A compass towards equity: a data analysis framework to capture children’s behaviour in the playground context

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CHAPTER 7

General Discussion and Conclusion

7.1 Summary

Playgrounds provide opportunities for children to grow and develop their social and physical skills. Yet, playgrounds might include barriers that hinder children's development, such as limited accessibility or discriminatory social behaviors. Playgrounds should become an environment where children feel safe, accepted, and included. Creating such an environment starts with understanding children's capacities and needs and then identifying playgrounds' limitations and possibilities in relation to these needs. While the availability of data has opened up new possibilities to tackle fundamental challenges in different communities, the question from a data science perspective is how to design an analysis framework that can effectively collect, process, and interpret data from children in playgrounds as objectively and comprehensively as possible and derive meaningful insights into playground dynamics. Designing such a framework enables us to address fundamental questions of various stakeholders, such as psychologists, designers, and policymakers.

The main goal of this thesis is to develop a data analysis framework for capturing children's behavior in playgrounds. The proposed framework addresses the three main characteristics of playgrounds that pose challenges to the design of our framework, i.e., multiple environments, individual experiences, and spatio-temporal dynamics, throughout Chapters 2 to Chapter 6. Specifically, our data-driven approach based on sensors, its feasibility to capture children's behavior comprehensively, consistently, and unobtrusively, and the identified interconnected environments are presented in Chapter 2. Chapter 3 proposes a novel spatio-temporal metric to measure the impact of physical designs, e.g., play structures, layout, etc., on children's spatio-temporal social networks. The proposed metric has also been used to analyze children's peer networks in playgrounds. Chapter 4 has examined the use of children's experiences in analyzing sensor data. The measure of loneliness via self-reports enabled us to explore how the duration of face-to-face contact in sensor data is correlated with the reported level of loneliness. In Chapter 5 and Chapter 6, we specifically focused on the spatio-temporal dynamics of individuals in social settings. Chapter 5 aims to model interactions beyond face-to-face contact by focusing on parallel movements to identify specific forms of interactions (e.g., bike riding, walking, or running side-by-side). Chapter 6 focuses on detecting interactions between pairs of individuals based on their movements to identify group behavior. This chapter further investigates the inclusion of movements of surrounding individuals, i.e., social context, and the interactions between pairs of individuals to model group behavior.

The following section presents the general discussion of these studies in greater detail.

7.2 General Discussion

By incorporating advanced data analysis techniques, our analysis framework addresses the three main characteristics of playgrounds that pose challenges to the design of our framework, i.e., multiple environments, individual experiences, and spatio-temporal dynamics. This section presents the main outcomes and general discussions per characteristics as follows:

7.2.1 Multiple Environments

In the context of multiple environments in playgrounds, we asked, **"RQ. 1. To what extent can modern sensing technologies capture individual interaction with multiple environments in playgrounds?"** To address this question, Chapter 2 adopted the theory of affordances [45, 240] to specify the environments around the child. Affordances are the actionable properties an environment presents to a child (e.g., a sand-pit affords to build a sandcastle) in relation to their desires, needs, and capacities, i.e., effectivities [45,240]. Accordingly, three types of affordances are identified in playgrounds, i.e., physical, social, and cultural. The physical affordances enabled us to include the impact of the physical design (e.g., play structures, layout, and materials in playgrounds). The social affordances examined children's social networks, while the cultural affordances defined the local rules and constraints (e.g., restrictions on using certain areas).

Moreover, in Chapter 2, we introduced our data-driven approach based on sensor data, which captures children's interactions with respect to these identified affordances. The sensor system adopted in this study includes GPS loggers, proximity tags, and MMR sensors to capture locations, face-to-face contacts, and physical activities, respectively. This sensor system enabled us to capture different aspects of children's behavior. For example, GPS loggers recorded the location of individuals in playgrounds, enabling us to understand which areas they used, how often, and for how long. Thus, GPS data mainly contributed to capturing the physical affordances.

On the other hand, the proximity tags captured children's face-to-face contact with peer groups and supervisors in the playground, addressing the social affordances around the child. Lastly, obtaining the physical activity level from MMR data and GPS and proximity data enabled us to verify the local rules and constraints in the cultural affordances. In addition to capturing multiple aspects, sensor data enabled us to include all participants simultaneously and unobtrusively over the entire break, whilst this was not possible using classical behavioral methodologies such as field observation.

These findings may benefit psychologists, designers, policy-makers, and relevant authorities. For instance, by providing an ethical and privacy-preserved approach to capture children's behavior via sensing technologies, schools can understand popular play structures and define a timetable for their use if necessary, especially if the crowd or noise is overwhelming for some children. They can also examine if certain rules or constraints have been followed by students, for example, when the use of a certain area is prohibited. Adopting our data-driven approach methodology also enables policymakers to validate specific playground policies. The primary steps have already been taken in this field by studying the role of movement data in facilitating evidence-based policy-making in schools, the summary of which is presented in the Data for Policy Conference [6].

The second question in this context was **"RQ. 2. To what extent does the physical environment around the child impact the child's social behavior in playgrounds during recess?"**. Chapter 3 focused on the impact of physical and social environments around the child. Specifically, this chapter introduced a novel spatio-temporal metric to examine the accessibility of individuals in a spatio-temporal social network. In a case study, this spatio-temporal accessibility metric has been adopted to analyze the spatio-temporal social network of children in two playgrounds. The results showed that, in general, children were more accessible to peers from the same group. Similarly, children more easily accessed peers from the same group. Moreover, the most accessible sub-groups utilized common areas, mainly around play structures during recess.

Schools, municipalities, designers, policymakers, and relevant stakeholders can benefit from this study by examining the spatio-temporal accessibility of children and analyzing the impact of social and physical affordances in playgrounds in different aspects.

First, municipalities, schools, and designers can optimize the layout of design elements to enhance accessibility in playgrounds. This includes strategically placing play structures (e.g., seesaw and sandpit) and physical features (e.g., bench and storage) so that children are equally accessible in their social network and can access their peer group equally. In this context, our proposed metric can validate a specific design regarding spatio-temporal accessibility. Similarly, policymakers can adopt our spatio-temporal metric to validate how implementing specific policies impacts children's accessibility in their social network.

Second, designers can use our proposed metric to validate whether their design caters to all children with different effectivities. Specifically, play structures might have different levels of impact on children's social and cultural affordances. Some require to define certain rules and constraints, e.g., areas for playing soccer with designated goals and borders, and some are more relaxed regarding rules, e.g., bench. Some design features might offer solid play, e.g., bar fix, while some might introduce collaborative games, e.g., sandpit or seesaw. Including these different designs with different affordances enables equal access to playground facilities and peer groups for children with different effectivities.

Third, analyzing and understanding this impact enables designers to implement line marks and designated areas for different purposes, e.g., pick-up and drop-off zones, to enhance safety in playgrounds.

7.2.2 Individual Experiences

While sensors provided continuous measurement from individuals, our subjective measurements provided more context, depth, and meaning to the sensor data. This has been the focus of Chapter 4, in which we used sensor measurements, self-reports, and peer nomination to understand children's experiences in playgrounds. In this context, we asked **"RQ. 3. To what extent does including individual differences in experiencing playgrounds facilitate a more accurate interpretation of data?"** Chapter 4 examined the social connectedness of autistic children in playgrounds compared to their non-autistic peers based on differences in effectivities [240]. We adopted various methods, including sensor data capturing children's face-to-face contacts, peer nomination data measuring their pairwise friendship status, and loneliness questionnaires to assess their feelings of loneliness. Our findings showed that according to peer nomination data, autistic children in this study had fewer reciprocated friendships than their non-autistic counterparts. Nevertheless, according to sensor data, both autistic and non-autistic children showed similar levels of peer interactions and similar levels of centrality in their social network during recess. Moreover, our self-report results showed no differences in the levels of loneliness in these two groups. These data combined suggested that the underlying reason for experiencing loneliness differed in the two groups of children: non-autistic children tended to feel lonelier (self-report) when they had shorter interaction time with peers during recess (sensor data), whereas autistic children reported higher loneliness levels (sensor data) when they were less well included as preferred playmates within their peer networks (peer nomination).

These outcomes show the importance of addressing differences in effectivities either at the group level or at the individual level in relation to the affordances of the environment. Accordingly, in our playground context, the rules and constraints (i.e., cultural affordances), physical features, accessibility, and capacity of sub-areas (i.e., physical affordances), group sizes, and peer populations (i.e., social affordances) are all essential elements in understanding individual differences and accommodating their effectivities. Therefore, it is crucial to consider different affordances in playgrounds, as well as differences in the effectivities of children in their interaction with these affordances. It is not about educating a child to fit in a community, but it is about adjusting the environment to accommodate the effectivities of all individuals.

This study highlights the necessity of multimodal methodology in our framework. Adopting modern sensing technology is an essential component for capturing children's behavior in the required level of detail. Sensors capture all participants' locations, activities, and interactions throughout every second of recess time. Yet, sensors alone cannot offer a clear picture of playground dynamics, as they struggle to accurately measure individual experiences, e.g., children's capacities and emotions (i.e., effectivities). For example, just because someone is alone in the playground does not imply loneliness; being with others does not mean feeling accepted and less lonely. Thus, extracting in-depth knowledge and insights from the data is only possible by combining modern sensing technologies with subjective measurements, such as self-reports, peer nominations, video observations, field observations, and questionnaires for parents and teachers, into the data collection methodology.

7.2.3 Spatio-temporal Dynamics

Analyzing and understanding children's social behavior plays a major role in examining their social affordances. In Chapters 2-4, social behavior has been defined by measuring face-to-face contacts. This is a known method adopted by various research studies in social and behavioral sciences [35,36,76]. Yet, social interactions may include more complex scenarios than face-to-face contact. In playgrounds, for example, children might bike together side-by-side, or they might play hide & seek. These types of play do not necessarily include face-to-face contact, yet they indicate strong forms of social interactions. To capture this, Chapter 5 and Chapter 6 particularly focused on analyzing complex spatio-temporal dynamics to obtain a clearer picture of social affordances around the child. We designed advanced machine learning algorithms via AI models to find meaningful patterns in the spatio-temporal data for detecting group interactions. Specifically, in Chapter 5, we asked, **"RQ. 4. To what extent can spatio-temporal data identify parallel movements as one specific form of social interaction?"**.

We addressed this question by designing a trajectory representation learning model, i.e., SiamCircle. The trajectory representations obtained via SiamCircle can be used to identify similar movements in a trajectory similarity computation task. While previous trajectory representation models predominantly focus on modeling structured movements within large-scale urban environments (e.g., vehicles or pedestrians on streets), this chapter tackles a more complex challenge of modeling free movements collected from small-scale social spaces, e.g., playgrounds. Our experiments demonstrate great promise in using SiamCircle to examine similar movement trajectories.

Yet, including more complex forms of group interactions embedded in the spatio-temporal dynamics of children makes our understanding of social environments around the child clearer. Therefore, we asked, **"RQ. 5. To what extent does spatio-temporal data of individuals enable us to model group interactions as one form of social behavior?"**.

Chapter 6 has addressed this question by discussing two parallel studies in detecting group interactions using individual spatio-temporal trajectories in constrained environments. The first study used WavenetNRI, a supervised learning approach based on graph neural networks for inferring complex group interactions from spatio-temporal data. WavenetNRI incorporates symmetric edge features and edge updating processes to account for symmetric group relationships. Moreover, WavenetNRI employs a gated dilated residual causal convolutional block to capture short and long dependencies in the spatio-temporal data. The second study proposed T-DANTE, which includes the contextual information embedded in the trajectories of the surrounding peers, along with the spatio-temporal dynamics of the individuals, to examine whether two pedestrians belong to the same interaction group. T-DANTE incorporates LSTM layers to capture the temporal dynamics inherent in the pedestrian's trajectories. In a comparative study, T-DANTE outperformed the other methods in the group detection task using real-world pedestrian datasets which include groups with smaller sizes. Whilst, WavenetNRI outperformed other models in simulation datasets, which include larger groups. This result shows that either of the models can be helpful in modeling group behavior depending on the characteristics of the given datasets.

This line of research provided valuable insights into complex social phenomena that occurred in the social affordances of micro-communities. In both chapters, the Opentraj benchmark dataset, due to the availability of ground truth information, has been used to train, test, and evaluate the proposed AI models. Since both Opentraj datasets and the playground datasets include free movements in constrained environments, the proposed AI models can potentially be used in playground settings to capture complex forms of group interactions among children. Understanding children's group behavior provides valuable insights for psychologists, designers, educational practices, and policy-makers to identify issues such as bullying and social isolation more effectively. Moreover, these insights enable schools and stakeholders to design and implement practical interventions to address the identified issues and create equity for all children.

Interdisciplinary collaboration is the key ingredient of this thesis. This project was primarily designed via a multidisciplinary collaboration and remained interdisciplinary in every step and decision. The choice of sensors in computer science, for example, depends on answering the question of 'what do we need to measure?'. From a psychological point of view, it is crucial to include social interactions and measures for analyzing children's social networks. From an architecture and design point of view, it is crucial to measure the use of space and the areas where children spend most of their time. Yet, there are also areas where psychology and architecture meet the same goal; for example, which locations offer more social interactions? These questions from different disciplines have formed the design of the sensors by computer scientists in our research. Yet, interdisciplinary collaboration is not only about choosing sensors and defining which variables to measure. We adopted excessive interdisciplinary knowledge to design our social network analysis and machine learning algorithms, reveal insights, and interpret the findings and patterns from sensor data. We required input from psychologists to understand the capacity and desires of children with autism. We needed the architect's input to understand the design concept and what environments offer to the users based on their capacities. We explored various playgrounds concerning the possibilities and limitations they might have for children in terms of the noise level, the density of use, the density of play structures, the variability of play the playground offers, etc., bearing in mind the effectivities of vulnerable children. All these different input sources are considered when designing a data analytics algorithm, e.g., social network analysis and machine learning model, tailored explicitly for analyzing children's behavior in playgrounds. Thus, interdisciplinary collaboration is essential in every step and every decision.

7.3 Limitations and possible directions for future works

This section discusses the limitations of the current work and points out the possible solutions to address the identified limitations in future work.

- **Enhancing the sensing system.** Our proposed sensing system accurately captured a wide range of subjects and activities. Yet, this system can be improved in several dimensions as follows:

  – *User-friendly hardware.* While younger children may find sensor-equipped belts engaging, these belts are unsuitable for older adolescents, for example, in high schools. The implementation of smartwatches or wristwearable devices can be investigated in future directions to enlarge the scope of the research. Moreover, future research may benefit from implementing a co-design process to choose the sensing technology that is most suitable for the target participants. In this process, the participants, including vulnerable children, help researchers to understand which design feature best suits their capacity and needs.

- *Accuracy and resolution.* GPS technology showed promise in tracking individual positions. However, it is unsuitable for indoor areas, e.g., classrooms or sports halls. Moreover, UWB technology (accuracy of 10 centimeters) might be a better fit for playground contexts than GPS (accuracy of 1–10 meters) regarding positional accuracy. Thus, future research may investigate using alternative technologies to enhance accuracy.
- *Real-time experiences.* Our current system lacks information about the value of contacts and movements in real time. For example, while we can detect a child playing alone, we do not know their underlying emotions or preferences at that specific moment. Future studies may study the inclusion of EMA (e.g., via smartwatches) to allow participants to express their emotions and preferences in real time.

- **Enriching datasets.** Our study only collected data from two special education schools, limiting the generalizability of our conclusions. One of the reasons was the COVID-19 crisis, which prevented conducting more data collection at schools. The other reason was that a limited number of parental consents were received due to privacy concerns. Future research may enrich the sample size in the following directions:

  - *Privacy-preserved data collection.* Implementing anonymous data collection aligned with GDRP and upon approval from the ethics committee might be a possible solution to maximize participation while preserving participants' privacy.
  - *Enhancing awareness about digital solutions.* The use of sensing technologies in children's research is a relatively new field. Creating catalogs, podcasts, and posts on social media can enhance awareness about the importance of this methodology to attract more participants to join this field of research.

- **Directions for data analysis developments.** Our analysis framework includes several advanced data analysis techniques to analyze spatio-temporal data. Yet, there are aspects overlooked in our proposed method that can be addressed in future works:

- *Tailoring spatio-temporal analysis to playground datasets.* More steps are required to make our proposed AI models functional at playgrounds. For example, access to representative data, i.e., data from different environmental designs from children with various age groups, capacities, and needs, is required to ensure that the designed model can perform reliably across various conditions and minimize the risk of harm to users or society. This could possibly be investigated in future works.
- *Developing automation process.* The design of the advanced AI models developed in this thesis highly depends on the characteristics of the given datasets. Adopting automated machine learning methods to design hyperparameter-free models can be investigated in the future.
- *Developing Data analysis techniques to tackle small sample sizes.* Advanced data analysis techniques might be able to address a small sample size problem. For example, developing GANs can be investigated in future research to create semi-synthesized samples similar to the original ones, thus creating a balanced and representative dataset from the research population.

7.4 Conclusion

This thesis aimed to develop a data analysis framework for capturing children's behavior in playgrounds. The proposed framework has addressed the three main characteristics of playgrounds, i.e., multiple environments, individual experiences, and spatio-temporal dynamics, by combining cutting-edge technological advancements in the light of the theory of affordances and a multidisciplinary collaboration involving psychology, architecture, and computer science experts. Specifically, our multimodal data-driven approach combined sensor data with other sources of information (e.g., observations, questionnaires, and self-reports) to ensure that children's interactions with the playground affordances have been accurately captured. Furthermore, by including individuals' experiences via self-report, our data analysis framework considered various effectivities in children. Lastly, the advanced data analytics and machine learning algorithms designed in this framework ensure that the spatio-temporal dynamics of group interactions have been correctly modeled.

Implementing this framework offers a valuable tool for academics, psychologists, sports clubs, policymakers, and designers. It enables them to analyze individual activities and identify individual—and group-level challenges and barriers in micro-communities. Moreover, this framework can validate a proposed intervention in micro-communities, e.g., adding a new design or setting a new policy.