Socially Aware Interactive Playgrounds

Social signal processing could enhance interactive playgrounds, letting them automatically sense and interpret children’s social interactions during play, adapt game mechanics to induce targeted social behavior, and learn from the sensed behavior to meet players’ expectations and desires.

Play has been widely studied in the human sciences because of its importance in children’s physical and cognitive development. Recently, computer scientists have also begun to address play by building interactive playgrounds—technology-enhanced installations that combine the fun and immersion of digital games with the benefits of traditional free play. The size of these colocated spaces can vary from a few square meters to the size of public squares, and they can be equipped with a wide range of interactive elements, such as slides, toys, or camera-projector combinations. Interactive playgrounds aim to provide engaging, entertaining, and immersive game experiences, while promoting physical activity, social interactions, or cognitive development.

Designing such interactive playgrounds is a challenging task. Ben Schouten and his colleagues argue that three criteria must be observed when designing the game experience: context-awareness, adaptation, and personalization. However, although many interactive playgrounds consider such criteria when designing interactive experiences for children, few of them address all three criteria simultaneously. We envision playgrounds that automatically sense and interpret social interactions during play (context-aware), adapt the game mechanics (adaptation), and learn from the sensed behavior to create engaging and fun experiences for all players (personalization). Moreover, such playgrounds could promote or discourage certain types of behavior by adapting the game mechanics while the children play.

To this end, we propose using social signal processing (SSP), an emerging field of research that addresses the automatic analysis of non-verbal social behavior. Applying SSP to interactive playgrounds could lead to a new generation of playgrounds, where each game unfolds differently depending on the children playing, how they play, and the type of behavior being promoted or discouraged.

Play and Interactive Playgrounds

Play helps children explore their bodies’ capabilities and develop their fine and gross motor skills and hand-eye coordination. Activities such as jumping, running, and tumbling can help develop and maintain muscular fitness and flexibility while creating positive social relationships between the players. Play also presents children with opportunities for cognitive development. Children practice their planning skills when determining what to do, improve their decision-making skills when several options are presented, and foster their creativity by inventing games and rules. Lastly, play allows children to feel part of a group, satisfying the inherent need of humans to belong to something and interact with others.

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Elements of Interactive Playgrounds

Interactive playgrounds are composed of three main elements: sensors, actuators, and gameplay (See Figure 1). Sensors are used to obtain information from the environment and the players therein and can range from cameras to touch-sensitive surfaces. Actuators are elements—such as projectors, speakers, or lights—through which the playground provides feedback to the children. Finally, gameplay refers to how the children and playground interact. Interactive playgrounds can be placed at various locations, such as schools, streets, or gyms.

Current Game Experiences

The type of experience that playgrounds are designed to elicit can differ significantly between playgrounds. Some interactive playgrounds focus on encouraging social competency, while others focus on promoting physical fitness. At the same time, these playgrounds might use cameras and pressure sensors as their main input modalities, while other could use microphones or accelerometers. For example, Daniel Tetteroo and his colleagues designed an interactive playground to stimulate not only social interaction but also physical activity.4 The playground contains a projector and an infrared camera, and children wear hats with infrared reflectors. Additionally, they are given wristbands and balls with wireless motion sensors. The playground measures the children’s locations and motions during the game using camera input. Colored shapes are projected onto the floor with which the children can interact. Additional kinds of interactions are made available when using the balls.

The Stomp platform, by Peta Wyeth and her colleagues, was also designed to physically and cognitively engage players—specifically, those with intellectual disabilities.8 However, instead of camera-based tracking, their installation requires children to stomp, slide, or employ other body movements to activate pressure sensors located on the floor.

Joan Soler-Adillon and Narcís Parés focused on context-awareness and developed an interactive slide to encourage physical activity and socialization in children.2 Their work projects a game onto a physical slide. A camera senses the movements of children sliding down and uses this information to control the game mechanics. Hisakazu Ouchi and his colleagues additionally focused on personalization, using pressure sensors to monitor children’s play behavior on an interactive climbing wall.9 Afterward, they created a model of how a child of a certain height would climb the wall, using the collected data. Alireza Derakhshan and his colleagues also implemented personalization by observing and creating behavioral models for different types of players.10 In addition, they implemented adaptation by using machine learning techniques to change game mechanics to match different types of players.

Sensing and Inducing Social Behavior

Children’s experiences in interactive playgrounds could be improved by considering the social component of play to automatically adapt and personalize the game mechanics. The automatic sensing and interpretation of social behavior would help us to

- interpret social interactions (context-awareness),
- change the interactions with the playground (adaptation), and
- analyze the effects of these interactions on a personal basis (personalization).

We’re particularly interested in adapting the game mechanics to encourage positive social interactions and to discourage negative ones. Additionally, children could be persuaded to assume different roles to explore and learn different behavioral patterns.11 We discuss scenarios and supporting research to convey how the inclusion of SSP could improve interactive playgrounds.

Child Exclusion

Consider the following scenario. Five children are playing in the playground, competing to gather balls that can glow in different colors and produce sound. One child is shy and doesn’t grab any balls so as not to affront the other children. The playground recognizes
that four children are competitively playing while one has been separated from the group.

To prevent further exclusion, the playground starts rewarding players for social interaction. The balls only start to glow and play a sound if they’re exchanged. Because the exchange between each pair of children results in a different glow and sound pattern, the four children start including the shy child to explore the patterns presented. Eventually, the playground starts to reward quick exchanges to different players by providing increasingly interesting visuals and playing cheering sounds.

Various studies support such a scenario. For example, Tilde Bekker and her colleagues have evaluated how children use “mixers”—that is, objects with similar affordances that change appearance based on the amount of movement or shaking or the presence of other mixers. Without any instruction regarding the types of interactions or games they could play, children ended up playing as a group.

Moreover, Alireza Derakhshan and his colleagues successfully implemented a “luring” strategy in their adaptive interactive playground. They achieved an increase in physical activity with several strategies—for example, luring combined with changing the speed and distance of the targets.

Also, previous research has indicated that human observers can distinguish between competitive and collaborative endeavors, which hints that automatic recognition might also be possible. Furthermore, there are good indications that deliberately assigning a more dominant or central role in an interactive game to a shy child can positively influence the child’s behavior.

**Restoring Engagement**

In this scenario, six children are playing cooperatively, attempting to stomp colored circles projected onto the floor. The children are talking to each other, assigning different areas for each child to cover, pointing and encouraging excitedly. As the game develops, the level of noise diminishes as does the overall movement of the children. The playground infers that this is caused by a loss of interest and diminished engagement.

The playground then creates new goals by modifying the feedback. The colored circles suddenly start glowing, and when children stomp on them, they split into two. Additionally, the rate at which they appear increases. The children discuss new strategies and are again engaged in their play. The playground senses that the noise goes up and the children are moving actively again, which it interprets as a regained interest in the game.

For a similar playground setup, Daniel Tetteroo and his colleagues found that catch-the-shapes is a naturally occurring made-up game. We’ve also witnessed that players frequently attempt stumping behavior in the interactive playground. Furthermore, informal observations of traditional playgrounds during primary school breaks show that stumping behavior occurs even without interactive technology.

Georgios Yannakakis and his colleagues used the absence of feedback, goals, and adaptive behavior to explicitly create a nonentertaining playground game. They noticed that these games were neither desirable nor engaging.

**Dominance and Conflict Resolution**

Imagine that five children enter a playground and start exploring how the environment responds to the different sounds they make. After some time, the playground senses that one child is dominant, continuously yelling to evoke a response from the playground. The other children become fed up and lose interest, because they don’t get the chance to explore the interactions.

The playground starts to ignore the dominant child and only responds to the other children. The dominant child recognizes this, stops yelling, and observes how the other children interact. After a while, the playground again considers the dominant child but starts to respond with more elaborate audio and visuals if the children interact simultaneously—singing together, for example.

Yun-Gyung Cheong and her colleagues proposed a set of five underlying phases in conflict resolution when researching a serious game on conflict resolution. Their first phase is “conflict generation,” which typically occurs when the goal of one player is blocked by another. The second and third phases are “conflict detection” and “player modeling and conflict strategy prediction.” The next phase is “conflict management,” which leads to the final phase of “conflict resolution.”

Therefore, by preventing the dominant child from hogging all the attention, the playground manages to solve the conflict and later persuade the children to play together.

**Adapting to Children with Disabilities**

Cerebral paresis is a permanent deficiency in motion function that can be treated using therapy. Consider a scenario where two children with cerebral paresis play in an interactive playground, where differently shaped objects are placed throughout the space. The children like horses and, on a big screen, a cartoon horse is displayed that asks them to find a specific shape. When a child returns with the object, he or she presses it on a grid of pressure sensors like a stamp. This will enforce a specific grip that the child must practice. The cartoon horse is happy when the children can keep the grip for a sufficient amount of time. It also offers encouragement when two children play together.
can help each other find objects to increase social interaction between them. To make the game more challenging, objects such as ladders or ropes can be added to train additional hand grips.

The use of interactive technology to stimulate children with cerebral palsy to train their grip seems promising, especially when combined with personalization in new ways of therapy. Also, for children with a mild intellectual disability, interactive installations can lead to enjoyable experiences. However, the development of the sensing technology, the realization of the environment, and the evaluation of the effects for sensitive target groups, such as children with physical or mental disabilities, is challenging. Classical principles of user-centered design and standard methods of evaluation won’t always work.

People with disabilities might have difficulty expressing themselves or might express their states and intentions differently, leading to misunderstandings. The same is true for their perception, depending on whether their hearing, vision, or cognition is affected. In addition, there’s the risk of overstimulation, which can cause severe problems. Automatic sensing and interpretation technology thus must be tailored to such user groups, requiring a highly personalized approach. In addition to offering interactive feedback on the playground, such an approach might also support other kinds of monitoring and care or help diagnose mental or social impairments, such as autism.

**Social Signal Processing**

SSP is an emerging research area that focuses on the sensing, interpretation, and reproduction of social signals—elements that humans use when communicating nonverbally. SSP applies theories from the behavioral sciences using practices from computer science fields, such as machine learning and computer vision. As such, SSP studies how humans produce, interpret, and detect social signals. It also considers how computer systems can be equipped with these characteristics to make them socially intelligent. Although SSP encompasses distinct research fields, collaboration between researchers is possible because the fields share common principles.

**Studying Social Signals**

A social signal is defined as a “communicative or informative signal that, either directly or indirectly, conveys information about social actions, social interactions, social emotions, social attitudes and social relationships.” Social signals are often ambiguous, and their interpretation depends on the environment and must account for the inherent uncertainty of recognition algorithms or cues exhibited at different time scales.

Nonverbal cues aren’t always associated with a single social signal, and the simultaneous presence of other cues might indicate a totally different social signal. Behavioral cues exhibited in parallel thus shouldn’t be excluded from any analysis. Context has a big influence on the social signals people elicit, and this variation is a key challenge in SSP. This applies not only to the interpretation of social signals from various modalities but also to signals from multiple people.

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**Interactive playgrounds should provide an immersive, fun, and engaging experience.**

**Sensors that restrict children’s behavior are inappropriate.**

**Pervasive SSP**

SSP research has typically addressed the automatic audiovisual processing of social signals in controlled environments, such as meeting rooms, offices, or debate stands. Most of these studies analyze face-to-face or small group interactions, because they represent the most common forms of interaction. Information in these settings is typically measured across modalities to ensure high quality and avoid missing cues that aren’t present in a given modality.

For example, numerous studies use sensors that measure gaze or facial expressions. This restricts not only sensor placement but also the type of behavior that can be exhibited. When facial expressions are being observed, the subject under analysis can only move in the limited area covered by the camera. In contrast, interactive playgrounds should provide an immersive, fun, and engaging experience. Therefore, sensors that could restrict children’s behavior or make them uncomfortable are inappropriate. For example, equipping children with microphones facilitates the measurement of vocal cues but restricts movement, because children typically run, crouch, and bump into each other during play. Instructing them to mind the microphones would prevent them from playing as they normally would, diminishing the levels of engagement and immersion.

Interactive playgrounds thus must consider sensors that can measure information unobtrusively, embedding them into the playground such that they don’t obstruct children’s play. Some SSP researchers have recently started exploring this direction, processing social signals in surveillance settings where cameras are located at considerable distances from the subjects. Such a setting facilitates studying social and affective information that drives human behavior, especially kinesics and proxemics.

**Kinesics.** Kinesics concerns the study of body movements as a mode of
communication (body language). Postures and gestures are important kinesic cues. The former refer to static body configurations, while the latter are movements of the body over time, typically performed with the hands or arms. Both can have both a communicative and affective meaning.

For example, crossing the arms is considered a closed body pose that might convey boredom or disagreement. In addition to the conscious display of body language, the analysis of social signals also focuses on body movements exhibited unconsciously.

In interactive playgrounds, these advances can be used to determine the affective state of the players. As such, it can be determined whether players are engaged or frustrated by the current gameplay. For example, reduced movement of the arms, as well as a less upright posture, might be cues of diminished engagement. In addition, these techniques provide opportunities to further analyze interactions between players. The amount of interpersonal synchrony or the imitation of postures and movements between players might provide valuable social information, indicative of the type of play that occurs in the playground.

**Proxemics.** Proxemics refers to the study of how people use the space around them in social settings—that is, how they group together and arrange themselves. This includes not only the distance between individuals but also the physical arrangement of groups. The idea that individuals negotiate personal space during interaction dates back to Michael Argyle and Janet Dean, who observed that two people dynamically adapt their physical proximity, postures, gestures, and gaze depending on the level of psychological intimacy between them.

Similarly, Edward Hall suggested that interpersonal distance is related to social distance and proposed four concentric circles corresponding to different levels of regulation when interacting. The social distances range from personal to public relationships and are affected by space constraints. Marco Cristani and his colleagues conducted an experiment with groups of people gathered inside a defined area, which shrank during several iterations of social interaction. They observed that interpersonal distances were relative to social distances, even though the space constraints changed.

Another common concept in proxemics research is the F-formation, which “arises whenever two or more people sustain a spatial and orientational relationship in which the space between them is one to which they have equal, direct, and exclusive access.” F-formations represent common patterns in which people arrange themselves in social settings such that all participants can maintain eye contact with the other group members.

Researchers have used this information to identify groups in social settings based solely on people’s positions and orientations.

The notion of proxemics is gaining attention in the computer vision domain, where considering the social and psychological forces that influence grouping behavior has been found to improve our understanding of how groups of pedestrians behave.

For example, Georg Groh and his colleagues developed a system that classified when people were engaging in social interactions by observing interpersonal distances and body orientation. Similarly, Loris Bazzani and his colleagues used body orientation along with spatial cues to infer when and with whom people were interacting. These studies argue that human behavior analysis shouldn’t be focused solely on the individual but on groups, because people naturally group into higher-level structures that affect and are affected by the actions of the individuals. Modeling this relationship can improve the understanding and recognition of human behavior of both individuals and groups.

These recent advances in a surveillance setting have paved the way for unobtrusive behavior sensing and interpretation in interactive playgrounds. However, the variation in behavior of children in free play is arguably higher than that exhibited by groups of pedestrians. On the other hand, the more controlled nature of interactive playgrounds enables the more robust and detailed observation of behavior. These differences present both challenges and opportunities for research and application.

**Toward Socially Aware Interactive Playgrounds**

Enhancing interactive playgrounds to automatically sense, interpret, and induce social behavior requires sensing behavior and offering feedback, modeling players’ profiles and appropriately adapting the system, and evaluating the playgrounds.

**Sensing Behavior and Providing Feedback**

To interpret children’s social behavior, sensors must capture behavior in sufficient detail. In addition, actuators should be used to provide feedback to the players to induce certain behavior. Both should be embedded into the environment to let children play without being hindered or distracted.

**Sensing.** Cameras are commonly used in interactive playgrounds to measure grouping, position, interpersonal distances, postures, and gestures. Several affordable types of cameras are currently available, each suitable for particular settings or to achieve particular goals. Infrared cameras are useful in low-illumination conditions or when using projectors. Stereo vision, time-of-flight cameras, or pattern overlays, such as those used in Microsoft’s Kinect, allow for the estimation of depth, which facilitates the segmentation of foreground objects. Computer vision algorithms are required to handle variations in
viewpoints, occlusions, and interpersonal appearance.

Microphones could be used to obtain the level and type of sound, such as yelling or singing, as indicators of fun, immersion, and engagement. In addition, they can be used to analyze patterns of imitation and synchrony. When multiple microphones are employed, the source of the sound can be determined. This is useful for the localization of players in more cluttered environments, where cameras don’t have an unobstructed view.

Sensors can also be embedded into the environment or the objects therein. Accelerometers are widely used to recognize actions, sudden movements, and physical activity levels. Similarly, pressure sensors have been embedded in many kinds of objects such as mats, walls, and floor tiles. They can be used to track positions, detect physical arrangements, and recognize subtle differences in actions such as stepping or stomping. They can even be used to identify people by creating walking profiles. The main disadvantage of accelerometers and pressure sensors is the limited amount of information that they provide.

We should keep in mind the limitations of recognizing social interactions during play from these sensors. Despite the advances in SSP, some social interactions remain ambiguous and hard to identify, especially with coarse data—for example, when using a distant camera or microphone. Multimodal approaches are beneficial if modalities carry complementary information.12

**Feedback.** Projectors are widely used actuators that can be placed almost anywhere in interactive playgrounds. They can display a wide variation of images, shapes, and animations. They require a projection surface, and the projector might need to be located fairly far from the playground to maximize this surface. Children might be between the projector and the projecting surface, casting shadows on the latter. This can be reduced by using multiple projectors to fill in the image. LEDs are other light sources, but their limited size and low energy demands make them more suitable in building blocks or buttons to signal their presence and affordance.9,10 Furthermore, light fixtures, including spotlights and stage lighting, can be used for visual feedback.

Speakers can be located virtually anywhere, even outside the playground. They can provide sound effects in response to actions performed by the children or can play music during the game.4 Speakers might interfere with the speech of the children, so careful volume control is recommended. Alternatively, directional speakers could be employed.

Haptic feedback employs technologies that exploit the sense of touch. Many devices can provide haptic feedback using accelerometers or pressure sensors embedded in objects. Touch carries a strong emotional component, and mediated touch thus focuses on social touch and affective interaction.10

**User Modeling and Adaptation**

Aspects such as personal experience, culture, age, gender, and physical and cognitive abilities influence how children play, so they must be carefully considered when designing playgrounds. This is especially true in user modeling and the adaptation of game mechanics. We discuss two strategies for adapting game mechanics that don’t depend on the characteristics of the playground and thus can be applied in a wider range of scenarios.

One strategy is to change the game mechanics when specific events or behavior are observed. This strategy is especially useful when behavior is sensed that should be stimulated or discouraged. This might be the same behavior for all players or different types of behavior depending on the specific player. For example, rough-and-tumble play often occurs in games that favor competition,12 but when this behavior evolves into aggression, it should be discouraged. When a playground detects rough-and-tumble play, the game mechanics could change to encourage more passive or collaborative play and prevent further hostility. In this approach, thresholds for detecting aggression might differ between players.
Another strategy is to create personal user profiles to adapt game mechanics to meet the player’s expectations or style of play. The benefit of this user modeling, personalization, and consequent adaptation is that children remain immersed in the experience. This can be achieved by developing models that reflect the player’s behavior or preferences.

For example, Alireza Derakhshan used a platform that learned (using neural networks) to recognize several player styles based on tempo, age, and continuity of play. The game tempo was adapted, along with other characteristics, to match what the player felt comfortable with to successfully promote physical activity.

Along these lines, children could be given different roles depending on their personality. Koen Hendrix and his colleagues designed a board game aimed at helping shy children overcome their social incompetency. User profiling was carried out prior to the game by asking the teachers to fill in questionnaires to identify shy children. The gameplay adaptation was simple: out of two roles, architect and builder, shy children were always given the architect role, which required leading others to successfully complete the game.

These two strategies could also be combined to adapt the gameplay. A playground could learn about players during play and apply the information in later sessions while still reacting to certain events. Moreover, given enough time, the playground could learn the player’s profile and personalize the game throughout the play session. This would be especially suitable for children who need special care, because the sensed behavior could be used to adapt the game when they’re feeling discomfort.

**User Experience Evaluation**

To determine whether interactive playgrounds have met their goal of providing the players with rich experiences, the interactions in the playground must be evaluated quantitatively or qualitatively.

In addition, other goals, such as the promotion of specific behavior, should be observed. In this case, validating whether the behavior has been encouraged becomes part of the evaluation.

The evaluation of entertainment installations—particularly those aimed at free play—is difficult. Current playgrounds are usually evaluated using questionnaires, group discussions, or observational studies. SSP could help in the evaluation process by automatically measuring raw data instead of annotated, subjective data. This could help better determine whether goals were achieved. For example, interpersonal synchrony is usually attributed to rapport and a feeling of belonging, which could imply high levels of engagement and fun. Automatically measuring synchrony could thus help evaluate some forms of user experience. In a similar vein, body movement is positively correlated with players’ perceived level of engagement. Moreover, if the high-end goal of the playground is to promote social interaction, automatically recognizing social behavior could help decide whether the goal was met without requiring manually annotated and recorded play sessions.

The benefits of using SSP in playgrounds go beyond improving the game experience for the players. For example, the evaluation of playgrounds could be automated by considering behavioral and affective cues interpreted from the observed behavior. It would also allow for the study of play in a broader sense—such as how changing the game mechanics affects play. Furthermore, the continuous sensing and interpretation of behavior could benefit groups of children requiring constant care and supervision. The interactive playground then also adopts a monitoring task.

Introducing socially aware technology in interactive playgrounds offers many opportunities for improved game experience in a broad range of scenarios. With advances in SSP, we expect current challenges to be addressed in the near future.
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