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Invisible walls: how pedestrians navigate interactional territories in public spaces

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Abstract

Public space simultaneously supports many activities, including conversation, free speech, and transit. Through the sharing of public space, society is made possible. However, individuals may have competing desires to use the same parcel of public space. For example, two people in conversation may stand where pedestrians would otherwise want to walk. Spatial coordination problems caused by these conflicts are partially solved with proxemic norms – tacit rules which govern the social use of space. But, while prior work has focused on how pedestrians orient to personal space, little is known about how pedestrians orient to interactional territory. We propose that interactional territory is co-constructed, on the one hand, by interactants who broadcast signs of their involvement in interaction, and, on the other hand, by pedestrians who both infer interactants' claim to a space from these signs and integrate this assessment into their navigational planning. In a field experiment with 1,138 participants, we show that pedestrians are acutely aware of others' body orientation and avoid walking between people who are approximately facing each other. We also show evidence of collective norm violations: pedestrians are more than twice as likely to breach a proxemic norm when preceding pedestrians have done so. This study shows how spatial claims in public space are coordinated and offers a promising framework for investigating the psychology of norms. Additionally, these findings have direct implications for the design of autonomous robots and the built environment.

Keywords: pedestrians; proxemics; social norms; collective rule breaking

Introduction

Public space simultaneously supports many activities, including conversation, free speech, and transit. Through the sharing of public space, society is made possible[1], but individuals may have competing desires to use the same parcel of public space. For example, two people in conversation may stand where pedestrians would otherwise want to walk (Figure 1). Codified rules for how public space ought to be shared are underspecified to regulate moment-by-moment everyday activity and often are entirely absent. In this study, we ask: how do people jointly recognize each others' involvement in interactions and coordinate the use of socially shared public space?

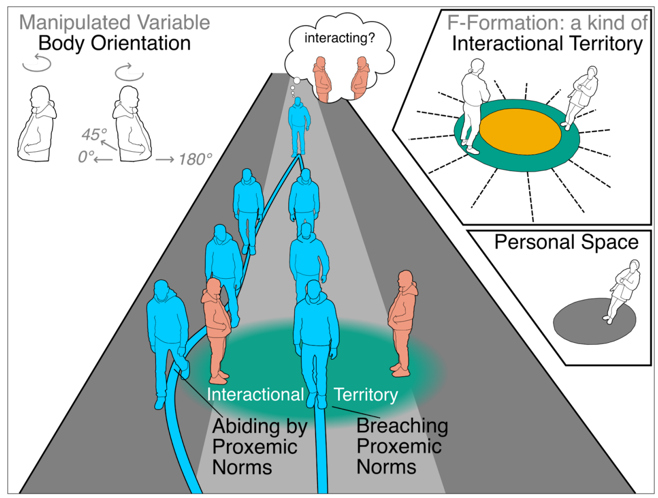

Figure 1: A sketch of our field experiment. Actors (shown in orange) stood in busy pathways while varying their mutual body orientation – a sign of interactional involvement. We observed whether pedestrians (shown in blue) walked between or around our actors and we measured pedestrians' walking trajectories. (In boxes) Diagrammed difference between interactional territory and personal space: the former is centered on interaction whereas the latter is centered on the body of an individual.

Spatial coordination problems are solved, in part, with *proxemic norms* – tacit rules governing the social use of space. For example, pedestrians avoid intruding into others' *personal space*: "an invisible boundary around [the] body into which other people may not come" Sommer (1969, pp. 26). Intrusions are face-threatening acts that undermine people's desires to be respected and unimpeded by others (P. Brown & Levinson, 1987; Goffman, 1955). Proxemic norms organize human behaviors so that they occur at normative distances [2] (Hall, 1966, 1973). Furthermore, pedestrians' disposition towards each others' race (Dietrich & Sands, 2023; Sobel & Lillith, 1975) and gender (Dabbs Jr. & Stokes III, 1975; Willis Jr et al., 1979) affects whom they walk near. Trespassing into

[1]Addressing the question "How is society possible?" Simmel (1971, pp. 23) proposed that "Society exists where a number of individuals enter into interaction." Public space is a primary arena where individuals enter into face-to-face interaction.

[2]Consider awkward social encounters in long hallways. Mutual eye contact and nonverbal greetings, i.e. *distance salutations* (Kendon, 1990b), may occur at 30 feet but conversations tend to occur at 4 feet. Early mutual recognition can result in awkward silence as you and your acquaintance close a 26 foot gap.

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others' territory does not just disrupt spatial order, it disrupts the social order (Ryave & Schenkein, 1974). However, many of the coordination problems that arise in public space entail spatial claims – not of individuals – but of groups. Groups of individuals impose *interactional territories* on spaces (Lyman & Scott, 2017), e.g. *F-formations* (Kendon, 1990a) (see Figure 1). Interactional territories function to regulate others' egress and access to a space. Compared to personal space, the proxemic norms of interactional territory and its cognitive underpinnings have largely been uninvestigated.

In this study, we argue that the proxemic norms of interactional territory are a critical infrastructure for the organization of public space and that the existence of this infrastructure is constituted by cognitive inferences about social interaction. To infer when the proxemic norms of interactional territories are imposed in a space, pedestrians must evaluate the type of others' social interactions and the extent of their involvement in those interactions. Unlike physical obstacles, others' involvement in social interaction are less directly observable: involvement must be inferred from *involvement signs* (Goffman, 1963). These signs include where others are looking, how their bodies are oriented, how they are dressed, etc. While inferences about involvement and group membership have been challenging for machines (Setti et al., 2015; Zhou et al., 2019), humans are especially good at making these inferences as this sort of information appears to be prioritized by the human visual system over other information (McMahon & Isik, 2023). For example, social interactions draw our attention more quickly (Skripkauskaite et al., 2023) and remain in memory longer (Vestner et al., 2019) than do groups of non-interacting individuals, and members of an interaction are processed together as a chunked unit (Ding et al., 2017).

Moreover, pedestrians who violate proxemic norms may not always act independently. Often, decisions to violate social norms are the result of both individual and collective decision making (Krause et al., 2021). For example, collective decisions influence pedestrians' violations of explicit laws such as jaywalking (Faria et al., 2010) and trespassing (Keizer et al., 2008). And so, when navigating past social interactions, pedestrians may be referencing each other's behavior.

Here, we investigate how pedestrians navigate around others' social interactions obstructing their way in a breaching experiment (Garfinkel, 1967). In this experiment, we position a pair of actors, silently standing 10 feet apart, on heavily trafficked public pathways and manipulate their mutual body orientation, which we hypothesized would be interpreted as a sign of their involvement in interaction. We then observed how many pedestrians walked between or around the actors. We also measured pedestrian trajectories as they navigate in these spaces to provide rich qualitative data on pedestrian behavior and descriptive proxemic measurements.

We focus on mutual body orientation as an involvement sign. Body orientation is an important resource for initiating (Kendon, 1990b), maintaining (Kendon, 1990a), and conducting conversations (Hall, 1966, 1973) which is also highly salient to the human visual system (McMahon & Isik, 2023; Papeo et al., 2019). While conversations in North America tend to occur at 4 feet (Hall et al., 1968), 10 is still within *social distance* (4-12 feet), the range in which people can hold conversations (Hall, 1966) – though they may do so more briefly at this distance. This *far phase* of social distance serves to reduce involvement while making conversation still possible. Additionally, placing our actors 10 feet apart creates space for pedestrians to pass without intruding into the actors' personal space or their reaching distance, i.e., their peripersonal space (Coello & Cartaud, 2021; Teneggi et al., 2013).

We hypothesize that pedestrians are less likely to breach the interactional territory when the actors stand facing each other than when they stand with their backs to each other. We also hypothesized that pedestrians would be slightly less likely to breach when actors stood face to face than when they rotated 45° to one side such that they are configured in an L-shape, because directly facing ones partner is a strong sign of involvement. This is despite findings that directly facing one's partner in interaction is less common in social interactions [3] (Kendon, 1990a; Schegloff, 1998; Sommer, 1959).

Methods

Field Experiment

We placed two women actors, standing 10 feet apart, on a pedestrian pathway at a university campus. We manipulated the actors' mutual body orientation. They stood directly face to face, back to back, or so that they were both 45° offset from the face to face condition (see Figure 1 and Figure 3A,C). We also observed pedestrian traffic when no actors were present to obtain baseline traffic patterns.

The research actors were instructed to switch conditions every 10 minutes. The order of conditions was counterbalanced across each session to control for minute-within-the-hour effects resulting from how students move on campus as a consequence of their class schedules. A typical session lasted one hour and included 6 conditions. We filmed a total of 1,138 pedestrians (535 men) at various times of day between November and December in 2023. We excluded from our analysis of breaching pedestrians who did not cross the space where our actors stood and rather remained on one side entirely. However, we included these pedestrians in contextual predictors of crowding. This exclusion process yielded 978 pedestrians (458 men).

We manually coded attributes and the behaviors of the observed pedestrians. These included presumed pedestrian gender (man or woman), their mode of transit (walking, biking, electric scootering, etc.), and whether they were distracted (looking at their phone or wearing headphones). We also coded whether they were a member of a group, the group's

[3] The default position – or home position (Sacks & Schegloff, 2002) – of one's body orientation, usually does not point directly at their interlocutor. People use body torque (Schegloff, 1998) to rotate their torso toward their partner, while keeping their feet or their seat pointed away.

size, and whether they were the leading pedestrian in that group. Finally, we coded whether they breached/passed between our actors (0 = no breach/passed around our actors, 1 = breach/passed between our actors).

Video coding was performed by two coders, JT and JD, who each coded the entire dataset and initially achieved moderate to almost perfect Cohen's Kappa agreement across all variables (mean κ = .84; [.60, .96]). A subsample of disagreements were discussed between JT and JD. A second pass improved Cohen's Kappa agreement across all variables (mean κ = .92, [.76, .99]) (see Table 1).

Table 1: Inter-rater agreement across coded variables.

Variable	Agreement (κ)
Transportation	.99
Condition	.99
Direction	.96
Gender	.95
Breach	.95
Talking	.94
Group Size	.93
Phone Use	.86
Lead Pedestrian in Group	.82
Headphones	.76

Measuring Trajectories

Unlike many previous studies on proxemic spacing in pedestrians (Dabbs Jr. & Stokes III, 1975; Dietrich & Sands, 2023; Sobel & Lillith, 1975), we measured distances between people in world coordinates (in feet) rather than image based coordinates (in pixels) or coarse manually labeled categories. To measure this, we used computer vision software we wrote for this study (see Figure 2). The crux of this software solves for a linear mapping (homography) between the pixel coordinates of video frames and coordinates on a ground plane in the world. This homography was then used to project pedestrian positions in an image onto positions in the world. The average hold-one-out reprojection error was 15.48cm.

In order to measure trajectories, we first detected the location of pedestrians in each video frame as well as the location of their feet using the default pretrained object & pose estimation weights from YoloV7 (Wang et al., 2023), a fast convolutional neural network architecture. We tracked pedestrians across video frames using Simple Online Realtime Tracking (SORT) (Bewley et al., 2016), and manually deleted tracking errors using a custom direct-manipulation annotation tool (Dragicevic et al., 2008; Hutchins et al., 1986). Finally, we imputed missing data, caused by visual obstructions or tracking errors, using a Kalman filter (Kalman, 1960) and Rauch–Tung–Striebel smoothing (Rauch et al., 1965).

Statistical Analysis

To measure the effects of body orientation breaching rates, we fit a generalized linear mixed model (GLMM) with a binomial link function (no breach/around the actors = 0; breach/pass between the actors = 1) and fixed effects for (1) the body orientation/baseline conditions, (2) the direction the pedestrian was walking (left or right: see Figure 3), (3) the gender of the pedestrian, (4) whether they were the leading pedestrian in a group, (5) whether they were the outer-most pedestrian in the group, (6) their mode of transportation, (7) whether their mode of transportation was motor powered, (8) which corner of the space they entered from, (9) which corner of the space they exited from, (10) how many pedestrians were present at the time they passed the actors, and (11) how many preceding pedestrians breached 5 seconds prior to when they passed. We also included an interaction between body orientation and pedestrian direction.

In order to control for temporal effects, e.g. class schedules, we specified random intercepts for the date and time of observation (in 10 minute buckets). The intercepts for time were nested in date.

The GLMM was fitted using the lme4 R package (Bates et al., 2015) (version 1.1-37). All data processing and statistical analysis were performed with the R computing software (version 4.5.1). Using a likelihood ratio test comparing a generalized linear model (GLM) without the hierarchical structure to our full hierarchical model, we found the hierarchical structure significantly improved model fit (χ^2 = 6.82, df = 2, P = 0.033). The GLM was fit using base R and the log likelihood

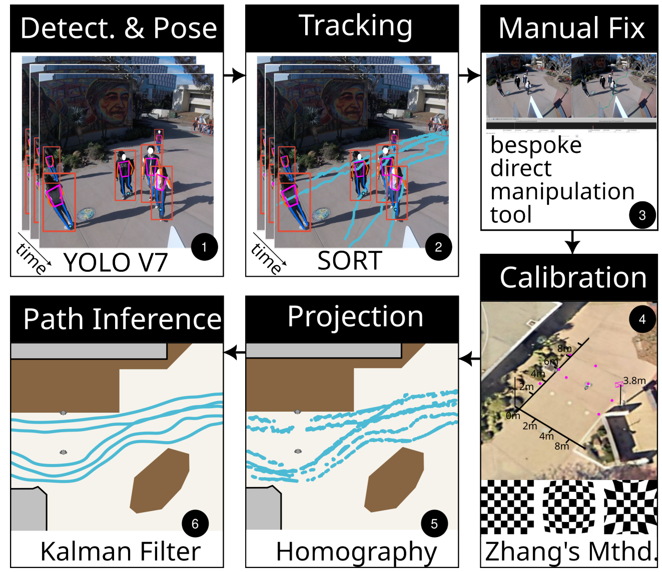

Figure 2: Our trajectory inference method with examples from experiment 2. (1) Results of person detection & pose estimation are shown. (2) Results of pedestrian tracking are shown with raw pixel-coordinate trajectories shown in blue. (3) A screenshot of our manual annotation tools. (4) To calibrate our camera, we needed to know its intrinsic properties (how the lens distorts light) and where the camera was located in space. Landmarks for calibrating our camera are in magenta. (5) Raw world-coordinate trajectory data is shown in blue. (6) Smoothed and interpolated data is shown in blue.

ratio test was performed using base R's anova function.

We used marginal means both for the confidence intervals in Fig. 2 and for the odds ratio tests. These marginal means were derived from the GLMM above and computed using the emmeans R package (Lenth & Piaskowski, 2025) (version 1.11.2-8). Estimated marginal means (EMM) allows us to investigate model predictions and to statistically contrast predictors. An EMM is computed by holding selected independent variables constant and using the fitted model to predict outcomes averaged over the remaining variables. For example, with an EMM, we estimated the expected probability and standard deviation of a breach for pedestrians in the four conditions (body orientations + baseline).

Results

Pedestrians navigation is affected by others' mutual body orientation

We tested whether the pedestrian traffic was sensitive to the mutual body orientation of two research actors. Specifically, we tested whether pedestrians would be less likely to pass between two actors than in the other conditions.

When the actors stood face to face, pedestrians were 1/6 as likely to breach compared to when the actors stood 45 degrees offset (OR = 0.17 ± 0.08, z = -3.61, $P < 0.001$), 1/34 as likely compared to when the actors stood back to back (OR = 0.03 ± 0.02, z = -4.84, $P < 0.001$), and 1/62 compared to the baseline condition (OR = 0.016 ± 0.01, z = -7.23, $P < 0.001$). We also observed a significant interaction between pedestrian walking direction and actor body orientation when they stood 45 degrees offset: pedestrians were 1/13 as likely to breach when they approached our actors head-on vs from behind (OR = 0.08 ± 0.04, z = -4.384, $P < 0.001$) (see Figure 2B). Finally, we observed that pedestrians who were using their phones while approaching the actors were twice as likely to breach compared to those who were not using their phones (OR = 2.01 ± 0.69, z = 2.032, $P = 0.042$), meaning that pedestrians own body orientations was also integrated in navigation decisions. These results suggest that pedestrians actively monitor their environment, using others' mutual body orientation, to infer the presence of others' social interactions.

Pedestrians collectively breach others' interactional territory

We test whether pedestrians collectively breach proxemic norms as a result of social contagion – a phenomenon where a behavior spreads to individuals as a consequence of exposure to others' enacting that behavior. We control for the physical effects of crowding and for temporal effects of class schedules which might correlate pedestrians' behavior without constituting social contagion. For example, with substantial crowding (a) our actors' interactional territory may be the only free space to pass through or (b) pedestrians may, independently, infer that our actors have weak claims to their interactional territory because they are impeding transit of the many.

In order to test for collective breaching, we first control for the effects of crowding and behavioral contagion, since greater crowding could cause pedestrians to use all available free space, even if it were an interactional territory. We measured crowding by counting how many pedestrians were in front of the art mural at the moment a pedestrian passed the actors (excluding the target pedestrian). The square-root of this count was used as a predictor in our GLMM. For behavioral contagion, we measured possible exposures to breaching behavior by counting how many other pedestrians had breached 5 seconds prior to the moment a pedestrian passed the actors. The square-root of this count was used as a predictor in our GLMM. For a pedestrian who moved at the average 20 year old human walking pace of 4.43 feet/second (Bohannon & Andrews, 2011), this would mean the average pedestrians is exposed to others' breaching behavior 22.15 feet before they reach the actors. Finally, we included random intercepts for the date and which 10 minute interval within the hour to control for time-of-day effects such as student class schedules.

For every pedestrian, we counted the number of other pedestrians who breached 5 seconds prior to when they passed the actors. We counted the number of pedestrians present at the moment they passed the actors.

We observed that pedestrians were over twice as likely to breach if a preceding pedestrian had also breached 5 seconds prior compared to when no preceding pedestrians had done so (OR = 2.77 ± 0.58, z = 4.88, $P < .001$). Previous research has shown a similar collective rule-breaking effect about jaywalking, e.g., a pedestrian is 1.5 - 2.5 times more likely to jaywalk when a preceding pedestrian has (Faria et al., 2010). See Figure 4 for a qualitative example of collective proxemic rule-breaking.

Our results for behavioral contagion do not depend on a 5 second exposure window. They manifest for exposure windows as short as .9 seconds and windows up at least as great as 10 seconds.

Discussion

As Robert Sommer wrote, "the best way to learn the location of invisible boundaries is to keep walking until somebody complains." (Sommer, 1969, pp. 26). We inverted the design of Sommer's breaching experiments in order to investigate interactional territory – a socially constructed invisible wall centered on the interaction between people. First, we showed that pedestrians tend to avoid walking between two people who are facing each other. This is evidence that pedestrians vigilantly scan their environment for social interactions. They infer the presence of these interactions, in part, by treating others' mutual body orientation as a sign of their involvement.

Second, we showed that, after controlling for crowding and time-of-day effects, pedestrians are significantly more likely to walk between two people if preceding pedestrians have done so. This is evidence that pedestrians actively reference other pedestrians' behavior in order to engage in collective rule-breaking.

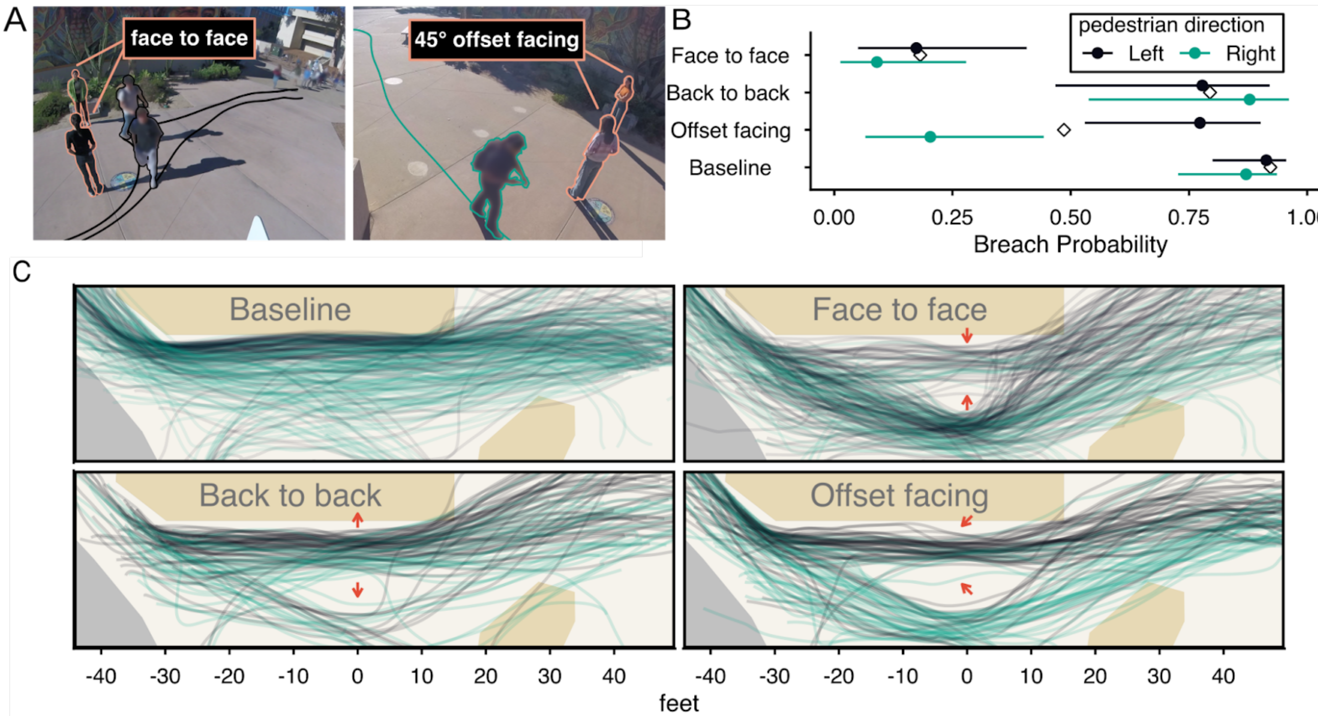

Figure 3: A. Video frames of the face to face and offset facing conditions. B. Breaching probabilities by body orientation condition and pedestrian direction of travel. Circles represent the estimated marginal mean and lines represent 95% confidence intervals. Empirical breaching rates are represented with white diamonds and are collapsed across pedestrian directions of travel. C. Pedestrian trajectories are plotted and colored by direction of travel. Green is rightward. Black is leftward. Actor body orientation is depicted by red arrows. Types of terrain are represented by the colored background. Offwhite depicts a pedestrian pathway, yellow depicts patches of dirt and vegetation, and grey depicts an asphalt roadway.

We interpret these pedestrian behaviors as cognitively underpinned by situated seeing (Goodwin & Goodwin, 1996; Hutchins, 1995; Kaufhold et al., 2025). In order to navigate through a public space, pedestrians do not just map the physical space; they superimpose aspects of social reality onto these spaces, namely, they superimpose invisible proxemic boundaries. Furthermore, inferences about others' involvement in social interaction are likely a product of social seeing (McMahon & Isik, 2023) in which pedestrians carve up visual scenes according to how a scene's constituent agents are involved in interaction.

This is analogous to Herb Simon's *parable of the ant*: "Viewed as a geometric figure, the ant's path is irregular, complex, hard to describe. But its complexity is really a complexity in the surface of the beach, not a complexity in the ant." Simon (1969, pp. 64). We argue that the complexity of pedestrian walking paths is also a product of interaction with their environment. But, unlike Simon's parable, the trajectories we observed in humans are the result of a socially constructed reality. Pedestrian traffic reflects the rich human social umwelt (Von Uexküll, 1992) as much as it reflects the dynamics of physical systems composed of people.

While we show evidence that pedestrians use body orientation to jointly infer (a) the presence of interactional territory from others' involvement and (b) the inferred social cost of breaching that territory, we did not attempt to disentangle these two inferences. Bayesian computational cognitive modeling (Baker et al., 2011; Jara-Ettinger et al., 2016), in conjunction with more detailed experimental manipulations is a promising future direction. We think it is likely that pedestrians integrate a social cost function and an energy criterion (G. L. Brown et al., 2021) for planning trajectories .

Additionally, by standing in pedestrians' way, our actors' behavior constitutes a norm violation. In such situations people likely dynamically offer easements to oncoming pedestrians or shield their interactional territory. Future work should investigate the negotiation and yielding of proxemic norms as well as the role of sanctioning in regulating and perpetuating these norms. Finally, as autonomous robots are introduced into society, it is imperative that they are designed to accommodate this umwelt order to operate acceptably (Ettinger et al., 2021; Rios-Martinez et al., 2011)

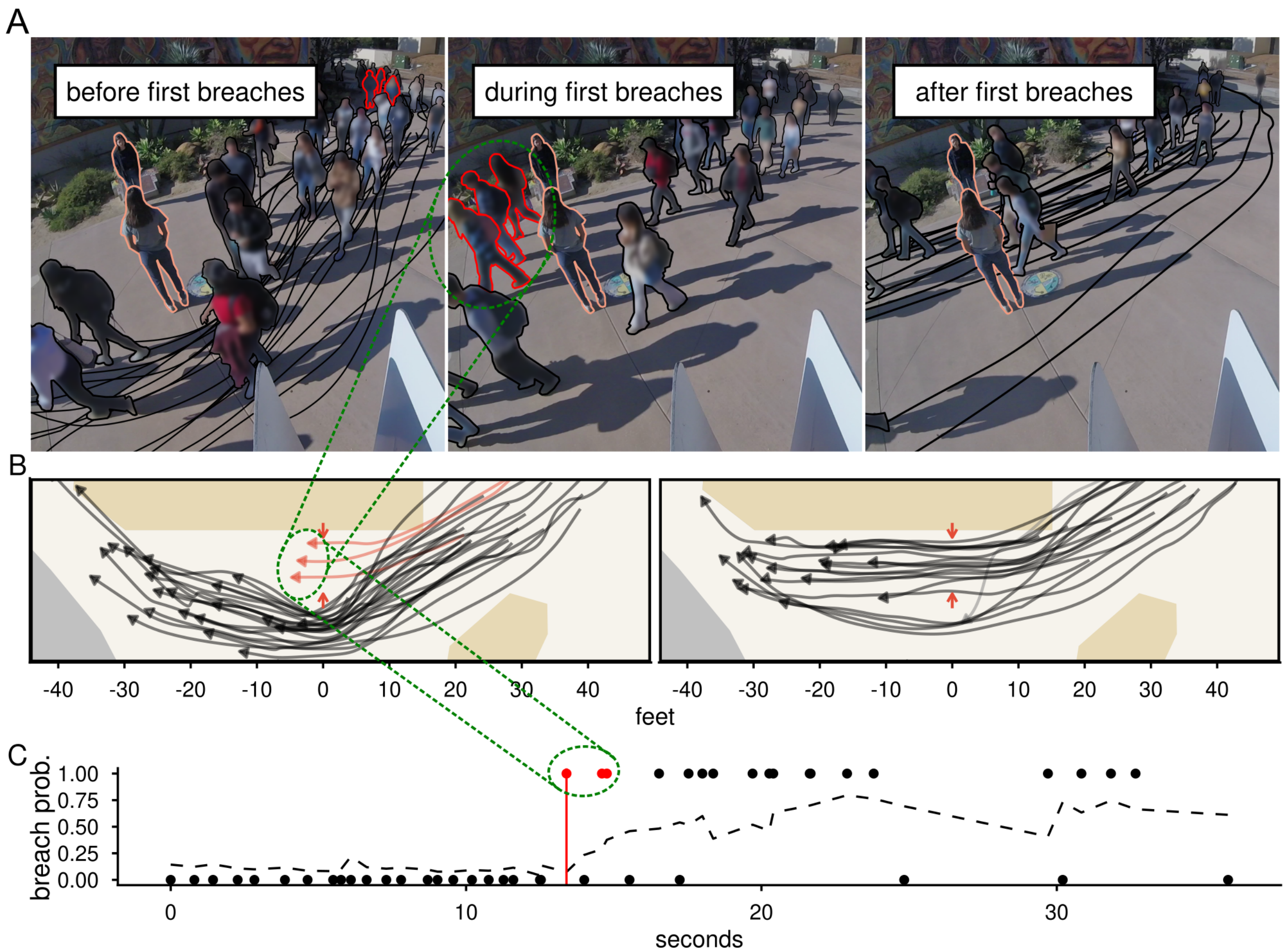

Figure 4: On December 7th, 2023 at 12:31:35, over the span of 35.5 seconds, a crowd of 46 pedestrians walked past an art mural while two actors silently stood 10 feet apart while facing and staring at each other. The first 22 pedestrians walk around the actors. 13.6 seconds after the arrival of the first pedestrian, a group of 3 pedestrians (in red) walk between the actors within 0.1 seconds of each other. Just 2.1 seconds later, the first of 12 of the 19 remaining pedestrians also walk between them. (A) Video frames before, during, and after the 3 instigating pedestrians walk between the actors. (B) Trajectories of pedestrians before/during and after the 3 instigating pedestrians walked between the actors. (C) Our statistical model's running predicted breach probability over time which takes into account the number of breaches 5 seconds prior and crowding for a given point in time (black line). Breaches/non-breaches are indicated with circles. The moment the group of three breaches is indicated with a vertical red line.

References

Baker, C., Saxe, R., & Tenenbaum, J. (2011). Bayesian theory of mind: Modeling joint belief-desire attribution. *Proceedings of the annual meeting of the cognitive science society*, *33*(33).

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of statistical software*, *67*, 1–48.

Bewley, A., Ge, Z., Ott, L., Ramos, F., & Upcroft, B. (2016). Simple online and realtime tracking. *2016 IEEE international conference on image processing (ICIP)*, 3464–3468.

Bohannon, R. W., & Andrews, A. W. (2011). Normal walking speed: A descriptive meta-analysis. *Physiotherapy*, *97*(3), 182–189.

Brown, G. L., Seethapathi, N., & Srinivasan, M. (2021). A unified energy-optimality criterion predicts human navigation paths and speeds. *Proceedings of the National Academy of Sciences*, *118*(29), e2020327118.

Brown, P., & Levinson, S. C. (1987). *Politeness: Some universals in language usage* (Vol. 4). Cambridge university press.

Coello, Y., & Cartaud, A. (2021). The interrelation between peripersonal action space and interpersonal social space: Psychophysiological evidence and clinical implications. *Frontiers in Human Neuroscience*, *15*, 636124.

Dabbs Jr., J. M., & Stokes III, N. A. (1975). Beauty is power: The use of space on the sidewalk. *Sociometry*, 551–557.

Dietrich, B. J., & Sands, M. L. (2023). Seeing racial avoidance on new york city streets. *Nature human behaviour*, *7*(8), 1275–1281.

Ding, X., Gao, Z., & Shen, M. (2017). Two equals one: Two human actions during social interaction are grouped as one unit in working memory. *Psychological science*, *28*(9), 1311–1320.

Dragicevic, P., Ramos, G., Bibliowitcz, J., Nowrouzezahrai, D., Balakrishnan, R., & Singh, K. (2008). Video browsing by direct manipulation. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 237–246.

Ettinger, S., Cheng, S., Caine, B., Liu, C., Zhao, H., Pradhan, S., Chai, Y., Sapp, B., Qi, C. R., Zhou, Y., et al. (2021). Large scale interactive motion forecasting for autonomous driving: The waymo open motion dataset. *Proceedings of the IEEE/CVF international conference on computer vision*, 9710–9719.

Faria, J. J., Krause, S., & Krause, J. (2010). Collective behavior in road crossing pedestrians: The role of social information. *Behavioral ecology*, *21*(6), 1236–1242.

Garfinkel, H. (1967). Studies in ethnomethodology. In *Social theory re-wired* (pp. 58–66). Prentice-Hall.

Goffman, E. (1955). *On face-work: An analysis of ritual elements in social interaction* (Vol. 18). Taylor & Francis.

Goffman, E. (1963). *Behavior in public places*. Simon; Schuster.

Goodwin, C., & Goodwin, M. H. (1996). Seeing as a situated activity: Formulating planes. *Cognition and communication at work*, *61*, 95.

Hall, E. T. (1966). *The hidden dimension*. Knopf Doubleday Publishing Group.

Hall, E. T. (1973). *The silent language*. Anchor.

Hall, E. T., Birdwhistell, R. L., Bock, B., Bohannan, P., Diebold Jr, A. R., Durbin, M., Edmonson, M. S., Fischer, J., Hymes, D., Kimball, S. T., et al. (1968). Proxemics [and comments and replies]. *Current anthropology*, *9*(2/3), 83–108.

Hutchins, E. (1995). *Cognition in the wild*. MIT press.

Hutchins, E., Hollan, J. D., & Norman, D. A. (1986). Direct manipulation interfaces. In *User centered system design* (pp. 87–124). CRC Press.

Jara-Ettinger, J., Sun, F., Schulz, L., & Tenenbaum, J. B. (2016). The naıve utility calculus unifies spatial and statistical routes to preference. *Proceedings of the Annual Meeting of the Cognitive Science Society*, *38*.

Kalman, R. E. (1960). A new approach to linear filtering and prediction problems. *Journal of Basic Engineering*, *82*(1), 35–45.

Kaufhold, S. P., Terwilliger, J., & Rossano, F. (2025). Socially situated navigation: Social rank and sex influence spatial navigation strategies in japanese macaques. *Proceedings of the Annual Meeting of the Cognitive Science Society*, *47*.

Keizer, K., Lindenberg, S., & Steg, L. (2008). The spreading of disorder. *science*, *322*(5908), 1681–1685.

Kendon, A. (1990a). *Conducting interaction: Patterns of behavior in focused encounters* (Vol. 7). CUP Archive.

Kendon, A. (1990b). A description of some human greetings. In *Conducting interaction: Patterns of behavior in focused encounters* (pp. 153–207). Cambridge University Press.

Krause, J., Romanczuk, P., Cracco, E., Arlidge, W., Nassauer, A., & Brass, M. (2021). Collective rule-breaking. *Trends in Cognitive Sciences*, *25*(12), 1082–1095.

Lenth, R. V., & Piaskowski, J. (2025). Emmeans: Estimated Marginal Means, aka Least-Squares Means. https://rvlenth.github.io/emmeans/

Lyman, S. M., & Scott, M. B. (2017). Territoriality: A neglected sociological dimension. In *People and buildings* (pp. 65–82). Routledge.

McMahon, E., & Isik, L. (2023). Seeing social interactions. *Trends in cognitive sciences*, *27*(12), 1165–1179.

Papeo, L., Goupil, N., & Soto-Faraco, S. (2019). Visual search for people among people. *Psychological Science*, *30*(10), 1483–1496.

Rauch, H. E., Tung, F., & Striebel, C. T. (1965). Maximum likelihood estimates of linear dynamic systems. *AIAA journal*, *3*(8), 1445–1450.

Rios-Martinez, J., Spalanzani, A., & Laugier, C. (2011). Understanding human interaction for probabilistic autonomous navigation using risk-rrt approach. *2011 IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2014–2019.

Ryave, A. L., & Schenkein, J. N. (1974). Notes on the art of walking. In *Ethnomethodology* (p. 274, Vol. 265). Penguin, Harmondsworth.

Sacks, H., & Schegloff, E. A. (2002). Home position. *Gesture*, *2*(2), 133–146.

Schegloff, E. A. (1998). Body torque. *Social research*, 535–596.

Setti, F., Russell, C., Bassetti, C., & Cristani, M. (2015). F-formation detection: Individuating free-standing conversational groups in images. *PloS one*, *10*(5), e0123783.

Simmel, G. (1971). *On individuality and social forms*. University of Chicago Press Chicago.

Simon, H. A. (1969). The sciences of the artificial mit press. *Cambridge, Ma*, 31.

Skripkauskaite, S., Mihai, I., & Koldewyn, K. (2023). Attentional bias towards social interactions during viewing of naturalistic scenes. *Quarterly Journal of Experimental Psychology*, *76*(10), 2303–2311.

Sobel, R. S., & Lillith, N. (1975). Determinants of nonstationary personal space invasion. *The Journal of Social Psychology*, *97*(1), 39–45.

Sommer, R. (1959). Studies in personal space. *Sociometry*, *22*(3), 247–260.

Sommer, R. (1969). *Personal space. the behavioral basis of design.* ERIC.

Teneggi, C., Canzoneri, E., di Pellegrino, G., & Serino, A. (2013). Social modulation of peripersonal space boundaries. *Current biology*, *23*(5), 406–411.

Vestner, T., Tipper, S. P., Hartley, T., Over, H., & Rueschemeyer, S.-A. (2019). Bound together: Social binding leads to faster processing, spatial distortion, and enhanced memory of interacting partners. *Journal of Experimental Psychology: General*, *148*(7), 1251.

Von Uexküll, J. (1992). *A stroll through the worlds of animals and men: A picture book of invisible worlds*. Walter de Gruyter, Berlin/New York Berlin, New York.

Wang, C.-Y., Bochkovskiy, A., & Liao, H.-Y. M. (2023). Yolov7: Trainable bag-of-freebies sets new state-of-the-art for real-time object detectors. *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*, 7464–7475.

Willis Jr, F. N., Gier, J. A., & Smith, D. E. (1979). Stepping aside: Correlates of displacement in pedestrians. *Journal of communication*, *29*(4), 34–39.

Zhou, C., Han, M., Liang, Q., Hu, Y.-F., & Kuai, S.-G. (2019). A social interaction field model accurately identifies static and dynamic social groupings. *Nature human behaviour*, *3*(8), 847–855.