Agents of Spatial Influence: Designing interactions with arrangements and gestures

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ABSTRACT

Humans are implicitly affected by spatial arrangements. From the round table leading us to egalitarian discussions to room partitions that attempt to isolate us as we try to get work done, the ways interiors are arranged, divided, instrumented, and outfitted affects the way we interact in the space. Machines in our environment, meanwhile, interact with us using explicit gestures rather than implicit means. They affect our behavior and perception by using human-like metaphors to communicate with us, giving us an impression of recognition, disagreement, or understanding.

How do implicit and explicit influences work together to shape human behavior in the real world? I first found a test case where both forms of influences are embodied in the interaction: the humble chair. The way chairs are arranged in a room can signal the purpose of the space, and chair movements can also signal their purpose and agency. Using autonomous chairs, we can both shape behavior by arranging space with certain activity goals in mind, and also affect human interaction by programming human-like movements and action sequences by locomotion and rotation.

I investigated implicit influences by using eyetracking to study perceptual attention of humans in a scene with different chair arrangements, and studied chair gestural interactions by getting human feedback on videos of chair-human interactions shown to them on a crowd-sourced data analysis tool. I then tested human response to both the arrangement and interaction capabilities of chairs in a VR experience that allows us to prototype hypothetical scenarios. I found that implicit spatial and explicit gestural factors of autonomic chairs interact with each other in human free-form exploration of a room, demonstrating a prototyping strategy using hypothetical situations and refined mechanical control that are difficult to realize in a spatial design with mechanical agents.

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KEYWORDS

Machine influence, space design, implicit interactions, smart furniture, persuasive technology, machine communication.

SPACE DESIGN

Space is the environment we live in, and live with everyday. It affects the way we perceive and behave. The way space is organized by interior elements, furniture, texture, color, and functional devices affect our perception and action. In terms of perception, the presence of windows in visual representations of space affects the social aesthetics and mood of the viewers (Kaye, 1982). In terms of behaviors, the way offices are arranged can promote differing levels of perseverant behavior by the way each room is partitioned (Roberts, et al, 2019). Moreover, human capabilities like creativity and productivity are linked to how free or confined people feel within movable walls and furniture that support different sized groups (Taher, 2008).

One of the most direct way to study the way space affects us to use different seating arrangements. In one study, subjects are asked to evaluate individual-oriented vs family-oriented vacation advertising. The way subjects sit around a room in an angular or a circular seating arrangement imperceptibly affects how persuasive these different endorsements became (Figure 1). Those sitting at an angle were more likely to perceive the individual-targeting ads positively, while those sitting in a circle found the family-targeting material more acceptable (Zhu & Argo, 2013). Other work finds that corner-table seating arrangements produces greater subject interaction than opposite-facing and side-by-side facing seating, and that subjects will choose rounded corner seats for purposes of discussion over other configurations (Sommer, 1959). Therefore the way seats are arranged in a room affects the way participants perceive the scene and think about possible space of interactions within the scene.

From these considerations I decided to study the way chair arrangements affect the way people pay attention to elements in the scene that directly lead to stereotypic behavior in a room. In addition to that study, I created a immersive environment to test how arrangements affect interaction in hypothetical environments where chair configurations and interactions can shape how and where people pay attention. By changing chair placement, we can affect what people do and where they go in a VR space.

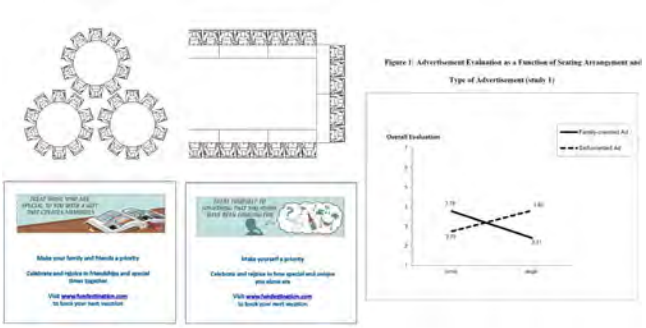

Figure 1: A study showing that seating arrangements in a circle led to family-oriented ads being more persuasive to the subject (left), while angular seating led to individual-oriented ads being most persuasive to the subject (center). Results showing evaluation scores as dependent on interaction between theme and seating configuration (Zhu & Argo, 2013).

MACHINE GESTURES

The first way we communicate with others is often with nonverbal cues like posture, facial expression, and gestures. Communicating with machines like user interfaces and robots rely on some of the same metaphors we apply to humans, such as "whether the system understand me," "where is it telling me to go," "what is going to happen now," etc. Effective communication with machine requires an understanding of how humans interpret gestures and nonverbal cues.

So far studies of gestures in human-machine communication have focused on understanding situations when humans use gestures in different contexts to communicate to different real or artificial agents (Mol. et al, 2009), and in designing artificial systems that detect and respond to human gestures. In another study, people were given the opportunity to evaluate the gestures of robotic agents, and showing that they prefer gestures most like their own (Luo et al, 2013). This is analogous to unconscious mimicking of gestures during human-human conversations.

Previous work has also examined which robotic lamp and micromachine gestures elicit human compassion and understanding by creating a story of a troupe of robots which perform when the audience is not looking (LC, 2019). This work begins to probe the type of robotic furniture gestures that are best at eliciting human empathy, gestures like turning away in shyness and up-down movements for agreement (Figure 2). In a study with a mechanical ottoman footstool, a furniture robot was able to get people to rest their feet on it, as well as understand a cue for getting the feet off as an up and down gesture (Sirkin et al, 2015). Finally a chair robot was able to get people to move out of the way after using overt gestures like moving forward-backward or side-by-side while it moved across the room (Knight et al, 2017).

Given these considerations, we studied the way people perceive gestures performed by chairs. In order to see which particular interactions are perceived to be human-like and sensible, we used crowd-sourced responses to videos of human-chair interactions to separate out potential gesture sets. In addition, I gleaned the insights from the gesture study to design explicit movements and interactions in an VR environment to see how people react to animated gestures in space. I found that we can represent communicative actions in VR with physically realistic but imaginary machine gestures that test possible interactions without having to build the machines themselves.

Figure 2: Machines that use gestures to interact with humans. A shy lamp that looks away when humans approach (upper left; LC, 2019). A set of performance micromachines that enact Shakespeare's *Romeo and Juliet* when audience is not watching (upper right; LC, 2019). A surveillance camera that follows your face to project it on a face sculpture (lower left; LC et al, 2019). Chair robots that roam in space, making locomotive gestures like "you go first" and "follow me" (lower right, Knight et al, 2017).

FRAMEWORK

To bring both implicit and explicit influences on human perception and action into one theoretical underpinning, I propose the Environment Support Model for human-robot-environment interaction (Figure 3). We study chair robots because they sit at an intersection between being arranged in space, and also endowed with gestural capabilities using locomotion and movement. Some furniture like tables or sofas can be used to divide space for spatial influence but cannot be easily moved using motors to elicit machine gestures. Other devices like robotic arms can give intimate and precise gestures but do not affect spatial perception easily the way chairs can arrange themselves in a room.

The model suggests that humans interact with machines with gestural capabilities (like the lamp, surveillance camera, etc) interactively and with explicit nonverbal cues, but that the agent aligns with the environment to shape human behavior subconsciously using space design that affect humans implicitly via arrangement (like furniture placement, space separation). In the context of chair robots, they can both serve as agents with gestures that interact with humans directly, and be the effector of environmental influence by arranging themselves in a room with little attention (e.g. when people are not looking). Chair robots then brings both wings of the model together to serve as agents with both explicit interactions and ability to influence spatially.

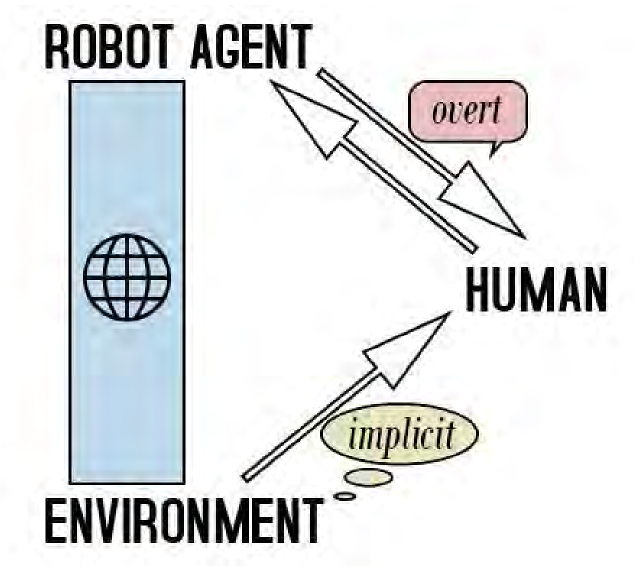

Figure 3: Environment Support Model for human-robot interaction. Humans give instructions and receive feedback from robot agents, expecting the robot to behave with social robotic norms, but in reality the agent communicates with or changes the environment to effect implicit influences on the human. In the context of chair robots, they make changes to the environment by moving themselves in different alignments to support perceptual changes that lead to behavioral results.

STUDY: SPATIAL INFLUENCE

To investigate how space affects human perceptual attention (the environment to human connection in Figure 3), I began with an experiment utilizing eyetracking to gauge human visual attention in a scene, and see how different arrangements of chairs in that scene affects where people are gazing.

I hypothesize that when chairs are configured in alignment towards a common screen at the back of the room, people will tend to look at the screen in that scene, but when chairs are arranged in a circle around the coffee table in that same scene, more gaze time will be spent on the table. The screen and the table serve as symbolic areas of interest (AOI) that signal to us what the purpose of the room would be: a place that shows a movie or stages a lecture vs. a room for human socialization and discussion.

Methodology

I first created photos of the same view of a room containing a TV and a table but with different arrangements of the same chair. I also varied presence of window, density of chairs, and different colored TVs (that are on) and different colored tables. The latter emphasizes those particular objects in the scene, serving as a control way of directing gaze attention to them. There is also an intermediate condition between total alignment and totally circular arrangement called the semicircular arrangement that should support gaze to the TV and the table equally.

Photos were shown to 8 students (2 female) from Northeastern University College of Art, Media, and Design who participated in the study, while their gaze was tracked using a Tobii X2 30Hz eye tracker. Subjects were asked to fixate on a cross before presentation of each stimulus image, and to subjectively score on a scale of 1 to 5 how pleasant the scene depicted is in their mind to divert suspicion about eyetracking and AOIs. Each stimulus corresponding to each condition was presented for 5 seconds after a 5 second fixation cross period, given in random order (Figure 4).

During analysis, the TV and table areas were drawn as areas of interest (AOI), and the percent time spent in the AOIs by the gaze points are calculated, allowing us to draw gaze heat maps summarizing participant gaze behavior. The result is exported from IMotions 7.0 to R 3.6.0 for subsequent statistical tests.

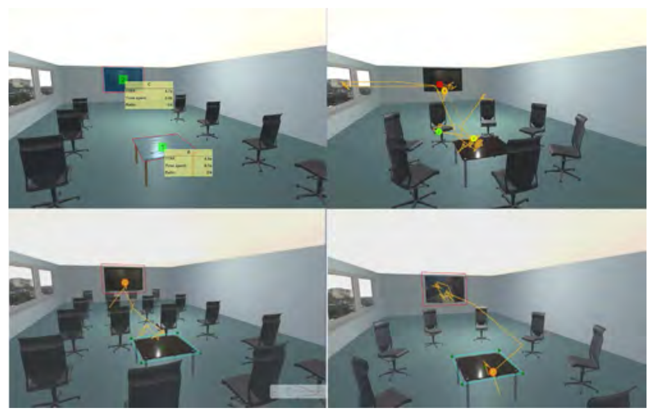

Figure 4: Example gaze traces for a subject showing eye tracking during the course of 5 second stimulus presentation. Defined areas of interest (AOI) on TV and table (upper left). A high density circular config where majority of time is spent on the table vs. TV and window (upper right). A high density aligned condition with fixation on TV (lower left). A regular density circular config with fixation on the table (lower right).

Results Summary

Examples of gaze heat maps of grouped data are shown in Figure 5, showing the concentration of gaze on the TV when chairs are aligned, and on the table when the chairs are arranged in a circle. To assess if the time spent gazing is affected by the location of the gaze (aoi factor) and the way chairs were placed in the scene (config factor), I performed a two-way ANOVA on data with the aligned, semi-circular, and circular config conditions. Results show only significant interaction aoi:config (F=6.698, df=2, p=0.00299), and no significance on aoi nor config by itself (Figure 6). The interaction plot shows that the biggest differences come when the chairs are aligned, in which case gaze to the TV is 15% more likely than to the table (lower left). The semi-circular config led to about equal amount of time spent between TV and table conditions, serving as a control for chairs facing the AOIs. In both aligned and circular conditions, chairs face the AOI with greater percent time spent, but in semi-circular config, the chairs as a group face both the TV and table AOIs, removing that bias.

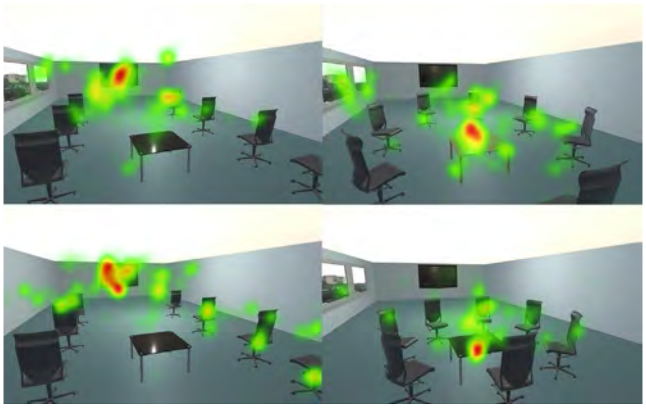

Figure 5: Example heat maps of grouped gaze activity during the course of 5 second stimulus presentation. Regular aligned config (upper left). Table-emphasized circular config (upper right). Window-less aligned condition (lower left). High chair density circular config (lower right).

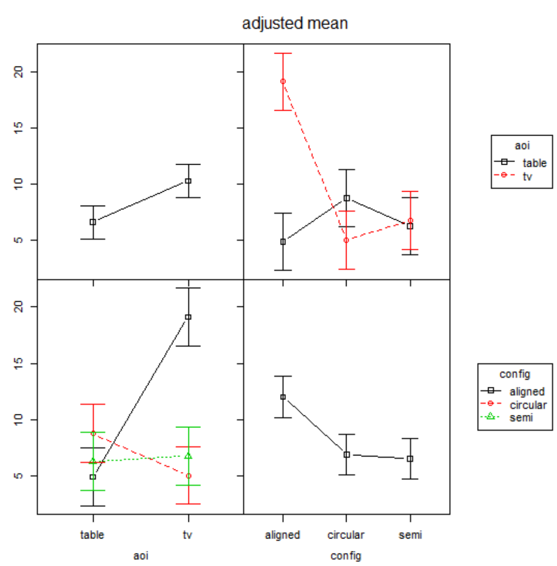

Figure 6: Interaction plot of percent time spent as a factor of aoi (TV, table) and config (aligned, circular, semi-circular). There's a gaze preference for TV when the chairs are aligned, and for table when the chairs are in a circular arrangement, but there's no gaze preference in the semi-circular condition.

Posthoc comparison (Tukey) reveals a significant difference between tv:aligned vs. table:aligned (p=0.0040745), showing that subjects are more likely to look at the TV if the chairs in two rows are facing the wall containing the TV. The tv:circular vs. tv:aligned comparison is also significant (p=0.0045019), showing a difference in the way gaze is directed towards the TV when chairs are arranged in a circle around the table as opposed to aligned towards the wall. The table:semi vs. tv:aligned (p=0.0118714) and tv:semi vs. tv:aligned (p=0.0172216) are also significant, showing that the bias for TV AOI in gaze in aligned config is not due only to the chairs facing the TV, for in the semi-circular condition the chairs also look at the TV from each side, but there's no preference for gazing at the TV. It's the alignment of the chairs (not the facing toward the AOI) that affected gaze.

Other data shows that interaction of TV:table AOI with aligned:circular chair config is not affected by whether windows are present in the scene, but that coloring the AOIs to make them more conspicuous for gaze has about the same attentional effect as the alignment of chairs for gaze to the TV. When chair density is normal, most of the effect comes from gaze to the TV in aligned config, but when chair density is high, the interaction comes more from gazing to table in circular arrangement.

Discussion

This study shows that chair arrangement affects attention of human gaze to targets that symbolize particular functions of a room. In a room with both a TV and a table, chairs aligned all facing the wall the TV is on focused gaze to the TV, implying a perception of the context for presentation, or watching video. Chairs arranged in a circle around the table shifted attentional gaze to the table, as perception shifts to discussion, meeting, and socialization. The way space is arranged by chairs can influence us, both in terms of what we look at, and also what we perceive to be the function of an environment.

STUDY: AGENT GESTURES

To investigate which particular overt gestures undertaken by chair robots best communicate to human about goals and intentions of locomotive agents (the robot agent to human connection in Figure 3), we created videos of different human-chair interactions and used crowd-sourced human data surveys to see how people perceive different chair gestures.

The expressive relationship of the chairs to the actors should depend on the chair both being an agent of change and being an agent receptive of change. The chair should have a relationship with the actors such that it can show understanding, disagreement, and responsiveness, while also being able to perform actions that communicate meaning to the actors. Therefore we hypothesize that the perceived most expressive chair gestures will also show a high rating of the chair being responsive to the person and the chair having a great effect on the person.

Methodology

We designed a set of gestures that involve one or more persons interacting with one chair that has agency, or with multiple chairs that work with or against each other. One-to-one gestures of communication include "Follow Me" where the chair moves forward in space in the direction it wants the person to go, “I Understand” where the chair moves back and forth to signal acknowledgment, “I am Not Going” where the chair shakes left and right to indicate it can’t move, “I am Occupied” where the chair shakes so that the human can take a different seat, and “I am Available” where the chair slides behind the human to show that it can be sat on. Other one-to-one gestures deal with human-chair co-locomotion, including “I am Tracking You” where the chair rotates in the direction of the human walking, “After You” where the chair lets the human go first when they encounter each other by stopping, “I Avoid Collisions” where the chair walks around the preoccupied human (on a cell phone) in a case where she is not cognizant of the interaction, and “I am on a Mission” where the chair is the one not stopping for anyone as it locomotes (Figure 7).

We further designed a set of interactions based on scenarios of multiple chairs helping to promotes certain types of activities in multiple people. This includes “Work Together” where two chairs arrange themselves opposite each other to promote people talking to one another, “Sit on Me Please” where two chairs compete to see where one human will choose to sit, “Let’s Help Out” where one chair comes into a situation with two humans and only one seat and offers itself to one of the persons, “Let’s Focus” where the chairs arrange themselves aligned looking forward (as in the aligned config in the Spatial Influence study) so that two humans can sit on them and focus on material on the wall, “Let’s Walk Together” where two chairs align themselves in speed so that the two humans following them can engage in chatting, “Stop Moving” where two chairs bind the moving human so that she cannot go forward or backward in space, and “Let’s Go” where a chair pushes for a human to get up from a different chair and start moving (Figure 8).

Figure 7: Examples of one-chair to one-person gestures. “I Understand” chair moves back and forth to acknowledge recognition (upper left). “I am Available” chair slides behind human to indicate presence (upper right). “I am on a Mission” chair doesn’t stop for human. “I Avoid Collisions” chair goes around human who doesn’t notice because she’s on a phone.

These gestures are all directed at influencing human behavior and cooperativity by using intrinsic chair-based interactions like locomotion and arrangement.

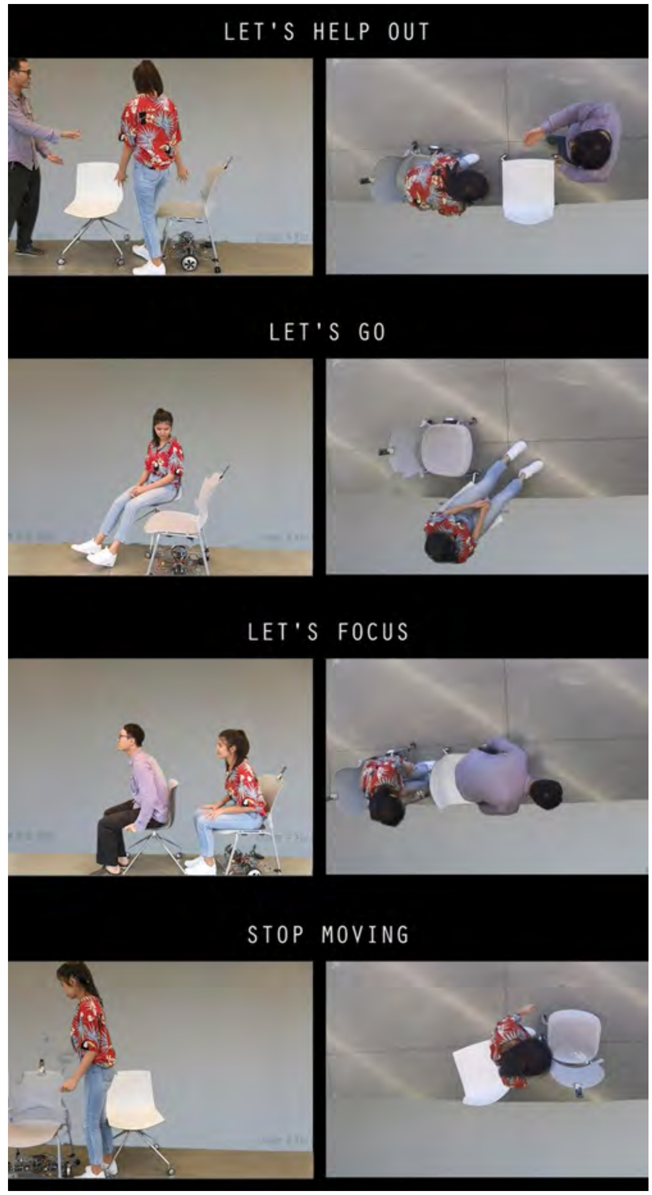

Figure 8: Examples of videographed multi-chair multi-person interactions that influence human behavior. Amazon mTurk studies used on the videos on the left side without labels. “Let’s Help Out” a moving chair helps out a group of humans who are short on chairs by making itself available. “Let’s Go” a moving chair urges a human to get out of her seat and walk. “Let’s Focus” two chairs arrange themselves to make two humans look at the content in front of them. “Stop Moving” two chairs stop a human on its track so she has to stop.

Next we made green-screen recordings of the interactions with student actors. One actor wore a green suit in order to play the role of the chairs making gestures, while two actors served as human participants. A chroma key is used to convert green-screen content to a background image of the wall in Adobe Premiere, and the results are cropped to the same size.

The videos are shown to human workers on Amazon Mechanical Turk. Participants are asked to rate for each video under the following criteria: "Chair was responsive to the person" (Responsive), "Relationship between chair and the person in the scene is satisfactory" (Relationship), "This chair is very expressive" (Expressive), and "The person in the scene is affected by the chair's presence" (Affected). The first question examines perception of the chair's reaction to the person's actions, while the last question studies perception of the person's reaction to the chair's actions. In addition to the ratings, qualitative questions like "Describe what you saw," "What's the chair's intent?", and "What is the chair communicating to the person?" are also given to the workers and the answers are coded by two independent raters whose correspondence is tested using Cohen's kappa.

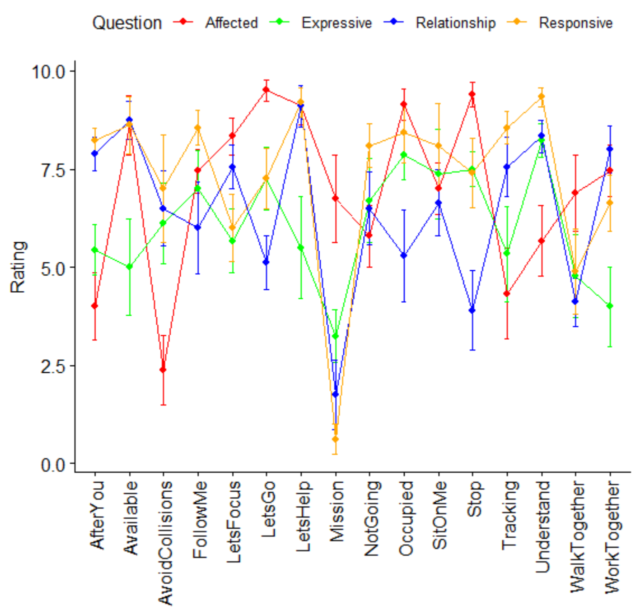

Figure 9: Human ratings on questions of Affected "the person in the scene is affected by the chair's presence, " Expressive "this chair is very expressive," Relationship "relationship between chair and the person in the scene is satisfactory," and Responsive "chair was responsive to the person" for each of the videos of chair-human interactions.

Results Summary

To see how ratings vary with the question asked and the interaction video showed, I ran a two-way ANOVA using Interaction*Question as explanatory variables, and found Interaction, Question, and Interaction:Question to be significant ($p < 0.05$). Posthoc test (Tukey) reveals Expressive-Affected, Responsive-Expressive, and Responsive-Relationship to be significantly different, but that Responsive and Affected ratings are not significantly different (p=0.6014), indicating that whether chair serves as agent of change or subject of change by the person does not affect ratings about its expressiveness and relationship with the person.

Summary data (Figure 9) shows that "I am on a Mission" scored the lowest in all questions except Affected, because the chair acts independent of the person in going its own way. Interactions with high ratings on Affected tends to have high Responsive scores also, as suggested by the posthoc comparison (e.g. "I am Not Going," "Stop Moving," and "Let's Go.") "I Avoid Collisions," "I am Tracking You," and "After You" all scored low on Affected because the person goes her own way without being interrupted by the chair in both cases. The proportion of variance attributable to Interaction (eta η^2) is 0.15, to Question is 0.027, and to Interaction:Question is 0.23, showing the different responses to each question based on the video.

To see how each of the questions correlate with each other on each video of interaction, I ran a multiple regression model using Interaction*Question as explanatory variables (Multiple R^2=0.4004). Only the coefficients for the Relationship and Responsive questions are significant, suggesting that the other variables may be correlated with these two, so that regression only need these two to explain the ratings. If I ran separate linear models for the ratings to each separate question, I get a similar result, where for the Responsive and Relationship data, the R^2=0.4617, and 0.4243, respectively, but for the Expressive data, R^2=0.2002 (Figure 10).

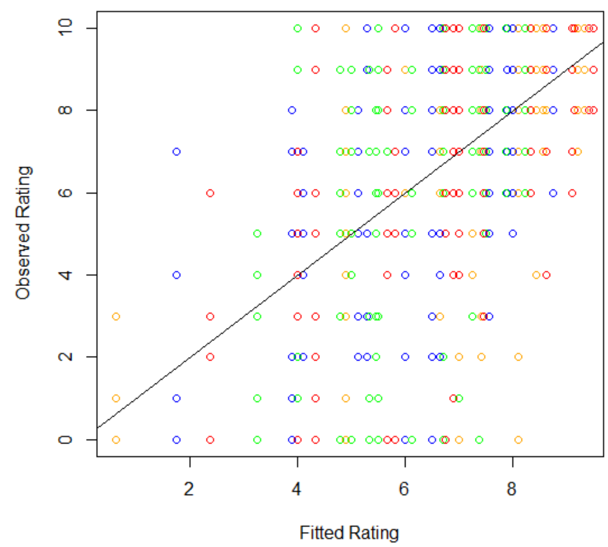

Figure 10: The observed ratings plotted against fitted values (means for each level) for each separate linear model for the Affected (red), Expressive (green), Relationship (blue), and Responsive (orange) ratings. Ideal fits would lie on the y=x curve plotted above.

To verify this finding, I computed the correlation coefficients between data from Responsive and Expressive (0.5657), Relationship and Expressive (0.1502), and Affected and Expressive (0.2239). This shows that Expressive is not a great explainer for the ratings because it correlates with Responsive, which explains a great deal of variance in the data. This lends support to one part of the hypothesis that chairs that appear to be responsive to the person in the video is perceived as expressive, even though its behavior is in reaction to the person.

Discussion

This study shows that people's perception of whether chairs are expressively affecting humans is linked to whether chairs are responsive to humans. This underlies the idea that chairs and humans affect each other in feedback loops, so that agency from one side is reflected in agency in the other, as they mutually influence each other. Both sides of the influence are reflected in the question of expressivity, which summarizes the interactions amongst chairs and people.

This methodology allows us to evaluate which robotic gestures are effective in communicating intent and response to humans using crowd-sourced data evaluation. For example, "Let's Go," "I am Occupied," and "Stop Moving" are most effective at evoking perception that the chair affects people by performing the gesture. On the other hand, chairs in "Follow Me," "I Understand," and "Let's Help Out" are best perceived as being responsive to the human. In particular, "I am Available" and "Let's Help Out" score high on both responsiveness and ability to affect, giving them a perceived high level of relationship with humans in the scene. This strategy allows us to plan and posit certain chair gestures as maximally effective at evoking particular responses from humans.

STUDY: 3D IMMSERSIVE PROTOTYPES

I've shown that arrangement of locomotive agents in space affects perceptual attention and people's understanding of possible interactions in a space. I've also shown that particular overt gestures of these locomotive agents (chairs) are best able to evoke perceptions of chair responsiveness or ability to influence human action. These two results begs the question of whether we can create prototypes of chairs in space that both rearrange themselves to affect us implicitly, and also make gestures that communicate with us their intentions directly. Since the power of space design relies in having many chairs all arranged in a particular configuration, can we prototype these interactions without having to build all these chairs with proper mechanical controls?

Instead of only measuring attention as in 2D screen-based prototypes, and of only evaluating audience perception as in the video-based prototypes, I endeavored to model interactions in VR space with virtual chairs that may do things that they don't do in real life, in order to evaluate the effectiveness of particular interactive gestures in different spatial configurations, and study the way audiences gaze in that space and interact with objects in locomotion.

Methodology

I created a set of possible chair arrangements in VR and ended up picking two for further analysis, the fully aligned and circularly assigned configurations (Figure 11). Instead of simply evaluating perception and attention, VR allows us to examine interactions with virtual prototypes that react to us in space and time. I chose to focus on the "look at" gesture, where the chairs orient themselves towards the viewer, and see how that interaction differs between chair arrangements. "Look at" is fundamentally the "tracking" gesture from the previous study, which we have found to have scored high on responsiveness and relationship to audiences. We now evaluate this particular gesture with different initial chair arrangements.

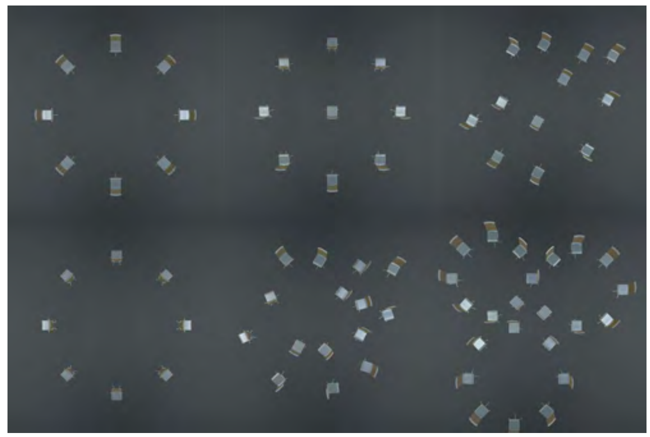

Figure 11: Examples of initial chair arrangements in the VR prototype. Circular arrangement looking inward (upper left), looking towards the walls (lower left), chairs aligned to look toward the back of the room (upper middle), random arrangement (lower middle), two groups of chairs looking opposite each other (upper right), three groups of chairs arranged as circles within each group (lower right).

Do viewers find the gaze of the chairs at them more pronounced when the chairs are initially arranged in a circle or in an aligned grid? I hypothesize that in the aligned configuration, people will focus attention mostly at the back of the room where the chairs are pointing, and thus will be more affected by the switch to the "look at" gesture where the chairs point towards the viewer. I created two scenes that arrange the chairs 1. aligned towards the sliding doors behind where the viewer starts in VR, and 2. around a circle about the center of the room near where the viewer is (Figure 12).

Intermittently during the experience, the chairs will switch to "look at" orientation and focus the front towards the viewer, at which point she will be surprised for the first time (Figure 13). I tested 9 university students from Parsons School of Design and Cornell Tech in each condition. I allowed subjects to move around in the environment for 30 seconds before making the first "look at" maneuver. I allow them to experience the environment for two minutes before surveying their experience with questions like "how stunned are you when the chairs looked at you," and "what purpose do you think the room serves." The statement-based answers are coded for the qualitative analysis as below.

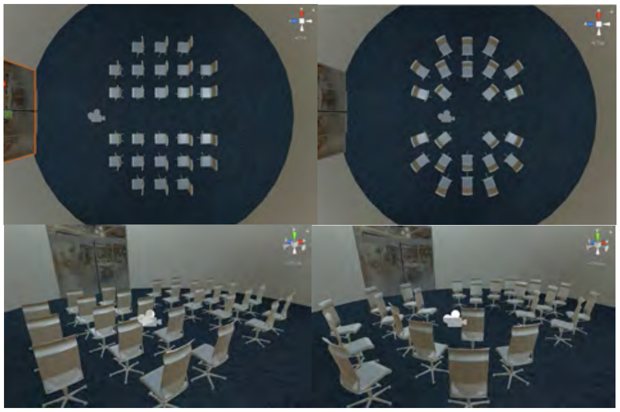

Figure 12: Starting chair arrangements in a VR scene for an experiment looking at reactions of viewers to sudden change into "look at" the viewer orientations. Chairs aligned towards the door where the viewer starts in VR (left), chairs aligned towards the center in a circle (right).

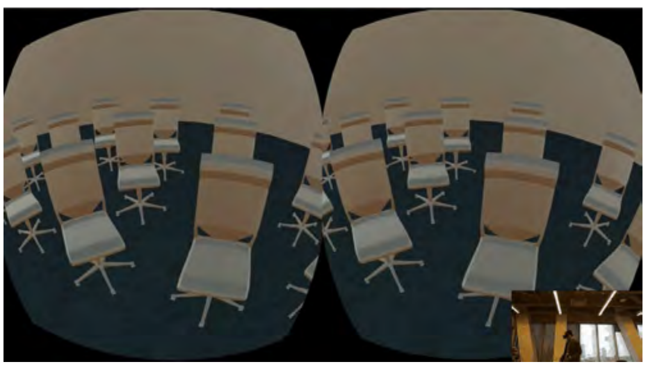

Figure 13: A point in the VR experience when the chairs all look towards the viewer (lower left). Wherever the viewer moves, the chairs follow around with their front side until the "look at" situation is turned off.

Results Summary

Ratings of the viewer to each question of "how expressive is the chair," "how responsive is the chair," and "how stunned are you when the chairs looked at you" are analyzed along with the configuration condition (aligned vs. circular) in a two-way ANOVA. The only significance found was in the configuration ($p = 0.0426$, Figure 14), and post-hoc test (Tukey HSD) also found only significance in aligned vs. circular conditions. Moreover the percentage of variance (eta squared) explained by configuration was 0.077, whereas the eta squared of question was 0.036, and eta squared of configuration:question interation was 0.030.

This shows that audiences are more stunned by the "look at" gesture employed by the chairs when they are initially in an aligned position towards the door rather than in a circular position around the center of the room. In the qualitative analysis, viewers assigned the room such functions as "meeting room" or "place of lecture" when given the aligned condition, consistent with the idea that aligned chairs provides a connotation of the room being used for events like talks and movie screenings. In the circular condition, people reacted that "chairs seem to be barriers," and wonder if the room is "a waiting area" or "a place of discussion," consistent with the idea of a circular arrangement for accentuation of the communal aspect of the environment.

The analysis shows that we can model interactions with audiences effectively in 3D in VR, and provides a method to test spatial designs together with machine gesture interactions.

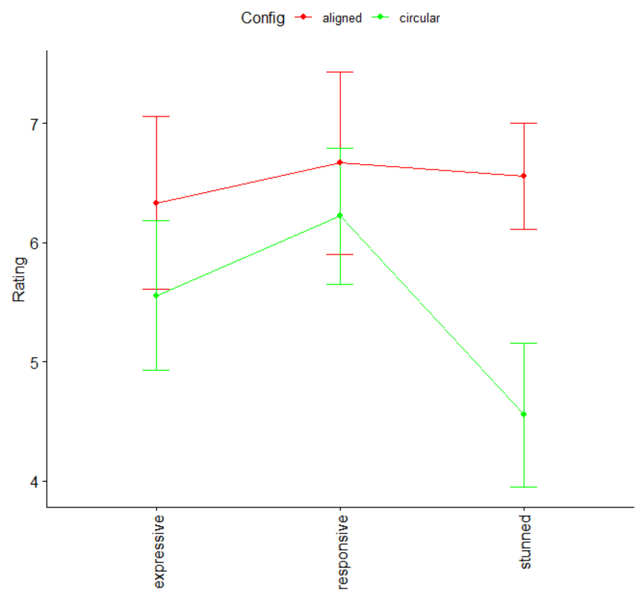

Figure 14: Ratings of how expressive chair is, how responsive chair is, and how stunned when the chair first starts to "look at" the audience, averaged across the population ($n = 9$). Audiences are significantly more stunned when the chairs are arranged in an aligned configuration as opposed to in a circle.

Discussion

Modeling interactions in VR has the advantage of not only showing difficult-to-realize prototypes, but also showing how such prototypes can interact with us. As this study shows, it also allows us to study situations of involving different spatial designs and impossible to choreograph interactions. The intricacies of physical prototypes that follow our faces exactly is difficult to execute, and in VR we have the opportunity to make as many of these prototypes and interactions as we desire, scaling up to monumental levels (like thousands of chairs in an auditorium) if we so choose.

In addition to testing spatial arrangements and how gestures can affect our perception in different arrangements, we can also study how locomotion affects our response. We have prototyped an 3D environment consisting of multiple moving chairs that follow paths in 3D, look at each other's movements, or stop and go along wezsome choreography (Figure 15). These environments allow us to propose hypothetical questions about virtual prototypes that would be difficult to realize in practice. For example, we can put moving chairs in the environment and see what speed of interaction captures optimal attention, and then look at how different gestures are perceived when the locomotion is paused at different speeds.

Figure 15: An interaction where chairs follow splines on their way to moving within a space. One chair's path (left), many chairs moving together in different paths (right). Each path is also animated to stop and go at multiple points of the path.

Unlike the video prototypes, in VR we model their interactions with respect to us as well, allowing us to test hypotheses regarding their interactions with us as we have shown in the space arrangement and "look at" gesture study. Whereas in the videos we can only examine one interaction at a time in particular contexts, in VR we can put in as many interactions as desired based on different rules of gestural interaction. Moreover we can put these gestures in any number of agents as we like arranged in space the way we want to maximally affect attention and perception. Unlike the space design study, in VR we can examine gestural efficacy through activity in the objects themselves, rather than passively showing audiences images that correspond to snapshots in time. The VR prototype thus serves the best of both worlds, allowing us to evaluate both chair arrangements that affect audience response, and trigger machine gestures that occur in particular arrangements and see how audiences interact with them.

We have outlined a VR experience that uses both arrangement of chairs in space and gestural interactions of chairs to influence player perception. By choreographing a consistent reaction that depends on where the user is looking and moving towards in different spatial arrangements, we can begin to understand how people react to robotic gestures and the space that robots mark out, by creating interactions that cannot be easily reproduced in physical reality.

Together these studies in spatial influence, agent gestures, and 3D interactive immersive prototypes show the capability of machines to affect human perception and behavior both in the way it is arranged in space and in the interactions they maintain with us. They foretell a future where interactive furniture embedded in environments can shape our attention and response psychologically for the better by using spatial and gestural cues that optimally alter human capabilities.

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