Social Triangles and Aggressive Lines: Multi-Robot Formations Impact Navigation and Approach

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***Abstract*— Spatial formations can give many social cues, such as illustrating a group of people are having a conversation (social affiliation), or that they are trying to move swiftly through a space (functional goal). This work explored how people perceive varied robots formations while navigating through a space and approaching people. Evaluation occurred across four different geometric formations: wedge, v-shape, vertical line, and horizontal line (Fig 3). Two studies were conducted: the first being an exploratory study of three robots *navigating* through a public space, and the second being a controlled user study of the same robots *approaching* humans in different formations. Results showed that triangle shapes were generally received more positively than lines, with wedge being the viewed as harmless, polite, welcoming, and encouraging the human to join the robot group, whereas horizontal line was seen as threatening and unwelcoming. From a path planning perspective, v-shape and wedge were also more robust to controller variance. Results from this work show that formation impacts how people perceive robots, and as a result may impact task success. Future researchers can use these results to inform their behavior design for multi-robot groups to increase task success and desired communication effects.**

I. Introduction

Groups of humans have the capability to move in complex ways and form many types of geometric formations. For example, imagine a marching band forming a school logo on a football field, or soldiers walking in perfect horizontal lines. Humans also do this in social situations. Imagine you enter a party and see a group of people in a tight circle. This formation may give you social cues as to if they are friendly, if they want you to join, or what they are talking about. As robots become more prevalent in our day to day lives, making deliveries, or working in factories and restaurants, it is important to consider how geometric formations affect peoples' perception of robots in their space. This work presents two in-the-wild studies exploring how geometry affects peoples' perception of robots approaching them and how that differs when robots are traversing a space.

II. Related Work

In this section we cover three relevant areas to exploring formation in multi-robot expressive motion: (1) the study of how humans perceive different shapes from a psychological lens, (2) formations in human groups, and (3) how formation has been previously used in human-robot interaction.

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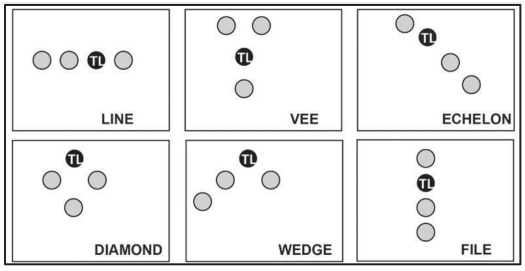


Fig. 1: Main military tactical formations. TL designates the tactical leader's position in the group [6].

A. Shapes in Human Psychology

Different two dimensional shapes have been shown to elicit different emotional responses in humans [1], [2]. One work summarized many prior works on shape and emotion, highlighting that shapes are interpreted emotively by people [2]. For example, multiple works have shown that v-shapes and down pointing triangles can read as threatening and are associated with a negative valence [2]–[4]. However, studies have found that upward-pointing v-shapes are perceived as less aversive than downward-pointing v-shapes [3]. Conversely, it has been found that rounded shaped evoke more positive emotions [1]. In three dimensional space, work has shown that shapes with a higher line-to-curve ratio and more acute angles read as more aggressive, which aligns with findings in 2D shapes [5].

B. Formations in Human Groups

One area in which we see groups of humans create formations is in military tactical formations. According to the *Ranger Handbook* [6] and the *Infantry Rifle Plantoon and Squad* [7], there are six main tactical formations, as seen in Fig. 1. Each formation has different advantages and disadvantages. For example, the line formation maximizes firing capability in the front direction, but can be slow and is harder to control, whereas the file formation is easiest to control and maximizes speed while sacrificing front firing potential [7].

Another example of human group formations is F-formations, which are a spatial arrangement that humans use for creating a shared physical space and facilitating social interaction, such as conversations [8]. F-formations involve multiple humans creating a formation around a collective open space and orienting themselves towards that space. There are several variations on F-formations, as seen in Fig. 2.

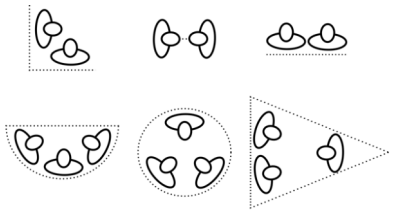


Fig. 2: Different spatial variations on F-Formations, which are formations human make to facilitate social interaction [8], [9].

C. Shape and Formation in Human-Robot Interaction

F-formations have also been leveraged in human-robot interaction. Work has been done in detecting F-formations in human groups so that a robot joining the group enters in a socially acceptable space [9]–[11].

In single robot HRI, shape can be explored in the path a robot takes. Work has shown that straight path shapes lead to participants perceiving a robot as goal-oriented and a curvilinear path was perceived as curious or confused [12].

In multi-robot HRI, works on generating expressive multi-robot motion have included using formation for expression. One work took inspiration from emotions to create different shape and size features for expressive swarm behavior [13]. One of the features was shape features, which described the shape of the group formation. Circular shapes with rounded pathways were used for happiness and sadness, whereas surprise, fear, disgust, and anger all had more irregular and disperse formations with angular movement trajectories. A user study found that these emotions were recognizable from the multi-robot behavior.

III. Study Conditions

This paper presents a pilot study and a user study, which both share the same four shapes as study conditions. We had two overarching shape categories, triangles and lines, with two variations each. For triangles we had wedge, which is a triangle with point forward in direction of travel, and v-shape, which is a triangle with flat side forward in direction of travel. For lines we had vertical and horizontal lines. These four shapes can be seen in Fig. 3.

A. Why these shapes?

These shapes were chosen based on prior work in psychology, human social formations, and ease of distinction. With three robots, the most distinct shapes were triangles and lines; curved shapes, such as arcs were not sufficiently distinguishable from triangle shapes with only three robots. Wedge was chosen due to the strong correlation between downward triangles and v-shapes in prior literature in human psychology [2]–[4], and was named after its military tactical formation cognate. V-shape was chosen due to its similarity to F-formations made in human social groups [8]. Horizontal and vertical lines were chosen because they are not necessarily shapes we see in social situations with humans, but are seen in military tactical formations [6], [7] and in non-social situations, such as waiting in a queue.

IV. Shapes in Navigation: Pilot Study

To explore how people react to different shapes, we ran an in-the-wild pilot study involving three robots in three shapes: v-shape, wedge, and horizontal line, as seen in Fig. 3. Due to robot failures vertical line has been excluded from the pilot study. These three shapes moved across the atrium of the computer science building. We found that people physically interacted the most with v-shape, the only shape people moved towards instead of away from. For both triangle shapes, people also acknowledged the robots either through facial expression or verbal comments in all trials. People physically interacted the least with horizontal line and additionally only acknowledged the robots in 60% of the horizontal line trials.

A. Study Setup

For each trial the robots began in an evenly space horizontal line facing an empty area of the atrium, as seen in Fig. 4. The robots first moved into formation, then moved forward in formation until they reached the end of the space shown in the overhead view (Fig. 4b). Once at the end of the space, the robots sat for approximately 10-20 seconds, then the robots would turn around and return to their starting positions. Over the course of four hours, we ran 13 trials: 5 v-shape, 3 wedge, and 5 horizontal line. To keep consistency with the formal user study, which was part of a themed demo, the robots were decorated to be turtles.

B. Evaluation Methods

A designated observer sat at a table in the atrium with a good view of the space the robots traversed and took notes during each trial. The observer noted if the people physically moved in relation to the robots, if they facially acknowledged the robots, and if they verbally acknowledged the robots. The observer also noted the time of the trial and the trial condition such that their observations could be confirmed and supplemented with video data. Video data was taken from an overhead camera looking down on the space.

C. Results

Overall, people interacted with the robots more in the triangle formations than in the horizontal line. In all trials, people either verbally commented on the triangle formations, facially acknowledged the robots, or moved to accommodate the robots. However, only 60% of people acknowledged the robots in a horizontal line. A summary of observation results can be seen in Table I.

V-shape was the only shape for which people moved towards the robots, rather than away from them. The first time a person moved towards the robots in the v-shape formation, they approached the robots, stared at them, and then left. In the second instance, as the robots approached the person, they moved towards the robots and the robots surrounded the person. The person joked about being afraid and then left. In both situations, the people appeared to feel safe enough to come up to the robots.

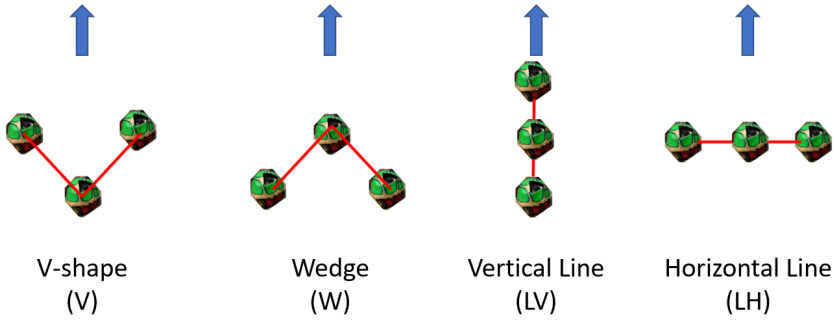
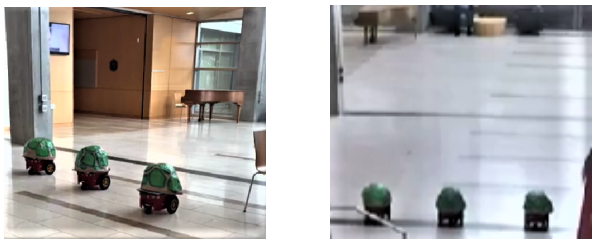


Fig. 3: Four study conditions



(a) Side view (b) Overhead view

Fig. 4: Starting positions for pilot study

TABLE I: Numerical Results of the Pilot Study

	V-shape	Wedge	Horizontal Line
Moved Towards Robots	2/5 trials	0/3 trials	0/5 trials
Moved Away from Robots	1/5 trials	2/3 trials	1/5 trials
Facial Expression Change	3/5 trials	3/3 trials	2/5 trials
Verbal Comments	3/5 trials	3/3 trials	2/5 trials
Overall Acknowledgement	5/5 trials	3/3 trials	3/5 trials

In all other formations, people moved away from the robots to avoid their path or did not move at all. For v-shape and horizontal line, people moved away from the robots in 20% of trials. For wedge, people moved away in 66% of trials.

People made facial expressions in 60% of trials for v-shape, 100% of trials for wedge, and 40% of trials for horizontal line. Out of these trials, all facial expressions were positive, such as giggling or smiling at the robots, except for one of the trials of wedge, in which one person gave the robots a confused look.

People also made verbal comments in 60% of trials for v-shape, 100% of trials for wedge, and 40% of trials for horizontal line. For each shape, exactly one of these comments was questioning what the robots were doing or where they were going. For example, one person said of horizontal line, "what the heck are they doing?" Apart from these three comments of confusion, the rest of the comments were either neutral, such as stating that the robots are moving towards something, or positive, such as calling the robots cute or expressing excitement at them being in the atrium.

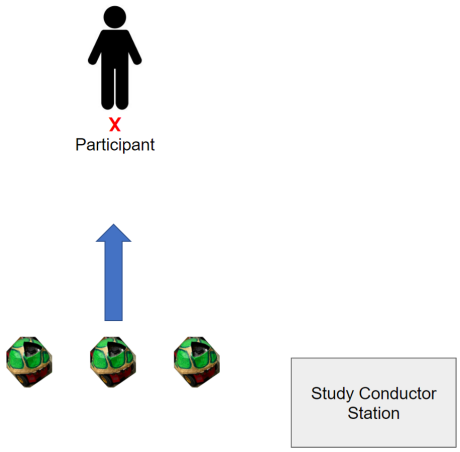


Fig. 5: Layout of the Study

V. Shapes in Approach: User Study

This study took place at the Southern California Robotics Symposium at University of California at Los Angeles as part of a demonstration entitled: Interactive Robot Aquarium. To stay on theme, the robots had turtle shells placed on them. In this study, robots approached participants in different formations, following which participants filled out a survey about their perception of the robot group. Results showed that triangles (v-shape and wedge) were seen as more positive and social than lines, with horizontal lines being the most negatively perceived shape.

A. Study Conditions and Setup

The same four shapes were evaluated in the formal user study as in the pilot seen in Fig. 3. Two study conductors ran this study: one spoke to participants and cued the robots, while the second study conductor took observations and videos of the study and ran the robot code. The study was between-participants. First, participants would be asked if they would like to participate in a user study exploring multi-robot expression and if so, the first study conductor would walk them through the verbal consent process. If the participants agreed to the terms of the study, they would be asked to stand on an X marked on the floor. The first study conductor would then cue the second to run the code and the robots would then create a formation and then move

(a) Wedge Condition (b) V-Shape condition

Fig. 6: Snapshots of participants being approached by the robots.

towards the participant. The robots would take a short pause after arriving at the participant, then turn around and return to their starting positions. While the robots were returning to their starting positions, the participants would be asked to fill out a short written survey on their experience. The study layout can be seen in Fig. 5.

B. Evaluation Methods

Two evaluation methods were utilized for this study. The first was a survey containing both seven point anchored scale questions and extended response questions, as listed below.

- **Anchored Scale Questions (7 point)**
  - The robot group was [threatening/harmless].
  - The robot group [did not want/wanted] me to join them.
  - The robot group was [welcoming/unwelcoming].
  - The robot group was [impolite/polite].
- **Extended Response Questions**
  - What do you think the robots were trying to do and/or communicate?
  - Did the robots remind you of anything?
  - Any other comments or feedback?

The second evaluation method was participant behavior observation. As the main study conductor spoke to the participants and cued the robots, the second study conductor took notes on participant reactions and behavior towards the robots.

C. Hypotheses

Eight hypotheses were made about the four shapes, based on the results of the pilot study. We hypothesized that wedge would be viewed as the most threatening (*H1.1*), as psychology has shown that humans often associate downwards v-shapes with threat and aggression [2]–[4]. Wedge also had the highest rate of participants moving away in the pilot study. We also hypothesized that people would think that wedge meant the robots did not want participants to join their group (*H1.2*), due to the fact that wedge was hypothesized to appear threatening. Next, we hypothesized that v-shape would be the perceived as most wanting the human to join the group (*H2.1*) and the most welcoming (*H2.2*), due to the fact that it is similar to the social F-formations found in human social interaction [8]. Additionally, this V-shape was the only shape that people approached the robots in the pilot

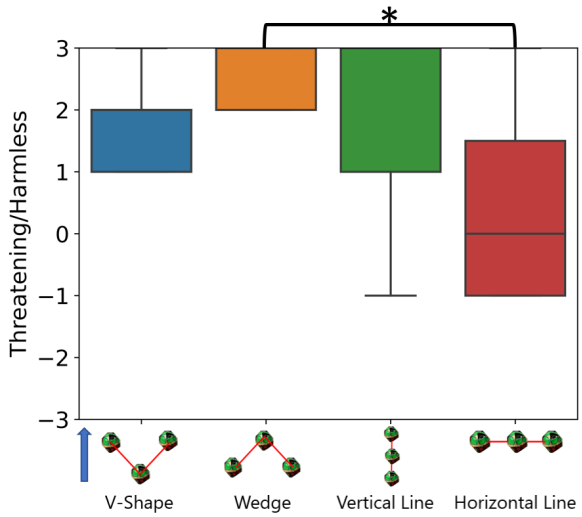


Fig. 7: Horizontal lines are the most threatening.

study. Vertical line was hypothesized to be the perceived as the most polite (*H3.1*) and harmless (*H3.2*), since it takes up the least space from an approach perspective as the robots are one behind the other. Horizontal line was hypothesized to be the most impolite (*H4.1*) for the opposite reason: it takes up the most space from an approach perspective and may be viewed as blocking. Additionally, we hypothesized that horizontal line would be the most unwelcoming (*H4.2*) as the robots are physically blocking the human from moving forward.

D. Results

To analyze the results of the anchored scale questions, pairwise Mann-Whitney U tests were used do determine significance as the data was not normal. The data is presented in Table II, and as box plots showing the median, 25% quartile, and 75% quartile. Significance in the plots is designated by an asterisk, where a single asterisk is p ¡ 0.01 and double asterisk is p ¡ 0.005. Extended response answers can be seen in the discussion to support numerical results.

1) Threatening vs Harmless: Horizontal line was seen as the most threatening, significantly more so than wedge (mean = 2.60), which was the most harmless (p = 0.036), as seen in Fig. 7. V-shape and vertical line were also perceived as harmless, with average ratings of 1.80 and 1.86. Horizontal line was the only condition perceived as neutral, with an average rating of 0.43.

2) Want to join?: Wedge was seen as the most wanting the human to join the group (mean = 0.8), significantly more so than vertical line (mean = -0.71), which was seen as most not wanting the human to join (p = 0.024), as seen in Fig. 8. V-shape and horizontal line were seen neutrally, neither as wanting or not wanting the human to join the robots, with average ratings of -0.25 and 0.14 respectively.

3) Welcoming vs Unwelcoming: Wedge was seen as the most welcoming (mean = 2.20), significantly more so than horizontal line (p = 0.008), as seen in Fig. 9. However, both v-shape and vertical line were still seen as welcoming with

TABLE II: Numerical Results of Shapes in Approach Study

Question	Mean (V, W, LV, LH)	Standard Deviation (V, W, LV, LH)	p-value (Mann-Whitney U Test)	N
The robot group was [**threatening/harmless**].	1.80, 2.60, 1.85, 0.43	0.84, 0.55, 1.57, 1.62	3.6e-2 (W, LH)	24
The robot group [**did not want/wanted**] me to join them.	-0.25, 0.80, -0.71, 0.14	2.06, 0.84, 0.95, 1.57	2.4e-2 (W, LV)	23
The robot group was [**welcoming/unwelcoming**].	0.60, 2.20, 0.86, -0.29	1.52, 0.84, 1.57, 1.11	8.4e-3 (W, LH)	24
The robot group was [**impolite/polite**].	1.80, 2.60, 1.71, 0.43	0.45, 0.89, 1.38, 0.98	2.6e-2 (V, LH) 1.2e-2 (W, LH)	24

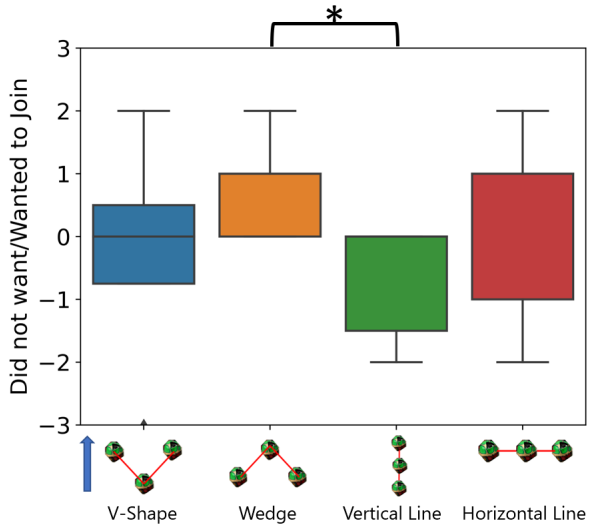


Fig. 8: Wedges want you to join, vertical lines do not.

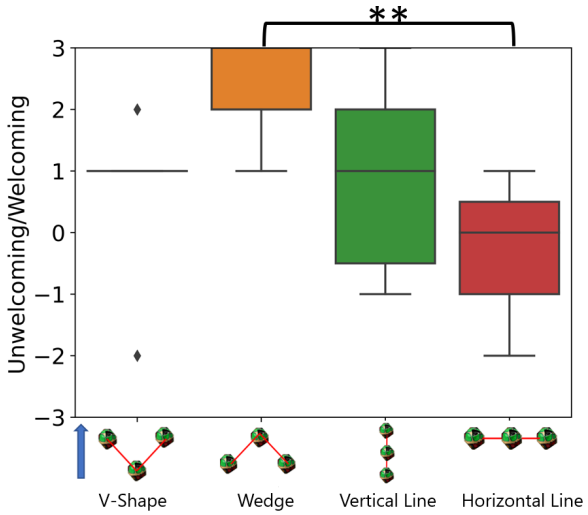


Fig. 9: Wedge is welcoming, horizontal line is not.

average ratings of 0.60 and 0.86. Horizontal line was seen as unwelcoming, with an average rating of -0.29.

4) Polite vs Impolite: Wedge read as most polite (mean = 2.60), followed by v-shape (mean = 1.80) and both were significantly more polite than horizontal line (p = 0.012, 0.026 respectively), as seen in Fig. 10. Vertical line read overall as polite (mean = 1.71), and horizontal line was the only condition reading closer to neutral, with an average rating of 0.43.

VI. Discussion

Wedge is perceived the most positively. Across all anchored scale questions, wedge was rated the most positively, which directly contradicts hypotheses *H1.1* and *H1.2*, which stated that wedge would be perceived as the most threatening and the least wanting the human to join. Wedge was significantly more positive than at least one other condition in all four questions, and trended more positively than the other conditions. These results suggests that while in visual arts downward facing v-shapes are often seen as negative [2], those results do not necessarily carry over to moving objects in space. One potential reason wedge may have been viewed so positively is that not all the robots came close to the human. Unlike vertical line, all three robots could be seen as clearly approaching the human, but only one came

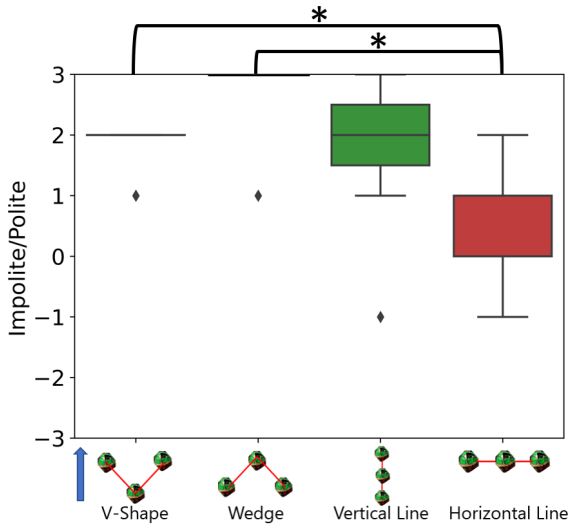


Fig. 10: Horizontal lines are impolite

close, which may have been less intimidating. Of wedge, one participant said, "they reminded me of a pet trying to get my attention," which also implies a social, non-intimidating perception of the robot group. This reasoning would also follow with how a group of people may approach an individual in a social setting. Typically, only one person from the group that approaches will speak to the human, so as not to overwhelm them. This interpretation was also supported by the results of the pilot study, in which people interacted with the robots in wedge in all three trials, demonstrating that they felt safe enough to interact with the robots. This interpretation was also supported by the extended response results. Participants described wedge as more inclusive than the other conditions. One participant described the robots in wedge as " want[ing] me to follow them somewhere" and another said they though the robots were trying to "reach out to people."

Horizontal line is perceived as the most negatively. Across three of the four anchored scale questions, horizontal line was rated the most negative. These results support hypotheses *H4.1* and *H4.2* that horizontal line would be perceived as the most impolite and most unwelcoming. These results were backed up by the physical responses of participants and their extended responses in the survey. During the studies, one participant said "I'm scared" as the robots approached in a horizontal line and moved back and forth hesitantly. Horizontal line was the only condition in which we saw such a negative reaction to the robots. One reason for this may be that horizontal line is not a formation we often see in innocuous human social situations, however we do see horizontal lines in situations like tactical military formation. One participant even wrote that the robots in horizontal line reminded them of a "military parade" and seemed like they were trying to "assert their presence." Therefore, people may associate such formations, especially as they approach them, with aggressive intentions like maximizing front firing. This interpretation is supported by the comments participants made in response to horizontal line. One participant even explicitly said it reminded them "vaguely [of] a military parade." Additionally, as this formation is not seen in human socializing, it may read as unnatural and cause more hesitancy from people who see it, since they do not have a human social parallel. These results are also supported by the data in the pilot study, in which people were least likely to interact with the horizontal line formation. This may be because they perceived is as aggressive or unnatural and either did not feel safe interacting with the robots, or did not know how to interact with the robots. One participant said they thought the robots were "trying to get past me, waiting for me to get out," which are supports that participants did not often see horizontal line as a social formation. However, this was not always the case. Some participants interpreted the horizontal line as a social intimidation. For example, one participant said horizontal line reminded them of "a group of cool kids who decided I wasn't cool enough."

V-shapes may need relative final orientations. Hypotheses *H2.1* and *H2.2*, that v-shape would be perceived as the most wanting the human to join and most welcoming were not supported. While v-shape was perceived as somewhat welcoming, it was not viewed as wanting the human join, which was unexpected, especially as this was the only shape that people approached in the pilot. One possible explanation for this is that the robots were all oriented forward, rather than facing the human. While the robots and the human made a space similar to the social F-formations [8] in humans after the approach, the robots were not oriented into the center of the space, which may have signalled a disinterest in the person. Another possible reason for this unexpected result may be that the robots were physically not close enough to the human in the final formation to appear as though they wanted to interact. Unlike in wedge, where the forward most robot is right in front of the human, in v-shape the robot in front of the human is much farther back and the remaining robots are to the sides of the human, which may not signal interaction to as great an effect as wedge. This interpretation is supported by the extended response in which participants said the robots communicated "nothing in particular," that they were "just very cute turtles travelling around" and that the robots "were approaching me, but kept a safe distance," implying that the robots did not get close enough to be interpreted as wanting a social interaction.

Vertical lines are not social. Vertical line was viewed generally positively, as harmless and polite, and somewhat welcoming. While this does not completely support hypotheses *H3.1* and *H3.2* that vertical line will be perceived as most polite and most harmless, vertical line was still perceived as polite and harmless. An unexpected result was that vertical like was perceived as the least wanting the human to join the robots. One possible reason for this could be the associations we have with humans moving in straight lines. Particularly in the United States, humans moving in straight lines is generally not a particularly social activity, but rather a means of efficient transportation, such as school children moving between classes in a line, or as a space efficient way of waiting for something, ie a line to check bags at the airport. While these situations are generally harmless and polite, they are not situations in which a group of people are inviting others in. The extended response answers support this reasoning, with many participants describing the robots doing something innocuous, but not human-focused, such as "scanning the environment they're in" or "sync[ing] with each other."

VII. Conclusion

This work advances knowledge in how different formations are perceived by people in both approach and navigation scenarios. The results of this work also paves the way for a deeper exploration of the utility and perception of formations in multi-robot groups and socially acceptable approach techniques for groups of robots. For example, a researcher using multi-robot groups for disaster response may need robots to approach a human while signalling that the human needs to stay back because the area is not safe, navigate quickly through crowds, or monitor a scene. Our results show that the formation the multi-robot group is in

may impact the success of the task, and researchers will need to take formation into consideration while designing their robot behaviors.

Bringing multi-robot groups into different use cases also paves the way to explore how the interpretation of shapes in approach change with context or task goals (ie are certain approach and navigation formations better for different things, like quick traversal vs monitoring). Humans often use the same motion in different contexts to convey different things, like running up to a close friend may convey excitement, while the same movement directed at a stranger may convey aggression or an emergency. It is likely that multi-robot formations would convey different meanings and intentions in different contexts as well. Future researchers could explore how context can change formation, and explore the relationship between context, formation, and communication effect as context is likely to affect different formations in different ways.

Our work shows strong results for what shapes were seen as more threatening, welcoming and polite, however all four shapes were close to neutral in communicating if the robot group wanted the human to join them. Future work could explore if there are additional factors that may help this sense of inclusion/exclusion. One factor that may affect a sense of inclusion or exclusion could be proxemics, both within the robot group and between the robots and the person. For example, decreasing the space between robots in a formation while increasing the space between the robot group and people may read as more exclusionary. Another factor could be final pose orientation. For example, changing the final pose orientation to face the human rather than a straight forward orientation may lead to an increased sense of inclusion.

In addition to inclusion and exclusion, another potential area for exploration is how final orientation affects the perceived intention of the robots. In the current study, all robots maintained a forward orientation after reaching their final positions. There has been much prior work on how gaze and orientation can be used in human-robot interaction [14], however the role of final pose orientation along with different formations during approach is yet unexplored. However, gaze in conjunction with formation could be a powerful tool to change the communication effect of the formation. Future researchers could explore how and if orientation can change the communication of a formation, and how this differs across varying formations. Another key extension to the work presented in this paper is exploring how different robot form factors and contexts change the perceived perception of the formations. The turtle form factors of the robots in the presented studies may have caused people to perceive the robots more positively than if they were not dressed up. Additionally, certain costumes or form factors may cause the base perception of the robots to be more negative, such as security robots or military robots. Further studies can be done exploring how form factor and geometry intersect and affect one another.

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