

Creating Artificial Societies through Interaction Analysis: Translating Qualitative Observational Study into Agent-Based Modelling

Selin Zileli^{1,2}, Jiayu Wu^{1,2}, Cyriel Diels^{1,2} and Stephen Boyd Davis^{1,2}

¹Intelligen Mobility Design Centre

²Royal College of Art

selin.zileli@network.rca.ac.uk

Abstract

The use of interaction analysis for creating agent-based models could lead to more empirical simulations. This study focuses on pedestrian-street interaction during negotiations at a signal-controlled crossing. It examines which data from interaction analysis could be used in the development of artificial pedestrian societies. This article sets out a framework for structuring the data deriving from interaction analysis and demonstrates the process of developing an agent-based model by translating the acquired data into the model. The data collected through interaction analysis serves as input for the agent-based model. The structuring performed on the interaction analysis data is used to define the outcome variables for agent-based modelling. The study concludes by proposing an initial framework that describes the use of interaction analysis in simulations.

Introduction

An empirically grounded agent-based model uses both quantitative and qualitative data to inform the agents' behavioural process and reasoning (Robinson et al., 2007). This claim builds on Yang and Gilbert's (2008) idea that "there is nothing inherently quantitative" in agent-based simulations. To address the qualitative aspects of agent-based modelling, modellers often use behavioural and social theories as well as desk research (Ghorbani et al., 2015). For example, in pedestrian studies, the modellers used theories from literature such as Gibson's perception theory (Turner & Penn, 2001), questionnaire data to estimate individual variables (Rad et al., 2020) or interview data to estimate parameters (Borgers & Timmermans, 2005). While qualitative data can be accessed through literature, questionnaires, interview data and other available resources, multiple levels of details can be achieved by gathering and structuring qualitative observational data. By qualitative observational data, we refer to the obtained data through a qualitative analysis of video recordings in order to identify processes of behaviours, interactions, situations and activities.

Throughout the literature, researchers used a variety of methods to create agent-based models. Some of them relied on assumptions about individual and social behaviour due to a lack of behavioural data (Pan, Han and Law, 2005), while others followed findings and theories from the literature (Pan et al., 2007; Luo et al., 2008). Another approach to creating

artificial societies, such as the one used by Reséndiz-Benhumea et al. (2019), indirectly relies on observation analysis. In the cited case, the agents were based on observations conducted on ants in a laboratory (Detrain & Deneubourg, 1997; Labella, Dorigo and Deneubourg, 2006). The observations aimed to count the number of instances of behaviour in order to determine the animal's decision-making process. Similar applications of observation can be found in human behaviour studies by Klügl and Rindsfuser (2007), Bandini et al. (2016), Willis et al. (2000). The main difference of this research is that we used qualitative observational data to both identify and model foreseen and unforeseen behaviours occurring in the real environment. This process aims to increase the heterogeneity of agents and reduce modellers' bias by providing an opportunity to observe and identify new behaviours.

Using qualitative data provides a solid foundation and insights into the behaviours of agents, an insight that statistical and numerical data lacks in micro-level simulations (Tubaro & Casilli, 2010). However, collecting and structuring qualitative data to form agents' decision-making processes, interactions, and behaviours is not straightforward (Janssen & Ostrom, 2006; Ghorbani et al., 2015). Several researchers provided examples of structuring qualitative data to design agent-based models. Some of the complete frameworks are those of Altaweel et al. (2010), Smajgl and Barreteau (2014), and Ghorbani et al. (2015). The literature shows that a conceptual framework is one of the key requirements for translating qualitative data to agent-based modelling. To address this requirement, in this research, we show a process of structuring the data from interaction analysis which is then applied to an agent-based model.

In this research, a unique approach is provided by using the combination of interaction analysis and agent-based modelling. We argue that the specific nature of agent-based modelling is especially suited to interaction analysis as they both provide a bottom-up approach through their application. Furthermore, they both provide behavioural sequences, interactions and relationships, making them comparable during the validation process of agent-based modelling.

The following sections provide background information on the case study, data collection method, and background information relating to the interaction analysis. The structuring of interaction analysis data and its translation into agent-based modelling covered in the modelling process

(section 3). Based on this process, we provide a general framework that shows the overall structure of the process and how the key elements of interaction analysis and agent-based modelling relate to each other. Then, a discussion of the benefits and limitations of this framework and final remarks are provided. The last section concludes the research by giving a summary and further steps. Since our explanation necessarily covers a number of disciplines, references to the literature are provided within each section rather than in a preliminary literature review.

Background

Case Study: Pedestrian Interactions on Crossings

This study's main objective is to investigate pedestrian behaviours and their interactions with their surroundings (vehicles, street infrastructure and other pedestrians) thoroughly to understand the underlying influencing, encouraging and deterring factors on the street.

The majority of collisions between pedestrians and motorised vehicles occur on the street, where the two modes interact with each other (Schoon, 2010). Therefore, street environments must be appropriately designed to provide safety with a preferred level of service for pedestrians. There is a need to understand the current street conditions, pedestrian interactions, components, and processes to answer critical questions about pedestrians' safety and safety perception. Furthermore, it is essential to have a good understanding of pedestrian behaviour to design and assess pedestrian-related systems.

The goal of this study is to investigate the emergent interactions between pedestrians, vehicles and street infrastructure. Interaction analysis is chosen to analyse video recordings of pedestrians' behaviours and their surroundings to obtain an understanding of how these observed pedestrian behaviour patterns emerge and how the underlying cues in the environment shape those behaviours. The rationale behind employing a fieldwork approach is that pedestrians' interactions and behaviours develop naturally in the street environment. They are embedded in the situations the pedestrians are in and can be studied by observing these behaviours in their place.

Data Collection

The study used video observation techniques for data collection to obtain static attributes (geometric characteristics, vehicle characteristics, pedestrian characteristics, etc.) and dynamic attributes (pedestrian behaviours, pedestrian density, vehicle speed, vehicle density, etc.) in the street. These data are obtained through camera recordings and counting sheets. The data collection was performed at different times of the day (am and pm) over four days. The area of focus included a signalised crossing, sidewalk areas and part of a roundabout. The study's focus was to understand how pedestrians negotiate their space with vehicular traffic, how they decide to cross, and, when they cross, what is the situational context on the street.

The analysis was performed through interaction analysis (Jordan & Henderson, 1995) to study pedestrian behaviour on

the street. It was an unusual method to study pedestrian video recordings. However, this method helped to understand the relationship between pedestrians' actions and the spatial context in which they perform these actions. Spatial context, here, means the dynamic and changing context of the street; vehicles, traffic lights, other pedestrians.

Interaction Analysis

Interaction analysis is an interdisciplinary method to explore the individual's interaction between themselves, environment and other objects (Jordan and Henderson, 1995). The roots of interaction analysis lie in ethnography, ethnomethodology, kinesics, proxemics and ethology (Jordan and Henderson, 1995). The method consists of content logs, transcription, identification of ethnographic chunks, segmentation, temporal organisation of the activity, participation structures, and activity's spatial organisation. Data extraction looks into data points by identifying hot spots, separating behavioural units through looking into boundaries between the events (start and end of the events), disintegrating through the analysis of how individual announce they have reached the end of an interaction, doing task analysis through examining gestures, movements, nonverbal behaviours, error in interactions, exploring temporal data such as rhythms, high and low points of the interactions.

The Modelling Process

This methodological approach aims to guide the formation of the collected qualitative data to build an agent-based model. There are two parts to this procedure. The first part structures the data from Interaction Analysis by identifying the behavioural sequences, feedback loops and physical structures. The second part uses structured data to build an agent-based model.

Agent-based modelling requires the systematic representation of three phenomena: agents, interactions and environment (Crooks et al., 2019). The framework presented here mainly focuses on identifying pedestrian agents behavioural framework and explores social networks and the environment depending on their interactions.

Structuring Data from Interaction Analysis

Initial structuring of the video data was conducted through a coding sheet on spreadsheets. This structuring aimed to identify each pedestrian's timeline, their identifiable attributes, and whether they have crossed the street or not. The following step was to identify the interactions and behaviours performed by the pedestrians who crossed the road. Primarily, the data created through interaction analysis was a written text. Thus, it mainly contained descriptive information regarding the pedestrian journey. To discover any correlation between pedestrians' behaviours and their surroundings, we first looked into each pedestrian's behavioural sequence, then represented the relationships through feedback loops. This section, therefore, did not deal with the quantity or frequency of particular actions amongst pedestrians but aimed to understand the causality of their behaviours.

Behavioural Sequence. Following the written text created through interaction analysis, we have created four parallel rows, signifying (1) time, (2) pedestrian agents, (3) vehicles and (4) environment. This segmentation was useful to identify the relationship between these four aspects (e.g. what happened in the vehicle section and how pedestrians responded). To identify behavioural sequences, we asked the following questions:

- *Agent Decisions:* What events take place during the process of the pedestrian's actions? Are these events changing or stopping performed actions?
- *Agents Priorities:* How long did the pedestrian take to cross the road? Did the pedestrian wait, and how long did they wait? How long did the pedestrian take to observe the vehicles? What was the last thing the agent considered before they acted?
- *Agents Behaviours:* What actions did the pedestrian perform? What are the typical actions across pedestrians? What actions differentiate between pedestrians? Was there any segmentation between interactions or behaviours during the observed time that can allow us to classify them? If there was, how (with which actions) did the agent announce the end and the beginning of these segments?
- *Reactions to Other Agents or Entities:* Did the pedestrian observe other pedestrians around them? Does the pedestrian look for vehicles around them? Do other vehicles or pedestrians movements around the pedestrian affect the actions the pedestrian performs?
- *Reactions to Environment:* Did the pedestrian pay attention to the traffic light? Which parts of the space (i.e. sidewalk, road, crossing) did the pedestrian occupy during their journey? Did the pedestrian encounter obstacles (i.e. trees, other pedestrians, street lights) during their journey? Did the environment have an impact on the journey? For example, did the pedestrian need to take a longer road because of the environment?

Feedback Loops. To represent the relationship between pedestrians and their surroundings, we created diagrams for each pedestrian that show feedback loops. Feedback loops aimed to represent perception-action loops of individuals. The generalised version of the pedestrian diagram is below as an example (Figure 1).

The priorities derived from situations on the street and the pedestrian characteristics can change according to where the pedestrian may or may not get the feedback. For this reason, we looked in detail at what can inform each pedestrian behaviour. These are defined as the agent's variables and physical/situational conditions.

- *Agent's Variables:* This part looks at the agents' characteristics that differentiate one agent from another. For example, having little time to be at the destination point can be one of the personal variables that could change the

pedestrian's interaction process compared to pedestrians who like to take their time during their journey.

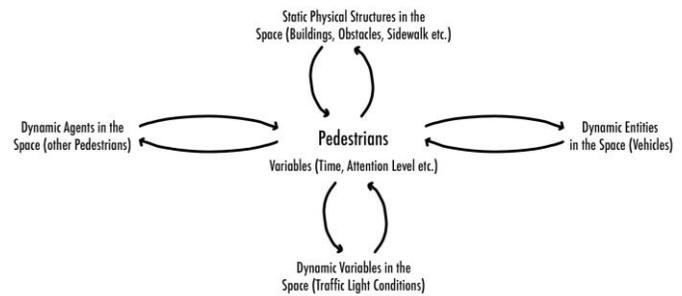


Figure 1: The feedback loops between the pedestrian agent and its surroundings.

- *Physical / Situational Conditions:* This part focuses on the dynamic, situational and changing conditions offered by the space. For example, a crossing decision can be influenced by other pedestrians, traffic light conditions or vehicle absence.

Physical Structures. This part identifies the spatial conditions during the agent's activities. These can describe the physical structures used by or interacted with or influenced by agents in their activities. It is important to identify the relationship between the physical structures and the agents through the questions posed in the behavioural sequence section. This analysis provides a map for each individual to demonstrate their path and physical structures around their path.

Building the Agent-Based Model

Upon the completion of the previous steps, the collected data is used to build an agent-based model. This process is conducted by extracting the relevant information from the data by using the following framework.

Defining Characteristics of Agents. The definition of agents' characteristics is made in two levels; strategic and operational. The feedback loop map, given in Figure 1, is separated depending on their strategic level or operational level in Figure 2 below.

The strategic level describes the elements which influence the agents' choices on when and how to act. In this research, the strategic level demonstrates the elements that influence pedestrian agents' choices when crossing the road. These elements include pedestrian agents' variables (time and attention level), dynamic agents in the space (other pedestrian agents), dynamic variables in the space (traffic light conditions, red or green) and dynamic entities in the space (vehicles).

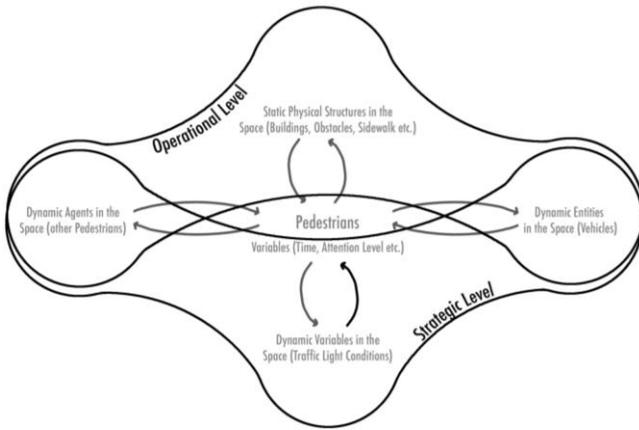


Figure 2: The feedback loops between the pedestrian agent and its surroundings.

The pedestrian agent's variables stand for the time available for an agent to reach its destination point and the level of attention the pedestrian has. These variables affect the pedestrians' strategy to cross by allowing the pedestrian agent to choose which element to engage. The behaviour of dynamic agents in the space affects the pedestrian agent's crossing strategy. On the other hand, dynamic variables such as traffic lights influence the pedestrian agent's strategy by allowing or disallowing them to cross. The dynamic entities such as vehicles have an effect on the pedestrian agent's strategy through their location and speed. The strategic level is dependent on longer-term decisions such as choice of priority or choice of route).

The priority given to these influencing elements on the street is different in each pedestrian. The priority alignment of each pedestrian defines the characteristics of pedestrian agents' strategies. According to their priority, they may or may not get affected by one or more of these elements. For example, if a pedestrian agent's priority is time and it has little time to reach its destination point, then it looks at its second priority. If the second priority is waiting at the traffic light, the priority shifts to risk-taking based on the vehicle presence in the area because the agent has limited time. Then, the agent would look for an opportunity based on the vehicles' location and speed and would ignore the traffic light.

The operational level describes the elements which affect the pedestrian agents' actions. The operational level looks into the influences on actions that pedestrian agents undertake. The condition of acting and the outcomes of the actions should be extracted from the behavioural sequence data. For example, in this research, the elements that affect agents' physical movements are other pedestrians, static physical structures in the environment and vehicles. These elements mainly affect the movement of the

agent or the path of the agent. For example, based on where the pedestrian agent is (such as a sidewalk, road or crossing), the pedestrian's speed might change. The operational level mainly represents the shorter-term decisions like physical movement.

The agent-types can be defined according to their priority sequences. One may classify the agents according to priority alignment in their strategic level; alternatively, one may classify the agents according to their operational level's priority alignment. In this study, pedestrians were categorised according to their strategic level and divided into five categories, distinguished according to their priority alignment. The first category is rule-following pedestrians who wait until the pedestrian light turns green, and their activities are oriented towards using the dedicated space and time through their journey. The other four categories are follower pedestrians (who follow other pedestrians), hesitant pedestrians (who are undecided to cross), opportunistic pedestrians (who look for an opportunity to cross) and eager pedestrians (who take risks while crossing).

Agent's Framework. The agent's framework shows how behaviours are connected and how they are triggered. Based on the classification of the agents, the norms of behaviour and shared strategies of behaviours can be extracted. The behaviours observed and structured in the behavioural sequence section are moved and structured through the agent's framework. If any of the agents perform a similar routine of behaviour, this routine can be considered as a shared behavioural process of that agents' type. For example, in this research, since the pedestrian agents are classified according to their priorities in the strategy level, five pedestrian agents' frameworks were constructed. In these frameworks, the responses and behavioural sequences of agents are different based on their priorities. The agents are formed through the choice of priority and route choice coming from the strategic level and physical movement coming from the operational level.

Physical Structures. Similar to building agents, the physical structures that affect agents' behaviour should be extracted from the collected data. These are defined as physical structures. In this research, physical structures include sidewalk, road, crossing or buildings, trees, obstacles. These structures are identified through structuring the interaction analysis data and can be implemented to the model directly.

Generalising the Process

Figure 3 shows the general structure of using interaction analysis to build an agent-based model. First, the collected data from interaction analysis is structured through behavioural sequencing by identifying agents' decisions, agents' priorities, agents' behaviours, agents' reactions to other agents or entities, and agents' reactions to the

environment. Then, the agent's variables, situational and physical conditions are identified through the feedback loops. The situational conditions included other dynamic agents in the space, dynamic entities in the space and dynamic variables in the space. Physical conditions included the physical and static structures in the environment.

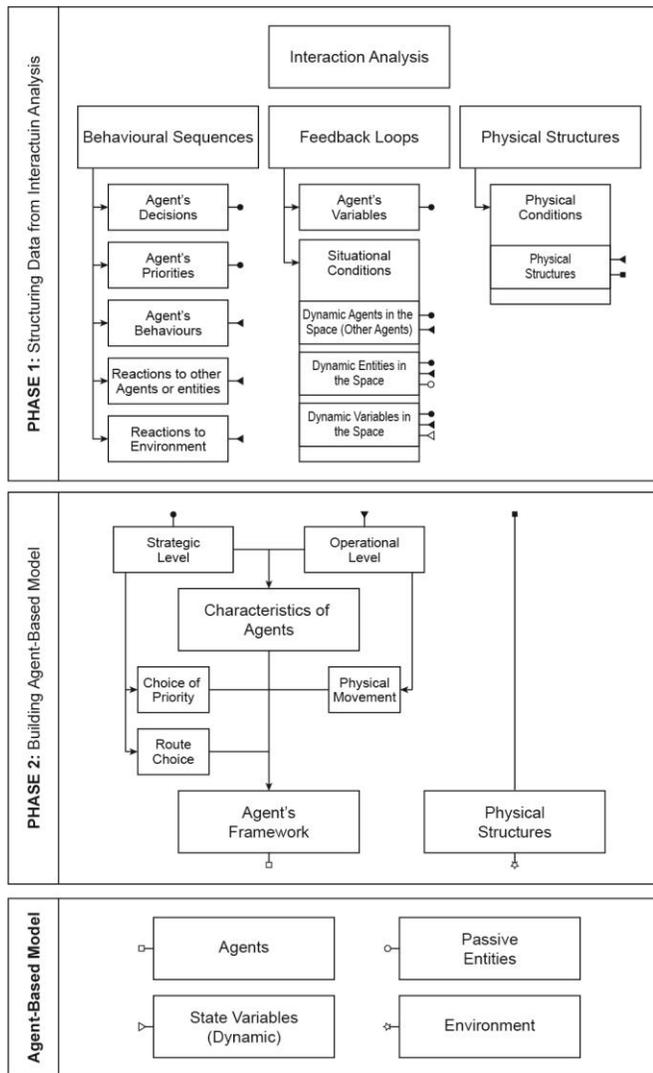


Figure 3: Framework to structure interaction analysis data and to translate the structured data into the agent-based model

In the second phase, building the agent-based model started with identifying the characteristics of agents. Characteristics of agents are defined in two levels: strategic and operational. The strategic level is constructed partially with the data from behavioural sequences (agent's decisions, agent's priorities) and partially by feedback loops (agent's variables, other dynamic agents in the space, dynamic entities in the space and dynamic variables in the space). A framework was developed for each characteristic. The agent's framework included a choice of priority, route choice and physical movement. While the choice of priority and route derive from a strategic level, the physical movement measures originate from the operational level.

In the agent-based model section of Figure 3, we can see that the agent's framework helps create agents, dynamic entities in the space create passive entities (such as vehicles), dynamic variables in the space construct dynamic state variables, and physical structures form the environment.

Besides building a framework for creating agent-based models, the structured interaction analysis data can also be used to analyse and validate the created model. The behavioural sequences of agents can be compared with the behavioural sequences occurring in the simulation. These comparisons can improve simulation performance through the modeller's reflection.

Discussion

Qualitative and quantitative data are required to construct an agent-based model. While much of the data can be interpreted quantitatively, the model's actual context, which represents the course of events, and how the agent's functionality is organised and through what kind of process agents replicate humans, need qualitative data. At both micro and macro levels, interaction analysis can provide rich data to build agent-based models. However, like any qualitative data, it needs structure and interpretation to apply to the simulation (Yang & Gilbert, 2008). This paper presents a framework as a tool to identify and structure qualitative observational data for agent-based modelling simulations. The process of building an agent-based model for the pedestrian agents helped to establish this framework and identify the benefits of using this framework.

First, this framework ensures an in-depth understanding of the video and interaction analysis data and presents a simulation consistent with the collected data. Therefore, the modeller can be confident that the collected and structured data is consistent with the simulation model.

Second, framing and structuring the interaction analysis helped to understand the agents' normative and procedural aspects. The micro-scale behaviours and cues provided by interaction analysis are often overlooked or not given importance by researchers who use statistical and automated tools to analyse.

Third, having interaction analysis data provides an iterative framework for validation of the model as well. The structuring performed on the interaction analysis data, such as behavioural sequences, helped control and contextualise the simulation. The defined procedural behaviours are compared with the simulated behaviours during the validation process.

Finally, it may be mutually beneficial to connect bodies of knowledge in interaction analysis and agent-based modelling. Researchers without a programming background may use the proposed framework to create agent-based models to supplement their research. Furthermore, researchers who are unfamiliar with modelling can understand the process and the structured data.

Building an agent-based model from video data presents challenges in terms of not being able to represent all types of behaviour as the data includes a limited number of individuals. Some of the strategic and operational behaviours can be individual, and drawing types of agents from them might be challenging. However, they can be arranged through parameters for variation, and the percentage of the types of

people forming the population can be adjustable to show different populations.

There can be many choices and interpretations that the modeller can make to transform qualitative observational data into an agent-based model. This research shows one way to structure and form the collected data, which is coming from the interaction analysis. This framework helps to understand the individuals' decision in the video and creates a traceable record of how the researcher arrived from qualitative data to a model.

This framework was developed in order to simulate human behaviour in complex and dynamic environments. The modelling is achieved by incorporating situation-specific knowledge to study real-life processes. This framework, we argue, can help in the understanding and modelling of human systems. Future research can employ this framework to identify agent typologies to connect agent-based models more closely to the world they intend to simulate.

Conclusion

Managing and structuring data, in particular qualitative observational data, is a significant challenge for agent-based modelling. This research proposed a framework for the efficient use of qualitative data to construct agent-based models. In particular, this framework has been developed to structure interaction analysis data that have not been implemented in agent-based modelling before. First, the framework identifies behaviours and their sequences and then discusses what these behaviours are affected by defining feedback loops and physical structures. In the second section, where the building agent-based model begins, structured data are used to identify the characteristics of agents, which creates the input for the choice of priority, route choice and physical movement to form the agent's framework. Then, a generalised version of the process is presented.

While this framework enabled the structuring of qualitative observational data, the next step of data collection on the simulation's quantitative aspects is supported by literature and the coding sheets. This phase is not presented here, and the next step of this framework could be to expand it to include the quantitative phase.

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