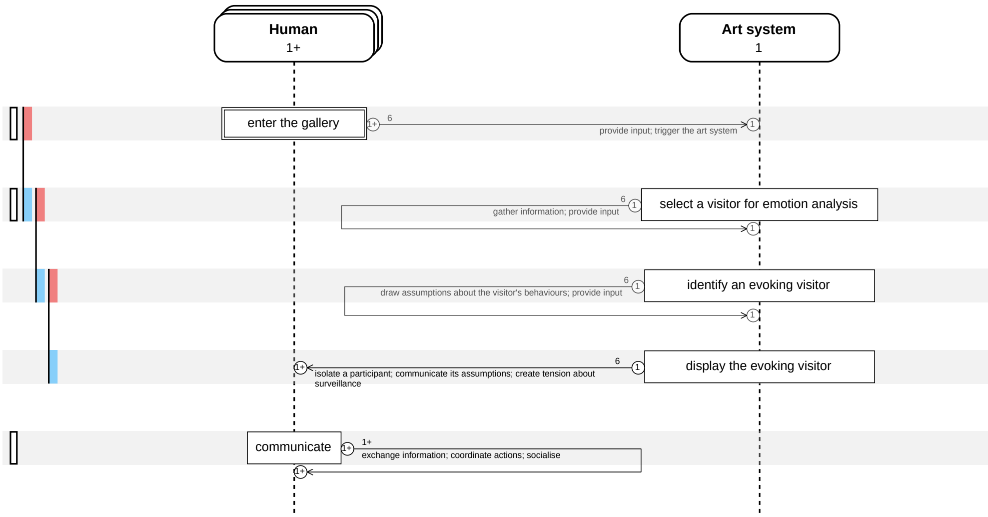

Figure 6.1: Visualisation of described post-participation in ***Vibe Check*** using RMT.

actions, we modelled it as a private direct communication to the art system itself with six instances. Following the emotional analysis, the art system identifies another nearby visitor who it assumes is responsible for evoking the identified emotions in the previously analysed visitor. This assumption represents a speculative interpretation of the interpersonal dynamics between visitors. Similarly, the art system processes this interaction internally, modelled again as private, direct communication with itself, and supports up to six simultaneous instances of this process.

The art system then publicly displays the image of the identified evoking visitor on a large screen installed on a gallery wall, alongside the emotions it attributed to them. This final step communicates the assumptions embedded in the art system and isolates the evoking visitor from the group, creating tension and drawing attention to the artwork's surveillance mechanisms. This communication is public and can occur in six simultaneous instances, depending on the number of visitors engaged.

Throughout the experience, visitors may also communicate directly and publicly with one another to exchange information, coordinate their actions, or socialise. These interactions occur spontaneously and are public, with multiple simultaneous exchanges possible. This layer of visitor interaction adds a social dimension to the experience, potentially amplifying the tensions and questions raised by the artwork's autonomous processes.

6.2.2 Hybrid Participation: *I Wish You Knew That You Are Me* (2023) by Dan Xu, Jonathan Thaw and Lauren Wedderburn

I Wish You Knew That You Are Me is a participatory performance that involves audience members both online and present at the performance location in collaboratively writing and performing a poem (Xu, Thaw, & Wedderburn, 2023)[3]. During the performance, online participants contribute thoughts, ideas, and feelings via text, while live participants act as their "voices", reading aloud these inputs. We consider that this performance exemplifies a form of hybrid participation, in which distinct audience groups engage with the performance based on the characteristics of their presence. By applying RMT to describe the hybrid participation in ***I Wish You Knew That You Are Me***, we aim to evaluate whether RMT can effectively account for the different roles of audience members, the performer, and the technical system within a multilayered performative setting.

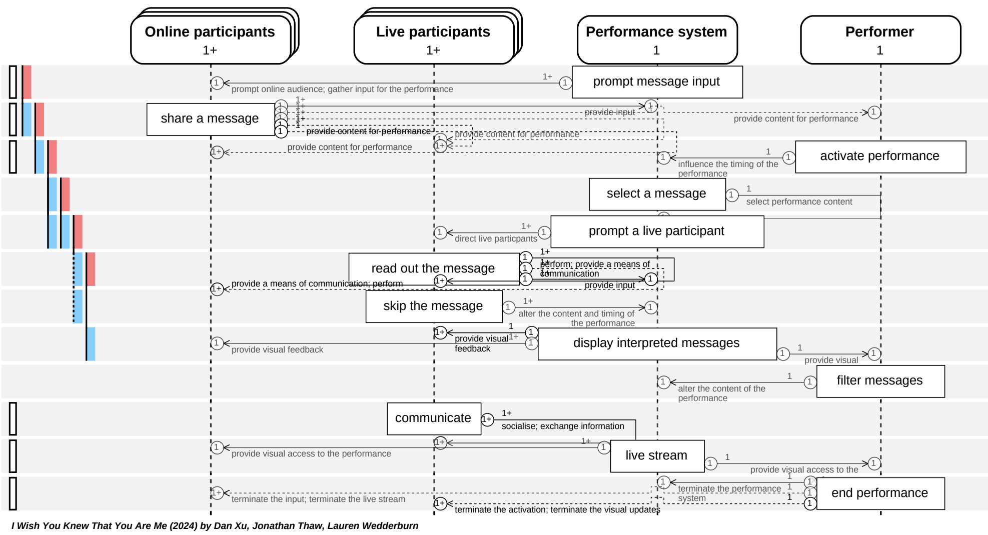

Figure 6.2: Visualisation of described hybrid participation in ***I Wish You Knew That You Are Me*** using RMT.

The detailed description of ***I Wish You Knew That You Are Me*** can be accessed in this worksheet[4] and the visualisation of the description is shown in Figure 6.2. Here, we describe four element profiles: online participants, live participants, the performance system, and the

[3] ***I Wish You Knew That You Are Me*** was developed by the thesis main author in collaboration with Jonathan Thaw and Lauren Wedderburn during the Experiments in Networked Performance course at the School for Poetic Computation in June 2023. More details about the performance is documented here: https://danxxxu.github.io/iwish.html

[4] https://danxxxu.github.io/relational-model/?artwork=iwish

performer. Both participant groups can join the performance via a designated webpage on their personal devices, such as computers or smartphones. Online participants are prompted by the performance system in a direct private communication to submit an intimate message beginning with "I" followed by a randomly selected verb, such as "I wish", "I love", or "I was". These messages, delivered via a direct private communication, serve as the primary content for the performance, allowing the online audience to contribute individual thoughts and feelings to the collective poem.

The performance system is the central technological hub, facilitating communication and managing the flow of interaction. It receives messages from online participants, processes commands from the performer, and transmits prompts and instructions to live participants. Additionally, the performance system employs randomisation to select messages and prompts and allocate a live participant, introducing an element of unpredictability to the performance. The system also integrates a speech-to-text component that transcribes spoken messages from live participants and displays them collectively on a public screen. This transcription creates a direct public communication visible to all participants, further enhancing the shared experience. Throughout the performance, it also streams the recording of the live performance to all other remote elements to provide them visual access to the performance.

The performer, situated remotely, moderates the flow of the performance and manages its timing. They access submitted messages via the performance system and can filter the inputs to ensure appropriateness and relevance. The performer communicates directly and privately with the performance system to influence the content and timing of the performance by deciding the moment to activate a live participant. Through their role, the performer maintains an overarching control of the performance dynamics, but not necessarily the performance content and how it is delivered.

Live participants, present at the performance location, act as the actual "performers" of the poem. Upon receiving messages and prompts from the performance system, live participants have two choices: they can skip the message, notifying the system of their decision in a direct private communication, or they can enact the message by reading it aloud while following the provided prompt. In the latter case, this action results in a direct public communication to the rest of the live audience. Simultaneously, it creates a mediated private communication to the online participants and the performer via the live stream facilitated by the performance system. Throughout the performance. live participants can also communicate with each other directly and publicly to exchange information, coordinate actions and socialise.

6.3 Reflection on the Modelling Capability of RMT

As demonstrated in the previous section, the modelling capabilities of RMT extend beyond interactive artworks. By applying RMT to describe ***Vibe Check*** and ***I Wish You Knew That You Are Me***, we have shown that the same concepts and descriptors can effectively capture the influences and relationships between elements across different participatory processes, which underscores RMT's versatility and potential for broader applications.

In ***Vibe Check***, RMT captures not only interactions between elements but also significant internal dynamics within a single element. Although the concepts of action and communication, along with their corresponding descriptors, were originally designed to describe exchanges between distinct elements, our modelling revealed that these same concepts can also specify significant internal processes, such as emotional analysis and behavioural assumptions. This adaptability highlights the utility of RMT in scenarios where internal mechanisms are crucial to understanding the art system's behaviour and the interactive dynamics, such as interactive installations driven by autonomous or algorithmic processes. Extending RMT's application to these internal dynamics opens avenues for its use in modelling and creating new forms of interaction that incorporate the nuanced internal dynamics of art systems where they process, analyse, and respond to inputs in surprising ways.

While effective, this approach also challenges RMT and the relational model's original conceptual foundation, which focuses solely on the external actions of elements within interactions. Moreover, it raises important questions about whose and which internal actions should be considered significant in the modelling process. To integrate the modelling of internal dynamics as a core feature of RMT, more concrete guidelines and refinements are necessary to ensure consistency and clarity in its application.

Meanwhile, the description of ***I Wish You Knew That You Are Me*** illustrates RMT's strength in analysing complex relational structures involving multiple elements with distinct roles and behaviours. RMT successfully mapped the relationships and communication flows between online participants, live participants, the performer, and the performance system. This analysis allows for a detailed understanding of how individual behaviours contribute to the overall performance and the different roles each element plays, showcasing RMT's potential as a tool for examining multilayered and dynamic processes. By providing a structured and consistent vocabulary for these processes, RMT enables a deeper understanding of the relational dynamics at play in such collaborative and participatory settings.

However, we also observed certain limitations of RMT in describing the complex exchanges within ***I Wish You Knew That You Are Me***. While RMT provides fixed and consistent input fields for various descriptors, this structure inherently restricts the types of descriptions that can be generated. For example, a mediated communication in RMT is defined as two elements communicating via a third element. However, in ***I Wish You Knew That You Are Me***, an online participant communicates their messages to other online participants through the livestreamed performance of live participants, which is mediated by both the live participants and the performance system. The current structure of RMT does not fully capture this layered dynamic. If needed, future developments of RMT should allow for more flexible structures to accommodate more complex forms of dynamics.

6.4 Discussion

In this chapter, we have demonstrated how RMT can extend its modelling capabilities beyond the initial focus on interactive artworks to encompass a broader range of participatory processes. Through case studies such as ***Vibe Check*** and ***I Wish You Knew That You Are Me***, we not only showcase its flexibility but also address some of its current limitations revealed by these participatory artworks. The consistent use of terms such as action, communication, and element underscores the potential of RMT to serve as a unified tool for facilitating comparative analysis between different systems and artworks. In doing so, we show its potential to evolve into a more comprehensive framework for analysing and creating participatory and performative processes across diverse domains.

Moreover, as previously noted, the dynamics observed in the participatory artworks described above can also inspire and inform the creation of interactive artworks. For instance, the specification of key internal processes within elements, as demonstrated in ***Vibe Check***, and the multilayered involvement of different elements in ***I Wish You Knew That You Are Me***, can also be incorporated in interactive artworks. Through this study, we also hope to highlight the value of developing a shared analytical language, fostering cross-pollination among different practices.

Chapter 7

Evaluation and Reflection on the Relational Modelling Tool

7.1 Introduction

In Chapter 2 and Chapter 3, we introduce the relational model and the Relational Modelling Tool (RMT), respectively, as a tool for describing and visualising interactions within the domain of interactive art [1]. Furthermore, we demonstrate the capability of RMT to model a diverse range of co-located interactions in Chapter 4, more-than-human interaction involving both human and nonhuman participants in Chapter 5, and participatory artworks beyond interactive art in Chapter 6. These analyses not only showcase the modelling capacities of RMT but also uncover valuable insights into the diverse forms of interaction and participatory processes by comparing the descriptions across selected artworks.

While RMT has proven effective as an analytical tool, we argue that it also holds significant potential for facilitating the creation of new interactive dialogues. Building on the formal input structures of RMT and leveraging a dataset of existing interactive artworks, we developed a generative component for RMT. This component introduces features that enable users to generate novel interactive elements, reconfigure their combinations, and expand on existing dialogue structures. Such functionalities are designed to inspire and stimulate creative exploration, offering avenues for imagining and exploring new interactive dialogues.

Thus far, RMT has primarily been used and tested internally, limiting the breadth and diversity of feedback on its usability and functionality. In order to evaluate it with a broader

[1] The latest version of RMT is accessible via: https://modeltool.liacs.nl/

user group, we organised a workshop, inviting researchers and practitioners from interactive art and interaction design to model existing interactions and explore new interactive dialogues using RMT. The workshop enabled collecting feedback on usability and functionalities of RMT while exploring additional benefits, opportunities, and potential improvements. In this chapter, we present the workshop outcomes, reflect on the discussions, and consider broader implications. We hope that these insights can not only lead to improvements of RMT, but also inform the design and development of similar tools in the future.

This chapter builds extensively on our submission to the 14th EAI International Conference: ArtsIT, Interactivity & Game Creation (Xu et al., accepted and in print). It is structured as follows: In the next section, we introduce the generative component of RMT, detailing the approaches developed for generating new forms of interaction; Following this, we present a report of the workshop, including the activities conducted, feedback received, and insights shared by participants; Finally, we reflect on the workshop outcomes, discussing their implications for the ongoing design and development of RMT, as well as considering the broader benefits and challenges of modelling interactive art.

7.2 Approaches to Generating Interactive Dialogues

As shown in Figure 7.1, the generative component of RMT can be accessed via a dedicated webpage with its own interface [2]. This component is built upon the description component and is realised with the following two approaches.

The first approach leverages the database’s existing artwork collection to generate new elements and behaviours. The *Generate element* button next to the element index automatically populates descriptors—such as *type* and *actions*—using randomly selected entries from the database. In contrast, the *Complete element* button only fills in empty input fields, allowing users to partially specify an element. Given the diversities of elements in the collection —including human, nonhuman organisms and technical systems—we believe that this feature can stimulate the discovery and imagination of new interactive behaviours and unconventional roles of elements.

The second approach takes advantage of RMT’s formal structure to randomly create new connections in terms of new forms of communication and action conditions. Once elements are specified, users can click on the respective *Generate* button to generate new forms of communication and conditions. The tool then randomly assigns receiving elements, selects possible values for relevant descriptors, and combines triggering actions and reactions. Each

[2] https://modeltool.liacs.nl/generate.html

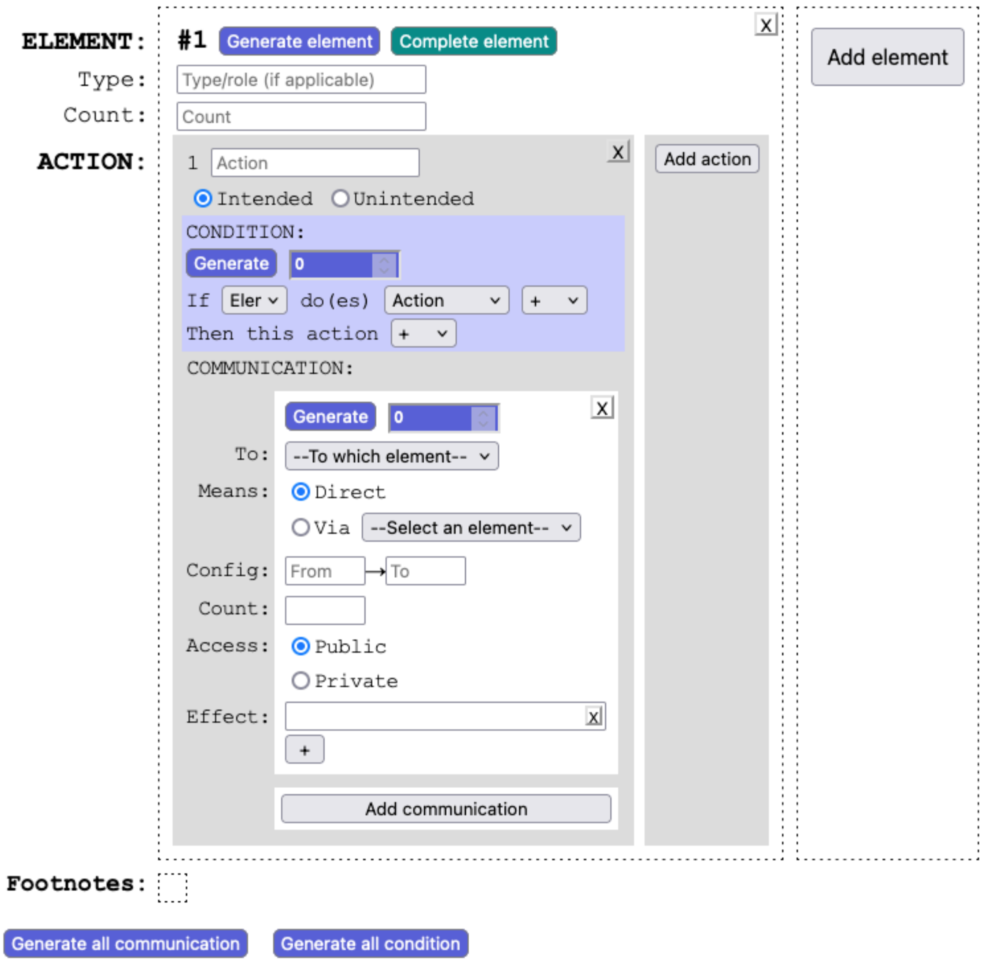

Figure 7.1: Screenshot of the generative component interface.

random combination is associated with an index number, allowing users to browse the different generations back and forth.

Before using the generative functions, users must first specify the interaction layout, including the number of elements, actions, and communications. They can either start with an empty worksheet or modify an existing interaction loaded from the database. It is important to note that these generative functions were developed as an exploratory experiment. The purpose is to provoke discussions about the generative potential of RMT, rather than to present them as definitive or finalised solutions.

7.3 Workshop on Describing and Generating Interactions

The half-day workshop, titled "Modelling and Creating New Interactive Dialogues in Interactive Art", was held at the 13th EAI ArtsIT conference in New York University Abu Dhabi Campus[3]. Seven participants, all professionals in interaction design and Human-Computer Interaction (HCI) research, attended the workshop. Two participants had to leave early due to other commitments, leaving five active participants for the hands-on exercises and discussions. The workshop was designed with the following main objectives:

- To introduce RMT to the participants;
- To evaluate the capability of RMT in modelling and visualising interactions;
- To assess the potential of RMT for generative new ideas for interactive dialogues;
- To create of new forms of interactive dialogues that do not yet exist.

Due to time constraints, the final objective—creating new interactive dialogues—was not fully addressed. Instead, the workshop was divided into two parts, focusing on the first three objectives.

In the first part, we introduced the background and purpose of RMT, followed by an explanation of the description and visualisation components. A brief demonstration was provided, showcasing how to describe an interaction using RMT with a basic example. Participants were then instructed to use RMT to describe an interactive dialogue of their choice. This segment concluded with participants presenting their own modelled interactions, followed by a group discussion where they shared their experiences and initial impressions of RMT.

The second part of the workshop concentrated on RMT's generative component. We introduced the generative functions, explained their underlying principles, and demonstrated their use. Participants were encouraged to experiment with these functions and conceptualise new forms of interaction. Following this exploration, participants shared their results and provided feedback on RMT's generative features. The workshop concluded with an open discussion, allowing participants to share general remarks and suggestions regarding RMT and the workshop itself.

7.4 Workshop Outcomes

In this section, we present the main outcomes of the workshop, including the visualisations of the interactions modelled by the participants.

[3]Official event page: https://artsit.eai-conferences.org/2024/workshop-session-modelling-and-creating-new-interactive-dialogues-in-interactive-art/

Overall, participants praised the simplicity and intuitiveness of RMT's interface, as well as the clarity of the visual symbols. During the modelling exercise, three participants successfully described their own interactive works using RMT. These interactions included: an augmented reality application that animates a picture in a textbook when users point their mobile phones at it (Figure 7.2); an application that plays an audio track accompanying a painting when users press a button (Figure 7.3); an interactive installation that translates a user' s heartbeat and respiratory signals into audio and visual biofeedback (Figure 7.4).

With our assistance, one participant managed to describe a basic interaction involving human participants and a fictional art system that plays back audio when participants activate a hotspot. In the end, only one participant was unable to successfully model an interaction using RMT.

During the generative exercise, participants did not propose any new forms of interaction. However, the exploration did stimulate discussions about the generative functions themselves, including their potential and limitations. These conversations, along with feedback on the description and visualisation components and general remarks about RMT, provided valuable insights. For clarity, we have grouped them into thematic categories, which we present in the following subsections.

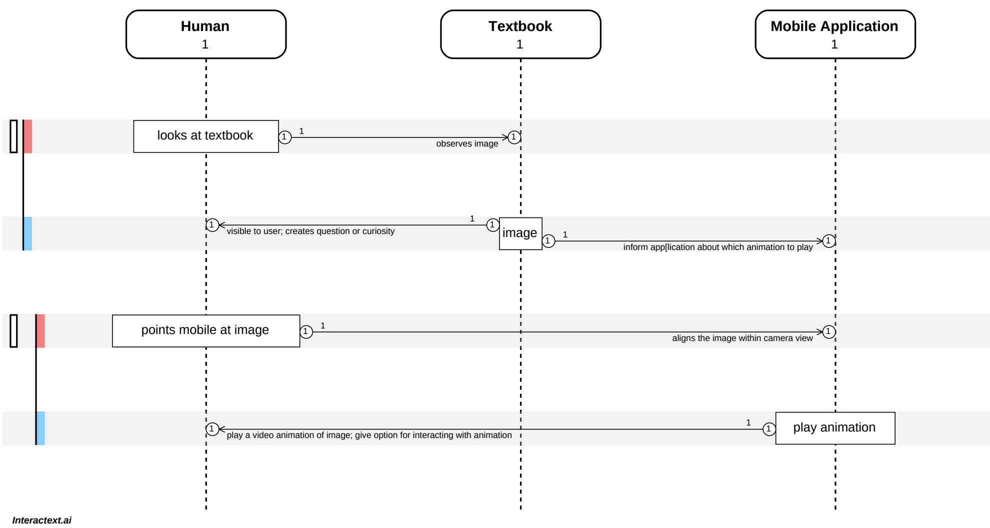

Figure 7.2: Visualisation of user interaction with an augmented reality application described by the participant.

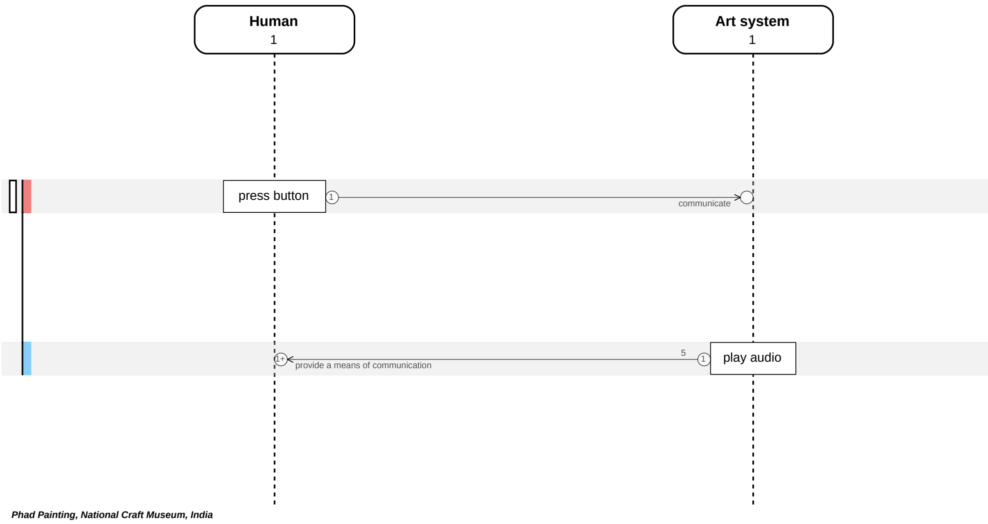

Figure 7.3: Visualisation of user interaction with an application accompanying a painting described by the participant.

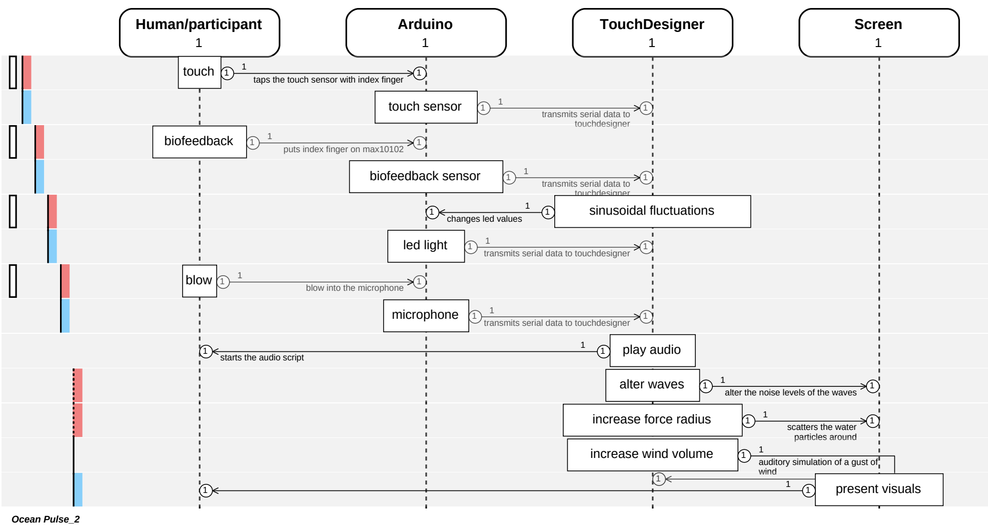

Figure 7.4: Visualisation of participant interaction with a biofeedback-based installation described by the participant.

7.4.1 Interface Design Issues

During the workshop, participants identified several design issues with the current interface of RMT. Some of these issues related to a lack of clarity in the terminology used. For example, some participants were hesitant to click the *Unlock* button, which generates an editable copy of a locked description, mistakenly believing that it would overwrite the current description. Similarly, while "condition" was frequently referenced, this term was not explicitly annotated within the interface. Additionally, one participant noted that in input fields referencing other elements, only their index numbers were used. They further suggested that including the element type alongside the index would make the interface more intuitive and "humane".

Participants also highlighted the absence of adequate feedback or error messages upon malfunctioning of RMT. As creators of RMT, we were accustomed to its quirks and had developed a habitual way of navigating around potential errors. During development, we relied on the browser console for diagnostics and debugging. Consequently, a robust feedback mechanism to alert users to errors had not yet been implemented. This lack of feedback left participants confused when RMT did not perform as expected, hinting at the need for more reliable error handling and clearer guidance.

7.4.2 Linking the Description and Visualisation Components

In addition to the technical design issues, participants suggested several general improvements to enhance the description process. The most prominent recommendation was to create a more seamless connection between the description and visualisation components. At the time of the workshop, the visualisation only updated when users clicked the *Visualise* button below the input fields. Consequently, the displayed visualisation might not reflect the most up-to-date description, leading to potential discrepancies and confusion. Participants proposed that automatically updating the visualisation as they describe an interaction would provide more timely feedback and potentially minimise errors.

Another suggestion involved the positioning of the visualisation. Participants noted that placing the visualisation below the input fields limited its usability during the modelling process. They recommended displaying the visualisation side-by-side with the input fields, for example, by opening it in a separate window and displaying on an additional screen. This arrangement would allow users to interact more effectively with the visual graph while working on their descriptions, without constantly needing to scroll down for the visualisation.

Participants also addressed the benefit of greater visual coherence between the input fields and the visualisation. For instance, they suggested using distinct colours to represent different elements and their actions across both components, making it easier to identify corresponding descriptions. Finally, participants expressed a desire for the ability to manipulate the visual graph directly to alter the description. Creating a bidirectional connection between the description and visualisation components would enable more flexible and intuitive editing, thus enhancing the user experience.

7.4.3 Challenges and Creative Adaptations

During the modelling exercise, we observed that participants often began by browsing the suggestion lists attached to the text input fields, selecting options that suited their needs. This approach is directly reflected in the final descriptions. However, some participants still reported confusion regarding certain concepts used in RMT, for instance, they hesitated to specify an action or a form of communication, as the distinction between these two was not immediately clear to them. Confusion about the concepts was the primary challenge participants encountered when using RMT.

It is interesting to note that participants adapted certain concepts within RMT in ways we had not initially anticipated. For instance, the concept of an element refers to an independent actor, typically a biological or technical system. In practice, however, some participants used RMT to break down the technical system into smaller components, treating these as separate elements. As shown in Figure 7.4, the participant divided the biofeedback system into different subcomponents, describing each as an independent element. Alternatively, in Figure 7.2, the participant referred to the textbook itself as an independent element within the interaction. These creative adaptations highlight the flexibility of RMT to suit broader needs and suggest potential refinements to the definitions of its core concepts.

Additionally, in Figure 7.4, we noticed that the participant did not maintain a consistent level of description across all elements. For instance, the actions performed by the Arduino were described as the various sensors attached to it, rather than as distinct behaviours. There was also some confusion between actions and their effects. For example, the touch and blow actions of the human participant were simply reiterated on their effects, blurring the conceptual distinction between the two. As such, the roles of these actions in the interaction were not clearly articulated in the description.

7.4.4 Learning Exercises

During the discussion, participants noted that their confusion regarding the use of RMT, as described earlier, was partly due to their unfamiliarity with it. Since they did not receive any preparatory materials prior to the workshop, this was their first encounter with RMT. Although we demonstrated its basic usage, this was insufficient for them to fully grasp its scope or how to apply it effectively.

In response, participants suggested that introducing a simple, concrete example of an interaction, followed by a step-by-step demonstration of how to describe it using RMT, would help clarify how RMT's various concepts map onto different aspects of an interaction. They also proposed that including basic hands-on exercises, such as sketching an interaction using RMT's visual symbols, would further aid in internalising both the concepts and the application process.

7.4.5 Application Scenarios

In addition to exploring the technical and design dimensions of RMT, participants identified several potential application scenarios. One prominent scenario refers to the use of RMT—particularly its visualisation capabilities—to facilitate communication between artists and development teams. A participant highlighted the challenges artists often face when conveying artistic concepts to developers and engineers, who may struggle to interpret these ideas accurately. The participant noted that RMT's visualisation helps to establish a shared mental model among team members, offering a concrete blueprint for discussion. This enables more focused and productive conversation, bridging the gap between artistic vision and technical implementation.

Participants also proposed that RMT could serve as a valuable tool for evaluating and assessing interactive artworks. For instance, audience members could be invited to describe their experiences of an artwork using RMT, and these descriptions could then be compared with the artist's original intent. Such comparisons could reveal discrepancies between the intended and perceived experiences, providing insights into the effectiveness of the artwork's design.

Finally, participants suggested that RMT could play a critical role in the conservation and archiving of interactive artworks. Given the complexity of these artworks—which often involve dynamic systems incorporating digital technologies—it is essential to document not only their physical components but also their interactive behaviours and intended audience engagement. RMT provides a consistent tool for describing such artworks and generating related datasets, enabling their systematic classification and indexing. This also paves the way for developing dashboards that allow researchers and practitioners to browse, search, and investigate interactive artworks in greater depth, thereby supporting both scholarly analysis and long-term preservation efforts.

7.4.6 Customising the Generative Component

After experimenting with the generative component, participants observed that the outcomes produced by the current generative functions were interesting and had the potential to serve as a source of inspiration. However, given the wide variety of interactive artworks in the database and the randomisation-based generative process, they noted that the resulting outputs were either too absurd or impossible to materialise.

Building on this feedback, participants proposed that allowing users to select and curate their own database could lead to more meaningful and relevant results. Specifically, users can select interactive works with shared characteristics or combine different forms of interaction that align with their creative goals. This tailored approach would allow the generative functions to explore more coherent and purposeful combinations. Moreover, it would provide users with greater control and focus for a more directed and productive creative process.

7.4.7 Co-creation with Artists and Designers

To further develop RMT into a practical resource that enhances the creative workflow of artists and designers, participants proposed that we could adopt a co-creation approach. This collaborative process could involve these practitioners using the current RMT as a foundation to refine and expand its functionalities. One potential method is through structured workshops, where artists and designers are invited to reorganise or subvert the existing interface layout and brainstorm ideas for new generative functions and strategies for their application. Such an iterative and participatory design process would ensure that the final tool is more closely aligned with the needs, preferences, and habits of its intended users.

7.4.8 Relations to Existing Modelling Tools

The discussion also touched upon existing modelling tools and how RMT could draw inspiration from them for its further development. One notable example is the Unified Modelling Language (UML), which is a standardised visual language used for modelling, designing, and documenting software systems (Eriksson et al., 2003). UML encompasses a range of diagram types, each addressing different aspects of a software system and its user interactions. Given that software development is often integral to the creation of interactive artworks, where the behaviours of art systems are frequently orchestrated by software programs, participants suggested that RMT, particularly its visualisation component, could benefit from the established norms and symbols already in practice within UML.

Furthermore, participants considered how a modelling tool could extend its utility to contribute directly to the development of a system or interaction. This insight is mainly inspired by the Building Information Modelling (BIM), a tool used in architectural practice to create digital representations of a building’ s physical and functional characteristics (Bryde et al., 2013). BIM integrates programs capable of automatically estimating required materials and their associated costs, streamlining the design and construction process. Drawing parallels to this approach, participants speculated that RMT could be connected to a program capable of simulating the behaviour of an art system based on its description. Such an integration could elevate RMT to a more practical resource for system development, bridging the gap between conceptual design and technical implementation.

7.5 Reflections and Beyond

Based on the results presented in the previous section, the majority of participants were able to grasp the core concepts of RMT and adopt it to some extent following a brief introduction during the workshop, despite having no prior preparation. It was particularly encouraging to observe that RMT stimulated meaningful discussions about its potential applications and the broader topic of interaction modelling. Given that most participants had backgrounds in HCI research and interaction design, these conversations naturally gravitated towards the design and modelling implications of RMT. Drawing on the insights generated during these discussions, we synthesised our reflections on the workshop outcomes and further developed the discussion under the following five topics.

7.5.1 Improvements to the Relational Modelling Tool

One significant outcome of the workshop was the identification of design issues and software bugs within RMT. In response, we iterated on RMT to address these concerns. Firstly, we automated the visualisation component to refresh whenever a data entry is changed in the input field, ensuring that the visualisation reflects the most up-to-date description. For the input fields, we replaced the term *Unlock* with *Copy* to clarify the safety of preserving the locked description. Additionally, we added the term *Condition* to label the section specifying the conditions for each action. To enhance usability, we added the display of an element’s type following its index when it is referenced elsewhere. Furthermore, we resolved some software bugs related to visualisation rendering. To improve error handling, we implemented a pop-up window with error messages whenever an issue arises during execution.

While participants acknowledged that more practice with RMT would be necessary to fully grasp its conceptual foundation and application process, the workshop also underscored the need to refine and expand the definitions of key concepts within RMT and its underlying relational model.

The current definition of element refers to “individual actors exhibiting the same or similar set of behaviours”, while action is defined as “something that is done or performed by the element to participate in the interaction”. These definitions are suitable for participants that actively influence their environment, such as biological organisms or technical systems programmed to act and react. However, they prove insufficient when considering static objects as elements. For instance, in Figure 7.2, the textbook is an independent element that plays a significant role in the interaction. Unlike the mobile application or human participant, the textbook does not actively impact other elements but influences them by presenting information that is captured by the other elements. Here, we propose adjusting the definitions to better account for passive participants, such as objects. The revised definitions are as follows:

- *Element*: Independent actors that play a significant and unique role in the interaction. An element can be a biological organism, a technical system, or an object.
- *Action*: An activity, behaviour, or natural response carried out or afforded by the element that has significant effects on shaping the interaction.
- *Communication*: The process by which an action reaches the receiving elements, which can be imposed by the acting element or actively captured by the receiving element. An action can be directed at multiple elements, creating diverse forms of communication.

7.5.2 Designing Intuitive Interface

A key lesson highlighted during the workshop regarding interface design is the importance of providing clear and timely feedback on the effects of users’ actions. Specifically, this feedback can take the form of informative messages that alert users to mistakes and suggest solutions, guiding them through mistakes and reducing their fear of making errors. Such feedback could be enhanced with predefined suggestions or machine learning tools with better contextual awareness. Additionally, immediate feedback is also crucial, as highlighted by participants’ preference for automatically updating the visualisation when input fields are modified. Such real-time updates maintain coherence between inputs and outputs, sufficiently informing users of the consequences of their actions.

Integrating the description and visualisation components can further optimise the workflow for users. Direct manipulation of visual objects aligns more with natural interactions with physical objects. For instance, some online UML tools enable users to create visual elements and annotate them directly (Lucidchart, 2025). However, structured input fields ensure that all described aspects are properly addressed, enabling comprehensive documentation and data aggregation. Therefore, if the visualisation and description components were to be combined, a truly intuitive and productive interface would need to balance the strengths of both approaches—preserving the structure of formal input while enabling direct manipulation of visual symbols.

Discussions during the workshop also highlighted the learning curve associated with adopting a new tool. Modelling tools like RMT are often built on specific theoretical constructs, requiring users to familiarise themselves with these terms and internalise them before using the tool effectively. Therefore, providing basic exercises linking the concepts used in RMT to real-world examples could significantly lower the barrier for first-time users. When designing modelling tools of this nature, it is crucial to consider users with varying levels of expertise. Offering exercises, tutorials, and documentations tailored to new users can help them not only learn how to operate the tool but also understand the underlying concepts and perspectives embedded within it.

7.5.3 User Involvement in Design and Development Process

Another insight from the workshop is the importance of user involvement at various stages of developing tools like RMT. As demonstrated in the workshop, engaging participants in hands-on exercises with RMT allows us to identify design and software issues that otherwise went unnoticed. Moreover, these activities also provide tangible materials and experiences to spark discussions about RMT’s potentials and its broader implications for the development of interactive art.

Beyond prototype testing, participants highlighted the value of co-creation, where designers and end users collaborate to ideate, develop, and refine solutions, ensuring diverse perspectives are integrated in the final design (Sanders & Stappers, 2008). Here, such user inputs can be crucial for determining the interface layout and shaping its functionalities. For instance, participants suggested greater control over RMT’s generative component, such as customising the database. Engaging practitioners in brainstorming sessions could generate ideas for new features, aligning functionalities with their creative processes. Co-creation could also lead to more customisable interfaces, allowing users to adapt components to their workflows.

However, it is crucial to recognise that the outcomes of co-creation are closely tied to the participants’ backgrounds. Clearly defining co-creation objectives and selecting participants accordingly is essential. For example, involving artists and designers is appropriate for tools supporting creative processes, while researchers and curators are better suited for tools aimed at analysis and curation.

7.5.4 Benefits and Limitations of the Relational Modelling Tool

As highlighted by participants, RMT provides an easy-to-understand interface that facilitates the application of the relational model to analyse interactions. RMT enables users to effortlessly define the structure of an interaction by adding or removing element profiles, actions, and communications. Moreover, its open and modular architecture also allows them to creatively adapt the tool to describe processes beyond the scope defined by the relational model. During the description process, RMT employs drop-down menus to either constrain inputs (e.g., specifying the recipient of a communication) or provide suggestions (e.g., element types and communication effects). While this mechanism certainly facilitates data entry, it may inadvertently encourage reliance on existing data, potentially producing too similar descriptions and overlooking the unique characteristics of individual artworks.

Another benefit of RMT lies in its potential for generating new interactive dialogues through data-driven techniques. However, the outcomes from the exercise using RMT's current generative component indicate that further considerations are necessary to fully realise this potential. We observed that simply populating the input fields with random data entries does not automatically result in new forms of interaction. While randomness may inspire the discovery of new elements, behaviours, or connections, a completely random configuration of elements is unlikely to produce a meaningful interaction. In complex scenarios involving multiple elements, the interaction may not take on the form of a one-to-one dialogue; however, the total configuration should still enable a mutually responsive interactive dynamic between two elements, potentially mediated by other elements. Thus, when developing generative features, the focus should not only be on exploring combinatory novelty, but also on identifying the interactive dynamics within the novel ideas.

Furthermore, RMT's formal structure and visualisation highlight certain limitations within the relational model's conceptual foundation. Although actions may appear to be properties of individual elements, they remain relational in nature because an action's significance and meaning are determined by both the acting and receiving elements. This is particularly evident when the acting element is passive while the receiving element is actively gathering information about it or its behaviour. For instance, as shown in Figure 7.2, the image of the textbook is *captured* by the human participant; however, within RMT, we consider the textbook to be *providing* the image, reflecting the flow of information from the textbook to the participant. Although we have refined the definition of action and incorporated its intention, it can still be conceptually challenging to differentiate various types of actions at a glance. In the future development of RMT, it is interesting to experiment with different ways to specify actions and reactions and indicate how they influence each other.

7.5.5 The Relational Modelling Tool in Context

Although participants responded enthusiastically to RMT as a potentially versatile tool for advancing interactive art in various contexts, it is important to stress that the primary goal of both RMT and the relational model is to facilitate understanding of interactive dynamics and the creation of new interactive dialogues. The model emphasises the relational exchanges among elements, treating them equally regardless of their type. This perspective is particularly valuable for uncovering the roles that individual elements play in an interaction and for envisioning unconventional roles they might assume. However, depending on the specific application scenario, a more detailed behavioural diagram of an art system—one that specifies internal processes and breaks down subcomponents—may prove more practical for communication during art system development, as well as for conservation and archiving purposes.

At first glance, RMT—particularly its visualisation component—appears similar to the UML sequence diagram. Sequence diagrams are widely used to depict interactions among systems, subsystems, and users, with the horizontal axis representing the interacting elements and the vertical axis illustrating the time sequence of messages or calls (Bell, 2023). Moreover, sequence diagrams provide notation for grouping messages to indicate conditional flow (e.g., “if-then-else” statements or “while” loops) and enable referencing other sequence diagrams within the current one. Nevertheless, we would like to point out some key differences between RMT and the UML sequence diagram.

First, sequence diagrams are primarily aimed at modelling user interactions with commercial software, where interactions are typically structured, ordered, and goal-oriented. In contrast, interactive art often involves more open-ended, erratic, or exploratory forms of interaction. RMT offers a more flexible framework, capable of capturing the layered conditional links among actions and allowing for complex relational structures. Additionally, while sequence diagrams specify the messages exchanged among elements, they do not account for the effects and intentions of actions in the way RMT does. Such considerations are critical for analysing the roles of elements and for understanding the broader dynamics that define an interactive artwork. Despite these differences, future development of RMT could draw inspiration from the well-defined notation system and the nesting structure of sequence diagram, potentially allowing for more clarity and capacity for modelling layered interactions.

7.6 Discussion

In this chapter, we present our workshop for evaluating the description and generation capabilities of RMT with a broader user group. The workshop included hands-on exercises and discussion sessions, enabling participants to share their experiences, feedback, and suggestions. With inputs from workshop participants, we are able to refine key features of RMT, gather insights for its future development, identify its benefits and limitations, and clarify its scope and positioning.

When modelling interactive art, it is important to recognise the limitations and biases inherent in any framework or tool. Modelling often requires simplifying complex, dynamic systems or scenarios into structured representations, which can lead to the omission of certain nuances or emergent behaviours. These complexities may be difficult to fully capture with predefined categories or descriptors. Additionally, the act of modelling inherently reflects the perspectives and priorities of the model’s designers, potentially privileging certain aspects of interaction (e.g., relational dynamics) while overlooking others. Therefore, it is essential to remain mindful of both the benefits and limitations of a modelling approach.

Furthermore, as previously discussed, the workshop participants were primarily researchers in HCI. In the future, it would be valuable to extend the evaluation of RMT to artists working in interactive art. This could provide insights more directly relevant to the development of interactive artworks, particularly in fostering new forms of interactive dialogue—an aspect that was not fully explored during the workshop.

Through this study, we hope to emphasise the importance of evaluation in the iterative development of modelling tools in general, not only as a means of generating practical feedback but also as a driver for advancing research and future developments.

Chapter 8

Conclusions and Discussion

The research described in this thesis started from exploration, discovery, and ended with critical reflection, leading to a thorough investigation into using a relational approach to modelling interactions in interactive art. We examined different approaches to describe interactions in interactive art and came to our relational model that focuses on capturing the relational exchanges among interacting elements (Chapter 2). Building on this foundation, we developed the Relational Modelling Tool (RMT), a versatile application for describing, visualising, and generating interactive dialogues[1] (Chapter 3). To demonstrate the modelling capacities of RMT, we applied it to analyse a diverse range of interactive artworks, including co-located interaction (Chapter 4), more-than-human interaction involving both human and nonhuman participants (Chapter 5), as well as participatory artworks beyond interactive art (Chapter 6). Furthermore, we presented the outcomes and reflections from a workshop conducted to evaluate the usability and functionalities of RMT with a broader user group (Chapter 7). In this final chapter, we synthesise the key findings of this study in response to the research questions outlined in Chapter 1, reflect on the challenges and considertations, as well as propose directions for future research and development.

8.1 The Relational Modelling Approach

At the core of our study is the establishment of the relational model of interaction and the accompanying tool we developed, i.e., RMT. Together, they provide both a theoretical tool for understanding interactions in interactive art and a methodological instrument for analysing a diverse range of interactive artworks explored in this thesis. In this section, we reflect on

[1] The latest version of RMT is accessible via: https://modeltool.liacs.nl/

the foundation of the relational model, the application of RMT, and its identified benefits and limitations.

8.1.1 Key concepts

The relational model is grounded in established theoretical discourses concerning the modelling and classification of interactive artworks. It consists of three key concepts—element, action, communication—that guide the analysis and description of interactions. In this section, we elaborate on the key concepts of the relational model, focusing on addressing the first research question:

> **Q1:** How can we model interactions in interactive art in a way that effectively and structurally captures the relational exchanges between the art system and its participants?

The relational model treats various types of interacting elements—such as art systems and audience members—equally, while accounting for the diverse relationships between them. These relationships are shaped by their actions and reactions and are realised through different forms of communication. This perspective not only enables the analysis of complex interactive scenarios involving multiple participants but also expands creative possibilities by allowing elements to take on unconventional roles.

It is important to emphasise that the relational model is not a static construct, nor has it remained unchanged since its initial introduction. Its definitions and structure have evolved iteratively in response to limitations identified during the development of RMT and its application to analysing diverse interactive artworks. In the following discussion, we trace the evolution of the key concepts of the relational model, aiming to present a more comprehensive picture of how they enable us to better understand the relational dynamics within various forms of interactive dialogues.

Element

An analysis or description of an interaction using the relational model begins by identifying the main elements, defined as "the independent actors between or among whom the interactive dialogue takes place." To identify an element, it is essential to recognise both its capacity to function autonomously as a unit and its behavioural impact on other elements. Therefore, the relational model provides a 'high-level' description of interaction, focusing on the exchanges among the key actors.

Initially, we distinguish an element from others based on its type and components. In an interactive artwork, the key elements are typically the audience and the art system. To account for scenarios where external factors influence the behaviours of the art system, we also introduced an environmental element. Furthermore, over the course of this thesis, we identified additional types of elements, such as nonhuman organisms and even static objects. While these elements may not intentionally participate in the interaction—as is often the case with nonhuman organisms—or perform any active gestures—as with static objects—their presence or actions afford inputs that can be captured by other elements. These inputs, in turn, trigger behavioural changes in these elements that are essential for the interaction to occur or progress.

Moreover, elements of the same type can take on different roles within an interaction, which requires them to perform different actions. To sufficiently capture the exchanges among elements, it is important to distinguish not only their types but also their roles in the interaction. RMT employs an element profile to group descriptions of elements with the same type, behaviours, or roles. This approach produces clear and concise categorical descriptions of elements, enabling a more direct and systematic understanding of their contributions to the interactive experience.

Action

After identifying the elements, the relational model dissects the interaction in terms of the actions performed by the elements that relate to one another. An action is defined as "an activity, behaviour, or natural response carried out or afforded by an element that has significant effects on shaping the interaction." Within the relational model, actions are the fundamental units through which elements perform their roles in the interaction and connect with one another. Consequently, every action described is directed towards (an)other element(s), making it an 'outward' action. Activities involving the reception of information—such as sensing or observing—are not explicitly listed as actions. This choice allows for a systematic tracing of the flow of inputs and information among elements, as well as an understanding of how they impact and influence one another.

Although actions may appear to be properties of individual elements, they remain relational in nature because an action' s significance and meaning are determined by both the acting and the directed-at elements. The direction of an action can manifest in two ways: first, the acting element intentionally performs an action directed at the receiving element; second, the receiving element actively captures aspects of the action performed by the acting element, even if the action is not initially intended for the interaction. The relational model, particularly through RMT, prompts us to specify the intention behind each action. This distinction is crucial, as it indicates whether an element actively or passively participates in the interaction, thereby reflecting the underlying dynamics among the elements. Furthermore, an action may not initially be intended for interaction; however, as the element learns about the impact of their actions, they may choose to intentionally perform the action, thus transitioning into an active participant in the interaction—much like how children learn to interact with their environment through trial and error.

A key characteristic of an interactive dialogue in interactive art is the capacity for elements to act and react to one another. In the relational model, we initially only captured this information when describing the role(s) of an action. However, during the development of RMT, it became evident that an additional structure was necessary to specify the relationships among actions. To address this, we introduced a condition for each action, which establishes causal relationships between actions. Under this frame of analysis, an action can be initiated by the element itself ("self-initiated"), and/or triggered by another action or combination of actions. Additionally, the condition allows us to specify relationships among reactions: whether they occur concurrently (an *AND* relationship) or one at a time (an *OR* relationship). The primary aim of the condition is to capture the formal or logical relationships among actions. More nuanced influences between actions can be described in the effects of the resulting communications, which we discuss in the following subsection.

Communication

When an element performs an action directed towards (an)other element(s), a form of communication is created. In the relational model, communications are understood as "the concrete mechanisms through which elements influence one another via their actions." The same action can also be directed at different elements, resulting in multiple forms of communication. A form of communication is described by its means—whether it is direct, occurring between two communicating elements, or mediated, facilitated by a third element; its configuration—the arrangement of elements at both ends of the communication; and its access—whether it remains private between communicating elements or is publicly accessible.

Initially, the impacts of an action in a specific interaction is described by its role(s), such as its function and impact within the interaction. This information is crucial for understanding the role of the acting element in the interaction and how it relates to the receiving element. However, since an action may be directed at different elements for different purposes, this contextual information can be further decomposed into the specific effects of each resulted communication. Collectively, these descriptors for specifying a form of communication elucidate the precise mechanisms through which the actions propagate and influence one another.

Furthermore, this approach to describing communication allows us to identify diverse mediated communication forms–and even generate of new ones. As demonstrated in Chapters

4 and 5, not only can a technical system—such as an art system—be employed by humans to convey information to one another or to reach nonhuman organisms, but the human body and our communicative abilities can also be utilised by art systems to transmit information to other humans or nonhuman entities. In these processes, the communicated information is not only determined by the sender element but is also filtered and negotiated through the channels of the mediator element. The concept of mediated communication is particularly relevant in non-dyadic interactions involving multiple elements, as it enables the identification of influence pathways and the configuration of complex relationships among elements.

In conclusion, these three key concepts—elements, actions, and communications—collectively establish the relational model as a robust analytical frame of analysis for interactive art. By treating elements as role-based actors with defined autonomy yet relational interdependence, the model enables comprehensive description of multi-agent interactions while preserving each participant's distinctive contributions. Through its action-condition architecture, the model systematically captures both the causal logic of intentional behaviours and the dynamics of responsive engagement. Meanwhile, the communication form maps complex influence networks, from direct exchanges to mediated connections. The model's strength lies in its dynamic treatment of interaction as negotiated relationships rather than fixed entities, while accommodating both human and nonhuman contribution with equal treatment. Although the model's interpretive flexibility presents certain challenges, this openness enables creative adaptations and application across diverse contexts. Ultimately, the relational model advances interaction analysis by providing both an analytical tool for existing artworks and a generative tool for new forms of interaction.

8.1.2 Application, benefits, and limitations

Building upon the theoretical foundations of the relational model, we operationalised its conceptual foundation through the development of RMT, aiming to facilitate the application of the relational model. This process not only allows us to make the relational model more accessible and usable, but also improve and refine its frame of analysis. In this section, we address the following questions specifically with regard to the application of RMT:

> **Q4:** What benefits and opportunities does a relational modelling approach provide for understanding and creating interactive art?
>
> **Q5:** What are the limitations of a relational modelling approach for understanding and creating interactive art?

In summary, RMT demonstrates significant strengths in analysing and comparing interactive artworks. It proves to be applicable to diverse forms of interaction involving both human and nonhuman participants. Its structured approach enhances analytical precision and usability through guided descriptors, conditional links between actions, and automated visualisations. Its formalised input fields enable systematic comparisons across artworks and generate consistent datasets of interactive artworks, allowing for potential applications of statistical and visualisation analysis techniques. Furthermore, RMT shows promising generative potential through creative adaptations and data-driven exploration of novel interactions.

Meanwhile, there are some limitations with the current version of RMT. As it focuses on describing exchanges among elements, more detailed technical diagrams of art systems may be needed for applications scenarios, such as system and software development. While the generative component of RMT demonstrates innovative potential, current random generation features often produce unrealistic and non-meaningful 'interactions', highlighting the need for more context-aware generative algorithms and greater user control.

In Chapter 2, we emphasised that an effective interaction model should support the description, comparison and creation of interactions. Subsequently, we structure the detailed discussion on the benefits and limitations of RMT from these angles below.

Describing interactions

Chapter 4 and Chapter 5 demonstrate that RMT is applicable to describe a diverse range of interactive artworks involving multiple participants, including both humans and nonhumans. The main concepts of the relational model—the identification of elements, their actions and forms of communications to each other—have been shown to be applicable across all examined artworks. By employing these concepts and their associated descriptors, we were able to systematically dissect these interactions and trace how elements relate to and influence one another. As a result, this approach allows us to identify the distinct roles played by different elements and the varying types of participation they engage in within the interaction.

Compared to using the relational model alone, RMT offers distinct advantages in describing interactions. Firstly, it significantly enhances the precision of both the modelling process and the resulting interaction descriptions. By providing a comprehensive and consistent scheme for each element, along with suggestions for each descriptor based on previously described artworks, RMT not only guides users through the modelling process but also aids in formulating detailed descriptions. This lowers the learning barrier and ensures that all aspects of the relational model are thoroughly addressed.

Another notable strength of the modelling capabilities of RMT lies in its emphasis on the relational exchange between actions. Prior to the development of RMT, the relational model did not explicitly require the specification of conditions for each action, leaving the decision of which actions to describe entirely to the modeller. RMT, however, necessitates a clear specification of triggering actions for reactions, ensuring that the relationships between audience actions and the art system are explicitly articulated through their conditional links. In doing so, RMT enforces the clear definition of all actions and reactions, leading to more comprehensive descriptions and aiding in the decision-making process during modelling.

Additionally, the formal structure of the input fields allows us to define a visual language for depicting an interaction and automatically generate a visualisation. The visualisation provides a direct visual impression of the description that facilitates the modelling process and comparisons of different interactions. It can also create easily identifiable visual patterns showing the characteristics of an interaction. Consequently, RMT enables the easy identification and contextualisation of known interaction model—such as feedback loops that can be recognised as the reverse symmetry of blue and red bars in the conditional links—within specific interactions, which also provides a broader context of how these models relate to other aspects of the interaction.

Moreover, the open and modular architecture of RMT also allows us to creatively adapt it to describe processes beyond the scope defined by the relational model. For instance, the concept of action and communication can also be applied to specify significant internal dynamics within a single element. While effective, such adaptation also raises important questions about whose and which internal actions should be considered significant in the modelling process. Therefore, if RMT is to be extended into a more versatile tool, more concrete guidelines and refinements are necessary to ensure consistency and clarity in its application.

Lastly, although RMT demonstrated potentials in different application scenarios spanning from facilitating communication to artwork conservation, it is worth emphasising again that the primary goal of both RMT and the relational model is to facilitate understanding of interactive dynamics among elements. Depending on the specific application scenario, a more detailed behavioural diagram of an art system–one that specifies internal processes and breaks down subcomponents–may prove more practical for communication during art system development, as well as for conservation and archiving purposes.

Comparing interactions

The key concepts and descriptors of the relational model and RMT not only facilitate the analysis of interactions but also establish a consistent frame of analysis and shared vocabulary for making meaningful and systematic comparisons between different interactive artworks. In Chapters 4 and 5, we illustrate how RMT enables the identification of common patterns across diverse forms of interaction, specifically in co-located interaction and more-than-human interaction, respectively. Additionally, as demonstrated in Chapter 6, RMT provides a powerful tool for translating insights from other participatory artworks that are not necessarily considered interactive into actionable inspirations for the creation of interactive art.

Additionally, datasets of interactive dialogues generated using the formal input fields of RMT present opportunities to develop novel analytical and comparative approaches. The unified data structure not only facilitates straightforward comparison and rigorous analysis across diverse forms of interaction but also enables the application of statistical and visualisation techniques to extract insights from large collections of interactive artworks, which are not always possible to achieve manually. For instance, we could explore methods to visualise and quantify stored artwork collections, generating an overview that highlights the distribution of data points across various descriptors. At an applied level, such techniques could support the automated curation of artwork collections, as well as enable advanced computational and visual analysis of larger datasets of interactive artworks, thereby enhancing our ability to interpret and engage with extensive collections systematically.

Generating interactions

Besides its application in describing various interactive artwork, RMT also showed potentials in inspiring the creation of new forms of interaction. Here we discuss our attempts to harvest the generative potentials of RMT as well as the lessons we learned through these exercises. This section also serves as a response to the research question:

> **Q3:** Can a relational modelling approach support the discovery and creation of new interactive dialogues?

In short, we believe that our relational modelling approach—the relational model and RMT—can support the discovery and creation of new interactive dialogues. As RMT treats humans, nonhuman organisms and art systems with equal terms, it allows us to view an interaction from the perspectives of all elements involved, including the nonhuman ones. Drawing on the patterns of interaction uncovered in Chapters 4 and 5, we can envision novel forms of interaction by reconfiguring the roles of these elements and experimenting with diverse combinations of existing communications and conditions. Additionally, similar to the comparative approaches enabled by RMT, we can also apply statistical and computational methods to explore and discover new forms of interaction. This line of inquiry directly inspired the development of the generative component of RMT, which seeks to provoke discussions about the generative possibilities of RMT through innovative, data-driven approaches.

Currently, the generative component applies random generation features to explore new combinations of element types and behaviours based on the collection of existing interactive dialogues, and draw new connections between them in terms of generating new forms of communications and conditions. While randomness may inspire the discovery of new elements, behaviours, or connections, we noted that a completely random configuration of elements is unlikely to produce a meaningful interaction. In complex scenarios involving multiple elements, it may be the case that not every pair of elements are responsive to each other. However, the overall configuration of the interaction should still enable a mutually responsive dynamic between two elements, potentially mediated by a third element. Thus, in the future development of generative features, the focus should not only be on exploring combinatory novelty, but also on identifying the interactive dynamics within the generated ideas.

Furthermore, feedback from the workshop participants highlighted the necessity of providing users with more control during the generative processes. For instance, instead of using the whole artwork collection, users could select artworks with shared characteristics or combine different forms of interaction that are more aligned with their creative goals. This tailored approach would allow the generative functions to explore more coherent and purposeful combinations. Additionally, we can also leverage machine intelligence further to facilitate greater customisation during the generation process. For instance, data mining and machine learning algorithms could be employed to generate new forms of interaction based on statistical patterns identified within the artwork collection. This could be complemented by allowing users to adjust the level of randomness in the generation process, similar to adjusting the *temperatures* in generative AI systems, thereby offering a balance between structured guidance and creative exploration.

8.2 Insights into Interactive Art

Another central focus of this thesis is to uncover insights into diverse forms of interaction within interactive art through the application of the relational modelling approach. In this section, we summarise these insights in response to the following research question:

> **Q2:** What insights into interactions in interactive art can be gained from a relational modelling approach?

In Chapters 4 and 5, we systematically analyse distinct forms of co-located interaction and more-than-human interaction using carefully selected interactive artworks as case studies. Through this analysis, we uncovered key insights emerging from these two types of interaction, highlighting common themes such as the interplay between actions performed by elements, the roles assumed by different elements, the ways in which art systems configure relationships among participants, and the various forms of mediated communication. In the following discussion, we further elaborate on these insights in relation to these two forms of interaction. These insights not only reveal patterns in existing interactive artworks, but also point to directions for creating new forms of interaction.

8.2.1 Insights into co-located interaction

In co-located interaction, two or more audience members engage simultaneously with an interactive artwork within a shared physical space. The interaction takes place not only between the audience and the artwork, but also between the audience members themselves. In Chapter 4, we selected eight artworks representative of a diverse range of co-located interaction and applied RMT in describing and analysing the relational dynamics within these artworks. Based on the similarities and differences across the generated descriptions, we derived insights into co-located interaction, addressing the following sub-question:

> **Q2a:** What insights into co-located interaction can be gained from a relational modelling approach?

In summary, our analysis revealed that co-located interaction extends the concept of an interactive dialogue between two elements into a network of intertwined actions and reactions among multiple elements. Specifically, in a co-located interaction: elements can relate to each other in various ways via their actions; art systems play different roles in mediating and establishing connections among human participants; both art systems and audience members can be a mediator in a communication. Below, we elaborate on these key insights.

Firstly, elements can act and react to one another in diverse ways. The reactions from art systems frequently provide feedback on the effects of audience actions, or deliver additional sensory feedback—such as auditory or visual cues—on these actions. In doing so, they enable the audience to grasp the intended interaction mechanisms and use the additional sensory cues to express themselves and communicate with others. Notably, in some instances, the art system simply reacts to the presence of the audience, signalling interactive possibilities and thereby initiating the interaction. This dynamic highlights the role of the art system not only as a responsive entity, but also as an active agent in shaping the interactive experience.

In addition to the action-reaction relationship, actions performed by elements can also influence one another in various ways. For instance, an action may serve as a prerequisite for subsequent actions, requiring an element to execute it either prior to or concurrently with other actions. Furthermore, a parallel action can disrupt, enhance, or facilitate the execution of other actions. A distinctive feature of co-located interaction is the ability of the audience to communicate directly with one another due to their co-locatedness. Since this communication frequently occurs alongside other audience actions, it can be configured to either facilitate or disrupt other actions, adding a layer of complexity to the relational dynamics. Alternatively, in some cases, the art system responds directly to the joint actions of the audience, making their direct communication a key mechanism driving the interaction.

A recurring theme across all the selected artworks is the active role of art systems in establishing or facilitating connections among audience members during the interaction. These connections can be formed arbitrarily, such as by selecting and pairing audience members to perform specific tasks together. This strategy often fosters collaboration among participants, encouraging them to engage with one another. Additionally, the art system can create interdependencies among audience actions, for example, by reacting to the joint actions of the audience members. A particularly intriguing approach observed is one that may initially appear counterintuitive: isolating an individual from the rest. In such cases, the art system deliberately focuses on a single participant, placing them in the spotlight. This heightened focus amplifies the actions of the chosen individual, prompting them to express themselves and connect with others.

Lastly, we highlight the various forms of mediated communication identified within the selected interactive artworks. The most prevalent example involves audience members communicating with one another through art systems. In such instances, the art system often serves as a platform or provides additional sensory channels, enabling participants to express themselves and perform in front of others. Another form of mediated communication occurs when the audience communicates with the art system, or vice versa, via another audience member. These audience-mediated interactions can leverage the properties of the human body as a conductive material or rely on our innate communicative abilities to express and convey information, challenging conventional assumptions about the roles of humans and technical systems within interactive contexts.

8.2.2 Insights into more-than-human interaction

More-than-human interaction reflects the growing interest in developing interactive technologies that engage animals and other nonhuman life-forms, emphasising the agency and influence of nonhuman entities in interactive contexts. In Chapter 5, we selected five artworks that exemplify diverse approaches to shaping interspecies relationships between humans and nonhuman life forms and applied RMT to examine the more-than-human interaction within them. Through the generated descriptions, we identified recurring patterns and biases in these artworks, thereby addressing the following sub-question:

> **Q2b:** What insights into more-than-human interaction can be gained from a relational modelling approach?

In summary, our analysis revealed a recurring tendency to cast nonhuman organisms as passive participants and humans as active. Additionally, we identified various ways art systems mediate communications and (re)configure relationships between them. Taking a more-than-human perspective, we challenge these conceptions of element roles and propose directions for new forms of interaction that highlight the agency of nonhuman elements, including art systems. Below, we further discuss these key insights in details.

Firstly, in the described more-than-human interactive artworks, humans often take on an active role in the interaction, while nonhuman organisms play a passive one. In most cases, humans are aware of how their actions impact the interaction and participate voluntarily. Meanwhile, although the nonhuman participants often trigger the art system to initiate interaction, we would argue that these actions are not intended for participation, and they may not be aware of how they affect the interaction. Although they receive feedback about their actions either directly from the art system or indirectly via the humans' actions, it remains unclear whether they could eventually learn about the interaction mechanisms and become active participants.

For future inquiries, it may be interesting to explore ways to engage nonhuman organisms as active participants and consider scenarios where they interact with humans who participate passively. However, since we lack direct access to the cognition of nonhuman organisms, assessing whether nonhuman participants willingly participating in the interaction remains speculative from a human standpoint. Clearly, such a proposal requires careful ethical consideration, as it inevitably necessitates humans interpreting the actions and responses of nonhuman organisms.

Similar to the cases observed in co-located interaction, we identified various forms of mediated communication in this context. The most prevalent is communication from nonhuman organisms to humans via art systems. In these instances, the art system typically detects the actions of nonhuman organisms and actively relays information relevant to the interaction to human participants. Additionally, art systems can also mediate another form of communication from humans to nonhuman organisms by providing food or physical stimuli to nonhuman participants triggered by actions of the humans. Furthermore, we also observe a form of human-mediated communication directed towards nonhuman organisms. In this case, the art system instructs the human to engage with the nonhuman, leveraging human abilities and skills to attend to and adapt to the nonhuman. This is particularly interesting as it encourages humans to reflect on the implications of the nonhuman's involvement in the interaction, fostering a deeper awareness and responsibility of interspecies relational dynamics.

Finally, art systems not only facilitate interspecies communication, but also reconfigure relationships between humans and nonhumans in various ways. Here too, art systems can provide a collaborative context for both groups of participants, prompting interdependences between their actions. In such scenarios, both parties—especially the humans—must actively engage with one another, negotiate and work together to achieve specific tasks. Alternatively, art systems can establish and mediate connections between humans and nonhumans by providing mechanisms that translate the actions of one party into sensory cues or physical stimuli perceivable by the other. In doing so, art systems allows both participants to influence and communicate with each other in ways that were previously unattainable. However, it is important to note that while art systems facilitate these connections, it also imposes constraints on the type of information that can be transmitted and may even limit the agency of the elements involved in shaping such processes.

8.3 Challenges and Considerations

In addition to reflecting on the key insights gained in this study, it is also important to acknowledge the challenges encountered in relation to the approaches and process. First and foremost, although RMT facilitates the modelling of interactions by providing structured guidance and encouraging relational thinking among elements, the decisions made during the modelling process—such as determining which elements to include, identifying significant actions, and describing the effects of the resulting communications—remain largely subjective to the modeller. In this thesis, we have acted as the primary modellers and users of RMT. The generated descriptions and insights are inevitably shaped by our own interpretative frameworks, habits, and assumptions. It is conceivable that different modellers would describe the same artworks in varied ways, potentially uncovering insights that we may have overlooked.

Additionally, as there are no formal criteria or established benchmarks for evaluating the accuracy or completeness of the generated descriptions, the effectiveness of RMT as a modelling tool has been assessed primarily based on our own judgment. While we have demonstrated its applicability across different cases, a more rigorous validation process—such as comparative studies involving multiple modellers or user studies assessing its consistency —would be beneficial to further substantiate its reliability. Future research could explore methods for standardising the evaluation of RMT, potentially through expert reviews, inter-modeller agreement studies, or even computational benchmarking techniques.

Meanwhile, although we have devised a rigorous process for selecting artworks for analysis, we acknowledge that the chosen artworks do not encompass the full spectrum of co-located interaction and more-than-human interaction. Consequently, it is reasonable to assume that there are other artworks that can not be fully captured by RMT, which would require further refinement and adjustment of the relational model and RMT. Moreover, given the relatively small sample size of selected artworks, the general trends and patterns observed in this study may not be universally applicable and could be contradicted by other artworks that were not considered in this thesis.

Another limitation in describing the artworks is that we lacked first-hand experience with most of them, relying instead on textual and audiovisual documentation for our analysis. Unlike static artistic objects, the dynamic and interactive processes between artworks and audiences in interactive art are notoriously difficult to capture fully using traditional documentation methods. This is where interaction modelling tools such as RMT prove particularly valuable, as they offer a structured approach to archiving and describing such artworks. Consequently, it is important to acknowledge that certain aspects of the described artworks may not have been fully captured in the available documentation, potentially resulting in incomplete descriptions.

Lastly, as most participants in the evaluation workshop had backgrounds in HCI research and interaction design, their feedback and discussions naturally gravitated towards the design and modelling implications of RMT. Since the relational model and RMT were specifically developed for the study of interactive art and inspiring the creation of new interaction forms, evaluations involving artists and researchers in this field could provide more significant and diverse insights into its applicability and potential within the field and a more comprehensive understanding of its strengths and limitations.

8.4 Future Directions

Before concluding the thesis, we outline several key directions for future research and development. Firstly, we emphasise again that the relational model and RMT are not definitive or finalised products. Rather, they function as research instruments to explore the benefits and potential of such modelling tools within the context of interactive art. On a practical level, future developments of RMT could draw inspiration from the well-defined notation systems of established interaction modelling languages, such as the Unified Modelling Language (UML) (Bell, 2023). This could enhance clarity and facilitate easier adoption of RMT by a broader user group. Additionally, organising co-design sessions with practitioners and researchers in the field of interactive art could provide valuable insights to refine the design of RMT, generate ideas for new features, and ensure its functionalities align with their creative processes.

Another promising direction for the future development of RMT and the relational model is to refine the description of actions and their interrelationships. Currently, the concept of action encompasses both actions and reactions of elements. Although we have refined the definition of action and incorporated its intention and conditions, it can still be conceptually challenging to differentiate various types of actions at a glance. Future iterations of RMT could explore alternative methods to specify actions and reactions more clearly, as well as different ways to indicate how they influence one another. This could involve developing more nuanced categorisations or visual representations to enhance the clarity of different types of actions, thereby supporting more precise analysis and interpretation of interactive dynamics.

In this thesis, we applied RMT primarily to model existing interactive artworks and explored its potential for generating new interactive dialogues. An interesting avenue for future research would be to integrate RMT throughout the entire development cycle of an interactive artwork—from initial ideation and conceptualisation to technical development and final evaluation. This holistic application could further demonstrate the versatility and utility of RMT, as well as reveal its limitations, in supporting the creation and analysis of interactive art.

Moreover, while we have demonstrated that RMT is applicable for describing participatory processes beyond interactive art, it is interesting for future studies to explore how its key concepts and descriptive approach can support the development of metrics to distinguish and evaluate interactive artworks. For instance, the conditional links between actions could be employed to evaluate the mutual responsiveness of an artwork and its audience–a defining characteristic of interactive art–while also enabling comparisons of levels of interactivity across different artworks. Such metrics could not only facilitate the curation and archiving of interactive artworks but also contribute to the conceptual advancement of interactive art by outlining the unexplored territories.

Meanwhile, our investigation into interactive art using RMT and the relational model also opens up avenues for exploring new forms of interaction. In our analyses of both co-located interaction and more-than-human interaction, art systems frequently function as a mediator or tool, facilitating connections and communication among participants, including both humans and nonhumans. One particularly intriguing direction is to explore how art systems might be created as participants in their own right. Given that RMT and the relational model treat all types of elements equally, they provide a valuable tool for conceptualising such scenarios. We could begin by assigning roles typically associated with human participants to art systems, specifying the behaviours that support these roles, and evaluating their technical feasibility. This line of inquiry not only points toward the creation of novel forms of interaction in interactive art, but also challenges our assumptions about the roles of technical systems and explores alternative ways to relate to these systems.

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Samenvatting

Interactieve kunst wordt vaak gezien als een dialoog tussen publiek en een kunstwerk. Met vooruitgang op het gebied van interactieve kunst, ontstaan steeds complexere en meer diverse vormen van interactie. Dit vraagt om uitbreiding van bestaande conceptuele kaders die beter de onderlinge dynamiek van interactieve elementen weergeven, en structuur kunnen bieden om analytische instrumenten te kunnen toepassen. Dit proefschrift beoogt dit door interactieve dialogen als relationele systemen te beschouwen, op deze wijze bestaande kunstwerken te analyseren, en zo te zoeken naar inspiratie voor nieuwe vormen van interactie. De belangrijkste doelstellingen, vragen en methodes hiervoor worden besproken in Hoofdstuk 1.

Hoofdstuk 2 introduceert een relationeel model dat is ontworpen om interacties binnen interactieve kunst systematisch te kunnen ontleden en analyseren. Het model identificeert sleutelelementen (zoals publiek en technische systemen), ontleedt hun acties (zoals beweging en schermupdates), en brengt de resulterende communicatiestromen in kaart. Door diverse soorten van elementen gelijkwaardig te behandelen biedt dit model ruimte om complexe scenario's met meerdere deelnemers te beschrijven, en stimuleert het creatieve beschouwingen van mogelijke onconventionele rollen die de elementen zouden kunnen aannemen.

Om dit model te operationaliseren hebben we de *Relational Modelling Tool* (RMT) ontwikkeld, een webapplicatie die in Hoofdstuk 3 wordt beschreven. Op basis van gestructureerde invoervelden om interacties te beschrijven, genereert RMT automatisch een grafische weergave van deze interacties. Dit maakt analytische precisie in het modelleringsproces mogelijk. De gestandaardiseerde structuur om gegevens te beschrijven maakt tevens onderlinge vergelijking van verschillende interactieve kunstwerken mogelijk, evenals het procesmatig genereren van nieuwe interactievormen.

Vervolgens hebben we RMT toegepast om een aantal interactieve kunstwerken te analyseren. Dit valideert niet alleen de mogelijkheden die RMT biedt voor het modelleren van interactie, maar biedt ook inzicht in de diversiteit van soorten interactie. Hoofdstuk 4 ontleedt acht kunstwerken met *co-located* publieksinteractie: meerdere deelnemers interacteren in de-

zelfde ruimte tegelijkertijd met zowel het kunstwerk als met elkaar. Met ons relationele model kunnen de hieruit volgende actie-reactie-patronen worden beschreven, alsook de onderlinge invloed van acties op elkaar die cruciaal is om de interactieve dynamiek te beschrijven en begrijpen. De uitkomsten hiervan benadrukken het inherent sociale karakter van co-located interactie, en suggereren dat interactieve kunstwerken de band tussen het publiek onderling kunnen versterken door hen verschillende communicatiepatronen te bieden. Deze inzichten maken het mogelijk om nieuwe interactieve dialogen te bedenken, bijvoorbeeld door de rollen van het publiek en technische systemen te verwisselen.

In Hoofdstuk 5 worden vijf interactieve kunstwerken geanalyseerd die interactie tussen menselijk publiek en niet-menselijke (*more-than-human*) organismen omvatten. RMT bracht patronen aan het licht van actieve menselijke participatie en passieve betrokkenheid van niet-menselijke organismen, naast het tonen van diverse gemedieerde communicatievormen (bijvoorbeeld van niet-menselijke organismen naar mensen via technische systemen, of van technisch systeem naar niet-menselijke organismen via mensen). Bovendien onderzochten wij de verschillende manieren waarop technische kunstwerken nieuwe vormen van intersoortelijke relaties tot stand brengen. Op basis van deze bevindingen stellen we voor dat toekomstig onderzoek naar zogenaamde *more-than-human* interactieve kunst zich zou kunnen richten op: (1) het betrekken van niet-menselijke organismen als actieve deelnemers, (2) het bedenken van nieuwe vormen van gemedieerde communicatie met niet-menselijke organismen op basis van menselijke communicatiemogelijkheden, en (3) het creëren van technische systemen als deelnemers aan interactie.

Wij hypothetiseren voorts dat concepten en methodes van het relationele model en RMT toegepast kunnen worden om participatieve processen in een bredere artistieke context te beschrijven—niet alleen betrekking hebbende op interactieve kunstwerken. In Hoofdstuk 6 is RMT toegepast om twee participatieve kunstwerken te modelleren met afwijkende vormen van publieksbetrokkenheid, die strikt genomen geen van beide interactief zijn. Dit toont de analytische veelzijdigheid en toepasbaarheid van RMT in een brede artistieke context, en laat zien hoe inzichten uit bredere kunstvormen wederzijds kunnen bijdragen aan de doorgaande ontwikkeling van interactieve kunst.

Voorts presenteert Hoofdstuk 7 de bevindingen van een workshop die wij hebben georganiseerd om de modellerings- en generatieve mogelijkheden van RMT met een brede gebruikersgroep te evalueren. Hiertoe ontwikkelden wij een datagestuurde component binnen RMT die automatisch nieuwe actoren en interactievormen produceert op basis van een bestaande kunstcollectie, door willekeurig nieuwe vormen van communicatie en voorwaarden voor acties toe te wijzen. Zo beoogden wij om discussies over het genereren van interactieve dialogen te faciliteren. De belangrijkste inzichten uit de workshop gaan over het ontwerp van de interface, mogelijke verbeteringen aan RMT, en de diverse toepassingsmogelijkheden ervan. Op basis hiervan hebben wij RMT iteratief verbeterd, maar ook gereflecteerd op het ontwerpen van intuïtieve interfaces, het betrekken van gebruikers bij ontwikkelingsprocessen, de voordelen en beperkingen van RMT, alsmede de toepasbaarheid en positionering ervan.

Hoofdstuk 8 presenteert de conclusies van het proefschrift door de belangrijkste bevindingen en onderzoeksbijdragen samen te vatten. Het reflecteert op de kernvragen van het onderzoek die in Hoofdstuk 1 zijn vastgesteld, onderzoekt kritisch de methodologische uitdagingen en stelt mogelijke nieuwe onderzoeksrichtingen voor. Een mogelijke en intrigerende onderzoeksrichting bevraagt hoe technische systemen binnen interactieve kunstwerken kunnen worden beschouwd en ontwikkeld als volwaardige deelnemers, gelijk aan menselijk publiek. Deze onderzoekslijn inspireert tot het creëren van nieuwe interactievormen en vereist mogelijk een herziening van de rollen die technische systemen in interactieve kunst spelen. Bovenal daagt zij uit tot het verkennen van nieuwe mens-computerrelaties.

Summary

Interactive art is often characterised as a dialogue between an audience and an artwork. Yet with the advancement of the field of interactive art, the emergence of increasingly complex and diverse forms of interaction demands an expanded conceptual framework that better captures nuances in dynamics among interacting elements and provides the structure to allow uses of analytical tools. This thesis addresses this gap by proposing a relational approach to understanding interactive dialogues, which analyses existing artworks and seeks to inspire new forms of interaction. The main aims, questions, and the approaches used to address them are further discussed in Chapter 1.

Chapter 2 introduces a relational model of interaction, designed to systematically dissect and analyse interactions within interactive art. The model identifies key *elements* (e.g., audience members, art systems), examines their *actions* (e.g., movement, display updates), and maps the resulting *communication* patterns. By treating all elements equally, the model accommodates complex, multi-participant scenarios while encouraging creative experimentation by allowing elements to assume unconventional roles.

To operationalise this model, we developed the Relational Modelling Tool (RMT), a web-based application detailed in Chapter 3. RMT combines structured input fields for describing interactions with an automated graph-based visualisation, ensuring analytical precision while supporting the modelling process. Its standardised data structure enables cross-comparison of diverse interactive artworks and potentially supports the generation of novel interaction forms.

Subsequently, we applied RMT to analyse a selection of interactive artworks. These case studies not only validate the modelling capabilities of RMT, but also reveal insights into the different types of interaction. Chapter 4 examines eight artworks featuring co-located audience interaction, where multiple participants engage simultaneously with both the artwork and one another. The relational model captures action-reaction patterns, and in addition the influences between actions that are crucial to understand the underlying interactive dynamics. A key finding underscores the inherently social nature of co-located interaction, suggesting that

art systems can foster audience connections by leveraging the different communication patterns among them. These insights open opportunities to conceive new interactive dialogues by subverting or exchanging the roles of audience and art systems.

Chapter 5 analyses five artworks showcasing more-than-human interaction between humans and nonhuman organisms. RMT revealed a general pattern of active human participation and passive nonhuman involvement, alongside diverse mediated communication forms (e.g., nonhuman-to-human via art systems, or art system-to-nonhuman via humans). In addition, we also examined different ways in which art systems reconfigure interspecies relationships. Building on these findings, we propose that future research in more-than-human interactive art could explore: (1) involving nonhuman organisms as active participants, (2) devising novel forms of mediated communication with nonhuman organisms based on human communicative abilities, and (3) creating technical systems as interaction participants.

Beyond interactive art, we hypothesise that the concepts and descriptors of the relational model and RMT can be adapted to describe participatory processes in broader artistic contexts. In Chapter 6, we applied RMT to model two participatory artworks with distinct forms of audience engagement, neither of which is, strictly speaking, interactive. It demonstrates the analytical versatility of RMT across artistic domains, while revealing how insights from these practices can reciprocally inform the development of interactive art.

Furthermore, Chapter 7 presents findings from a workshop we organised to evaluate the modelling and generative capabilities of RMT with a broader user group. To facilitate discussions on generating interactive dialogues, we developed a data-driven component that automatically produces new elements and behaviours based on the existing artwork collection and draws novel connections among them by randomly assigning new forms of communication and conditions for actions. Key insights from the workshop centred on the interface design, potential improvements to RMT, and its various application scenarios and potentials. Based on the participant feedback, we iteratively refined RMT and reflected on lessons related to designing intuitive interfaces, user involvements in development processes, understanding the benefits and limitations of RMT, and clarifying its scope and positioning.

In Chapter 8, we present the conclusion of the thesis by synthesising the key findings and research contributions. It provides comprehensive reflections addressing the core research questions established in Chapter 1, critically examines the methodological challenges, and proposes future research directions. One intriguing direction is to explore how art systems can be conceived and developed as participants in their own right. This line of inquiry inspires the creation of novel forms of interaction, as well as challenges our assumptions related to the roles of technical systems, opening possibilities for exploring new human-computer relations.

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Curriculum Vitae

Dan Xu is a creative researcher and new media artist from China and currently based in the Netherlands.

From 2011 to 2015, Dan studied Applied Physics (BSc) at Beijing Institute of Technology. In 2015, she moved to the Netherlands to enrol in the MSc Media Technology programme at Leiden University. She completed the programme in 2017 with a Cum Laude distinction.

From 2018 to 2020, Dan worked as a Digital Transformation Designer at the Digital Society School, affiliated with the Amsterdam University of Applied Sciences.

Since 2020, Dan has been a PhD candidate at the Leiden Institute of Advanced Computer Science at Leiden University. During her PhD studies, she took courses in scientific conduct, among others.

In 2024, Dan and her collaborators were awarded the Processing Foundation Fellowship for their collective project "Screen-to-Soundscape", which explores how AI and spatial audio technologies can benefit online experiences for blind and visually impaired individuals.