Towards Modelling Group-Robot Interactions Using a Qualitative Spatial Representation

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Abstract

This paper tackles the problem of finding a suitable qualitative representation for robots to reason about activity spaces where they carry out tasks interacting with a group of people. The Qualitative Spatial model for Group Robot Interaction (QS-GRI) defines Kendon-formations depending on: (i) the relative location of the robot with respect to other individuals involved in that interaction; (ii) the individuals' orientation; (iii) the shared peri-personal distance; and (iv) the role of the individuals (observer, main character or interactive). The evolution of Kendon-formations between is studied, that is, how one formation is transformed into another. These transformations can depend on the role that the robot have, and on the amount of people involved.

1 Introduction

Robot tour guides appeared in the late 90s: Rhino [5] was located at the Deustche Museum in Bonn, Germany; Minerva [24] at the Smithsonian's National Museum of American History in Washington; Robox [23] at the Swiss National Exhibition, Expo02. Nowadays even flying quadcopters are used at MIT for personal guiding to labs (Skycall[1] project). Some of those works studied social interaction when navigating, specifically when passing people [22, 1]. However, none of these systems applied qualitative representations or reasoning.

Qualitative descriptors for reasoning about moving objects have been used in the literature to represent Human Robot Spatial Interactions in navigation situations where one robot and one human (or a group of humans as a whole) were involved(i.e. [13]). Qualitative spatial representations for activity spaces where a robot carry out a task or collaborate with more that one person are not available in the literature, as far as we are concerned. This paper refers to social interactions among humans (Human-Human Interaction HHI) and Human-Robot Interactions (HRI) in social environments, which may involve several individuals (sometimes arranged as a group) and one robot –from now on named as Group-Robot Interactions, GRI.

A result of this recent interest in the community is the "Groups in Human-Robot Interaction" full day Workshop held in the IEEE International Symposium on Robot and Human Interactive Communication (IEEE RO-MAN 2016)[2] where research discusses how studies in social psychology and HRI indicate that inter-group interaction varies crucially from inter-individual (dyadic) interaction [20], by modulating the effects found in dyadic HRI, introducing variables that are not possible to study in dyadic HRI, and requiring different technical solutions to problems of perception and interaction. Besides these variations between dyadic interaction and group-robot interaction, it is interesting to find common factors in this interactions that allow robots to identify situations and to reason about the spatial relations when interacting either with an individual or with a group. We claim that the use of qualitative metrics leading to consider the group as a whole can help to develop techniques in group-robot spatial interaction in a more general form, allowing to inherit techniques from the usual human-robot spatial interaction. Any individual or group has

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[1] `http://senseable.mit.edu/skycall/`

[2] `https://grouprobot.wordpress.com/home/`

a characteristic interaction region. In the case of a group, individuals often have some type of arrangement around this inner, shared region (i.e. sometimes named as *o-space* by Kendon [18]). The use of this interaction region in a qualitative descriptor can help to represent more generally both individuals and groups in a Human-Robot Spatial Interaction.

This paper is organised as follows. Section 2 describes how challenging is for robots to follow social behavior rules and it also presents the F-formations defined by Kendon [18] for group behavior. As these F-formations are described in a linguistic manner, we propose a qualitative model to formalize them using a qualitative representation based on distances, locations and orientation (Section 3). Final sections provide a discussion, conclusions and intended future work.

2 Background

Robotics are getting gradually involved in human daily living activities, making their way towards the so-called social robotics. In those human environments, social robots must have the ability to communicate with people closely and fluid [8] both in a verbal and in a non-verbal way.

Social robots as physical entities that co-inhabit a place with people in HRI (eventually, sHRI) are involved in what is known as *spatial relationships* [17, 19]. Spatial relationships, a mode of non-verbal communication, are a combination of distance, relative position and spatial arrangement that occur naturally whenever two or more people engage in an interaction [21] and convey significant and relevant social information (e.g. how each of them is involved) and also define an interpersonal space for developing activity.

Many disciplines can contribute to our understanding of spatial relations in HRI, or Human Robot Spatial Interaction (HRSI) in open and crowded natural scenarios. Next, relevant concepts in HRSI such as proxemic behavior, F-formations, group behavior and Qualitative Spatial Representations are introduced and discussed.

Proxemic behavior

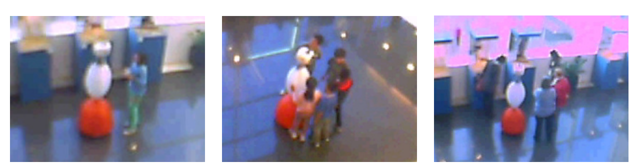
The term *proxemics* was introduced by the anthropologist Edward T. Hall in 1966 [15] to refer to *"the interrelated observations and theories of man's use of space as a specialized elaboration of culture"* [ibid, p. 1]. In this regard, Hall defines 4 kinds of interpersonal distances, each with its own significance in a social context: intimate ($0 - 0.46$ meters), personal ($0.46 - 1.22$ meters), social ($1.22 - 3.66$ meters) and public (> 3.66 meters). These interpersonal distances may vary depending on culture. Figure 1 shows some examples of proxemic behaviors in a public space.

(a) (b) (c)

Figure 1: HRI in a Cultural Center showing proxemic behaviours regarding: (a) intimate, (b) personal, and (c) social distances.

F-formations

The *F-formation* system was proposed by Adam Kendon [18] to study the spatial structures, both in position and orientation, that are generated when two or more people interact and affirm that *"behaviour of any sort occurs in a three dimensional world and any activity whatever requires space of some sort "* [ibid, p. 1.] This space allows an organism to perform any activity and it is differentiated from other spaces [21]. According to Kendon, in any scenario is common that several individuals are co-present, but the way they are positioned and oriented in relation to the others reflects directly how they can be involved together. Based on his observations, Kendon defines a transactional space, known as *o-space*, defined as the space where people can interact and manipulate shared objects. In dyadic interactions, Kendon observed two types of formations: 'vis-a-vis' (individuals who are facing one each other) and 'L-shape' (individuals are standing perpendicularly to each other facing an object). When the interaction occurs between two or more people, Kendon observed three types of formations: 'circular form' (when all people are looking each other), 'side-by-side' (when people stand closely together and facing the same segment of the environment), and 'horseshoe shape' (a kind of compromise between side-by-side and circular form). Figure 2 shows some real examples of these spatial arrangements. Typical spatial arrangements also happen in occasions where there is an unequal distribution of rights to start a conversation or



(a) (b) (c)

Figure 2: HRI in a Cultural Center showing spatial arrangements regarding: (a) 'vis-a-vis', (b) 'circular form', and (c) 'horseshoe shape'.

action, for example, in the 'performer-audience' interaction. In contrast, if a group of people do not follow any spatial arrangement between them is known as 'cluster'.

Empirical studies in robotic applications [19] have identified the management of spatial relations between people and a robot as a main issue in order to improve the quality of interaction taking into account that interpersonal distances which convey significant and relevant social information. An interesting conclusion is that when physical constraints (e.g. narrow passages) in combination with navigational requirements unable the robot to maintain the convenient spatial behavior, it can compensate this situation with other interactive behaviors (e.g. verbally apologizing for an inappropriate distance or reducing the eye-contact) to maintain an overall degree of desired intimacy.

Group behavior

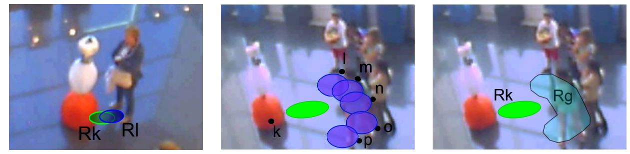
An interesting approach related to spatial relations in crowds of pedestrians was conducted by Bandini *et al.* [2]. They analysed the group behavior from a socio-psychological perspective, in terms of groups, that is, the basic elements which compose the crowd, and in terms of proxemics, chosen as an analytical indicator of spatial behavior dynamics within the crowd. Based on the observations of proxemic behavior of walking groups, the work focused on: spatial arrangement (degree of alignment and cohesion, e.g. 'line-abreast', 'v-pattern' and 'river-like'), walking speed, level of density, group size and gender.

Spatial arrangements in human-robot interactions

Some exploratory studies to evaluate the human-robot interaction in terms of spatial relationships were carried out by Díaz-Boladeras *et al.* [9]. From their observations, it has been possible to distinguish different types of spatial arrangements and group sizes, and to chose a discretization of group individuals to points (Figure 3) in space or regions in space (Figure 4).

(a) (b)

Figure 3: QSR primitives in HRSI: as points in (a) one-human-robot interaction and (b) group-robot interaction.



(a) (b) (c)

Figure 4: QSR primitives in HRSI: as regions in (a) one-human-robot interaction, (b) group-robot interaction (individual region), and (c) group-robot interaction (group region).

Qualitative Spatial Representations in HRSI

Few approaches in the literature have dealt with the challenge of formalizing social conventions so that robots would be able to behave more cognitively in human populated scenarios.

Several qualitative studies use the Qualitative Trajectory Calculus (QTC) to model HRSI [10, 11, 3, 16]. QTC use points as primitives in order to represent both the human and the robot, and their relative motion is expressed in a set of tuples of qualitative relationships.

Qualitative social rules for robots to have a polite pedestrian behavior while navigating were proposed [12]. The relative orientation calculus $OPRA_4$ was used to formalize polite navigation rules in situations such as: crossing, bottleneck or narrow passages, passing groups from the outside, crossing them if they are too large, etc. And motion planning and pedestrian behavior was simulated using JWalkerS and SparQ toolbox[3] to investigate how traveling time is influenced by being polite (i.e. following social norms, etc.). Then, the same authors [13] modeled these pedestrian rules in QLTL (Linear Temporal Logic with Qualitative Spatial Primitives) and presented one exemplary case study using a Kinect camera and a laser range scanner on a mobile robot. However, they did not deal with spatial arrangements of a robot interacting with a group of people (i.e. carrying a joint action).

3 A Qualitative Spatial Descriptor of Group-Robot Interactions (QS-GRI)

This section presents a descriptor for representing the qualitative spatial arrangements for group-robot interactions defined by Kendon [18].

First, an iconic representation is provided (Section 3.1) and then the F-formations are described: vis-a-vis (Section 3.2), L-shape (Section 3.3), circular (Section 3.4), horse-shoe (Section 3.5), side-by-side (Section 3.6), performer-audience or cluster formation (Section

[3]SparQ toolbox: `http://www.sfbtr8.uni-bremen.de/project/r3/sparq/`

3.7).

3.1 Iconic Representation

From the point of view of spatial features, interactions between robots and people depend on two factors: (i) distance and (ii) orientation. People are oriented entities in space, which *front* is indicated by their eyes. Then, robots need to know social conventions indicate that, in order to talk properly to somebody, they must try to make eye contact with them, which is more feasible if robots approach people from the *front*.

Moreover, robots must be aware that people's personal space usually is not interfered by other people unless they are family, and this space is not allowed to be interfered by robots. So, an interactive distance for a robot is that distance which is not too close to any person but not too far away for them. Kendon [18] defined the *o-space* as the space where people can interact and manipulate shared objects. Similarly, in psychology, peri-personal space is defined as the space wherein individuals manipulate objects, whereas extra-personal space –which extends beyond the peri-personal space– is defined as the portion of space relevant for locomotion and orienting [14, 7]. Therefore, two individuals that share their peri-personal space can be considered to have an interaction.

In this section, the iconic representation of an individual (robot or person) is shown in Figure 5. That is,

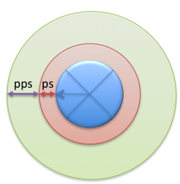


Figure 5: Iconic representation of an individual (robot or person) showing their personal space (ps) and their peri-personal space (pps).

any individual fills an area in space (in blue), and (s)he has a personal space (in red) which is private, and a peri-personal space (in green) which is that space that (s)he can reach using their body or a tool. The rest of the white space is the extra-personal space.

Any person distinguishes spatial locations inside his/her personal and peri-personal space. These areas are usually named as: *front, back, right* and *left*. A person is also an oriented entity in space, defined by his/her *front* where his/her eyes are located. The width of the personal space (ps) depends on the person, their social abilities and culture. Some people would need a wider personal space than other people. These areas can be customized according to the individual person but also parameterized based on psychological experimental studies [4]. The peri-personal space (pps) is dynamic and adaptable, depending on the tool used by the person/robot and their abilities (i.e. flexibility of legs/arms for a person, actuator possibilities in a robot, etc).

3.2 Vis-a-vis Formation

In the vis-a-vis formation by Kendon [18], individuals are facing each other. A spatial situation suitable for interaction is defined as that situation in which individuals share part of their peri-personal space. In the vis-a-vis formation, the peri-personal spaces intersects in the front area of both individuals, as it is shown in Figure 6. Note that the front of each individual must be turned about 180° to be transformed into the other individual perspective.

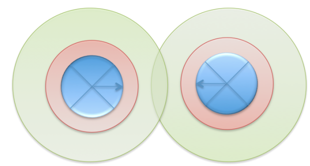


Figure 6: Vis-a-vis formation: 180° relationship.

3.3 L-shape Formation

In the L-shape formation by Kendon [18], two individuals are facing an object having 90° or L-shape separation between them (see Figure 7). These two individuals must share some peri-personal space between them. The intersection of this peri-personal space intersects at their *front-left* area of one individual and at the *front-right* area of the other individual. The object observed is not animated, so it has not personal or peri-personal space. The object must be located in the front area of both individuals, which is shared.

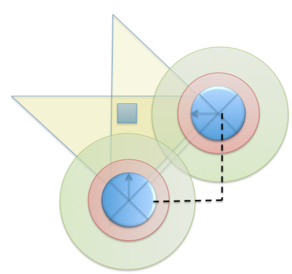


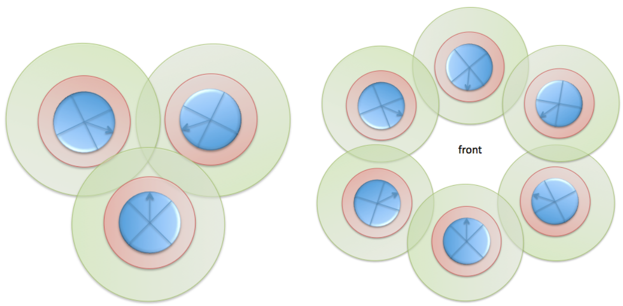
Figure 7: L-shape formation.

The individuals are observers, they are not physically interacting with each other, otherwise they would face each other. They are talking about the object. The roles of speaker and listener can be taken in turns. Note that the front of each individual must be turned

90° to be transformed into the other individual perspective.

3.4 Circular formation

The minimal circular formation by Kendon [18] is a triangular spatial formation oriented towards the common shared peri-personal space (see Figure 8 (a)). In the general case, individuals share their peri-personal space with their neighbors, in the *right* and *left* area. They all share their *front* area (see Figure 8 (b)).



(a) (b)

Figure 8: Circular formation: (i) minimal circular formation, (ii) general circular formation.

The individuals are not only observers, they can interact with each other. The roles of speaker and listener can be exchanged constantly. Note that, in the minimal circular formation, the *front* of each individual must be turned 120° to be transformed into the other individual perspective. In the general circular formation, the front of each individual must be turned $360°/N$ according to the number of individuals, N, to be transformed into the other individual perspective.

3.5 Horse-shoe formation

In the horse-shoe formation by Kendon [18], individuals share their peri-personal space with their neighbors, in the *right* and *left* area. They all share their *front* area. The individuals are all of them observers, they are displaced to listen to somebody or to see some object (see Figure 9).

Hence, they hold the role of listeners. This is a passive role which can be changed with permission of the speaker, which is usually located at the shared *front*. Note that, in the horse-shoe formation, the *front* of each one of the N individuals must be turned $180°/N$ to be transformed into the other individual perspective.

3.6 Side-by-side formation

In the side-by-side formation by Kendon [18], individuals have the same perspective. They share their peri-personal space with their neighbors at their *left* and at their *right*. In the queuing variation, individuals have also the same perspective, but they share their peri-personal space with their neighbors at their *front* and at their *back* (see Figure 10). In both cases, individuals' role is passive. They are listeners-observers. Usually, they do not take the speaker roll unless they are given permission for (i.e. for the queuing variation, since they are the head of the queue). Note that, in both side-by-side and queuing formations, as individuals have the same perspective –they are oriented towards the same direction– they must turn 0° to get the same *front* as their neighbors.

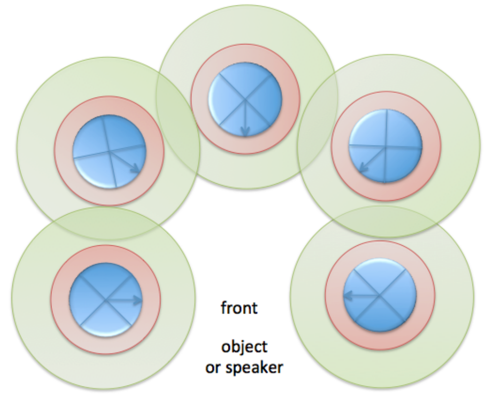
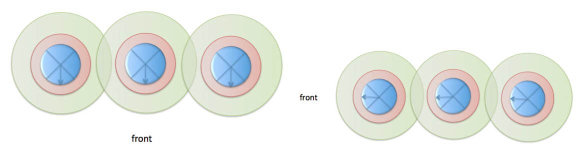


Figure 9: Horse-shoe formation.



(a) (b)

Figure 10: Side-by-side formation and the queuing variation.

3.7 Performer-audience or cluster formation

All the individuals have the same perspective and they share their peri-personal space with their neighbors at their *front*, *right*, *left* and at their *back* (see Figure 11). Their role is passive. They are listeners-observers. They do not take the speaker roll unless they are given permission for, that is, they are asked.

3.8 Conceptual Neighborhood Situations

In previous sections, we have observed how the Qualitative Spatial descriptor for Group Robot Interaction (QS-GRI) defines the Kendon-formations depending on: (i) the relative location of the robot with respect to other individuals involved in the interaction; (ii) the

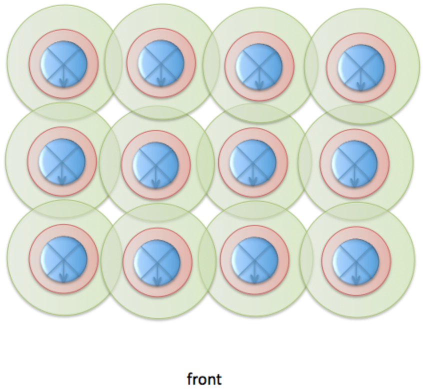


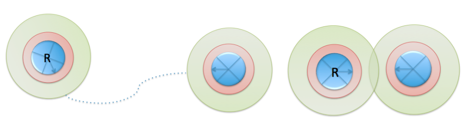
Figure 11: Performer-audience formation or cluster formation.

orientation of the individuals (shared front) or not; (iii) their shared peri-personal distance; and (iv) the role of the individuals (observers or interactive).

In this section, we deal with the following challenge: *where the robot should locate itself if its goal is to be included in a group? and towards which direction should it be oriented?*

In order to approach this challenge, the evolution of Kendon-formations between them must be studied. That is, how one formation is transformed into another. These transformations can depend on the role that the robot has, and on the amount of people involved.

Figure 12 shows a situation in which the goal of the robot is to interact with one person. So, it selects the vis-a-vis Kendon-formation to start this interaction. For that, it must be located in front of the person, oriented towards the person, and it must share the person's peri-personal space but not their personal spaces must not be intersected.

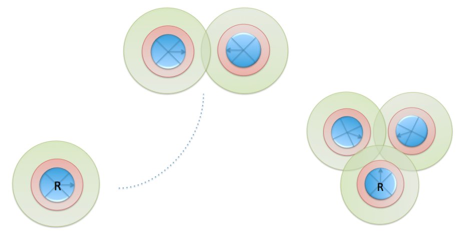


(a) (b)

Figure 12: How the QR-GRI is evolving from an initial situation –where an individual is alone– to a vis-a-vis formation.

Figure 13 shows a situation in which the goal of the robot is to interact with two people who are placed in a vis-a-vis situation, and which is the Kendon-formation selected for the robot to start this interaction, that is, the minimal circular formation.

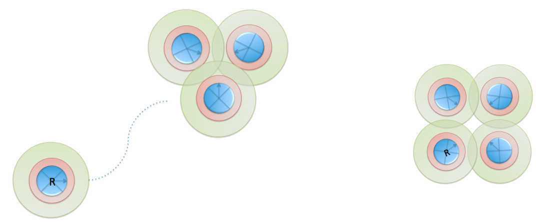
Figures 14, 15 and 16 show situations in which the goal of the robot is to be involved in a group of people who interact among themselves. The initial situation



(a) (b)

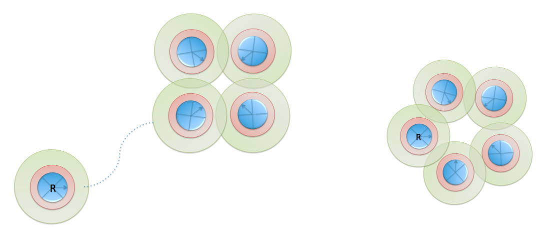
Figure 13: How the QR-GRI is evolving from a vis-a-vis situation –where two individuals are interacting– to a minimal circular formation.

is a group of 3 people situated in a minimal circular formation, and the evolving situations are those where the circle is getting bigger (4-circular formation, 5-circular formation, n-circular-formation).



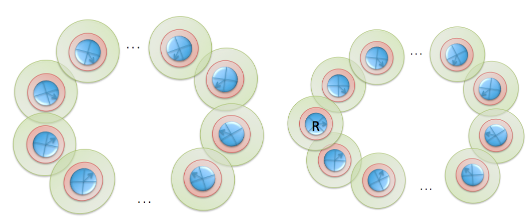
(a) (b)

Figure 14: How the QR-GRI is evolving from a minimal circular situation –where 3 individuals are interacting– to a 4-circular formation.



(a) (b)

Figure 15: How the QR-GRI is evolving from a 4-circular situation –where 4 individuals are interacting– to a 5-circular formation.

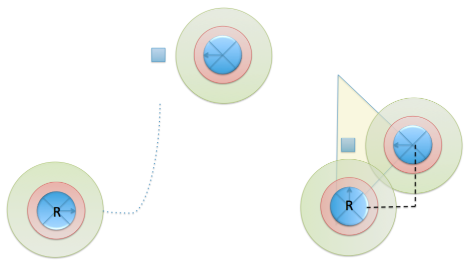


(a) (b)

Figure 16: How the QR-GRI is evolving from a n-circular situation –where individuals are interacting– to another n-circular formation.

In situations where individuals are not interacting with each other, some of them take the role of observers or listeners. In these situations, the following Kendon-formations are suitable for the robot to place itself.

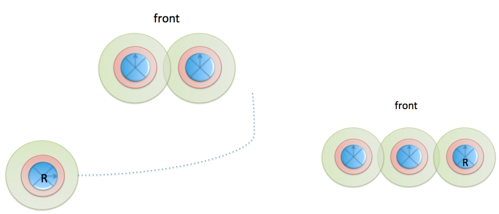
A situation where the goal of the robot is to interact with one person while observing an object, the Kendon-formation selected for the robot to start this interaction can be L-shape (see Figure 17).



(a) (b)

Figure 17: How the QR-GRI is evolving from an initial situation –where an individual is observing an object– to a L-shape formation.

Another situation is shown by Figure 18 where the goal of the robot is to be involved in a group of people who observes something or someone and with whom they cannot interact (i.e. in a performance). These two people are located in a side-by-side formation, and the robot incorporates itself in this side-by-side formation.

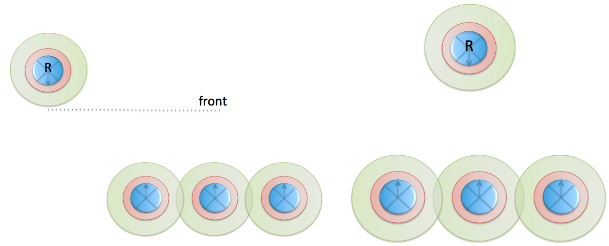


(a) (b)

Figure 18: How the QR-GRI is evolving from a 2-side-by-side situation –where two individuals are observing someone or something sharing its left/right peripersonal space– to a 3-side-by-side formation which includes the robot.

Figure 19 shows a situation in which the goal of the robot is to perform some speech to a group of people who are located in a side-by-side formation. The robot chooses to locate itself at the front.

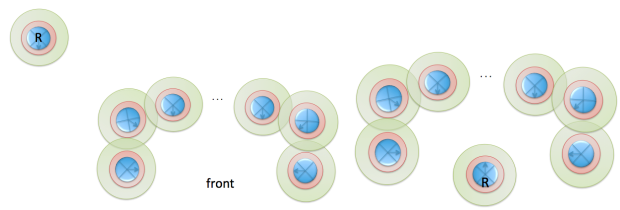
A new situation happens when the goal of the robot is to perform some speech to a group of people who are located in a horse-shoe formation (see Figure 20). The robot must locate itself at the front. While in Figure 21, the goal of the robot is to hear some speech by somebody else or to observe something, then the



(a) (b)

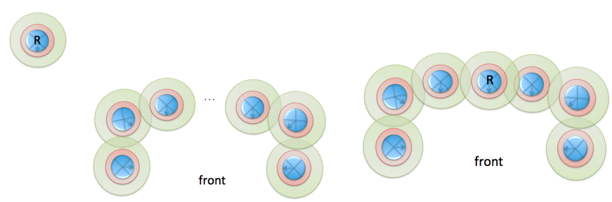
Figure 19: How the QR-GRI is evolving from a 3-side-by-side situation –where 3 individuals are observing someone or something sharing its left/right peripersonal space– to a 3-side-by-side formation which includes the robot at the front.

robot chooses to locate itself among the people. The robot shares its left and right peri-personal space with its neighbors.



(a) (b)

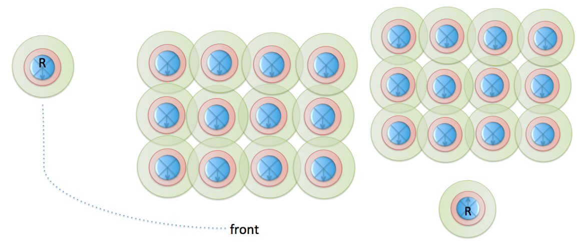
Figure 20: How the QR-GRI is evolving from a horse-shoe situation –where individuals are observing someone or something sharing its left/right peripersonal space and also its front– to a horse-shoe formation which includes the robot at the front.



(a) (b)

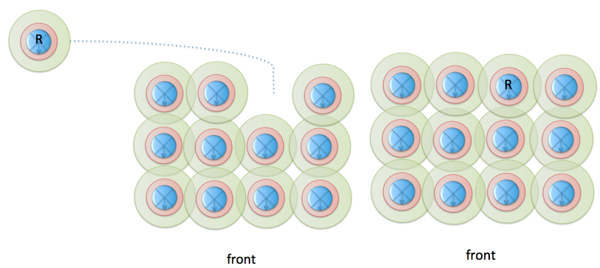
Figure 21: How the QR-GRI is evolving from a horse-shoe situation –where individuals are observing someone or something while sharing its left/right peripersonal space and also its front– to a horse-shoe formation which includes the robot among the individuals.

Another situation is showed in Figure 22 where the goal of the robot is to perform some speech to a group of people who are located in a performance/cluster formation. The robot must choose to locate itself at the front. While in Figure 23, the goal of the robot is to hear some speech by somebody else or to observe something, then the robot must locate itself among the people. In this case, the robot can have more than 2 left-right-neighbours and up to 4. In the situation depicted, the robot must also share its front peri-personal space with the person in front of it.



(a) (b)

Figure 22: How the QR-GRI is evolving from a performance/cluster formation –where individuals are observing someone or something– to a performance/cluster formation which includes the robot at the front.



(a) (b)

Figure 23: How the QR-GRI is evolving from a performance/cluster formation –where individuals are observing someone or something– to a performance/cluster formation which includes the robot among the individuals.

All these Kendon-formation transformations have been summarized in Table 1. Note that a change of the robot activity/role involves a change in its location in the corresponding formation (see lines in Table 1), while adding a new person in the group also make the formation to evolve to a different one (change in columns in Table 1).

4 Discussion

There are several studies analyzing the spatial interactions from a quantitative approach, expressing spatial relationships in terms of distances and absolute orientations. Since the distances and directions are constantly changing, the representation of the interaction based on these primitives are complex.

The use of Qualitative Spatial Representation techniques can help to abstract and model HRSI. A first approach to use Qualitative Trajectory Calculus HRSI

Table 1: Table of conceptual neighborhood situations.

	Guide	**Observer**	**Interactive**
1 person	vis-a-vis	L-shape	vis-a-vis
2 people	at front in: side-by-side or minimal circular	L-shape	minimal circular
3 people	at front in: side-by-side or horse-shoe	observer in: side-by-side	circular
4 people	at front in: side-by-side or horse-shoe	observer in: side-by-side horse-shoe	circular
5 people	at front in: side-by-side or horse-shoe	observer in: side-by-side horse-shoe	circular
N people	at front in: side-by-side, horse-shoe or performance	observer in: side-by-side horse-shoe or performance	circular

represent qualitatively, using points as primitives to identify the person and the robot in a one-by-one interaction type, as shown in Figure 2. Since in real situations HRI can present a great variability in the size of the group, it is possible to use this technique in these cases?

Some research works in the literature [22] and [12] divided the robot space following proxemics, and they divided the space in: intimate, personal, social and public. In this paper, we propose a more psychological point of view dividing the space in personal and peri-personal, which is more related to Kendon definition of o-space [18], where people can interact and manipulate shared objects. Our representation is envisioned to be applied in future human-robot collaboration (HRC) scenarios [6].

As far as we are concerned, there is no previous works in the literature that study the change/evolution of Kendon-formations to help robots to locate themselves following a social convention depending on the role they are assigned (main character/guide, observer/listener, or interactive).

5 Conclusions and Future Work

QSR techniques can be a valuable tool for modeling and representing HRSI. In previous works by the authors, a brief analysis was carried out on types of interactions proposing the use of points/regions as primitives to represent the interaction between people and a robot [9].

In this paper, a Qualitative Spatial model for Group Robot Interaction (QS-GRI) is presented which defines Kendon-formations depending on: (i) the relative location of the robot with respect to other individuals involved in the interaction; (ii) the orientation of the individuals (shared front) or not; (iii) the shared peri-personal distance; and (iv) the role of the individuals (observer, main character or interactive). The evolution of Kendon-formations between them must be studied. That is, how one formation is transformed into another. These transformations can depend on the role that the robot have, and on the amount of people involved.

As future work we intend to validate this definition to different types of group-robot interaction in real environments. We can use the data from an exploratory study of HRI as a guide robot exhibition in a cultural center.

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