THE INFLUENCES OF LOCATION AWARENESS ON COMPUTER-SUPPORTED COLLABORATION

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Abstract

"Where are you?". This recurring question when opening a mobile conversation attests the importance of spatialisation in social interactions. More and more applications support mutual location-awareness: they enable members of a group to locate their partners both in the physical environments and virtual worlds. This thesis contributes to the research in the field of Computer Supported Cooperative Work (CSCW) by examining how location awareness tools influence collaboration and what interpretations are drawn upon them in a collaborative context. Our research question concerns the effect of location-awareness on group cognitive processes such as communication and the modeling of others' intents (a process we referred to as "mutual modeling").

After a critical review of the existing mutual location-awareness interfaces, a theoretical framework grounded in psycholinguistics is introduced. It describes location-awareness as a "coordination device" that allow members of a group to have a shared understanding upon which they could mutually infer their respective intentions. Three studies have been realized in the form of semi-controlled experiments in two multi-user games; one in a 3D virtual world and two others in the physical environment, based on a location-based game.

The first study demonstrated how the presence of a location-awareness interface did not necessarily imply its use. More surprisingly, in the second experiment, this type of interface had inhibiting effects on communication within groups and on the recall of partners past positions. It also made the group more passive than those who did not have this interface. Our third study showed how location-awareness is integrated among a set of coordination devices, namely the plan players established before the game. In addition, the three studies brought forward the various roles of mutual location-awareness ranging from a resource for division of labor to the facilitation of situation understanding or the use of past positions to draw hypotheses about the partners future behavior. We also developed visual representations of coordination to depict the effects of location-awareness tools on collaboration. These visualizations allowed us to represent these negative effects and to refine our understanding of their influence over time. Such results finally allowed us to discuss how automating location-awareness can be detrimental to group collaboration in certain situations.

As most of the research in human-computer interaction has rather focused on optimizing the accuracy of location sensing and representation, the work done in this thesis is meant to ponder this agenda by bringing forward unexpected issues regarding how collaboration can be undermined by location-awareness.

Keywords: coordination, CSCW, geolocation, group cognitive processes, location-awareness.

Résumé

"Où es-tu?". La récurrence de cette question dans les conversations sur téléphones mobiles atteste de l'importance de la spatialisation dans les interactions sociales. Ainsi, de plus en plus d'applications proposent des fonctionnalités et interfaces de géolocalisation mutuelles permettant de localiser des individus tant dans l'environnement physique que dans des mondes virtuels. Cette thèse contribue à la recherche en Travail Coopératif Assisté par Ordinateur (TCAO) en examinant l'influence de ces interfaces de positionnement sur la collaboration. Notre question de recherche concerne ainsi les effets des outils de géolocalisation mutuelles sur les processus cognitifs de groupe tells que la communication ou les inférences des intentions des autres.

Après une revue critique des différentes interfaces de géolocalisation mutuelles, un cadre théorique psycholinguistique est introduit. Celui-ci décrit ces informations de positionnement des autres comme des "clés de coordination" qui permettent de créer une base commune de compréhension sur laquelle les partenaires peuvent inférer les intentions respectives. Afin d'examiner notre question de recherche, trois études ont été réalisées sous la forme d'expériences semi-contrôlées dans deux environnements de jeu multi-utilisateurs; l'un dans un monde virtuel 3D et l'autre dans l'environnement physique sous la forme d'une jeu géolocalisé.

La première expérience a ainsi montré comment la présence d'une interface de positionnement des partenaires n'aboutissait pas nécessairement à son utilisation. De manière encore plus surprenante, dans la seconde expérience, ce type d'interface a eu un effet inhibiteur sur la communication au sein du groupe et sur la mémorisation des positions passées des partenaires, rendant également les membres du groupe plus passifs que ceux n'ayant pas ce type d'interfaces. La troisième expérience a montré que la information relative à la position des partenaires n'était qu'une clé de coordination parmi d'autres. De plus, ces trois études ont mis en avant les divers rôles des interfaces de géolocalisation mutuelle comme source d'information pour la réalisation de ses propres actions, facilitatrice de la compréhension de la situation ou bien en tant que source d'hypothèses par rapport aux comportements futurs des partenaires. Nous avons aussi développé des représentations graphiques de la coordination afin de visualiser l'influence des interfaces de positionnements. Ces visualisations nous ont permis de représenter les effets négatifs mentionnés ci avant et de faciliter l'exploration de leur influence au cours du temps. De tels résultats permettent finalement de conclure sur l'automatisation de tels processus de géolocalisation mutuels et de ses effets négatif dans certaines situations.

Contrairement à la grande majorité de projets en interaction homme-machine qui tente d'optimiser la précision du positionnement et de sa représentation, ce travail vise à pondérer cet agenda de recherche en mettant en avant des effets inattendus sur les processus collaboratifs dues à ces technologies.

Mots-clés: coordination, TCAO, géolocalisation, processus cognitifs de groupes, positionnement de l'autre.

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Introduction

A: Hello!
B: Hi there
A: Eh, where are you?
B: I just stepped on the train
A: mmh okay, let me call you back when you reach your office
B: okay, bye

Excerpt from a mobile phone conversation

Each wave of technological development has often led to the expectation that the spatial environment would make less sense. Telephones, the Internet and mobile phone networks were supposed to remove the spatial dimension and eventually lead to a "flat world" (Friedman, 2005). Through real-time shared workspaces, massive multi-player games or always-on mobile phone connectivity, the discourse about the Internet and mobile phone networks fueled a vision that people could work, play, learn and socialize together despite geographical distance.

What the fragment of mobile phone conversation quoted above exemplifies is that such technologies do not necessarily hold this promise. Even though we have freed ourselves from spatial constraints through some technologies, our spatial environment is still meaningful and omnipresent in verbal interactions, as attested by the recurring "where are you?" question in mobile phone conversations. This knowledge of others' whereabouts – that we term **Mutual location awareness** in this thesis – appears to be pertinent for social interactions. In the aforementioned example, one can see that the giving of B's location enables the speaker A to (1) make an inference about B's non-availability to have a conversation, (2) adjust his behavior and hence propose to call later. This location formulation is therefore more than a social convention since it provides people with a basis on which they can act, make decisions and in the end, collaborate. That is, the knowledge that a person is located in a specific place makes sense to both parties involved in a social interaction.

Recent technologies not only allow the self-disclosure of one's location as in the above example, but also the automatic display of each others' locations, either in virtual environments or in the physical world. "Location-based services" or "location-awareness tools" detect the locations of users in virtual or physical environments and broadcast them to the others. As we will see in this thesis, CSCW (Computer Supported Collaborative Work) scholars and designers rapidly acknowledged the potential of these services and interfaces to enhance collaboration, which led to a surge of applications based on tracking people in the collaborative space.

Collaboration can be defined as a situation that involves two or more persons carrying out a joint activity. Dillenbourg (1999) characterized collaboration by focusing on three aspects: the situation, the interactions that occur and the cognitive mechanisms implied. Concerning the situation, collaboration implies a problem solving activity in which participants share common goals or interests which are the reason for their interaction: performing a task (this does not prevent them from having personal motivations and purposes). Collaboration also concerns the interactions, which take place between the participants; it implies communication, discussion and negotiation between them. Finally, it also refers to a mix of cognitive mechanisms that operate as in individual cognition. Since collaboration is a shared activity that involves individual cognitive mechanisms, scholars often use the term "distributed cognition" (Hutchins, 1995) to illustrate how the group can be thought of as a cognitive unit. This is also exemplified by a definition of Roschelle and Teasley (1995), which states that: "collaboration is a coordinated activity that is the result of a continued attempt to construct and maintain a shared conception of a problem". The notion of a shared understanding is the cornerstone of collaboration and the goal of CSCW has thus been to reduce the effort of maintaining a shared understanding of the situation and the participants' actions. This has led to the development of so-called "awareness tools" that were aimed at automatically supporting the construction of this shared understanding (Dourish and Belloti, 1992; Gutwin et al, 1995, Gutwin and Greenberg, 2002). Mutual location-awareness (MLA in the remainder of this thesis) is one of the elements that these awareness tools convey.

This thesis deals with **how collaboration**, as a specific type of social interaction, **may be influenced by location-awareness tools and interfaces**. Our purpose is to understand the affordances of spatial awareness for group behavior and to investigate how it impacts the group cognitive processes at stake in collaboration. This work thus belongs to the fields of cognitive sciences and computer science since we are interested in the effects of a technological artifact on cognitive mechanisms. Though it does not specifically address learning processes per se, our work also has consequences for Computer Supported Collaborative Learning (CSCL) since it addresses cognitive processes at stake in collaboration. The investigation of the effects of location-awareness on collaboration can be seen as a preliminary step to researching its potential learning processes.

We conducted different experimental studies based two platforms. They correspond to our interest in location-awareness that spans from virtual space to the physical environment. We therefore tackle the effects of MLA in both environments.

This thesis targets **objectives at three levels**, which are expected to be our three main scientific contributions of the thesis. The first one is **a basic research objective: to understand the role of MLA on collaborative processes** through controlled experiments. Our **second objective** is more **applied: to translate these results into a critical discussion of MLA in collaborative applications**. Finally, our **last objective is methodological**: analyzing collaborative activities in terms of log analysis is still problematic because there is no agreed format for log data and no readily available suites of analysis tools (Benford et al., 2002). Thus, this project aims to develop innovative and systematic methods of analyzing collaboration using visualizations.

We structured this thesis into eight chapters.

In Chapter 1, we define the notion of mutual location-awareness, as a subset of the CSCW concept of awareness. A basic premise of computer-supported collaboration is that the broadcast of information concerning participants can improve collaboration. We therefore review the different kinds of MLA tools and prominent results about their impacts on collaboration. In addition, this chapter expands our discussion about the importance of the spatial environment in the structuring of social and cognitive interactions.

Given that the purpose of this thesis is to understand the influence of a technological artifact on collaborative processes, we needed a theoretical framework to describe the relationships between awareness and group collaboration. As a consequence, Chapter 2 presents the model we used, namely that of Herbert Clark. This psycholinguistic framework defines collaboration as an exchange of “coordination devices”, information upon which participants are able to draw inferences about their mutual intentions.

In Chapter 3, we show how MLA can be seen as a peculiar type of coordination device that may influence collaboration. The chapter is geared towards the description of our research questions, the methodologies and the design choices of the studies we carried out. The underlying rationale of our studies is to compare the automation of location-awareness to situations in which participants disclose their location when they want.

Chapter 4 presents our first experiment that aimed at investigating the influence of MLA on collaborative processes in a 3D virtual world environment. We tested two modalities: the presence or the absence of an awareness tool that allowed participants to see in real-time the location of their partners in the virtual environment. Chapter 5 explores the same question with a second experiment in the physical environment using a location-based application running on a mobile device; it also expands our investigation by looking at a third modality: the past location of the partners. Because of the tremendous opportunity given by the advent of mobile computing, this experiment delved more deeply into the investigation of the relationship between location-awareness and collaboration. We explored how MLA affects communication and the exchange of coordination devices among partners at a more finely detailed level. Chapter 6, through a third experiment study, goes further by testing the influence of another coordination device and how it can change the use of the location-awareness tool.

Chapter 7 draws on our theoretical framework and the results of the second study to propose a model of coordination that can be graphically represented. We therefore use the model to depict visualizations of group behavior over the course of the experiments, which then allowed us to more thoroughly discuss how MLA affects the collaboration dynamic.

Chapter 8 discusses the results drawn from our experiments and visualizations, as well as their limits and the potential for further research. The chapter concludes with a critical discussion of how automating mutual-location awareness is not a simple issue and how automating it with awareness tools can lead to unexpected drawbacks.

Chapter 1 • Mutual Location-Awareness in Collaborative Situations

This chapter presents the object of our research: mutual location awareness interfaces and the roles they play in computer supported collaborative situations. It reviews the literature of existing interface systems and shows how locational awareness cues can impact group cognitive processes.

1.1 Awareness in CSCW

1.1.1 Definitions

The last twenty years of research in the field of CSCW acknowledges the relationship between collaboration efficiency and the visibility of group members' activities across time and space; namely enabling what has been called *awareness* by the research community (Dourish and Bellotti, 1992, Dourish and Bly, 1992; Gutwin et al., 1995).

Historically**, the notion of awareness has been drawn from two domains**. On one hand, it emerged from **field studies of collaborative work in co-present work settings** (Heath, & Luff, 1992; Heath and Hindmarsh, 2000), which focus on how workers systematically coordinate their activities by relying on changes in the local context as well as on their partners visible contributions. In this context, awareness is seen as the 'mutual visibility' of each other's actions, conveyed by the continuous broadcast of information generated during the course of action. Of course, as Heath and Luff (1992) point out, this mutual visibility/observability of actions relies on the active practice of team members who make their own actions 'visible/observable' to the others. On the other hand, the notion of Awareness appeared in **computer science**, as a concept relevant to design collaborative technologies (Dourish and Belloti, 1992; Gutwin et al, 1995, Gutwin and Greenberg, 2002). As opposed to the richness of a co-present situation, geographically dispersed collaboration engages participants in joint activities with a low visibility of each partner's contribution to the main goal of the group. This is why 'awareness interfaces' or 'awareness tools' have been designed to convey more visibility, showing group members representation and actions.

As stated by Schmidt (2002**), the term awareness is highly equivocal** in the sense that it is used in a lot of different ways and is often qualified by many adjectives like 'general awareness' (Gaver, 1991), 'workspace awareness' (Gutwin and Greenberg, 2002) or 'informal' or 'passive' awareness' (Dourish and Belloti, 1992). Definitions indeed range from knowing who is present in the environment to the visibility of others' actions (Heath and Luff, 1992). These limits, however, did not prevent the CSCW community from using the 'awareness' concept as the starting point for many original and innovative collaborative technologies. In this thesis, we will not enter into this debate about setting a proper definition but instead focus only on the awareness of people's location in a shared environment, be it physical or virtual.

Even though awareness is a broad and blurry concept, in the epistemological sense, there are some recurrent definitions set by scholars. Among all the terms that are used in conjunction with this notion of awareness, the one that has received the most important attention is certainly the "workspace awareness" that Gutwin and Greenberg (2002) describe as "*the up-to-the-moment understanding of another person's interaction with the shared workspace*" (Gutwin & Greenberg, 2002). More precisely, according to these authors, awareness refers to the perception of changes that occur in the shared environment. These authors also highlight that awareness is part of an activity, such as completing a task or working on something. The main objective of awareness is not only to perceive information but also to recognize the contextual elements required to carry out a joint activity. This is what Dourish and Belloti expresses by saying that awareness corresponds to: "*an understanding of the activities of others, which provides a context for your own activity*" (Dourish and Bly, 1992, p.107). These definitions emphasize the idea that awareness is meant to enrich the context of collaboration; they also implicitly state that maintaining awareness is not the purpose of an activity but instead a basis for completing the task.

1.1.2 Types of awareness

Starting from the previously described definitions of awareness, Gutwin and Greenberg (2002) differentiated **the core components of awareness** according to simple questions such as "**Who, What Where, When**". According to these authors, awareness can be described in terms of the period of time it covers, conveying information about the present state of the environment ("*synchronous awareness*") and or about past occurrences of events ("*asynchronous awareness*"), which corresponds to the "When" question. Table 1 describes the most important synchronous awareness information, which answer the "Who, What, Where" questions. The same table can describe asynchronous awareness, answering the same question for events that occurred in the past.

Table 1. Elements of Awareness related to the present (taken from Gutwin and Greenberg, 2002).

Category	Element	Specific questions
Who	Presence	Is anyone in the workspace?
	Identity	Who is participating? Who is that?
	Authorship	Who is doing that?
What	Action	What are they doing?
	Intention	What goal is that action part of?
	Artifact	What object are they working on?
Where	Location	Where are they working?
	Gaze	Where are they looking?
	View	Where can they see?
	Reach	Where can they reach?

In sum, awareness cues correspond to the different contextual elements defined by the questions presented in this table.

1.2 Roles of awareness

As we stated in the previous definition, awareness and awareness tools are not an end *per se*, but a set of means that enable the members of a group to share a context so that they can achieve their own actions more effectively. Awareness interfaces have been designed for fairly diverse purposes, and thus they are comparable only in the sense that they provide awareness information of some type. For example, we can discriminate an awareness for managing coordination in shared real-time workspaces (Gutwin and Greenberg, 1996, 2002; Espinosa et al., 2000) versus an awareness for contact facilitation for casual interaction (Isaacs et al., 2002). Considering how awareness is deployed in CSCW, Gutwin & Greenberg (2002) describe **five types of roles supported by awareness.**

First, awareness can be used to assist in the **management of coupling.** Coupling is tight when people are working closely together on an artifact. Loose coupling occurs when people are working somewhat individually, perhaps on different aspects or different artifacts/parts of the environment, but are more or less aware of what the others are doing. By allowing group members to know what a partner is doing with the appropriate awareness information, they can recognize when collaboration is possible, when they can present their work to a partner, etc. This is also what Hutchins and Klausen (1996) show in their study of collaboration in an airline cockpit: when the airline captain called the air traffic controller, the other members of the crew, who were also monitoring-the same radio frequency could overhear what was being said. This distribution of access to information to the crew allowed them to adjust their own actions or set the expectations of the crew members, which played a powerful role in coordinating individual contributions to the joint activity.

The second role of awareness interfaces is the **simplification of communication**: it facilitates, for instance, referential communication, the process by which a speaker indicates to his or her addressee what objects he or she is talking about (Krauss and Weinheimer, 1966). As pointed out by Gutwin and Greenberg (2002), deictic references (the practice of pointing or gesturing towards an object), visual evidences (for example looking for backchannel feedback) and gaze awareness (knowing where another is looking) allow this kind of referential communication. “What You See Is What I See” (WYSIWIS) tools have been designed in order to support this process when conversants are not co-present (see Stefik et al., 1987 for a discussion about that topic). Instead of describing or citing the object the speaker is referring to, the awareness tool displays the object. The addressee can then refer to what is being shown without discussing its positions or by using deictic gestures. For example, in order to study the effects of such awareness, Kraut et al., (2001) designed a system that allows a helper to monitor the activity of a worker repairing a bike.

Figure 1. (a) Worker wearing the collaborative system, (b) Display for the helper showing as video windows what the worker is looking and his eye gaze (taken from Kraut et al., 2001).

The device, represented in Figure 1a, allows the helper to see on a display what the worker is looking at and where is his eye-gaze as shown in Figure 1b. The advantage of such a device is that the helper does not have to ask the worker what elements he is touching or using since they are displayed on the screen.

Third, awareness **aids people** in the coordination of collaborative activity by setting the temporal and spatial boundaries of others' actions, which provide participants with resources for action. To avoid concurrency control problems, visual markers on shared documents, for instance, show that a partner modified the document or is currently changing its content, as shown on the webpage depicted on Figure 2. By informing partners about where the teammates are, what they have already done or what they intend to do, visual markers allow people to know how they can collaborate.

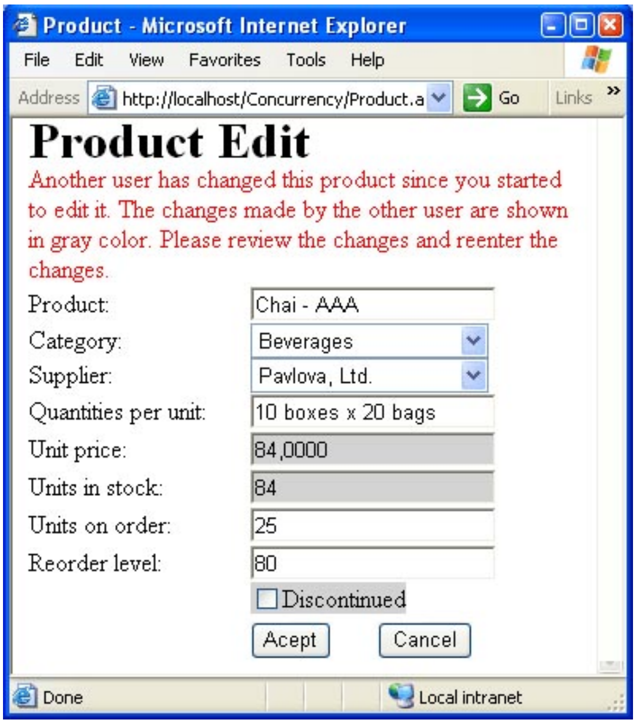


Figure 2. Avoiding concurrency control problems by showing the users that some changes are currently being made to a document. The grey fields are the ones edited by the partner (Example taken from a computer science course).

Fourth, awareness **supports inferences regarding the partners' intentions**. Anticipation and predictions are based on extrapolating from present situations. For example, from seeing that a partner is using an object, one can infer that this artifact is going to be used.

Finally, awareness can be employed **to know if a partner needs help and how**. Knowing what he or she has done, where he or she is and what he or she intends to do is useful in helping him or her to contextualize the interaction. For example, Hutchins and Klausen (1996) emphasized the importance of visibility of actions to check their coherence and help to detect the presence of errors. Overhearing others' verbalizations offered relevant cues to prevent or repair problems.

1.3 Mutual Location-Awareness

Among the different types of awareness cited previously, the field of CSCW shows a considerable amount of work on the "who" category, namely the awareness of persons present in the environment, which can be a mediaspace (Dourish and Bly, 1992), a 3D workspace (Dyck and Gutwin, 2002), a web-portal (Jan et al., 2000), or a mobile environment (Vogiazou et al., 2006). **The "where" category, that is to say the awareness of group members' whereabouts, received much less attention** (Dyck and Gutwin, 2001). In this thesis, we focus on what we call **Mutual Location-Awareness** (**MLA** hereafter): **the presentation of partners' position in the environment (be it virtual or physical)** conveyed through technological means. We will then speak of MLA interfaces or MLA tools. MLA can be defined as having the following properties:

- Mutual: we used this term to differentiate the knowing of one's own location to that of partners. By "mutual" we refer to knowing both one's and partner's location. This term also implies a notion of reciprocity. It means that a person A can be aware of her partners B and C's location, and that B and C also have access to that information (not necessarily in real-time).
- Location: the type of information conveyed by those interfaces is bound to locations in space. As we will see in Section 1.5 , what we mean by "location" can take different forms depending on how this information is conveyed.
- Awareness: tools and interfaces that support MLA are used to convey awareness of others in CSCW environments (be it mobile or desktop computing)

Our interest in mutual location-awareness is derived from research about the spatial environment and how its properties structure or afford social and cognitive interactions. MLA relates to space in the sense that it allows for the articulation of the location to others and of spatial features such as topology or environmental infrastructure.

1.4 How space influences cognition and interactions

This issue has been tackled by various disciplines ranging from environmental psychology to sociology, architecture and human-computer interaction when technology is involved. This section summarizes some important notions and results arising from these fields.

1.4.1 The distinction between space and place

A recurrent discussion concerning spatiality targets the differences between the concepts of "space" and "place". Harrison and Dourish (1996) indeed advocated for talking about **place rather than space**. They claim that even **though we are located in space, people act in places**. This difference opposes space defined as a range of x and y coordinates or latitude/longitude to the naming of places such as "home" or "café". By building up a history of experiences, space becomes a "place" with a significance and utility; a place affords a certain type of activity because it provides the cues that frame participants' behavior. For instance, a virtual room labeled as "bar" or "office" will trigger different interactions. In a sense, it is the group's understanding of how the space should be used that transform it into a place. Space is turned into place by including the social meanings of action, the cultural norms as well as the group's cultural understanding of the objects and the participants located in a given space. However, as Dourish recently claimed, this distinction is currently of particular interest since technologies pervade the spatial environment (Dourish, 2006). This inevitably leads to the intersection of multiple spatialities or the overlay of different "virtual places" in one space.

Thus, MLA also relates to how people make sense of a specific location: depending on the way the location of others is described, it could lead to different inferences. For example, knowing that a friend is at the "library" (place) frames the possible inferences about what the friend might be doing there.

Additionally, **partitioning activities** is another social function supported by spatiality (Harrison and Dourish, 1996). For example, in a hospital, corridors are meant to be walked in to go to waiting rooms where people wait before meeting doctors who operatein operating rooms. Research concerning virtual places also claims that a virtual room can define a particular domain of interaction (Benford et al. 1993). Chat rooms, for example, are used to support different tasks in collaborative learning: a room for teleconferences and a room for class meetings (Haynes, 1998). Different tasks correspond to virtual locations: a room for meetings related to a project, office rooms related to brainstorm, public spaces related to shopping and so on. Fitzpatrick et al. (1996) found that structuring the workspace into different areas enables people to switch between tasks, augments group awareness and provides a sense of place to the users as in the physical world. Since work partitioning can be supported by space, knowing others' whereabouts is an efficient way to make inferences about the division of labor in a group. Once we know that a person is in a particular place, we can infer that he or she is doing something (as we saw in the distinction space/place) and how this may contribute to the joint activity.

1.4.2 Person to person relationship in space

A large amount of research about how spatiality shapes one's behavior has focused on co-present settings since it is the most recurrent situation of our lives. The best-known example of how space structures social interaction is **proxemics**: **the distance between people is indeed a marker that expresses the kind of interaction that occurs**, and reveals the social relationships between the interactants (Hall, 1966). Depending on the distance, Hall proposed four kinds of spheres (intimate, personal, social and public) that each affords different types of interactions. His point was also to show how these interactions are culturally dependent and how distance constrains the types of interactions that are likely to occur. The perception of the "others" in space thus communicates to participants as well as to observers the nature of the relationships between the interactants and their activity. Studies of 3D worlds show that proxemics are maintained in virtual environments (Jeffrey and Mark, 1998; Krikorian et al. 2000). These authors found that, even in virtual worlds, a certain social distance is kept between participants' avatars. They noticed how spatial invasions produced anxiety-arousing behavior (like verbal responses, discomfort and overt signs of stress) with attempts to re-establish a preferred physical distance similar to the distance observed in the physical world.

Proximity has also proved to improve various processes like **conversation initiation**. Communication is easier in physical settings than in mediated contexts. The physical environment increases the frequency of meetings, the likelihood of chance encounters and therefore community membership and group awareness, thanks to informal conversations triggered by repeated encounters (Kraut et al., 2002). Furthermore, distance between people has an important influence on friendship formation, persuasion and perceived expertise (Latané, 1981). Latane shows that people are more likely to deceive, be less persuaded by and initially cooperate less with someone they believe to be distant.

1.4.3 Person and artifacts relationships

Another topic the literature about spatiality addresses is the **relationship between people and artifacts located in the vicinity of the participants of a social interaction**. Indeed, when a speaker talks about an object to his hearer, they are involved in a collaborative process termed **referential communication** (Krauss and Weinheimer, 1966). As a matter of fact, the practice of pointing, looking, touching or gesturing to indicate a nearby object mentioned in conversation is essential to human conversation; it is called **deictic reference**. This spatial knowledge can be used for mutual spatial orientation. Schober (1993) points out that it is easier to build mutual orientations toward a physical space (versus a shared conceptual perspective) because the addressee's point of view is more easily identified in the physical world. There has been very little research focusing on referential communication in virtual space. Computer approaches, like "What You See Is What I See" have been designed in order to support this process but studies show that such tools are not as powerful as deictic hand gestures (Newlands et al., 2002). The authors found fewer deictic acts in computer-mediated interaction; a possible reason for that can be the lack of adequate tools. Researchers, for example, attested that it is actually more difficult to see where avatars are pointing in a 3D virtual environment compared to the real world (Fraser et al., 2000). Consequently, if we think about the role of MLA, knowing the location of others can allow one to make sense of deictic acts and promote referential communication. By projecting oneself to the known partner's location, one can infer meaning from the deictic references.

Moreover, **how the spatial environment is used in abstract cognition** is a fundamental issue addressed in cognitive psychology (Kirsh and Maglio, 1994; Kirsh, 1995). These authors explain to what extent space between objects and people is used as **a resource in problem solving**. According to them, actions like pointing, writing things down, manipulating artifacts or arranging the positions and orientations of nearly objects are examples of how people encode the state of a process or simplify perception. Studies in virtual environments have shown similar results concerning the use of tools in space (Biocca et al., 2001). Biocca explores how people organized virtual tools in an augmented environment. Users had to repair a piece of equipment in a virtual environment. The way they used virtual tools showed patterns of simplifying perception and object manipulation (for instance by placing reference material like a clipboard well within the visual field on their right). MLA should then be seen as another set of resources to augment cognitive processes such as memorization or problem solving.

What is also interesting with regard to human activity is the notion of **social navigation** (Dourish and Chalmers, 1994), which refers to **situations in which a user's navigation through an information space is guided and structured by the activities of others within that space**. Social navigation can be defined as "*navigation towards a cluster of people* or *navigation because other people have looked at something*" (Munro et al., 1999, p. 3). This refers to the notion of "social space" inferred from the traces left in the environment (virtual orphysical) by people's activity. As a matter of fact, we all leave signals insocial space that can be decoded by others as traces of a previous use: fingerprints, crowds, footsteps, graffiti, annotations and so on. From these cues, other persons can infer powerful things: others were here, this was popular, where can I find something, and so forth. This process takes place in both virtual and physical settings through recommender/voting systems or collaborative filtering. The most known example of such filtering is the Amazon's recommendation system, which gives us pointers on books that may interest us based on others' previous purchases.

1.4.4 The importance of territories

When dealing with people and location, the fundamental use of space concerns human **territoriality**. It reflects the **personalization of an area to communicate ownership**. Territories as specific context support social roles among a community (Prohansky et al., 1970). Therefore, the meaning of a particular place is endowed through its exclusive use. Each place thus corresponds to a set of allowed behaviors. There is a strong inter-relation between group identity (feeling that we belong to a larger human group) and spatial identity (based on our habits, experience and knowledge about the environment). Jeffrey and Mark (1998) found that territoriality was an important feature in the context of virtual worlds. For example, building one's house in Active World is a way "*to provide a territorial marker and provide a feeling of ownership for the owner*" (Jeffrey and Mark, 1998, p. 30). Furthermore, it seems that people build their house in existing neighborhoods rather than in uninhabited places.

Additionally, territoriality could be defined as **a way to achieve and exert control over a segment of space** (Prohansky et al., 1970) and then to maintain and achieve **a desired level of privacy**. According to Minami and Tanaka (1995, p45), "*group space is a collectively inhabited and socioculturally controlled physical setting*". The activity then becomes a group activity in terms of interactions with and within space as well as a control to the degree of space maintaining.

Another concern linked to the topic of human territoriality deals with the visibility and the permeability of its boundaries. There are not only fixed and impermeable community perimeters (closed by walls for instance), but also invisible temporary group territories. Small conversing groups in public places are an interesting example: fixed barriers are replaced by what Lyman and Scott (1967) call "*social membranes*". Knowles (1973) studied which factors affect the permeability of those invisible boundaries. Using spatial invasions, he showed that people tend not to invade other group territories even if they are in a public space or path (Knowles, 1973). Furthermore, Cheyne and Efran (1972) found that group spaces feel invaded if the boundaries become fuzzy or if the distance among group members becomes large. If this distance is above four feet, the boundary becomes ineffective and passers by begin to walk through the group. Space thus models group interaction. Agreements on spatial territory (Lyman and Scott, 1967) or the closeness of members (Cheyne and Efran, 1972) are examples of rules that govern group interaction.

1.4.5 Space and mobile communication

It is certainly through the use of mobile communication that we experience the importance of space in interactions. The advent of mobile telecommunication indeed created new techno-social situations such as the possibility of being in contact with people in a large number of locations (the phone number was no longer related to a specific place). As we have seen in our introduction, one of the most common features of these conversations **is the giving of a geographical formulation as part of an opening of a phone call**. A number of scholars recently focused on this process:

Laurier, 2001; Green, 2002; Cooper, 2002; Relieu, 2002; Arminen, 2003; Weilenmann, 2003.

Relieu (2002) explained that asking the other’s whereabouts is **a common social norm** in terms of Goffman’s rites of interaction (Goffman, 1959). It happens during three “location events": when asking or giving one’s location at the beginning of the phone interaction, when giving one’s location at the end of the phone interaction or during conversations dedicated to location. Weilenmann (2003) also claimed that the location formulation might **be a strategy to give the caller a chance to end the conversation**.

In an ethnographic study about mobile phone conversations, Arminen (2005) intensified the investigation of such phenomena. He described the **three distinct “social functions” of location**: (1) to **address the interactional location** (availability of the answerer, conditions of the discussion), (2) to **negotiate a practical arrangement** and (3) **to bring a socio-emotional content** as described in more detail in Table 2. As one can see, the location of conversationalists seems to be commonly relevant but it is more relevant depending on the activities each party is involved in. Arminen states that location is not very often discussed but that the inferences drawn from location are meant to negotiate further actions and coordination issues.

Table 2. The social functions of location for mobile communications (drawn from Arminen, 2005).

Location	Function of location
I Interactional availability	– audio-physical and social features of proximal location: noise (disco), network availability (train, remote areas), involvement with proximal interaction, intimacy of situation (toilet, etc.)
II Praxiological	– spatio-temporal availability: readiness to engage in action (Are you doing anything special? Can you come to x?) – spatio-temporal location of a party vis-a`-vis the engaged activity: temporal distance (half an hour [by car, by train, on foot, etc.]) – real-time perspicuous location in an ongoing action: visibility (I’m at x where are you), real-time location (I just saw a reindeer by the road, beware—[told to the car driving behind]) – instructable location: spatialized requests (I’m/accident at the crossroads of A and B, etc.) – proximate praxiological location: microco-ordination of activity (I’m feeling his pulse, the wound stretches from elbow to breast, etc.) – virtual location (I’m on the web page x)
III Socioemotional	– socio-emotional significance of location: biographical relevance (I’m at the cottage of x/my friend, I’m driving car with x), cultural significance (I’m visiting x (old church, museum, medieval city, etc.), aesthetic significance (it’s very scenic here)

Weilenmann (2003) found in her analysis of recorded mobile phone conversations, that location was relevant in planning a future meeting. Thus, giving one’s location is useful for group coordination of meetings. The location is made relevant by the activities parties are involved in as formulated by Arminen (2005). For instance, joint activities make spatio-temporal location, such as distance in minutes from the meeting point via the vehicle used.

Besides, drawing on ethnographic studies of mobile workers, Laurier (2001) pointed out that these “locational formulations” allow dispersed cell phone users to **mutually establish and share a spatio-temporal context**. The answerer’s locational formulation seems to set up a mutual appraisal of his/her context. Green (2002) added that it also serves to establish relationships of "mutual accountability" and trust: "*monitoring of location and activities in this instance serves both to cement personal or intimate relationships and to make an individual's activities transparent, visible and accountable to both co-present and tele-present others*" (Green, 2002, p. 32)

Moreover, giving one's location also seems to **orientate the content of the message as well as privacy** issues as found by Cooper (2002): "*information on whereabouts often serves to establish the grounds for the conversation in terms of constraints and sensitivities with regard to possible topic, privacy duration and so forth*" (Geoff Cooper, 2002, p. 26)

1.4.6 Conclusion

The term "space" does not only refer to the topological and geometrical constraints of the environment, nor to the elements that constitute a place. **Spatial features like distance between people or the repartition of objects in the environment are affordances to structure actions and interactions** between partners of a team. They indeed act as visual markers of possible interactions with a person or an artifact, cues to draw inferences or information to rely on to make a decision.

This has led researchers and designers to insist on the importance of taking space into account in CSCW (Spinelli et al., 2005). The environment in a various ways shapes coordination of action:

- environmental constraints (such as corridors and doors) leading to 'channelling' and harmonisation of activity;
- conversely, the complexity of the environment (enclosure, lack of a clear view, physical obstacles and dead-ends) providing impediments to regular and coordinated action (such as moving in a straight line);
- familiarity with the environment and its configuration providing cues to coordination (e.g. well-known landmarks);
- ability to display aspects the environment through external representations such as maps and routes, providing an essential background to a location-awareness tool (a map for annotation) and aids to group coordination.

Therefore, we consider Mutual Location-Awareness conveyed by interfaces or disclosed in communication, as an essential type of spatial feature that influences collaboration. Before focusing on these impacts, let us describe how tools and interfaces support MLA in CSCW.

1.5 MLA tools classification

1.5.1 Criteria for a classification

There is **no established classification of the MLA tools**. Nevertheless, according to Jones et al. (2004)'s framework of location-based and social applications, three characteristics are prominent: the focus of the service (people or place), the content of the awareness (absolute location, relative location or proximity) and the time-span (present versus past, which has been referred to as synchronous versus asynchronous). These characteristics constitute a starting point for developing our own classification of MLA tools. Based on Jones' framework**, we determined five criteria for the classification of MLA tools**, as represented in Figure 3:

- The **mode of capture of users' location**, which can be self-disclosed (user initiative) or automatically captured with different degrees of accuracy. For example, the user can be asked to send his or her own location so that it can be displayed on the contacts' lists of his or her partners.
- The **way location is described** (and/or stored by the system) includes two aspects: the **position** and the **referential**. Position could either be discrete (such as place names) or continuous (coordinates in a 2D or 3D space). This corresponds to the space/place distinction we discussed earlier. Of course, there is a need to have a referential, which can be the physical environment, a virtual world or a document.
- The **mode of retrieval**: user can access information about others' location in space **upon request** or by receiving it **automatically** (if the application is opened). If the retrieval is based on the user's initiative, it can be based on two focuses: the user can look for information about people ("Display my friends location") or look who is located in a specific place ("Who is in that room"). This is what Jones et al. (2004) described as a people or place focus.
- The **scope of retrieva**l: whether MLA is **geographic** (representation of the proximity or the whole space), **social** (displaying everyone or only specific contacts such as friends) **or bound to a specific period of time**. This last characteristic corresponds to the different between synchronous (information about real-time position in space) and asynchronous MLA (information about real-time and post position in space).
- The **format of delivery** is twofold. First, the **location referential** can be **absolute** (a place or location coordinates) or **relative** (indication that a friend is close to you for instance). Second, the final **format of display** can be **verbal** (name of a place), **symbolic** (shown as a symbol), or **geographic** (depicted on a map metaphor). Since position capture is sometimes very sporadic, some interfaces also report the time of the capture.

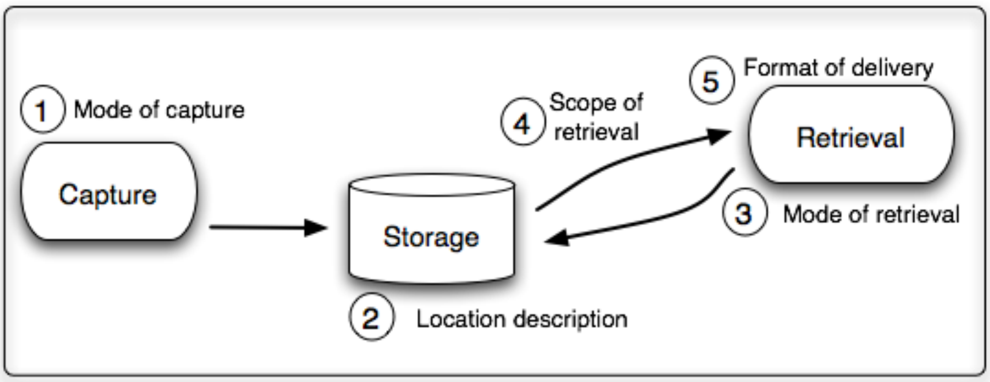


Figure 3. Five criteria to describe MLA interfaces.

As shown on this figure, the first step is about how one's location is determined and made available to the others. Step 2 corresponds to how location is described and stored. The third step concerns how this information is consumed (requested and used). Step 4 consists in parameters for retrieval and search to achieve step 3. The fifth step is further data formatting for delivering the location information.

In the following sections, we review the most relevant MLA tools both in virtual and ubiquitous computing applications. This list should not be considered as exhaustive but rather as a way to illustrate the different types of interfaces defined by the criteria we give above. To do so, we chose to present them using the last criteria: the format of delivery to the user.

1.5.2 Verbal and text-based description

The simplest form of MLA is a verbal or text-based description of the place (or the spatial position) where a person is located. Of course, this is often an explicit disclosure of one's location in space by cell phone (audio communication, audio message or SMS), e-mail or Instant Messaging. Alternatively, MLA can be conveyed verbally by various systems, which automatically capture the user's position (either in virtual or physical space) and display it to the partners with a short sentence, such as a place name.

An example of such MLA interface can be found in MOOs, usually employed as a social platform to play, work or learn in the 90s. MOOs are a particular form of a MUD (Multi-User Dungeon) with an object-oriented programming interface that engages users in a text-based representation. Interactions with this kind of virtual environment are achieved through text commands (inputs) and textual descriptions (outputs) as shown on Figure 4, which represents a MOO client snapshot (tk-MOO light). In this example, one can see at the top of the window the description of the current location: the current user sees that he is in "The Laboratory" with two individuals called "Oad" and "Dao" and that there are different exits.

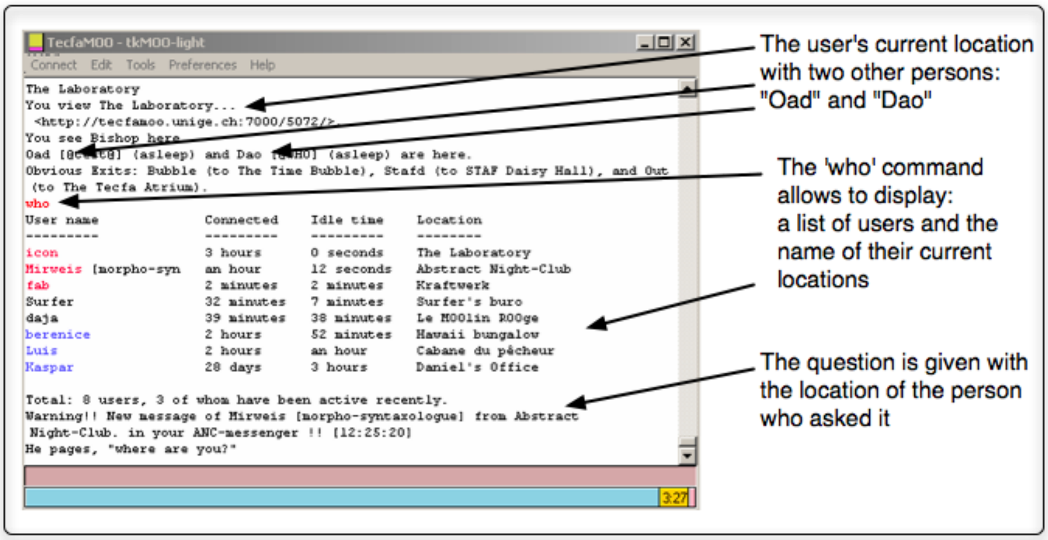


Figure 4. The MOO environment accessed through a MOO client (tkMOO-light). The "who" command triggered the display of a list presenting who is where in the environment. The question asked by the player "Mirweis" is given with the location of this character: "Abstract Night Club".

Two features support MLA in this environment. Typing the command 'who' allows for the retrieval of information about his/her partner: connection and idle time as well as location in the MOO world. In addition, when a partner (called Mirweis in this figure) sends a message, his location ('Mystery House') is embedded in the message. Conversely, in massive multiplayer on-line role playing games (MMORPG) like Everquest, a special command can be issued so that players can see which of their friends are logged on and where they are in the game space.

Many instant messenging (IM) clients such as Trepia or Meetro[1] - also display a verbal description of location (see on Figure 5). Trepia provides an MLA feature to an IM client: it asks the user about his or her own location (which should be verbally described) and contacts are notified about it directly in the buddy list. Meetro is slightly different because it is based on an automatic recognition of the users' location (by comparing the user's MAC address of wireless access points to a database of known access points): the user has to confirm the detected location or to give it if the system is unable to find it. The contact list is then classified according to the proximity of friends (within a mile, within 5 miles). Clicking on a user allows one to see his or her precise place.

[1] http://www.meetro.com

Figure 5. Two IM clients with MLA features: (left) Trepia, (right) Meetro. Both display the location information of the contact list. Trepia asked the user for his location and displayed it under the username in the contact list of others. Meetro automatically detects the presence of friends and displays them with regards to different levels of proximity.

Similarly, a simple form of MLA is provided by StickySpots, a location-based messaging system that enables household members to exchange short messages from various places in their home (Elliot, K., Neustaedter, C. and Greenberg, 2006). Instead of having an IM client, this system, which is scenario-based, enables people to create a note in context, send it and it appears on a receiving display in the form of a small post-it with the message preceded by its location. What people do is that they send the message to a location rather than a person. That is, they use their knowledge of people's routines to direct messages to locations that they will be at, so they will be read at the appropriate time/moment/context.

This text-based type of description of partners or friends' location are also a solution proposed by MLA applications running on mobile devices. The Hummingbird (Holmquist et al., 1999) is an early prototype of location awareness on a pager. As represented in Figure 6, it detects the proximity of other Hummingbird users and shows that "b" is in the vicinity. This application is a presence-awareness tool since it displays only who is in the area but it can be considered as a primitive form of MLA interface.

Figure 6. The Hummingbird display, showing that it detected the presence of devices b and d in the vicinity. The arrow indicates that “d” was the most recent detected.

The Clicmobile service[2] allows a user to send his or her position as text and the system replies with the friends and friends-of-a-friend’s positions in the vicinity (10 blocks) as shown on Figure 7a. The Finnish system Hunaja[3] is similar but provides the user with the position of users only in a small building through SMS exchange (contacts are tracked through RFID tags only in the building). Unlike Hunaja or Clicmobile, which rely on an active model (the user has to send his or her’s position to get the contact’s ones), Jaiku[4] is more passive: the information about others’ whereabouts is displayed as a line in the phone book updated in real-time (see Figure 7b).

Figure 7. Displays of two MLA interfaces on cell-phones: (a) Clicmobile: MLA based on verbal description of location, (b) Jaiku: MLA a one-line description in the phone book.

Some MLA systems that rely on explicit definition of one’s location are referred to as place-based annotation systems. For instance, GeoNotes (Espinoza et al., 2001) is another example of text-based MLA. GeoNotes is a PDA-based application that enabled users to leave short written messages attached to specific location. It conveys asynchronous MLA in the sense that messages are the traces of the passage of a known person at a specific location.

In sum, verbal forms of MLA, often in both mobile and fixed settings, can be **either conveyed explicitly by the user or captured by the system**. When automatically

[2] http://www.clicmobile.com
[3] http://www.aula.cc/hunaja/
[4] http://www.jaiku.com

captured, it can be sent to the users upon request or when a certain event occurs (like entering the same place).

1.5.3 Symbolic description

A second form of MLA representation consists in **displaying people's location as a symbolic representation with "place descriptors"** as in the Microsoft's Whereabouts clock shown in Figure 8 (Sellen et al., 2006).

Figure 8. Microsoft's Whereabouts clock's prototype depicting family members' location for one day. The discrete locations that have been chosen for this prototype are: "home", "work", "school".

Designed for the context of the kitchen, this MLA interface displays family members, essentially for family activities coordination (e.g. planning a meal, knowing whether someone is on his way to home). The clock metaphor is used to provide coarse-grained information such as "home", "school" or "work" and no precise position, which can be irrelevant in the context of the use of this artifact. In this example, information about others' whereabouts is automatically provided by SMS that are sent to a family member when one of them moves from one registered zone ("work" for instance) to another registered one (such as "home"). A similar project by Fahlén et al. (2006) also displays people's position with a similar artifact but the time component has been added: a knob allows one to see the past location (captured through GPS reporting and radio beacons scanning) and the planned location proposed by the users.

What is also noticeable in both projects is that MLA is conveyed without any geographical representation. Location is divided into discrete categories, which are supposed (or designed) to be meaningful for the user and the granularity of these categories is loose and provides a context to family members. For instance, in the Clock device, since the MLA is mostly meant to support family coordination, there was no need to show detailed information about work room positions.

These projects illustrate **the difference between space and place** we already mentioned: the location conveyed by them is related to people's places rather than spatial coordinates. The designers indeed chose the locations that make the most sense from a socio-cultural standpoint such as work, school or home.

1.5.4 Proximity MLA

The third type of MLA interfaces is based on **the RADAR paradigm** (Radio Detection And Ranging) that displays persons or artifacts present in the vicinity. As a recurrent representation for locating objects in the physical world (air traffic control, military applications), this paradigm inspired virtual space versions. The simplest examples come from the field of computer games in which RADAR views are very common as depicted on Figure 9: they are deployed as separated window or overlaid on the game screen.

Figure 9. Two examples of RADAR views in computer games: (a) The Quake II Radar shows the items, participants and ammunitions available in the area, (b) The Quake II radar that can also be overlaid on top of the display window.

This type of MLA interface has a relative format of delivery (that we could call proximity awareness), since some elements remain hidden (those which are not in the vicinity). Moreover, even though the "Radar view" displays the positions of participants, it does not provide the users with a representation of spatial features like topography or position of area boundaries (apart from circles than indicates distance to the user). The representation is limited to a small portion of the space and is only directed towards the presence of objects and people in the area. The equivalent of the Radar view in pervasive computing applications can be illustrated by the application Jabberwocky used in the "Familiar Stranger" project from Intel Research (Paulos and Goodman, 2004). The authors created a mobile phone application that displays the proximity of familiar strangers (i.e. the person you often come across but you don't know) as shown on Figure 10. The projects presented here do not reveal the identity of users in the vicinity, but this is not an intrinsic feature of Radar views; one could design non-anonymous radars.

Figure 10. Display of Jabberwocky, providing a quick way to visualize the current and past strangers encountered. Newly encountered strangers appear at the top of the screen as red squares. As time elapses, the strangers slowly move down towards the bottom of the screen. Once they reach the bottom they slowly fade out.

1.5.5 Map MLA

Slightly related to the Radar paradigm, is the mapping of participants' position on a representation of the environment in the form of a map. The difference between this type of MLA and the Radar is that in this case, **the environment is depicted** and not the sole elements in the vicinity. This solution is the most common in pervasive computing, 3D virtual games and shared workspaces. Mobile computing applications (on PDA or cell phones) offer a peculiar situation since there is a direct mapping between the physical environment and the information displayed on the device.

Two very well known examples of such MLA interface are the "Active Badge" system and the "Active Campus" application depicted on Figure 11.

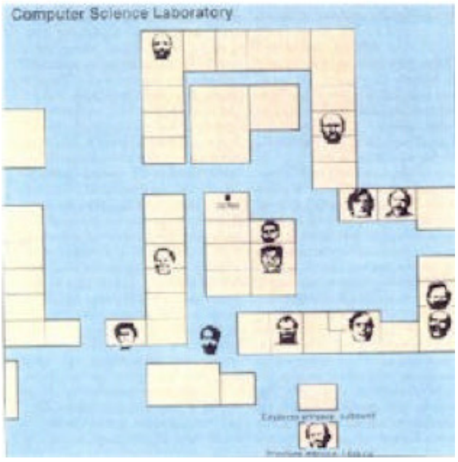


Figure 11. Two examples of reduced maps MLA: (a) Active Badge running on a desktop computer, (b) Active Campus running on a PDA.

The seminal radio-based tracking application Active Badge (Want et al., 1992) showed people's positions in the physical environment on a desktop computer display and Active Campus (Griswold et al., 2004) expanded this idea at the campus level. Both proposed a reduced version of the environment with people's location superimposed on top of it; Active Badge, as a desktop application could show the whole environment on a map whereas Active Campus required users to scroll on the map.

This sort of MLA interface is prominent in location-based games such as BotFighters (Hoff et al., 2002) that shows the whole environment on the small display or Can You See Me Now? that only depicts small part of the environment (Benford et al., 2006), as depicted in Figure 12.

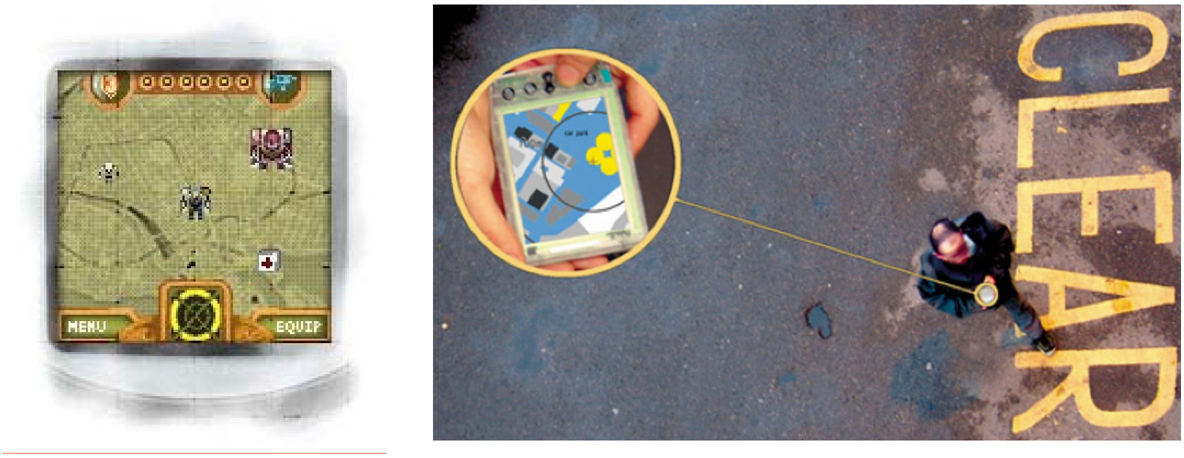


Figure 12. Two examples of MLA interfaces in location-based games: (a) BotFighters 2, showing the entire environment, (b) Can You See Me Now, showing a part of the environment, where the user is currently located. The game allowed to zoom between a global view of the gameplay zone and a close-up (local view), that centered on their current player's position.

The map approach has also received some attention by researchers who designed awareness features in shared workspaces such as multi-user text editors. In this case, there is a correspondence between the shared environment and the map. Figure 13 shows how Greenberg et al. (1996) proposed an overview of a document with elements that represent where the other people are looking, which corresponds to their positions in the shared document. The "telepointer" is a variation on this type of MLA interface: a small cursor, which tracks the location of the other user's mouse as they move around the window (Gutwin et al., 1996).

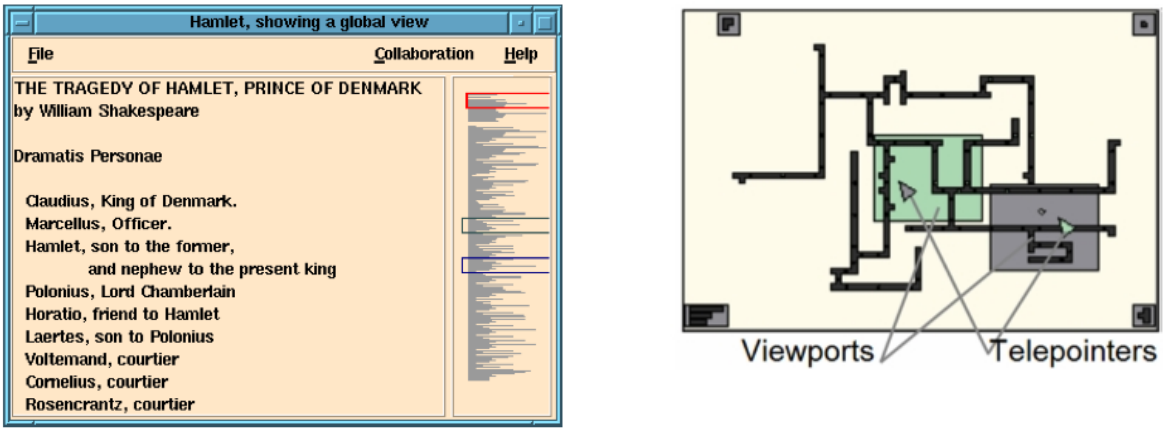


Figure 13. Two examples of awareness features on a shared workspace: (a) a map MLA interface corresponds to what is called "Radar view": the miniature on the right shows the entire document with viewports of participants overlaid as colored boxes, (b) telepointers: a small cursor that consists in the view of the partner's mouse cursor in the document (Gutwin et al., 1996).

Finally, "map" MLA interfaces also propose a decay function that represents the past position of persons in space. For instance, "Areacode" is a SMS mapping system designed to reveal personal memories and the hidden histories behind 5 key sites in Manchester city centre. The website allows the users to get a map such as the one pictured on Figure 14a, which shows an asynchronous MLA since it depicts the past positions of people. These past positions are connected and represented as a path, as seen on this map.

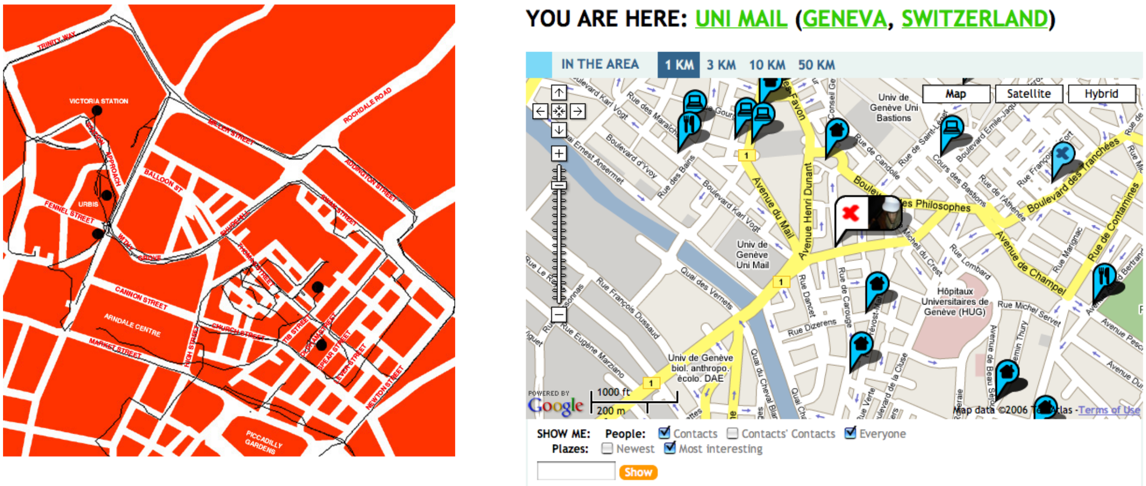


Figure 14. (a) Areacode map interface, showing the path of participants: an asynchronous MLA, (b) Plazes interface showing how the system proposes different ways of location-awareness (verbal description, map position, proximity of contacts).

1.5.6 Combinations of representations

Some MLA applications combine several of the features presented in the previous paragraphs. Plazes[5], for instance, is a web service that shows the user his or her position in the form of a verbal description and a position on a Google map as represented on Figure 14b. The map scale can also be modified so that users can see who is in the vicinity. Plazes automatically detects the users' location by scanning the MAC address of wireless access points and by comparing them to a database of known access points. If a location is not recognized, the user is required to set it. In both cases, it is possible to name the location in the users' terms. A recognized location, along with a description given by the user is then called a "plaze". Once a "plaze" has been recognized by the system, it is displayed on the map (as shown on the figure below) with contacts or "plazes" nearby. An additional feature allows the use of a different range of location information retrieval: one can search for specific "plazes" or contacts that can then be displayed on the map interface.

1.5.7 Conclusion

Given the characteristics of MLA systems described at the beginning of this review**, we have categorized all the systems presented according to the five criteria described** in 1.5.1. As we have mentioned, this list of systems is not exhaustive, we

[5] http://beta.plazes.com

rather selected the most representative systems that show the diversity of design choices.

Table 3. MLA interfaces classification according to the criteria.

Systems	**Mode of capture**	**Information type**		**Mode of retrieval**	**Scope of retrieval**		**Format**	
		Position	**Referential**		**Query**	**Time frame**	**Reference**	**Display**
Moo	Auto	Place name	Virtual Environment	Upon request / Auto with a message	Social	Synchronous	Absolute	Verbal
Trepia	User	Place name	Physical environment	Auto	Social	Synchronous	Absolute	
Meetro	Auto/user	Place name	Physical environment	Auto	Social	Synchronous	Absolute	
Sticky Spots	User	Place name	Physical environment	Auto	Social	Synchronous-Asynchronous	Absolute	
Humming-bird	Auto	(x,y) coordinates	Physical environment	Auto	Geographic	Synchronous	Relative	
GeoNotes	User	Place name	Physical environment	Upon request	Social and geographic	Synchronous-Asynchronous	Absolute	
Hunaja	Auto	Place name	Physical environment	Upon request	Social	Synchronous	Absolute	
Dodgeball	User	Place name	Physical environment	Auto	Geographic	Synchronous	Relative	
Jaiku	User	Place name	Physical environment	Auto	Social	Synchronous	Absolute	
MS clock	Auto	Place name	Physical environment	Auto	Social	Synchronous	Absolute	Symbolic
Fahlen clock	Auto	Place name	Physical environment	Auto	Social	Synchronous-Asynchronous	Absolute	
Quake 2	Auto	(x,y) coordinates	Virtual Environment	Auto	Geographic	Synchronous	Relative	Proximity MLA
Jabberwocky	Auto	Place name	Physical environment	Auto	Geographic	Synchronous	Relative	
Active Badge	Auto	(x,y) coordinates	Physical environment	Auto	Geographic	Synchronous	Absolute	Map MLA
Active Campus	Auto	(x,y) coordinates	Physical environment	Auto	Geographic	Synchronous	Absolute	
Botfighters	Auto	(x,y) coordinates	Physical environment	Auto	Geographic	Synchronous	Relative	
CYSMN	Auto	(x,y) coordinates	Physical/ Virtual Environment	Auto	Geographic	Synchronous	Relative	
Telepointer	Auto	(x,y) coordinates	Virtual Environment (shared editor)	Auto	Geographic	Synchronous	Absolute	
Areacode	User	(x,y) coordinates	Physical environment	Auto	Geographic	Synchronous-Asynchronous	Absolute	
Plazes	Auto/user	Place name / (x,y) coordinates	Physical environment	Auto	Social and geographic	Synchronous-Asynchronous	Absolute	Mixed

Based on the content and the mode characteristics, we can graphically map the MLA interfaces we reviewed (Figure 15). The mapping is not a measure of the quantity of systems in each of the quadrant, it only provides **examples of prominent systems**. The horizontal axis represents the scope of retrieval: is it about knowing where is a person (people-centric)? About knowing who is in a small portion of space (place-centric)? or about knowing who is in the whole environment (space-centric). As for the vertical axis, it represents the user's degree of proactivity in capturing his or her own location (detected by the system or explicitly disclosed by the user) and in getting the contacts' whereabouts (automatically sent by the system or on-demand by the user).

From a commercial standpoint, MLA interfaces are present in instant messaging applications, “location-based services” and “mobile social software” which received a very important amount of attention in the last few years.

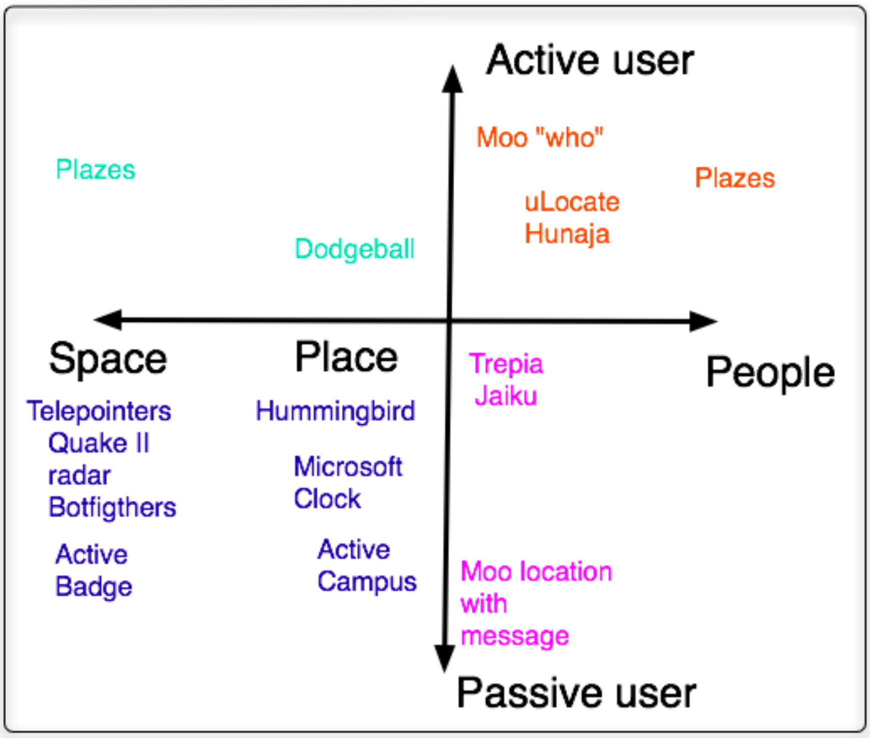


Figure 15. Mapping of the reviewed MLA interfaces according to the scope of retrieval (horizontal axis) and mode of retrieval characteristics (vertical axis).

In addition, while most of the applications that include MLA interfaces are stand-alone systems (Dodgeball, Plazes, Microsoft Clock), some are included as features in existing applications (Radar view in video games) or as new layers that can be interconnected with other systems (like Trepia or Meetro which are multi-protocols IM clients). Some commercial products are indeed more innovative than prototypes developed by academic researchers; proposing new interfaces that result in new research questions. Plazes, for example, combines different types of MLA interfaces and has different levels of implications for the user.

In many of these systems, the main function of MLA is social matching between persons who do not know each other but share similar interests (for business or dating reasons). The underlying hypothesis is that there is matching between locations and interests, mediated by activities (Eagle and Pentland, 2004). And, of course, invaluable to the CSCW community, MLA is also seen as an important source of information for coordination; either in informal contexts (rendezvousing in a city) or more formal joint activities (military missions or air traffic control). As one can notice, the types of activities in which MLA interfaces are deployed are very simple from the collaborative standpoint; our experiments will also be focused on simple tasks.

In the context of this thesis, we are interested in the relationship between MLA and coordination practices. We evaluate whether MLA improves coordination within small groups of people. Previous research addressed this issue of how knowing other’s location in space impacted group collaboration. The next section examines results in both virtual reality and pervasive computing contexts.

1.6 Empirical studies on MLA

1.6.1 In virtual space

The importance of **MLA in virtual environments has not been widely addressed with user studies**. Most of the existing work about it focused on the first kind of MLA interface we describe in section 1.5.2: verbal description of MLA in the context of text-based virtual reality.

Dillenbourg and Traum (1997) however investigated the effects of MLA in a text-based virtual reality (MOO environment). In this context, pairs of participants had to collaborate in finding a killer in a virtual and closed environment by gathering various clues located in different rooms. The authors found that location awareness supported implicit coordination. Indeed, the subjects did not check systematically where their partner was, but rather maintained this knowledge without explicit acts. MOO features correspond to several MLA tools. One of these is the fact that the MOO environment automatically provides information about mutual positions: every time a message was received in the chat, every time users met or separated, plus every time when one saw the consequence of an action being performed by one's partner, and so forth. The authors describe how **MLA supported implicit coordination**: since each partner could observe where the other went without asking him explicitly, it eased the game resolution given that each visited room meant that the clues had been collected. **The user path indeed reflected his or her strategy** (at least if it seemed to follow a direction) and one partner might have anticipated the other's intentions by tracing his or her spatial path (if the user knows that the upper corridor has 4 aligned rooms and that his partner had visited the three first ones, he would have certainly expected the partner to visit the fourth room). **Mutual understanding was also improved** by knowing where one's partner has been. For instance, if A knew that B had gone to room 5 and that a suspect was located in room 5, then A might infer that B had probably collected information from the suspect. This was due to the direct mapping between virtual space (rooms) and the problem space (one suspect or object was located in each room). MLA then helped to know what one's partner knew, a first step in building a shared understanding of the task.

Other results from the experiment accounted for the importance of spatial features in collaboration. For instance, the authors describe how **space was the main criterion for division of labor** among the participants of groups. The subjects had to collect information from 12 suspects located in different rooms. All of the 20 pairs coordinated their work on a spatial basis (e.g. one member explores the rooms in the upper corridor and the other does the same in the lower corridor). A final lesson from the experiment was that **MLA supports grounding** through the creation of a micro-context: when the users met, they expected their partner to say something about the suspects or the objects located in that room. This micro-context helped to establish mutual understanding: knowing what one's partner knows is a first step in building a shared comprehension of the task.

Montandon (1996) also dealt with virtual textual environments. In her experiment, pairs of participants had to find four letters that constituted a word. To do that, they had to answer to questions located in MOO rooms: each letter was obtained by answering questions and each question was located in a room. For each question, a clue was available in another room. The subjects had to explore the rooms to get the questions and, if necessary, the clues. However, if the two players met in a room, they were punished and sent to a room far away. They hence needed good coordination to avoid accidental meetings. Montandon found that **users performed lots of explicit acts of spatial coordination when they were not provided with MLA**. She described explicit acts of coordination as communication regarding the current position, the future position and use of the "who" command which allows one to see who is where.

A usability study of MLA in groupware has also showed the benefit groups can draw upon when using telepointers and a map (Gutwin and Greenberg, 1998). The authors tested how the presence of "workspace miniatures" (map and telepointers) would affect the group task performance. They compared two conditions (having or not having these MLA interfaces) in three tasks using a shared workspace that consisted of a virtual representation of a pipeline construction kit. Each of the tasks was a variation on the pipeline collaborative construction. What Gutwin and Greenberg found was that in two tasks completion time was lower with the MLA interface, and in the third one, communication was less efficient. The authors counted the visual communication provided by the map as a factor in success, as well as the **potentiality of the tool to provide a continuous feedback to the others** (people did not have to wait the end of the interaction to see the what was being done).

1.6.2 In physical space

It is in the field of mobile computing that MLA usage has recently drawn more attention, because of the frenzy of development of location-based systems (LBS). A relatively important part of the features developed for LBS concern collaborative components enabling people to be aware of others' location. Mostly technology-driven, the exploration of MLA's roles and influences has been done to test the potential of LBS applications. The investigations of how LBS applications would be used have been conducted in different contexts using field experiments, ethnomethodological studies and surveys. Three recurrent kinds of tasks have been used in pervasive computing for that matter: games in which participant had to find people and/or objects (Benford et al., 2004, 2004; Licoppe & Inada, 2005), simple real-world tasks such as rendezvousing and navigation (Dearman et al., 2005; Axup et al., 2005) and museum exhibit exploration (Brown et al., 2003). Note that these studies only address synchronous and "position-based" MLA interfaces (information about partners' in space, shown on a map in real-time), delineating the different roles such systems play in collaboration.

Based on a review of how MLA was used in the pervasive environment described above, **four roles stood out:** initiation of communication, a resource for conversation, an "ambient virtual copresence" tool, and finally a means to monitor the task completion. With regards to the interfaces described in section 1.5 , all the studies about MLA only address synchronous location-awareness conveyed by maps (scrollable or not).

Mutual Location-Awareness indeed influences different moments of verbal interactions in pervasive games. For instance, Licoppe and Inada (2005) studied a location-based game, deployed in Japan called Mogi Mogi, in which players have to collect virtual localized artifacts in Tokyo. Players had a MLA interface in the form of a map on cell-phones similar to the Botfighters version showed in section 1.5.5. The authors noticed that knowing the others' positions on the cell phone screen **created an affordance for social encounters and led to specific forms of conversational openness**. Location awareness in this context was often used to trigger a conversation. For Brown et al. (2003), a different component of verbal interactions was influenced by the presence of MLA: the content of the conversation. They explored how a mixed reality system would augment visits to museums by allowing voice communication and sharing information concerning location and orientation (represented as a map). Their experiment of this location-awareness tool showed that **MLA was a powerful resource for conversation, easing referential communication** (the understanding that an item which is present in an individual's vicinity is the topic of the conversation). Knowing the partners' location indeed helped to derive deictic cues: it enabled participants to understand what the partner was looking at and thus encouraged either talk about it or incited the partner to look at the same thing. Similarly, in a study of the pervasive game "Uncle Roy All Around You" Benford et al., (2004) demonstrated that MLA (in the form of a map) provided cues that can be perceived as "deictical" linguistic elements to give directions or tell one's location. In this game, on-line and street players have to collaborate to find an elusive character called "Uncle Roy". In this context, MLA was used to indicate direction in two ways: either by using the known location to derive possible directions ("you are very close now, stay on that side of the road") or by giving directions using absolute geographical references (such as landmark: "Go to 12 Waterloo Place").

Additionally, when studying how location-aware technology impacts social behavior within the context of rendezvousing (meeting at an agreed upon time and location), Dearman et al., (2005) compared three different technology conditions: using a mobile phones, using a PDA displaying MLA as a scrollable map and using both devices. All of the groups were able to complete the rendezvous tasks without much difficulty but participants exhibited very different behaviors depending on the technology used. The phone appeared to be relevant for discussing actions ("what are you doing?") and intentions ("where are you planning to go?") but the MLA displayed on the PDA was more efficient to find partners and to provide users with **a feeling of "ambient virtual copresence"**; MLA was, in the authors' words, a "*background communication channel to monitor their partner*" (Dearman et al., 2005, p. 561). Furthermore, by seeing in an unobtrusive manner people's position and movement, the MLA feature provided **information about partner's contribution to the task**, as well as their progress.

1.7 Limits of MLA

Research concerning the limits of location-awareness brought forward **3 major issues**: the location accuracy, the difficulty to interpret MLA and above all its social acceptance.

The first problem of location-awareness is that **technological pitfalls can lead to flaws or bad positioning accuracy** (Benford et al., 2006: CYSMN; Benford et al., 2005): ubiquitous computing is still a maturing field in which frequent problems arise like unreliable network, latency, bandwidth, security, unstable topology, or network heterogeneity. However, users acquire strategies to adapt to the aforementioned system failures. For instance, one of the solutions to cope with MLA discrepancies was to let users manually reveal their positions (Benford et al., 2004). These authors found that rather than reporting themselves to be at a different place, the users were in fact reporting themselves to be at a different time. Their results showed that revealing one's position was an act of communication that also revealed past or future intentions. However, self-reported positioning required users to know where they were and/or where they were heading, which is not always the case. What is interesting though is that self-reported positioning is not neutral, but as the authors say "imbued with meaning" at the moment the message is generated, conveying more information than solely location.

The second problem is the **difficulty in interpreting the information conveyed by MLA tools**. In the previously mentioned study, Dearman et al. (2005) underline how the display of location information provided little assistance to users in interpreting the associated state of the person. As a matter of fact, when a user was lost or not making any progress, participants were disconcerted because there was not enough information to understand what the problem was. This kind of uncertainty in interpreting locational information can lead to detrimental effect of MLA on users' understanding of the situation. Another important limit of MLA is the form of MLA information: the position offered or described by technology often does not correspond to the positions people want to refer to when they are conversing (Rudström et al., 2005). Hightower et al. (2005) also raised this issue by saying that location-based technologies have the problem of moving from "location" to "place"; for instance, of making geographical coordinates meaningful to the users. In most cases, the solution is to show the MLA information on a map of the environment, turning the naming problem into a tuning of the map to show finer-grained information.

However, **the most important problem** regarding MLA is certainly that it raises **privacy concerns.** Location privacy that Beresford et al. (2002) defined as "*the ability to prevent other parties from learning one's current or past location*" (p.1536) is thus harmed by location-aware technology. The applications we described indeed allow people to have access to timely and positional information and hence generate potentially sensitive information. This then leads to difficulties in the social acceptance of MLA technologies in terms of user rejection or reluctance to employ certain features. A possible answer to these concerns is to provide abilities to switch off or to define different levels of permissions to access to the location information. The fact that awareness threatens privacy has been acknowledged both for virtual environments and ubiquitous computing (see Bellotti, 1996; Bellotti and Sellen, 1993 on this topic) since both enable the capture and storage of people's positions and their activities. This relates to the long-term debate in the CSCW field about the balance between awareness and privacy (Hudson & Smith, 1996): designers of multi-user applications face the problem of providing enough information transmitted to others (so that they can benefit from it) without threatening the protection of users' privacy.

1.8 Synthesis

In this chapter, we started by describing the general concept of awareness as proposed by CSCW researchers to represent the set of contextual information and cues occurring due to group interactions within members of a team and with the environment. We then focused on one specific type of awareness we called MLA (Mutual Location Awareness), which refers to awareness about people's whereabouts both in physical or virtual environments. We saw that MLA interfaces allow users to gain information about their partner's location in space; we described them as MLA tools, giving an overview of the existing systems.

As we have seen, different representations of MLA have been designed both in virtual environments and mobile applications based on five criteria such as the mode of capture of the position, the type of information, the mode and the scope of retrieval, and the format. Most of the research regarding how these interfaces influence collaboration concentrates on synchronous awareness of others conveyed by maps (displays either on cell phones, PDA or small portion of the virtual environment). The few studies about MLA interfaces and collaboration show how these tools are important in terms of implicit coordination cues, mutual orientations and in offering resources for communication, mostly as deictic practice. Some studies also mention how MLA could create an ambient co-presence and might enable conversants to coordinate themselves by drawing some inferences. We saw that this phenomenon was also present in mobile phone conversations.

The literature review therefore shows that **MLA interfaces could improve collaboration** through two sorts of enhancement: both **in terms of group cognitive processes** (such as referential communication) **or by enabling proper conditions of collaboration** (i.e by allowing affordances for communication or creation of a feeling of co-presence).

Nevertheless, the little research about how MLA influences collaboration does not really deal with collaborative task performance, collaborative processes (such as division of labor, strategy negotiation, communication practices) or the user over time. As well, among the list of interfaces we presented in the review section, user research has mostly addressed scrollable maps, verbal descriptions of MLA in text-based virtual reality and location detected by pervasive gaming applications.

We therefore identified **three needs in regards to MLA research**. The first general issue is **to test the assumptions designers have about awareness benefits to the reality by studying MLA usage**, so that we could expand the range of work described about it. Secondly, we should **focus on more diverse types of MLA** such as asynchronous interfaces or maps that show a global overview of the environment. Finally, the little research we have about MLA is very often a by-product of larger research projects; meaning that it was not the central question addressed in these studies. **MLA has then been rarely studied as such**, especially regarding topics like collaborative processes or coordination practices, which will be the central research question of this thesis (more deeply discussed in Chapter 3). However, prior to describing our purposes, we will need to establish a proper framework about collaboration and how human actors carry out joint activity, which is the topic of the next chapter. Such a framework gives us the proper concepts and methodologies to analyze the relation between location-awareness interfaces and their cognitive affordances in collaboration.

Chapter 2 • A Framework for Studying Awareness in Collaborative Situations

This chapter presents the theoretical framework we use to apprehend the object of our research: mutual-location awareness. It shows how the psycholinguistic theory of Herbert Clark is relevant in addressing awareness and coordination.

2.1 Introduction

As described in the previous chapter, a large number of studies about collaborative work highlight the importance of awareness and awareness interfaces for collaboration, whether computer-supported or not. These studies employed diverse theoretical constructs and methods to support this claim; and different disciplines among social sciences are relevant to address this issue. As a matter of fact, the interest in awareness and contextual elements is a paradigm shift in the field of Human Computer Interaction (HCI in the remainder of the document). At first, HCI (and consequently CSCW) drew its inspiration, methods and frameworks from cognitive psychology and the information-processing paradigm. Then, the advent of situated cognition theories emphasized the importance of contextual elements and led the field to expand its boundaries by taking into account situated, social and organizational practices (Kuuti, 1995). There is thus **a wide array of frameworks in CSCW that explain or support the importance of awareness**. They range from the information-processing paradigm to situated action (Suchman, 1986), distributed cognition (Hutchins, 1995) or activity theory (Kuuti, 1995). Even cognitive sciences have integrated the importance of context (see Sperber and Wilson, 1986 for instance). However, each theory explores the role of context from its own perspective and methodology. Distributed cognition, for example, seeks its inspiration in cognitive anthropology whereas situated action is derived from ethnomethodology. As well, the importance of more situated and less mentalist frameworks has increased due to technological developments. Namely ubiquitous computing, by raising mobility and contextual issues, has expanded the need to employ broader and more systemic accounts of technology usage and influence.

Our concern in this thesis is to investigate how a certain type of awareness influences collaborative work among small groups of people. The crux of the issue here is to understand whether and how coordination is affected by mutual location-awareness. We therefore **need a theoretical framework** that will give both **conceptual constructs and explanatory mechanisms** to describe how awareness of spatial interactions impact coordination.

Since we are interested in the social and cognitive effects of location-awareness interfaces on cognitive interactions, we need a framework that takes into account both mental and behavioral phenomena.

2.2 Awareness, intersubjectivity and psycholinguistics

The discussion of awareness usages and its effects on collaboration is related to the topic of **intersubjectivity** and the role it plays in coordination. Awareness refers to the perception and the understanding of others' interactions in the environment. In the end, awareness provides information that assists in finding out what teammates are doing in the environment and, by extension, what will happen next.

As Schmidt pointed out: "*Displaying and monitoring are thus complementary aspects of the same coordinative practices. My monitoring the activities of others is facilitated by their displaying those aspects that are relevant for me and my displaying aspects of my work to others presupposes that I am monitoring their activities and thereby am aware of their concerns, expectations, and intentions*" (Schmidt, 2002, p. 291). This quote shows how awareness is bound to both productions of visible signs and the monitoring of these signs and how people use them to make inferences about what others are up to and why. In a way, as we saw in the previous chapter, CSCW researchers and designers assume that awareness is meant to help figuring out the partners' intents, beliefs and knowledge, which corresponds to the process of intersubjectivity described by phenomenologists such as Schutz (1967). According to him, observable information available in the environment is the starting point of a joint action. He also states that the understanding of another person depends on the lived experience of the observer and on the assumptions that can be made about the observer's perceptions. The outcomes of these assumptions are what Schutz calls intersubjectivity. Heritage (1984) describes it as follows: "*the intersubjective intelligibility of actions ultimately rests on a symmetry, between the production of actions on the one hand and their recognition, on the other*" (Heritage, 1984, p. 179). Achieving a collective action depends on intersubjectivity, namely **the maintenance of a relationship between two or more people's subjective experience drawn from the present and the past experience of the individuals involved**. Depending on the viewpoint and methodological concern, intersubjectivity has been described as common ground (Clark, 1996), mutual intelligibility (Garfinkel, 1967), attribution theory (Heider, 1958), intentionality theory (Searle, 1983; Dennett, 1990) or "**mutual modeling**" (Dillenbourg, 1999) as we refer to it at the end of this chapter. These terms have slight differences but they are all connected to how people make sense of actions of other people. Some of these concepts refer to diverse approaches: Garfinkel, for instance, focuses on how people produce mutual intelligibility in the course of their actions whereas the attribution theory is about how people assign causes to the behavior of others. These concepts are ultimately all about how people achieve a common experience based on intersubjectivity. The idea of intersubjectivity sparked years of debate concerning the "mutual knowledge" problem and its existence in communication (Smith, 1982). The "mutual knowledge" issue refers to how joint participants develop a shared or mutual understanding of what they perceive that allow them to act altogether. Different theories have tried to deal with this problem and we will discuss Herbert Clark's own contribution to the discourse.

Because of the similarity between the questions raised by awareness in CSCW and the "mutual knowledge" debates-described above, **we chose to use a psycholinguistic framework** for our analyses. Since we are interested in how awareness, conveyed by technological interfaces, influences coordination practices, we need to address human-human communication. We chose a linguistic theory **that explains how individuals produce intersubjectivity**. Moreover, as we stated in the previous section, the theory should take into account both internal and external representations of cognitive phenomena. For this reason, the pragmatic area of linguistic is a relevant domain for our purposes. Nevertheless, using such a framework does not mean that we want to do micro-analysis of conversations, but rather that we want to consider language (verbal and non-verbal communication) as action and as a means of understanding the group cognitive processes at stake in coordination.

This leads us to a subset of **Herbert Clark's theory** that focuses on how people coordinate group actions (1996). Most of Clark's work is devoted to pragmatic linguistics; but the last version of his communication theory is framed in the broader context of coordination of human action. The next section will describe the elements of this theory that we found pertinent for comprehending awareness.

2.3 Clark's theory

2.3.1 Clark, the intersubjectivity problem and coordination

For about thirty years, Clark addressed the intersubjectivity problem through different studies and conceptual models that he developed with his colleagues (Clark and Marshall, 1981, Clark and Schaeffer, 1989; Clark and Brennan, 1991; Clark, 1996 among others). The development of his theory, which is often referred to as the "grounding" theory, has followed the trend we mentioned previously about cognitive sciences: the increasing importance of contextual and situated elements in cognitive phenomena. We will describe his approach as well as the criticisms it received, to **show how it provides a relevant framework for studying awareness**. We will use the last iteration of Clark's theory (Clark, 1996) and will not refer to past versions (such as the "Contribution Model") in this thesis. Clark has not produced a theory of coordination *per se* but the issues and concepts he tackles target verbal and non-verbal communication as the basis for joint actions, which is very relevant to the investigation. Clark relied heavily on past work about coordination written by Schelling (1960) and Lewis (1969) in the development of his own theory. According to Clark, **language**, be it verbal or non verbal, is **used** when a group of people has to perform **joint activities that require coordination with each other**. Joint activities, performed by two or more participants, range from playing chess, paddling in a canoe or playing in a string quartet. As shown on Figure 16, they are composed of set of identifiable tasks that Clark named "joint actions".

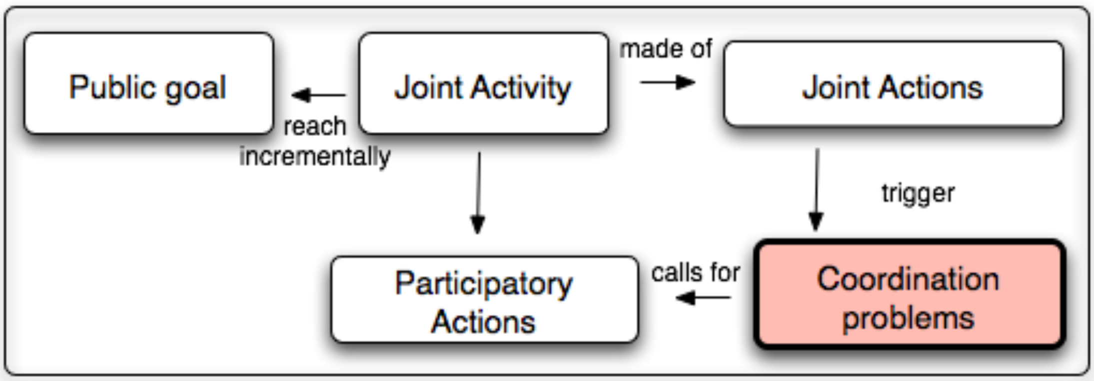


Figure 16. Clark's discrimination of different granularity levels from the joint activity to the participatory actions when coordinating (interpretation based on Clark's work).

What makes these actions "joint" ultimately is the need for the participants to coordinate their individual contributions to the task through what he calls "participatory actions". When playing in a string quartet, each of the actions performed by the four musicians depend on the others': when do they have to begin, how fast they have to go, whether they should play some parts pianissimo or forte. **Coordination implies the management of dependencies**, as explained by Malone and Crowston (1994), and this dependency results from by the goal shared by participants (i.e. playing music together in front of an audience).

In each joint action, participants face what Schelling (1960) called **coordination problems**: "*Two people have a coordination problem whenever they have common interests, or goals, and each person's actions depend on the actions of the other. To each of their goals, they have to coordinate their individual actions in a joint action*" (Clark, 1996: p62). Meeting at a particular time and place or drivers on a one-lane road are simple examples of coordination problems. In Clark's terms, the problem for the participants in a joint activity is thus to infer **what individual actions they can expect from each other** so that they can pursue the public goal of their joint activity.

Nevertheless, as Schelling argued, coordination is not simply a matter of a participant making predictions about the actions of other group members: "*What is necessary is to coordinate predictions, to read the same message in the common situation, to identify the one course of action that their expectations of each other can converge on. They must "mutually recognize" some unique signal that coordinates their expectations of each other.*" (Schelling, 1960: p54).

2.3.2 The importance of "coordination devices"

To solve the aforementioned coordination problems, **participants need** what Schelling called "*a key*" or "*a focal point*" or what Clark, with Lewis (1969), termed a "**coordination device**": **a rationale for mutual expectations that make partners believe that they will converge on the same joint action**. As represented on Figure 17, Clark expands Lewis' definition through the discrimination of **4 kinds of coordination devices**: conventional procedures, explicit agreement, precedent and manifest elements.

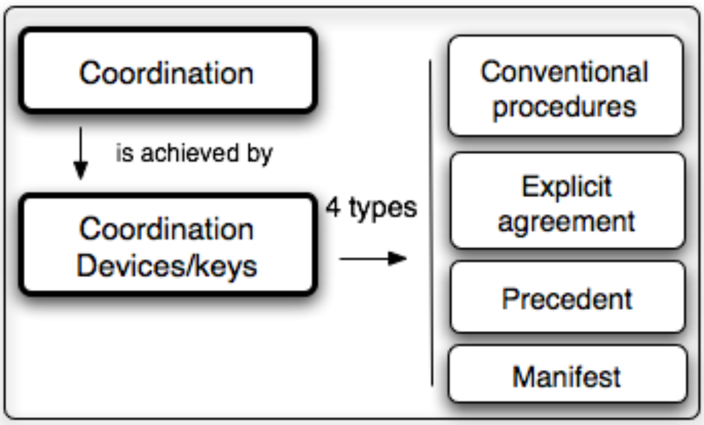


Figure 17. Clark's model of coordination devices (interpretation based on Clark's work).

Of all the coordination devices, the most important are certainly **explicit agreements**, which are occurrences of dialogues in which parties explicitly communicate their own intentions. When two persons want to meet at a certain place, they often solve that problem by talking to each other and agreeing on the place and the time.

Another important type of coordination device is the **convention**; which Lewis (1969) describes as the community's solution to a recurrent coordination problem. Conventions or conventional procedures range from rules and regulations to less formal codes of appropriate conduct. They are not habits or practices but rules such as stopping at the red traffic light or placing knives on the right. Conventions can also be more "local" and less bound to the community; for instance three persons who want to meet for lunch every Tuesday (a joint action) can agree on meeting at a certain place at 12:15. They then each go there at that time every Tuesday (their participatory action). In this case, going to the meeting place is not a habit but a convention that has been set by participants of the joint activity. According to Clark, this is because "*that is what they mutually expect each other to do based on the regularity in their recent behavior*" (Clark, 1996, p. 70). As we see in this example, an explicit agreement can evolve into a convention if it is established as the agreed solution to a recurrent problem.

In addition, people ordinarily solve coordination problems using non-conventional coordination devices. Clark identifies two types of devices: precedent and manifest. **Precedent** applies to norms and expectations developed within the on-going experience of the join activity. If I remember that my friend Paul was at the local pub on Friday afternoon of last week, I may expect him to be there this week. Unlike the convention of meeting every Tuesday at 12:15, precedents do not depend on mutual agreement about an action, they are only expectations based on the previous experiences of participants. Malle (1999) also coined the term "causal history explanation" to refer to expectations based on knowledge of previous behavior of that concept because the factors that predict a possible behavior lay in childhood experiences, past behavior or the agent's traits.

The second type of non-conventional coordination device is **manifest elements** from the environment. Clark also called this "perceptual salience": it refers to situations in which the environment (or the available information) makes the next move apparent within the many moves that could conceivably be chosen. During surgery, for example, pointing a certain element of anatomy can make it clear to all parties involved what to do next. Coordination by manifest elements or perceptual salience is thus produced by the very conduct of the joint activity itself.

These four coordination devices refer to mental representations (conventions, precedent), perceptual elements from the environment setting (manifestness) and communication (explicit agreement). The construction of mutual expectations about participatory actions is consequently both cognitive (i.e. expresses the need to access to mental representations) and situated, given the set of coordination devices people can rely on. Coordination devices thus produce mutual intelligibility between participants. By producing and perceiving those elements, people are actively enabling intersubjectivity with each other. Nevertheless, this exchange does not mean that coordination is an explicit and permanent process in which participants constantly monitor and interpret the devices that are available or that has been produced. Coordination should rather be seen as a mutual alignment process during which people takes advantage of the available elements.

2.3.3 The "common ground"

The *principle of joint salience* (Clark, 1996) states that the ideal coordination device for any problem is the solution that is the most salient, prominent or conspicuous with respect to the common ground of all participants. This is where Clark brings the notion of mutual knowledge among joint participants, in the form of what he calls (after Stalnaker, 1978) the "**common ground**" (CG henceforth): **the knowledge, beliefs and suppositions participants share about the activity, and that accumulate over the course of actions**. The CG can be simply described as **the accumulation of information exchanged as coordination devices**, which are nothing more than different types of signals to form mutual expectations: "*In the cumulative model of joint activities, participants use utterances and other signals to increment their common ground. A signal is then the speaker's way of introducing into the discourse a shared basis for the piece of common ground to be added*" (Clark, 1996, p. 132). This quote shows the cumulative characteristic of the CG, which is updated over time, and how coordination devices that can be added to the CG. Historically, this notion is derived from Lewis' Common Knowledge (1969), Schiffer's mutual knowledge and mutual belief (1972). The process and effort of constructing and, updating the information in the CG is named grounding (Clark & Schaeffer, 1989; Clark and Brennan, 1991). One should keep in mind that coordination devices are only the form information takes in order to be included in the common ground. For example, a discussion a person has with a friend about a movie she has seen leads to the inclusion of this story in the common ground.

Clark divides the CG between two persons into two types. The communal common ground is initiated with the information inferred on the basis of the cultural communities a person is believed to belong to (from occupation to nationality or gender). The personal common ground is enriched with information based on personal acquaintances: unlike intimates, strangers do not have a great personal common ground. The different types of coordination devices fall in those two categories: conventions can be communal or personal while explicit agreement/precedent are only personal.

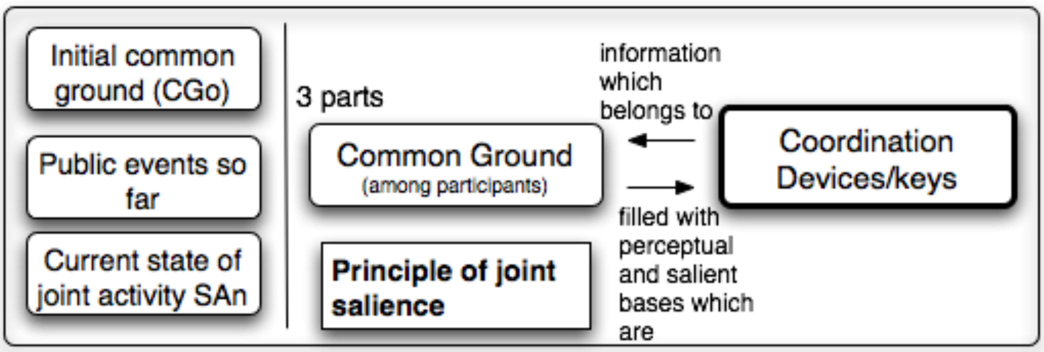


Figure 18. The common ground, as the accumulation of coordination devices is made of different components (interpretation based on Clark's work).

In itself, the CG is not homogeneous, as one can see on Figure 18, where Clark identifies three parts to describe its different components:

- The **initial common ground** (CGo) composed of the set of background facts, assumptions and beliefs that participants presupposed when they entered the joint activity. Precedent and conventions belong to this category (except conventions that that are set during the activity). This forms the initial context of an activity.
- The **current state of joint activity** (SAn), which is what the participants presuppose to be the state of the activity at the moment. The environment and artifacts play an important and reliable role as external representations of the

current state. This includes the manifest elements and conventions set during the activity.

- The **public events so far**: participants also keep track of events that they presupposed occurred in public prior to the current state of the joint activity: manifest elements from the situation and explicit agreements.

2.3.4 Coordination and common ground

The relationship between coordination and the common ground is twofold. On one hand, the process of **coordination** can be described as **updating this common ground** through the addition of new information (in the form of coordination devices). On the other hand, **coordination devices** are nothing more than **a shared basis** meant to enable the coordination of participatory action that would eventually contribute to joint actions. Shared bases refer to the fact that when it comes to coordinating, participants could not rely only on the information they have about each other; they must establish mutual expectations, namely that the right piece of common ground is shared (through the use of coordination devices). This shared basis then enables participants to draw inferences about something: "*To infer (...), people try to select the object that both fits the descriptor and is the most salient against the common ground. They assume the speakers and addressees must mutually recognize some unique signal that coordinates their expectations of each other*" (Clark, 1992, p. 97).

Figure 19 summarizes the framework we described so far, showing the whole process according to Clark. It starts from a public goal shared by a group of people (ranging from 2 to large groups) and then depicts the coordination procedure that leads individuals to accumulate a range of coordination devices (forming the common ground) so that they have a shared basis from which to form mutual expectations and select the proper participatory actions.

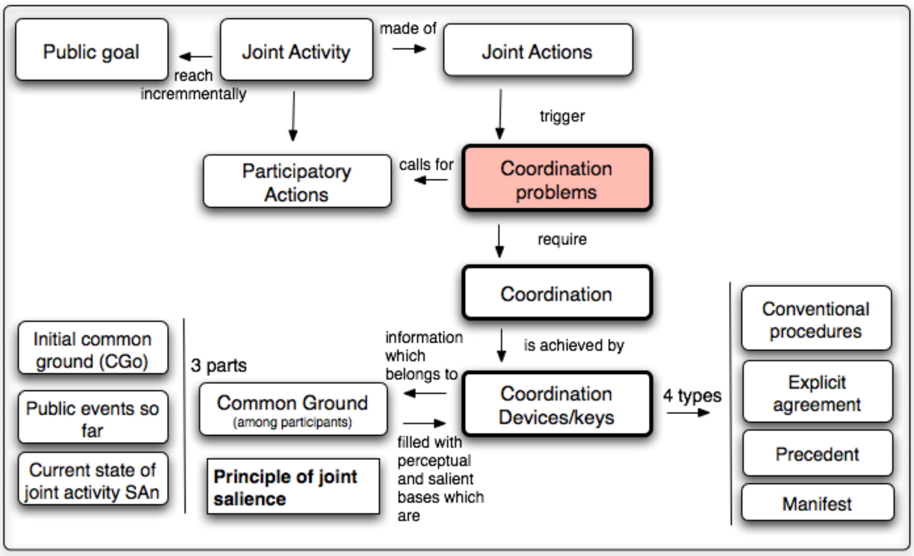


Figure 19. An overview of Clark's framework of coordination (intrepretation based on Clark's work).

This mechanism of coordination devices exchange to establish and update the common ground is what has been called "**grounding**: *"... to ground a thing is to establish it as a part of the common ground well enough for current purposes*" (Clark, 1996, p. 221). It is the process through which shared knowledge is mutually established in interaction.

Of course, the shared basis is the ideal solution people tend to reach in maximizing their CG.

As Clark and Schaeffer state "*the contributor and the partners mutually believe that the partners have understood what the contributor meant to a criterion sufficient for the current purpose*" (Clark & Schaeffer, 1989, p. 262). In an interaction, from the initiation of a contribution to its mutual acceptance, the two partners provide a collaborative effort. To improve the efficiency of the communication, this effort must be minimized. Clark & Brennan (1991) summarized this by the rule of the least collaborative effort: "*Don't expend any more effort than you need to get your addressees to understand you with as little effort*". It is sometimes more efficient to provide an incomplete utterance and repair it later on because the production cost of a complete utterance might be higher than the cost of repairing it. Thus grounding is the mechanism by which the participants try to establish that their partner has understood what they meant to a criterion **sufficient for the current purpose**.

2.3.5 Clark's theory and mediated interactions

Clark's framework has been **widely used in the CSCW and CSCL** but as a model of discourse and communication rather than a model of coordination (see for example Dillenbourg, 1999, Gutwin and Greenberg, 2002, or Monk, 2003).

Clark and Brennan (1991) provide a more concrete framework for how diverse media can impact the establishment of the common ground. They insisted on how the grounding process is affected by communication medium: coordination devices are indeed conveyed differently. For instance, in a face-to-face conversation, saying "ok" is an easy sign of acknowledgement and grounding. The situation is very different in a computer chat. Indeed, timing precisely an acknowledgement is much more difficult, the "hmm hmm" can be understood as an interruption. Clark and Brennan (1991) also stress the fact that each medium has different costs, for example the acknowledgement cost is higher in a computer chat than in a face-to-face meeting. They describe the constraints imposed on communication by diverse media such as telephone or IM as described in Table 4 such as how it may affect the production of an utterance, or how to repair it.

Table 4. Constraints on grounding and examples (inspired from Clark and Brennan, 1991).

Constraints	**Definitions**	**Examples of medium satisfying the constraint**
Copresence	Participants A and B share the same physical environment	Face-to-face conversation
Visibility	A and B are visible to each other	Videoconference and face-to-face conversation
Audibility	A and B communicate by speaking	Telephone, Videoconference and face-to-face conversation
Cotemporality	B receives at roughly the same time as A produces	Chat, Telephone, Videoconference and face-to-face conversation but not in e-mail
Simultaneity	A and B can send and receive at once and simultaneously	Chat, Telephone, Videoconference and face-to-face conversation
Sequentiality	A's and B's turns cannot get out of sequence	Chat, Telephone, Videoconference and face-to-face conversation but not in e-mail
Reviewbility	B can review A's message	e-mail and chat but not the others cited above
Revisability	A can revise message from B	e-mail and face-to-face conversation but not the others cited above

This table shows how media constraints affect the exchange of coordination devices among a group of collaborators. Each constraint has pros and cons; for example, the co-presence setting maximizes the real-time accessibility (and the cost of production) of coordination devices but e-mails or chat conversations have the advantage of providing an history of past interactions.

Research has tried to benefit from such frameworks to design or predict interactions, but more and more criticisms have arisen about Clark's theory, as we will describe in the next section.

2.4 Criticisms of Clark

Clark's contribution to the mutual knowledge research has raised much controversy over time. Two research communities criticized it: linguists from other schools of thought and CSCW researchers. However, as we will see, some of these critiques can be addressed.

2.4.1 Criticisms of the Mutual Knowledge issue

Clark's theory has been attacked for a long time (see Smith, 1982 for an overview of the controversies). Linguists from the "pragmatic school" have issued two majors comments regarding the "Common Ground" theory and its various instances. Both are related to different aspects of the Mutual Knowledge issue, a recurrent problem in linguistics.

The first criticism concerns the representation of Common Ground. Historically, there have been **two conflicting types of representation of the CG**: CG-iterated and CG-shared[6]. Although they look similar, the two versions are not equivalent as we can see in Table 5. The CG-iterated representation refers to the series of checks an individual should do to ground the mutual understanding, whereas the CG-shared representation states that there is no need for these checks but that simply recognizing that a piece of knowledge is "shared" between the two conversants is sufficient.

Table 5. The two different representations of Common Ground for a proposition *p* in a community C of people (drawn from Clark, 1996).

CG-shared	**CG-iterated**
p includes the beautiful day, the beach, the sea, A, B and a shell between A and B. *p* includes A's awareness of situation s *p* includes B's awareness of situation s The situation s is the shared basis for a common ground.	*p* is common ground for members of community C if and only if: 1. members of C have information that *p*; 2. members of C have information that member of Chave information that *p*; 3. members of C have information that member of C have information that members of C have information that *p*; 4. And so on ad infinitum.

[6] There is also the CG-reflexive but we will not enter into these details here since the reflexive version has been less important and the two others were more prominent.

Paradoxically, most criticisms of Clark (and Lewis) have assumed that the only proper representation of the Common Ground was CG-iterated. They focused on sequences such as the one represented in the Table 5 and argued that such infinite regression is impossible from a cognitive load or time point of view (Green, 1987; Schiffer, 1972; Sperber and Wilson, 1986). As Clark also pointed out, CG-iterated is untenable as a representation of people's mental state because it would require an enormous mental capacity: "*CG-iterated obviously cannot represent people's mental states because it requires an infinitely large mental capacity*" (Clark, 1996, p. 95). By pointing out this fundamental problem, Clark contenders dismissed the very notion of Common Ground and left aside the CG-shared representation, which is less problematic.

This leads us to the second criticism of Clark's theory. Even with the CG-shared version, some linguists still considered that the common ground notion and its components were flawed. Harsh comments have been made by the "inference" school of pragmatics, criticizing the Mutual Knowledge theories. To them, mutual knowledge or what Clark called common ground is **not necessary for communication**; they then developed a different framework based on **looser notions**. Sperber and Wilson (1986) are the most prominent authors who propelled this view, using concepts such as "**cognitive environments**" and "**mutual manifestness**" of facts in the participants' environment. As they propose, "*A fact is manifest to an individual at a given time if and only if he is capable at that time of representing it mentally and accepting its representation as true or probably true*" (Sperber and Wilson, 1986, p. 39). Therefore, if two individuals A and B have the same perceptual and cognitive abilities, a fact will be considered manifest to A and B and the two of them would easily infer that, having the same abilities, this fact is "mutually manifest" (i.e. manifest to each of them). Sperber and Wilson state that the conversants share the same "*cognitive environment*". An individual cognitive environment is the set of facts that are relevant to a person (i.e. that he or she can perceive and draw inferences upon it). When the same facts are manifest to two or more people, the participants share a "mutual cognitive environment", which is the intersection of the individual representations. Additionally, sharing such a cognitive environment does not imply that they make the same assumptions since cognitive or perceptual abilities are not strictly identical among people. Sperber and Wilson then base their argumentation on how facts become relevant to individuals (what they call principle of relevance) and how people make them manifest to others (what they call ostensive behavior). The difference with Clark's description of Common Ground, is that saying two people share a cognitive environment does not imply they make the same assumptions; merely that they are capable of doing so, as expressed by Sperber and Wilson.

Moreover, Sperber and Wilson's criticisms also point out the fact that the idea of having "shared knowledge" is bound to a vision of language they define as *passé*. To them, this approach indeed emphasizes the "conduit" metaphor of communication, in which speaker's interactions are thoughts encoded as verbal or non-verbal interactions which are decoded by an addressee. To these authors, the pragmatic level of communication is a new code layer added on top of the linguistic code. This is why, for Clark and others "within the framework of the code model, mutual knowledge is a necessity" (Sperber and Wilson, 1986: p18).

We will not go further into a description of Sperber and Wilson's theory here. The point here was rather to show an alternative view.

However, these criticisms of Clark's theory have focused on earlier versions (Clark and Marshall, 1981; Clark and Wilkes-Gibbs, 1986). In the final iteration of Clark's theory, the introduction of the coordination devices as a part of the Common Ground seems to be a way to take into account the problems raised by Sperber and Wilson. The notion of coordination devices exchanged during a joint activity is actually not far from the mutual cognitive environment. As we saw, the Common Ground consists of the accumulation of coordination devices exchanged over time. We can then differentiate a local version of the CG that would only be made of the coordination devices available in the environment (manifest and perceptible elements, conventions discussed by participants or the messages exchanged). This **local CG would correspond to the mutual cognitive environment**. The problem is certainly that Clark contenders misunderstood the CG: to most of them, they reduce it as a stock of anterior knowledge, which is false. Like the mutual cognitive environment, the common ground, filled with situated facts (manifest or perceptually salient), is updated but in a more discrete way (devices after devices). To bridge the gap between both theories, we should name Clark's coordination devices as "relevant element for inferences" using Sperber and Wilson's terms because they offer a basis for drawing inferences. Choosing between different information sources to take a decision is an inference phenomenon, based on the relevance of the coordination devices.

2.4.2 Criticisms of the use in CSCW

Clark's approach and theories also received a fair amount of **disapproval from researchers in the CSCW field**. Among the disciplines and "flavors" that constitute this field, the most important criticisms have been formulated by scholars from the situated cognition perspective.

For instance, Koschmann and LeBaron (2003) described how features of the material and social environment that people draw upon to make decisions were also neglected in Clark's theory. They also complained about the difficulty they had to locate common ground in the discourse utterances they studied in their research: to them, it could not be treated as an empirical fact, because it could not be observed, either directly or indirectly. Similarly, Arnseth et al. (2004) stated that according to Clark's view, communication was conceived as a process of coordinating knowledge that participants already possess. They rejected Clark because he presumably neglected that social interaction was the main "site" where participants' mental states were articulated, as if intersubjectivity was independent of the situation and the activity. Their criticism is thus that there would be too much mentalism in Clark's words.

What is very surprising is that those two criticisms dismissed Clark's work on the basis that the common ground was not situated, which is wrong and definitely based on an overly mentalist interpretation. These **authors complain about the mentalism** (the over-reliance on mental representation of the participants to coordinate among each others) as well as the difficulty of observing the CG. **But they forget the elements that constitute it** (i.e. coordination devices) are not all mental representations: explicit agreements and manifest elements from the situations are, by definition, situated and they are hence observable in the course of action. As Clark puts it: "*The participants can assume that each coordination problem has a unique solution they can figure out with the available information*" (Clark, 1996, p. 91).

The discussion about the situatedness of Clark's theory also refers to Suchman's discussion of plans and situated actions (Suchman, 1987). Suchman defined the notion of situated action in the context of human-computer interaction: she argued that human actions are not planned in a strong sense (as supposed by some cognitive scientists) but that they are linked to the current situation. She showed that actions are to a great extent linked to the specific situation at hand and are therefore hard to predict by using generic rules. To her, various kinds of information are available as “resources for action” and she describes how plans are such resources but that they must not be treated as control structures. Plans, to her, are local, situated and opportunistic: people only create a plan for local problems. This is actually not contradictory with Clark’s theory, in his own terms, Suchman’s plan is a local convention that is set by participants to solve coordination problems. The plan can therefore establish a relevance hierarchy in the inference process by creating preferential coordination devices to solve the joint task. A plan is actually nothing more than the discussion of a local convention to solve a local problem. Finally, the way situated action describes human action is not contradictory with the coordination problem-driven theory of Clark: we underlined how coordination devices, as plans, are event-driven resources for action. The main difference is, however, that Clark accounts for some cognitive resources such as precedent or conventions.

2.5 Conclusion

Even though **some criticisms cannot be dismissed, most of the comments** that have been issued by CSCW and linguists **can be countered** by two arguments. The first one is that some critics only focused on early versions of Clark’s work, not taking into account the recent contributions: the coordination devices. This aspect actually highlights the importance of cognitive, situated and social aspects of interactions, in the construction and the update of the common ground. As a second argument, these more recent elements about coordination devices counterbalance the very cognitive interpretations of Clark that dismissed his theory.

We did not aim at answering to all the opinions against Clark, as we only wanted to show that it is possible to have a more social and situated interpretation of Clark, which corresponds to our belief that coordination is both a situated and cognitive phenomenon. This is consistent with our belief that coordination is a group cognitive process that implies situated elements such as actions or environmental features, and access to mental representations. The spatial environment should therefore been seen as a coordination device in itself.

Additionally, as explained in Section 2.2 , our point was also to use pragmatic linguistic rather as theory of action than as a framework to investigate the micro-content of utterances. This is the reason why we did not enter into too much detail about the finer-grained aspects of Clark’s work. What we want stress here is the notion of coordination devices as resources for coordination, based on inferential processes. Moreover, we would like to point out that the criticisms against Clark’s model are geared towards aspects that are not relevant to us e since our aim is to employ only the elements about the coordination of actions. This why we focused on a somehow ignored aspect of Clark’s work related to the coordination devices and the role they play in coordination.

Figure 20 summarizes the framework we discussed, starting from a coordination problem that occurs with people engaging in a joint activity. Coordination is situated in the sense that it is driven by peculiar situations: coordination problems in which a participants have to figure out how to contribute to the joint action by inferring what partners did and will do. This dependency mechanism is based on the presence and the exchange of coordination devices, which forms a "common ground".

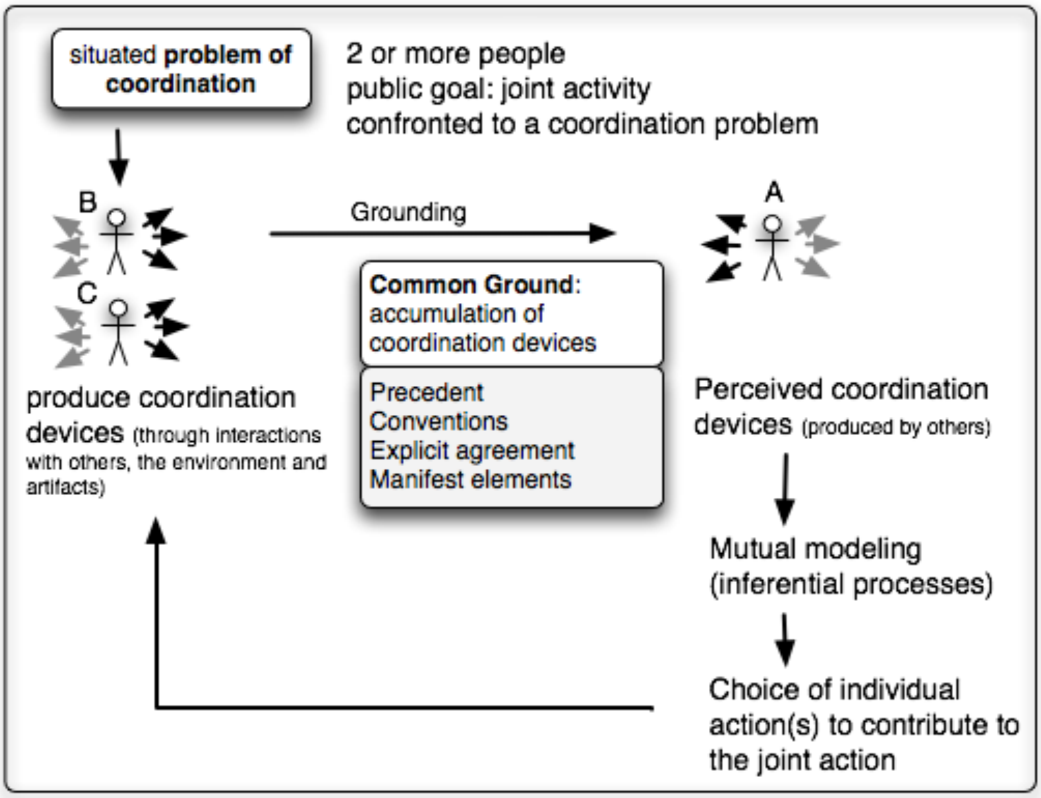


Figure 20. Summary of the theoretical framework.

The figure describes how an individual A relies on this "bag" of coordination devices to make inferences about partners B and C: what we termed "mutual modeling". This is the process by which inferences are made to solve a particular coordination problem, that is to say inferring which relevant individual actions they would pick up. This process is situated in the sense that it does not happen constantly but it is rather bound to specific situations: when there are coordination troubles. The mutual modeling hence corresponds to the inference made upon the available coordination devices.

In this thesis, **we are less interested in the inference mechanism *per se* than in how a coordination device influences processes** such as communication, mutual modeling, division of labor and, for this reason, we did not detail the inference process.

As we say in the introduction, the concepts and processes presented here will help us in understanding how the location awareness of others influences coordination. The next chapter will present the research questions we have by examining the link between mutual location-awareness and the concept of coordination devices, which is central to our research.

Chapter 3 • Research Questions

This chapter describes the scope of research on Mutual Location-Awareness effects on collaboration that we chose to investigate, based on Clark's theoretical framework. We present here our general research questions as well as our methodological choices.

3.1 General rationale

3.1.1 MLA and coordination devices

In chapter 1, we presented how awareness and awareness interfaces are meant to support collaboration. Our summary of the literature in the CSCW/HCI field describes the value of awareness in terms of coupling, coordination or simplification of communication. We also account for the fact that geographically dispersed collaboration requires that awareness of what is lost compared to copresence should be conveyed by interfaces or tools. We show how various MLA tools provide users with different ways of displaying others' location in space so that this knowledge can facilitate collaboration and eventually enhance the performance of group tasks. The literature review about MLA roles in collaboration show its importance in terms of cognitive processes such as referential communication or by enabling proper conditions of collaboration (i.e. by creating affordances for communication or creation of a feeling of co-presence).

Given the theoretical framework we discussed in the previous chapter, we can return to our research topic, Mutual Location-Awareness, and inspect it through a psycholinguistic lens as Mastrogiacomo (2002) did. According to the vocabulary we defined, **MLA will be described as a specific type of coordination device**, in which content is about participants' location in space. The location of a person can be considered as a signal that can be either produced or perceived by partners of a team. It acts as a coordination device because it provides participants with a shared perspective of contextual elements: the presence and the location of each other. Moreover, awareness interfaces, such as the ones described in Chapter 1, can be referred as a means of broadcasting coordination devices among a group of participants (Mastrogiacomo, 2002). Similarly, Gutwin and Greenberg (2001) described how the awareness of others' activity enabled the reduction of the effort required for coordinating tasks, anticipating others' actions and giving a more efficient context for interpreting partners' utterances.

Consequently, it is the production of the coordination devices, in the form of MLA that is automated in either virtual or physical environments. This production refers to the capture of an individual's location (by technological means) and the sending of this information to the partners. The perception of MLA is left to the users, integrated into what Clark calls common ground or what Sperber and Wilson refer to as "mutual cognitive environment". MLA is then available to the participants as a shared basis to form what Clark defined as "mutual expectations" and inferences about what their partners did and what individual actions should be carried out. As a "linguistic copresence" cue, MLA can be used to derive these mutual expectations. We used the term "mutual modeling" to refer to the inferences people make about their peers' actions and intents based on the available coordination devices.

How would **MLA be used as a shared basis to develop mutual expectations**? This question leads us to hypothesize what sort of inferences could be drawn about MLA or conversely how MLA supports the mutual modeling process. As a matter of fact, due to the geographical dispersion of actors, tools or access to certain information in distant collaboration, coordination problems might occur with the use of MLA interfaces. As we saw in the previous chapter, the main cause of these problems is the management of dependencies between these actors and tools. MLA, by enabling spatial inferences can be seen as a way of solving coordination problems. A possible reason for this would be that an MLA system allows partners within a team to have access to some of the shared information and resources that may enable a group of people to better coordinate. Based on the time span of the MLA interface, one can speculate about the kinds of inferences that are being made due to mutual location awareness in terms of present situation, past action, and future trajectories:

- From the knowledge of the partners current position, one could know what he/she is doing or looking at, or what information/tool he/she has access too.
- From the past positions (traces), one could infer where the partner has been and hence what has been achieved or collected so far, what was his or her strategy.
- From the direction, it is possible to infer where the person is heading and thus what are the intents or the strategy. As well, direction can be inferred from body orientation or gaze or from the past positions since a succession of traces may depict a trajectory.
- It is also possible to infer the type of social interactions from the clustering of people in specific locations or the movements to or from locations.

As one can see, **multiple levels of mutuality of knowledge and intents** can be derived from the spatial positions of dispersed team members. Inferential mechanisms are the core processes of such mutual modeling capabilities. For instance, in the context of an hospital, if you are aware that your partner, who is a surgeon, is in the operating room, you infer that he may be busy and then you will not call to ask him to give you the results of an analysis you need. Or, if in order to save time and effort geologists need to know if colleagues (or other teams) have already explored an area and collected some data on the field, they look for asynchronous MLA: cues that would indicate previous visit either on the field (tags and left signs) or on a different platform (web, lab notebook, database). So, if they find a tag on the field, it means that the location has already been investigated.

Consequently, our theoretical framework leads us to assume that (1) **shared models of each others' course of action are a major factor in the coordination of joint activities**, (2) **a coordination device such as MLA, conveyed by technological interfaces, is expected to improve these shared models by supporting a more efficient "mutual modeling" process**. MLA indeed provides group participants with shared information to better mutual model each other in order to solve specific coordination problems.

3.1.2 Research scope

In sum, mutual location awareness is supposed to improve collaboration because of two sorts of contributions. On one hand, previous research in the field of Human-Computer Interaction (HCI) and Computer Supported Collaborative Work (CSCW) has shown MLA is beneficial to group cognitive processes and a relevant way to provide the conditions of collaboration. The literature review in Chapter 1 showed examples of how MLA in virtual and pervasive environments could support this view. On the other hand, we gave this issue a new dimension by looking how a pragmatic theory of communication, such as Clark's, could explain the importance of MLA in carrying out joint activities. The previous section described how awareness interfaces convey "coordination devices" that enable small groups to have a shared basis from which to draw inferences about participants' course of actions, and eventually their intents.

This thesis explores how MLA interfaces influence the group cognitive processes at stake in collaboration through two main strategies. First, we adopt a **"Distributed Cognition" approach** (Hutchins, 1995) in which we consider groups and the artifacts they use as forming one global cognitive system. This means that we do not only focus on individual behavior (memory, problem solving, communication) but also on the mechanisms of group behavior. Second, we use the term "cognitive processes" to refer to the faculty of individuals to manage information. More specifically, **we are interested in cognitive processes that occur within groups**, mostly communication and mutual modeling. These processes, which enable the achievement of group performance, are the core components of group collaboration (Dillenbourg, 1999).

3.1.3 Research questions

Our research methods are hypothetico-deductive. We conduct **controlled experiments** to verify the hypothesis that MLA is beneficial to collaboration. By giving more coordination devices, or by enriching what Sperber and Wilson call the mutual cognitive environment, these tools may allow better inferences of others' intents, reduce communication needs and therefore enhance group performance. We then aim at verifying those hypotheses. However, since there is very little research about MLA as a coordination device, the exploratory dimension of these experiments will also be a prominent component of our studies. This means that we will both test our hypotheses and explore several qualitative aspects of MLA influences.

The first research questions we address are: **Do mutual location-awareness interfaces modify group coordination?** and how do mutual location-interfaces modify participants interactions and group coordination?

Therefore, our first hypothesis H1 is that mutual location-awareness improves coordination; the underlying mechanism could be mutual modeling based on this specific coordination device. We then hypothesize H2: this MLA tool should contribute to the mutual modeling (MM) process and as a consequence would improve the group performance.

We would also like to study how information about others' whereabouts is used, especially with regards to spatial coordination, how participants build a common ground of the situation, how they maintain a representation of the joint space, and how this modifies the mutual coordination process.

Additionally, our research is also concerned with a second research question about the importance of time-span in MLA tools: **Is an asynchronous location awareness tool more efficient than a synchronous location awareness tool?** Does showing information about past location foster better mutual models during the interaction? The main reason that motivated such a choice was our interest in studying how the presentation of previous paths would impact the mutual modeling process, namely, the understanding of the partners' intentions based on the perceived trajectory. A second reason for looking at the differences between the synchronous and the asynchronous version is the lack of research about this issue in the literature, as we have seen Chapter 1.

Our hypothesis H3 posits that the asynchronous MLA will improve coordination. Since it conveys more information, we hypothesize that it will be a better coordination device. We then expect that the group performance will depend on the richness of the coordination devices available: asynchronous MLA will be more efficient than synchronous MLA, and both, in turn, will allow better performance than no MLA.

Moreover, an additional exploratory issue is to address the potential side-effects of location awareness tools: **how can spatial information modify communication patterns? How is information about others' location integrated, misinterpreted or missed?** The aim is to discover the underlying mechanisms influenced by location information conveyed through MLA interfaces.

We will detail how we operationnalize these hypotheses in the experiment sections.

3.2 Methodological choices

3.2.1 Three experiments

In this thesis, we present **three experiments** that have been conducted **in different technological contexts**. The first study has been carried out using a 3D virtual reality environment and the two others using the physical world through a pervasive computing application. The former is a preliminary experiment that helped us shaping the second and third experiments, which have a broader scope. In each of them, we have different conditions based on the presence or the absence of an MLA interface. The studies are not comparable strictly speaking but we aimed rather at understanding the salient and common trends in both environments, and not at making a point-by-point comparison of the results.

In addition, in line with our choice to have a deductive approach, we carried out experiments in two contexts. In the 3D virtual environment, the experiment was classic and easily controlled (because of the fixed setting). However, the study in the pervasive computing context was trickier. Empirical studies of pervasive applications generate various epistemological problems, especially about the confrontation of different experimental conditions. Using laboratory experiments (Kjeldskov et al., 2004) to control all the variables appears to be the wrong approach since it is not possible to artificially recreate an ecological validity. There is indeed a lack of physical (e.g. people's movement during mobility) or socio-cultural context (e.g. the role of place, as described in Harrison and Dourish, 1996).

Another common methodology is to draw on ethnographic methods. In this case, the problem is the lack of objective measures such as the performance of the device or finding solid evidence to make comparisons between experimental conditions. This is why our objectives as well as the need to have the most natural context led us to use a 'field experiment' approach (Goodman et al., 2004), derived from the notion of "quasi-experiment" developed by Cook and Campbell (1979). Field experiments are quantitative experimental evaluations conducted out in the field, drawing from aspects of both qualitative field studies and lab experiments. On the one hand, they involve real users in an activity that is setup in the real world. On the other hand, we can control variables and have different experimental conditions.

3.2.2 Benefiting from quantitative and qualitative analyses

Although we used controlled and semi-controlled experiments, we **did not limit ourselves to quantitative data**. As we mentioned previously, our research also has an exploratory dimension; this is why we also collected **qualitative sources** of information such as group interviews or messages content. Concerning the operationalized research questions, we will not present here the data we used in each experiment. It will be detailed in the descriptions of each study.

Each kind of data is meant to address our research questions. Our questions are addressed through quantitative measures such as mutual modeling evaluations or group performance; these indexes are used to compare situations in which players have a MLA interface to "control" situations (without MLA). Ethnographic methods will also be used to intensify our investigation of how MLA is interpreted and used among group participants. This research is therefore grounded in a quantitative dominant paradigm, with which we also used qualitative techniques (Creswell, 1994). Our aim is to gain a greater understanding of MLA influences on collaboration from the use of both qualitative and quantitative research methods. This is why we have chosen a developmental combination, in which quantitative analyses are used sequentially to test our hypotheses and qualitative techniques are used to illustrate them.

In terms of analytic orientation, given that these studies address the cognitive processes at stake in collaboration, we are interested in observable behavior (from an external observer) as well as the point of view of the participants. This is why we employed interviews and self-confrontation techniques in the second experiment to complement the observer's analysis with the actors' perceptions of what happened during collaboration.

3.2.3 Multi-user games as a collaborative platform

The tasks we used to assess the influence of MLA interfaces on collaborative processes were bound to a specific type of joint activity. First and foremost, we only studied **small groups** of participants, consisting of 2 persons in experiment 1 and 3 persons in experiments 2 and 3. In addition, these groups were engaged in a **decentralized collaboration**: the activity they carried out did not require any central command hierarchy. They were all participating in the task environment with the same information and there was no centralized control structure. The roles participants took during the collaboration thus emerged from the group dynamic, through conversations during the activity (or before in the case of experiment 2-3 in which there was a planning phase). Conversely, they were not given any normative principles to achieve the task: the way they completed the mission they had to undertake was entirely and not imposed by experimenters.

In order to conduct both experiments, we chose to use **collaborative games, as** proposed by Chalmers and Juhlin (2005). The use of such kind of platform has already been discussed in the human computer interaction field for a long time (Donchin, 1995; Holmquist, 1997). Several scholars have stressed the interest of using virtual environments like video games as research tool for psychological investigation (see

Slangen de Kort, 2001 for a general review about this topic) by citing **three major reasons**.

First, computer games are motivating and fun, and successful experimentation is easily achieved. Maintaining one's undivided attention in video games is certainly easier than in other experimental environments. The use of a game metaphor has the advantage that it allows the presentation of complex problem solving tasks in an enjoyable environment, thus maintaining a high level of motivation amongst subjects. Besides, recent developments in augmented reality (Nilsen et al., 2004) have highlighted the motivational value of using game in HCI. Second, a game, especially a mobile computing one, involves participants in a real context (the physical world) with a certain ecological validity. A game in public space indeed creates a certain kind of complexity with passers-by or real-world features. Another useful aspect is the fact that they attract "*participation by individuals across many demographic boundaries such as, age, gender, ethnicity, educational status and even species*" (Kowalski, 1997). We thus expected participants to have a higher level of involvement in a game than in another kind of complex task.

However, these statements only hold for subjects that find such games enjoyable, those with little interest in games can fail to engage with the game, finding both the task and the interface difficult and confusing. Therefore, we chose to design simple games to avoid failures and misunderstandings.

3.2.4 Unit of analysis

As described in the research scope, we are interested in **group cognitive processes**. Research about collaboration has to deal with the "unit of analysis" problem: should we analyze social interactions at the individual or at the group level? This problem is of importance when one wants to carry out quantitative studies of collaborative interactions, as in this research. Kenny (1998, 1996) discussed those issues by highlighting how the non-independence of observations could be problematic. If the individual is used as unit of analysis, the assumptions of independence are likely to be violated because persons within groups may influence one another (Kenny and Judd, 1986). Alternatively, if groups (e.g. couple, team, organization) are used, the power of the statistical tests is likely to be reduced because there are fewer degrees of freedom than there are in an analysis that uses a person as the unit of analysis. This is the reason why Kenny (1996) promoted multi-level analyses since it allows more flexibility (explanatory and outcome variables can be of any type) and also allows for group and time heterogeneity to be included in the model.

Kenny (1998), however, also points to another simpler method to measure the non-independence of the data using the intraclass correlation[7]. This index can be viewed as the amount of variance in the persons' scores that is due to the group, controlling for

[7] This method can only be applied to nested data: when groups are assigned to levels of the independent variable such that every member of a given group has the same score on A with some groups at one level of A and other groups at other levels of A.

the effects of the variable. When the intraclass correlation is not large and total sample size and the group size are small, power is very low. If there is non-independence, then the group must be used as the unit of analysis and if there is independence, the individual may be the unit of analysis.

Therefore, when we analyzed social interactions in groups, we computed intraclass correlations to determine the level of analysis (Kenny, 1998). However, for certain variables, such as the group performance, the team was the unit of analyses because the activity was joint and could not be carried out alone. Moreover, group measures were either measured at the group level (e.g. time to solve the game) or resulted from the aggregation of measures at the individual level (e.g. sum of player's scores).

3.3 Summary

In sum, this thesis will describe results from three experiments focused on the influences of interfaces that convey Mutual Location-Awareness on collaborative processes. Our literature review, along with the psycholinguistic framework that we chose, leads us to posit the hypothesis that MLA would improve group work, through mutual modeling. As summarized in Table 6, we have three main research questions.

Table 6. Summary of our general research questions.

Research question 1	Does mutual location-awareness interface modify group coordination and performance?
Research question 2	Is an asynchronous awareness tool more efficient than a synchronous location-awareness tool?
Research question 3	How can spatial information modify the coordination process? How is MLA integrated, misinterpreted or missed out?

These questions will be investigated in to two different environments: a 3D virtual reality game for study 1 and a pervasive game, played in the physical environment for studies 2 and 3. Nevertheless, the status of each study is not equivalent: the first study should be seen as a preliminary research project, since its purpose is to start comprehending MLA and its effects in a controlled environment. The following ones correspond to a longer project divided into two separate experiments. Experiment 2 is directed towards the exploration of MLA influences in a more ecological context, namely the physical world and the definition of a model of coordination based on the coordination devices participants used. Experiment 3 is meant to refine this model, aimed at describing how various coordination devices are used over time. Our goal is to use this model to visualize how group members coordinated over time. We will thus compare visualizations from the second experiment to describe the influence of MLA on coordination. To put it in a nutshell, these visualizations will be used as a tool to further our understanding of the effects of MLA on collaboration

The three studies will therefore allow us to test our hypotheses described in 3.1.3 and explore MLA affordances in different settings.

Chapter 4 • Study 1: Mutual Location Awareness in Virtual Reality

This chapter describes the first experiment we conducted concerning how MLA may affect coordination in a 3D virtual game.

4.1 Research scope

4.1.1 Goals and motivation

The previous chapters have shown that in order to support fruitful interaction between dispersed teammates, multi-user environments have to provide awareness interfaces that support what we describe as an exchange of coordination devices.

This first study constitutes **a preliminary investigation** of how MLA as a coordination device influences collaboration. It aims at investigating the relevance of MLA tools and their effects on collaborative processes regarding group performance, mutual modeling and team coordination. We investigate whether providing users with a location-awareness tool could help them in building a more accurate model of their partner's intentions and eventually in being more effective collaborators. This research, by augmenting mutual modeling with an awareness tool, is thus a first step in grasping the group cognitive effects of location awareness on mutual modeling.

This study was carried out using a computer game in the form of a 3D virtual world played by two players. The reasons we chose a 3D world were twofold. First, the environment should be complex enough for an MLA tool to make sense: 3D games indeed offer this kind of complex setting; for example objects can be hidden by the topology. Second, location-awareness tools have always been a topic of interest in games such as 3D first-person shooters or role-playing games. As we have seen in the second chapter, games in virtual worlds use a reasonable number of MLA tools. Our game only involves two players for methodological reasons. Since we want to grasp the effects of an interface from a cognitive standpoint, we need to isolate these fine-grained processes, which would be hard to distinguish in large groups.

In this experiment, we focused on a **synchronous location-awareness tool**, which, by definition, only conveys information in real-time about the partners' position in the spatial environment.

4.1.2 Hypotheses

We hypothesize that **this MLA tool should contribute to the mutual modeling (MM) process and as a consequence would improve the group performance**. However, users need to interpret the information provided by the awareness tool to infer his/her teammates knowledge, strategies or plans. It is possible that MLA increases the workload of collaboration because more information needs to be processed. Indeed, partners could be less effective if there were no attentional resources available to think about the task.

The first hypothesis we state is that pairs with the MLA tool will be more effective than pairs without it. By automatically providing coordination devices to the players, the MLA information should indeed enable players to complete the task more efficiently. The underlying reason for that is articulated in the second hypothesis.

The second hypothesis postulates that pairs with the MLA tool will build more accurate model than pairs without it. The giving of the location of a partner would facilitate the inferences an individual makes about his or her partner's intents.

4.2 Material and methods

4.2.1 Participants and design

Thirty-six persons participated in this study, all French native speakers. They were students from the University of Geneva who voluntarily agreed to participate. We chose only men in order to avoid gender bias. Subjects were all familiar with computer and video games as well as with joysticks. We created 18 pairs of participants (N = 18), which were assigned to one of the experimental conditions forming two groups of 9 pairs. Within a team, participants were paired with a partner they were not familiar with; we randomly created pairs by selecting students from different faculties.

The 18 pairs were assigned to either the *Control* condition (*without Mutual Location-Awareness*) or the experimental condition (*with Mutual Location-Awareness*). These conditions differed by the availability, in the experimental condition, of an awareness tool that allowed participants to see the position of their partner in the virtual space.

4.2.2 Material

The environment

SpaceMiners[8] is an experimental platform in the form of a video game deployed to elicit collaborative behavior. The game engages **two players** in basic space missions: cooperating for the **collection of minerals located in asteroids and bringing them back to a space station**. To do so, players control a spaceship that shoots drones through asteroids to eventually reach a space station.

Figure 21 depicts an overview of the game environment that includes various artifacts such as planets, asteroids, the space station (the circles on the left) and the spaceship. The line shows the trajectory of a launched drone whose direction is modified by the planet's gravity. To prevent players from being lost in space, the interface shows a compass (in the lower right-hand corner), similar to a normal compass. One line shows the player where he is pointing. The horizontal line shows if one is looking up (if the line is at the bottom of the compass) or down (if the line is at the top of the compass). Finally, there is an indication of the score (individual and team) in the upper right-

[8] Developed by Yvan Bourquin, Jeremy Goslin and Thomas Wehrle at the Geneva Interaction Lab

hand corner. The time limit and the game level are also indicated near the score (on the left).

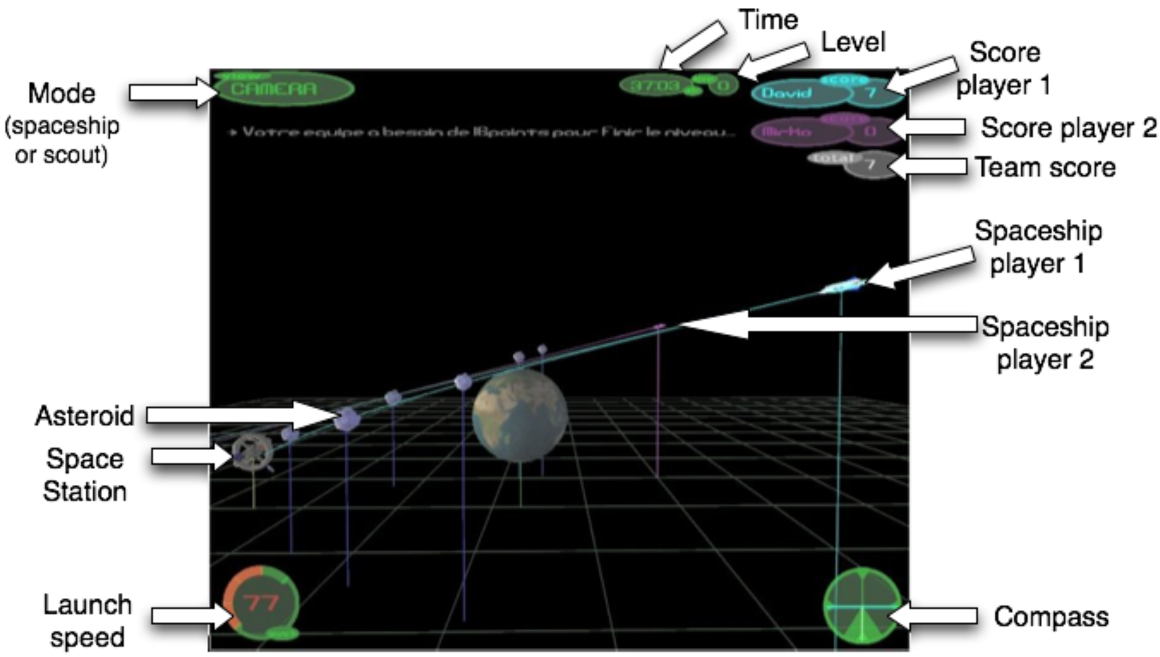


Figure 21. The game environment made up of a planet (at the center of the picture), asteroids (on the left of the planet), two spaceships (on the right) and a space station (on the left). This screenshot depicts the scout view (since we see the spaceship) as indicated in the upper left-hand corner. David (the player who controls the ship) manages to collect asteroids and to dock his drone to the space station. Thus he wins 7 points.

Users can play in **two modes** that correspond to two viewpoints: the **spaceship mode** and the **scout mode**. They can switch from one mode to another by pressing a key on the joystick.

In the scout mode, players can move their "scout" vehicle around in space by moving the joystick. The scout, depicted on Figure 22, has two uses: to see the space from another viewpoint and to place different artifacts in space.

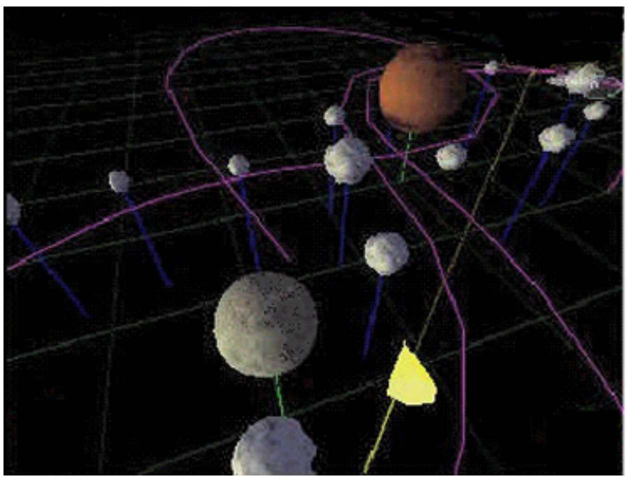


Figure 22. The scout as it can be seen in the "spaceship" mode.

In the spaceship mode, the position is fixed: it cannot move in space. Players launch drones that pass through as many asteroids as possible on their way to the space station. Figure 23 depicts those spaceships and shows the surrounding environment.

Once the drones are launched, players have no control over them. Their trajectory depends on a) the direction of the spaceship, b) the launch speed of the drone controlled by the player, and c) on the gravity of planets. The aim of the player, in the spaceship mode, is to control the first two variables in order to plan the trajectory of the drones. To change the orientation of the spaceship, players can move a crosshair located in the centre of the screen in the spaceship view with the joystick. Moreover, using the slider on the joystick can change the launch speed. In the lower left-hand corner, there is a graphical indication of the launch speed. Additionally, different tools dragged into space by players can modify the drone's trajectory.

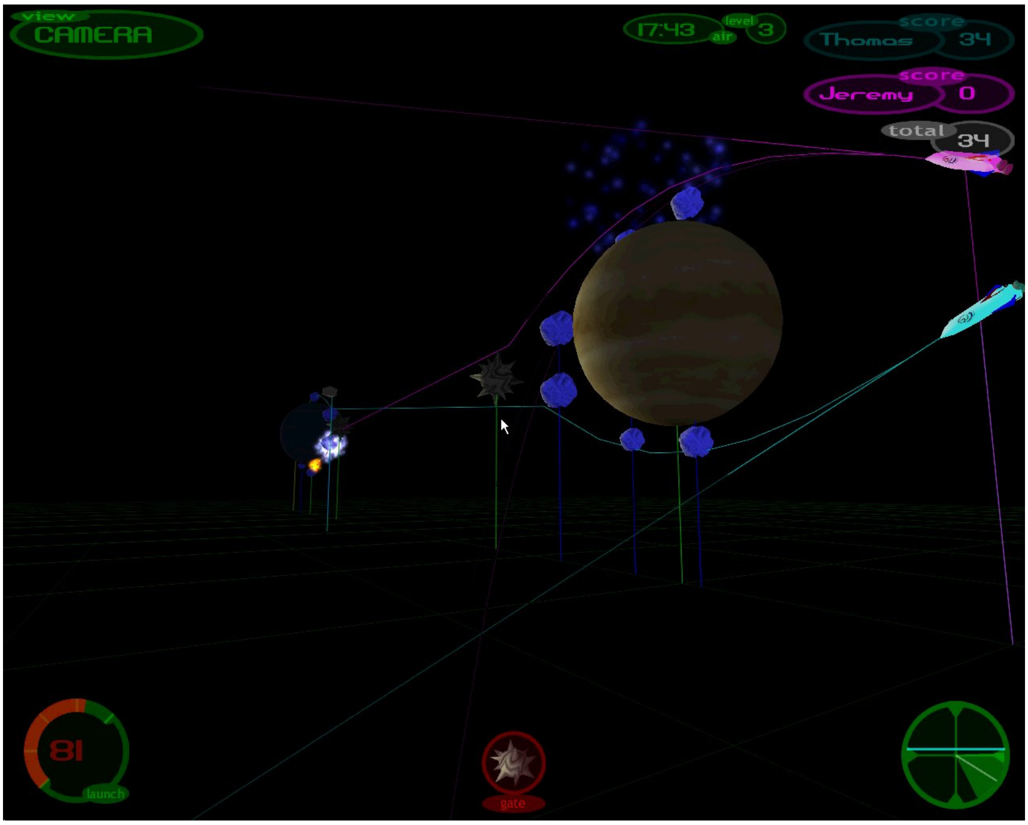


Figure 23. The spaceship as they can be seen in the “scout” mode.

Moreover, **different artifacts are provided** to modify the trajectory of the drones players shoot in space. Figure 24 presents the two available spatial objects that can be dropped in space or dragged behind the player's scout: the black hole and the gate. The black hole has a very high gravitational pull: it pulls drones towards it. Gates are stabilized entrances to wormholes in space-time. If two of them are placed in space, then a gate will transfer a drone from one position in space to another one instantaneously. Players see the spatial objects available represented in a toolbox. When someone drops spatial objects in space, the icon is removed from the toolbox and the object stands in space just behind the player's spaceship. If he wants to see it, he has to rotate.

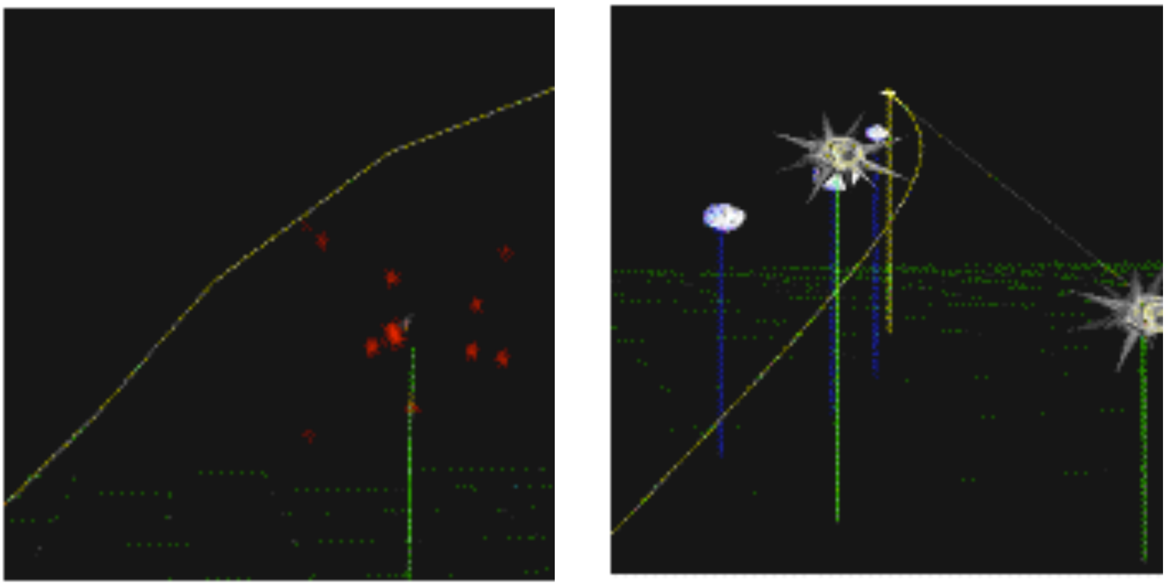


Figure 24. The two spatial objects: black hole on the left and gates on the right. The black hole pulls the drone; that is why the trajectory is curved. The picture on the right shows that the drone is sent on the first gate (which is on the right), after a while, it will go out of the left gate.

Mutual Location-Awareness

In the context of this experiment, **the MLA tool is a view that shows the partner's scout** as presented in Figure 25. Seeing the scout of his partner gives information about the teammate’s viewpoint in space. The presence or absence of this MLA tool constitutes the experimental condition of the study. We expected players to use this location awareness interface so that they avoid revealing each other’s location.

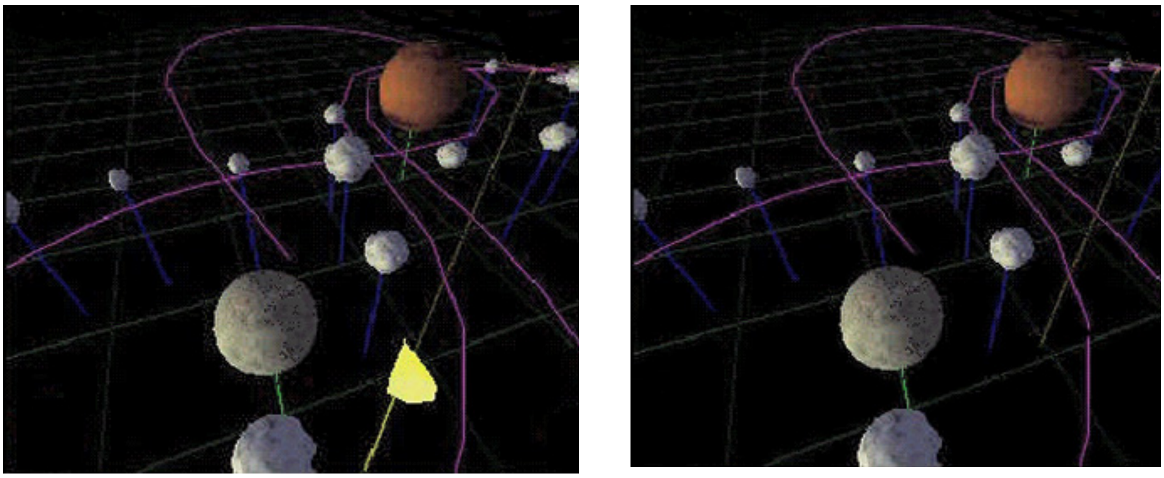


Figure 25. Presence (*MLA condition*: figure on the left) or absence of the awareness tool (*Control condition*: figure on the right). The view of the scout, represented by a polygon, is basically the mutual location-awareness tool. This view can only be seen in the spaceship mode. Thanks to this awareness tool, the player can know where his partner is and also where he is pointing by seeing the direction of the cone.

The collaborative task

The purpose of this game is to **collect the largest amount of minerals** located in asteroids and to bring them back to a space station. Achieving this aim requires the players, in the spaceship mode, to plan the trajectory and launch speed of the drone they have to send so that it goes through the asteroids. The group score then represents the number of collected minerals docked to the space stations by the two players. It is influenced by several factors such as the drone trajectory, the launch speed, the tools' positions (that influence the drone trajectory), the number of asteroids in the environment and the planets' positions (that modify gravity).

The game itself consists of three levels, of increasing difficulty. Difficulty depends upon the number of elements that disrupt the drone trajectory: the number of planets and the positions of asteroids are potential means for that matter. An additional way to increase the complexity of levels was to position planets and asteroids in such a way that players had to use objects. In game level one, players were given no objects; the environment was simple with only one planet and a row of asteroids. In level two and three, each player had different objects that fostered collaboration. In level 2, each player had only one gate with one planet and asteroids put in a row behind the planet. In level 3, one player had a black hole and a gate and the other had only one gate; there were two planets and two rows of asteroids behind the planet.

In Spaceminers, collaboration consisted in the fact that game level configuration **obliged players to play together**. Levels had been designed in such a way that players had different perspectives in the virtual space and were obliged to talk to each other in order to navigate, to drop an object, to adjust his shot as well as to discuss role distribution.

Another primary issue was that pairs needed to negotiate about the position of those objects in space since it was not possible to finish a certain level without using spatial objects. They were thus forced to discuss and decide where to put a tool.

In terms of collaborative problem solving, this task engaged players in a different set of activities:

- the observation of the environment, from the player's perspective, sometimes augmented with information about the partner's perspective: where asteroids were located, which tools were available, how a planet could modify a shoot, etc.
- the discussion about what to plan to adopt to reach the goal: participants had to discuss elements such as identifying the asteroids to reach or the planet to avoid.
- a negotiation about the implementation of this plan: who will do what, which angle to shoot from, which tool to drop, which launch speed to select were important parameters they had to discuss.

Apparatus

The game was played on two computers (866 MHz Intel Pentium III systems equipped with 256 MB of RAM and ATI Radeon 8500 graphic cards) over the local network. Each player sat in front of a distinct computer located in different rooms and could communicate by voice thanks to headsets. They interacted with the game using a regular Logitech joystick represented on Figure 26.

The most important buttons on these joysticks were:

- The A button that allowed to switch from the explorer mode to the scout mode and vice versa.
- The left and right joysticks, which enabled the players to orientate the scout or the spaceship or to move around in the spatial environment.
- To control the launch of a drone, a slider allows to change the launch speed and the R button can be used to shoot.
- Menu navigation (at the beginning of the game and between levels) can be done through the joypad (for items selection) and with the L button to choose an item.

Figure 26. Joystick configuration with controls in both view (in black) and in scout view (in grey).

The experiment was run on three personal computers: two for the client interfaces (located in two different rooms) and one for a server. The server was used to run the game engine and to log the game actions as well as the audio communication. CoolEdit was used to record the conversations, between the two players. We employed Battlecom to enable players to talk to each other, over the local network. We ran a Battlecom server on our server and two Battlecom clients, on the client's computers used by the two players.

Modeling questionnaires

Given that we want to evaluate how an MLA interface influence mutual modeling, we need a way to apprehend this variable. In order to evaluate the mutual modeling accuracy, we deployed **two different "modeling" questionnaires** presented in Table 7 and Table 8. Both of them were displayed during each level, as a transparent layer appearing on the game level.

The first questionnaire was about the player's intended actions. It asked each player about what they were intending to do at that moment (guide his partner, try to understand his strategy, try to establish a common strategy, adjust a shot, etc.). Then, the second one asked each player about what he thought the partner was intending to do (same propositions as the previous questionnaire).

The idea was to use those questionnaires as a **way to compare player A's predictions about B's intentions with B's real intentions**. We constructed the questionnaires around the individual or joint actions that could be carried out in the game. Thus, in both questionnaires, there were similar questions (like "adjusting a shot") referring to individual actions Joint actions required us to reverse the questions; for instance we changed the "guide my partner" into "guide me" to make them correspond. Each questionnaire then had 10 questions that covered the basic actions that could be performed. We did not go further into the differentiation of the possible actions because a finer granularity would have lead to more questions (for instance about drone movement amplitudes). This might have lead to a lower probability of common answers, which would not have been efficient in measuring mutual modeling accuracy.

Table 7. Questions asked in the first modeling questionnaire in each of the 3 levels.

What do you intend to do now?
Adjusting a shoot
Tune my drone launch speed
Guide my partner
Understand what my partner wants to do
Establishing a common strategy with my partner
Understanding my drones' trajectory
Understanding the trajectory of my partner's drones
Drop a tool to deviate my drones
Drop a tool to deviate his drones' trajectory
Other

Table 8. Questions asked in the second modeling questionnaire (displayed after the first one) in each of the three games.

What do you think your partner intend to do now?
Adjusting a shoot
Tune my drone launch speed
Guide me
Understand what I want to do
Establishing a common strategy with me
Understanding his drones' trajectory
Understanding my drones' trajectory
Drop a tool to deviate his drones
Drop a tool to deviate my drones' trajectory
Other

In game level 1, questionnaires were displayed 5 minutes after the beginning. At that time, the players did not know each other very well. Thus, with the first questionnaire, we evaluated a baseline for the accuracy of the pairs' mutual modeling. MM1 represents the accuracy of evaluations of the two partners' representations of each other's strategies when the players are not very familiar with each other. The questionnaire in levels 2 and 3 appeared after one of the players dropped an object in space, which occurred two or three minutes after the beginning of the game. Consequently, the questionnaires in level 2 represented the mutual modeling accuracy just after the first level. By the same token, the questionnaires in the third level represent the mutual modeling accuracy just after level 1 and 2.

We compared the first answer of a player (about what A is intending to do) to the answer of his partner to the second question (about what B believes A is intending to do). The evaluation of the MM accuracy is consequently the number of common answers given by the two players to these two questionnaires. We verified whether A's prediction of B's answer matches with B's actual answer. Since there were 3 evaluations (one per level), we could have a mutual modeling accuracy index per individual for each level. The global mutual modeling accuracy index was thus the sum of these 3.

4.2.3 Procedure

Each experiment lasted approximately 2 hours and had been conducted in French. The first part of the game was an individual tutorial that lasted nearly thirty minutes that explained the aims of the game, the interface, how to move and how to shoot. It was basically a walk through illustrating the different interfaces elements that could be used. The participants were asked to try out proposed exercises to learn how to play individually.

After this tutorial, players received the instructions they had to follow: playing the game together to complete three levels using different objects. They had to complete three levels, lasting 30 minutes for each. The transition from one level to another was automatic once it had been completed or after 30 minutes. We did not want the whole experiment to last more than 2 hours that is why we had 3 levels of 30 minutes with a tutorial of the same duration.

At the end of the 3 games, player had 5 minutes to complete a paper-based questionnaire with two questions: how they were guessing their partner’s intents and how Mutual-location awareness information was useful for playing (only for player in the experimental condition with MLA). These two questions were meant to be used in the qualitative analysis for the data: to gain insight about MLA was used and interpreted.

4.2.4 Variables

The **presence or absence of the location-awareness of the pair** (conveyed by the MLA tool) constituted the **experimental condition of the study**: it is our independent variable. As for the dependent variables, we used task performance and different mutual modeling indexes.

Concerning task performance, since the task could not be carried out alone, we used the pairs' combined score: player A's score added to player B's score. As for the mutual modeling accuracy, we used 4 different quantitative variables presented in Table 9. Each of them had been calculated as explained in the Section 4.2.4. They were calculated for the individuals, but a group version is computed by taking the mean of the individuals’ measure among the same pair. As for the scale of analysis, computing the intraclass correlation will tell us whether the analysis of the mutual modeling indexes should be carried out at the individual or the group level as proposed in the previous chapter.

Table 9. Description of the dependent variables concerning mutual modeling calculated for each player.

Evaluation	Description
MMg = MM1 + MM2 + MM3	Global mutual modeling evaluation for the individual
MM1	Mutual modeling evaluation for the individual measured in the first game level
MM2	Mutual modeling evaluation for the individual measured in the second level
MM3	Mutual modeling evaluation for the individual measured in the third level

In addition, thanks to automatic logfile analysis, we collected interaction variables: the number of actions performed by the players, the number of drones launched, the number of drones docked to the space station, the number of spatial objects dropped in space. This logfile analysis allowed us to compute the number of switches between the scout and the spaceship mode as well as the time spent in the scout mode. These variables have been used to further the analysis of the collaboration process. We did not have precise hypotheses regarding these variables but intended to use them as covariates with regard to the outcomes of the collaborative activity.

4.2.5 Hypotheses

The first hypothesis **H1** posits that **the MLA tool has a positive effect on task performance**. We predicted that the team score would be higher in the experimental condition. We based this hypothesis on the assumption that the information conveyed by the awareness tool would enable them to better coordinate and better carry out collaborative problem solving activities. We then made the hypothesis that the team score would be higher in the experimental condition "*With MLA*" than in the *Control* condition.

Our second hypothesis **H2** postulated that the **mutual modeling accuracy could be improved by the presence of the MLA** because MLA conveyed information about the partner's current position in space. Hence we made the hypothesis that the global accuracy of the mutual modeling evaluation (MMg) should be higher for players in the experimental condition "*with MLA*".

A third **H3** posited that the **mutual modeling accuracy improves over time**: as partners began to know each other, the representation of each other's strategies was more accurate. As a consequence, we expected MM3 to be higher than MM1.

Moreover, the analysis of qualitative data such as the questionnaire and the interaction players had with each other is meant to deepen our understanding of how of Mutual Location-Awareness is interpreted and used. It also aims at investigating the link between MLA and mutual modeling.

4.3 Quantitative results

This part summarizes the quantitative results we obtained, focusing first on collaboration and on how the presence of MLA modified the performance of the game. It then presents results about mutual modeling and how it has been influenced by the experimental variables. The section finally discusses the interactions between mutual modeling, task performance variables and the effects of MLA.

4.3.1 Collaboration and problem solving

MLA and task performance

Since it is a collaborative game, performance is a group variable: it is the team score obtained by the two players after playing the three levels of Spaceminer. Most of the pairs (15) played the game for the entire two hours. Only three pairs managed to finish the three levels of the game in less than two hours. We then decided not to use time as a variable. Our hypothesis H1 stated that groups in the experimental condition "With MLA" would reach higher score. Figure 27 shows a boxplot that represents the group score obtained in the two experimental conditions.

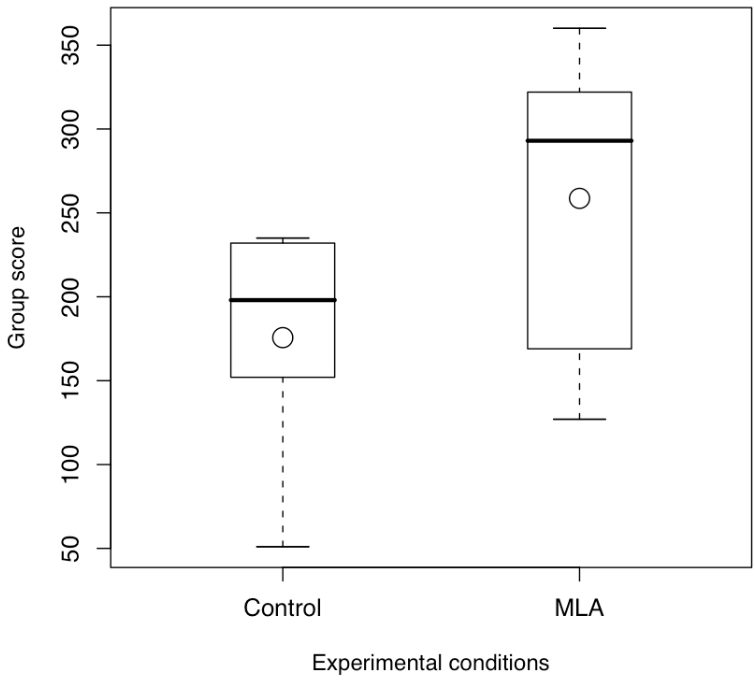


Figure 27. Group scores in the two experimental conditions (MLA: with the Mutual Location-Awareness tool, Control: without). The circle indicates the mean and the line shows the median.

shows that pairs with MLA reached higher score (m = 258.7, sd = 90.8) than the others (m = 175.7, sd = 67.48). Besides, no pairs without MLA reached the mean score of the pairs with the tool. The MLA tool enabled players to be more efficient. A one-way analysis of variance test confirmed that there is a significant difference between the conditions "MLA" and "without MLA" (F [1,14]= 4.84, p = .043). In addition, using the total time played to complete the 3 levels as a covariate did not led to different results. Therefore, **our first hypothesis is validated: the MLA tool significantly enhanced task performance**.

Furthermore, the standard deviation is higher in the MLA condition. The median also shows that half of the pairs reached higher scores than the mean in the two conditions. This heterogeneity might be explained by different ways of playing the game: some players and groups did not apparently take advantage of the MLA tool, which eventually lead to lower scores.

Problem solving actions

To detail the analysis of the collaboration process, we focused on problem solving actions carried out by each player and stored in the log files. The point was to analyze whether the MLA changed the way users played. We counted the number of events performed by players and the whole team. We looked specifically at the time spent in the "scout view, the number of view changes (spaceship/scout), the number of launched drones and docked to the space station, and finally the number of spatial objects dragged and dropped into space.

On average, it appears that these numbers of events are quite similar in the two conditions (with awareness tools and without) as presented in Table 10. A Student test was also conducted to see if there were differences. This test showed no significant differences between the two conditions.

Table 10. Number of events for each pair in the two conditions, standard deviation and student test findings.

	Drones launched	Drones docked	Spatial objects dropped	Spatial objects dragged	View changed
Mean (With AT)	416	70.11	14.44	14.67	384.67
Mean (Without AT)	514.11	75.67	14.67	15.78	317.78
Std Dev. (With AT)	90.80	60.29	5.98	7.14	141
Std Dev. (Without AT)	280.84	57.28	4.47	4.60	176
Sig. (Student test)	0.48	0.84	0.93	0.70	0.39

There were no differences concerning the actions performed by the pairs. There is thus no impact of the MLA interface on the different actions that have been carried out.

4.3.2 Mutual Modeling

Individuals modeling indexes

The mutual modeling accuracy had been calculated for each individual. As described by Kenny et al. (1998), we checked the non-independence of the results through the computation of intraclass correlation. This index reflects the correlation between the evaluation of how player A estimates player B's strategies (calculated thanks to the results of the in-game questionnaires and compared to B's answers: MM(A,B)) and the evaluation of how player B estimates player A's strategies (calculated thanks to the results of the in-game questionnaires and compared to A's answers: MM(B,A)). We found a positive and significant correlation ($r = .38$, $p < .05$) between the representation B made about A and the representation A made about B.

Two conclusions can be drawn from this result. The first one is that the mutual modeling appears to be a group variable rather than a personal activity. We expected accuracy of mutual modeling to be a personal parameter, i.e. that some participants spontaneously pay more attention or engage more effort in monitoring their peer. This could be due to some social attitude or to specific cognitive skills required to build a mutual model. This strong correlation supports a different hypothesis in which mutual modeling emerges as a property of the quality of interactions among peers: some pairs seem to collaborate in such a way that their verbal and non-verbal interactions produce more cues available to both partners so that they can build a mutual model. However, since the correlation was not equal to 1, this does not remove the fact that there is an individual variability. Besides, if we consider the presence of the MLA tool, the correlation is bigger for players who did not have the MLA ($r = 0.44$) than for the others who had it ($r = 0.24$); but the difference is not significant ($F[1,13]= 0.1445$, p-value = 0.7097). Perhaps this result could be explained by the fact that as the players without MLA had less information about each other, they were forced to communicate much more and to be more explicit.

The second conclusion is that this positive correlation expresses the non-independence of the results among groups. Then, when we investigate the influence of the MLA on mutual modeling, we will have to use the group as the unit of analysis.

Mutual Modeling and MLA

Hypothesis H2 predicted that the MLA would have a positive effect on the mutual modeling accuracy. Since we have to use the group as the unit of analysis, the group measure of mutual modeling was obtained by taking the mean of the mutual modeling index within a pair. This group measure was defined as MMg in Table 9. Figure 28 shows a boxplot representing this accuracy for pairs in the two experimental conditions.

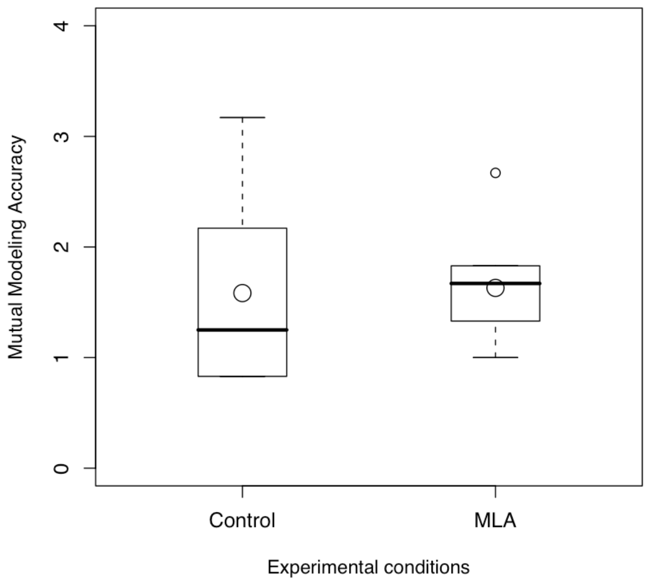


Figure 28. Mutual modeling measures for the groups in the two experimental conditions (MLA: with the Mutual Location-Awareness tool, NoMLA: without).

Figure 28 shows that the means of Mutual Modeling accuracy in both conditions were very close (*With MLA*: m = 1.58, sd = 0.87; *Control*: m = 1.63, sd = 0.48), although the standard deviations are quite different. The ANOVA test invalidated our hypothesis H2: the difference between the two conditions is not statistically significant ($F[1,14] = 0.02$, $p = .889$). The representation of one's partner strategy seemed not to be facilitated by the information conveyed by the MLA tool. But this is mainly due to the huge heterogeneity of the control group. Our **second hypothesis is then invalidated**.

Mutual modeling evolution over time

The third hypothesis H3 predicted an effect of time and collaboration on mutual modeling. At the beginning of the game, the players were not familiar with each other. We postulated that playing together during two hours would enable them to improve the accuracy of their mutual modeling. Like the preceding analysis, we looked at this index at the group level (as indicated by the intraclass correlation). Figure 6 depicts the evolution of the MM accuracy for pairs in the two experimental groups.

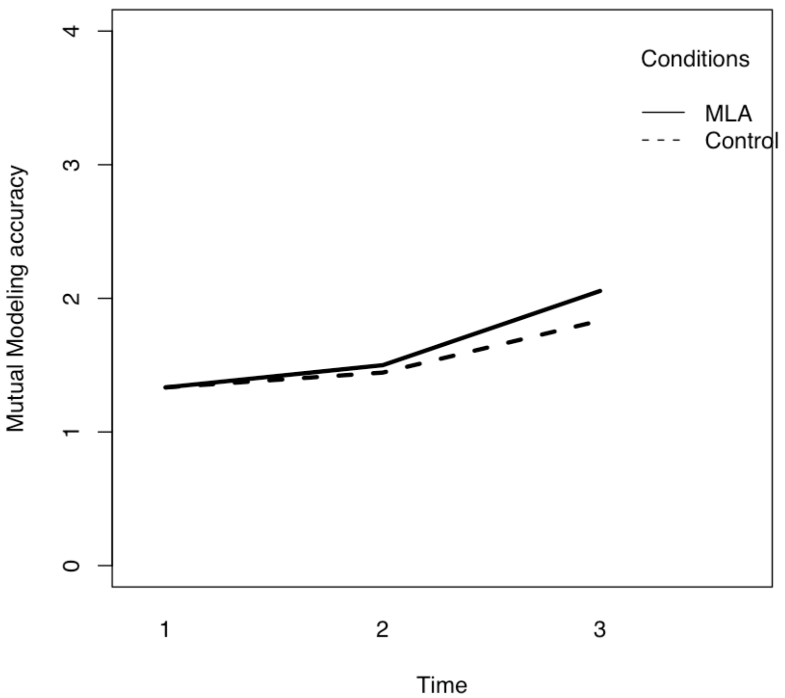


Figure 29. Evolution of mutual modeling accuracy from level 1 to 3. The horizontal axis expresses the time discretized in 3 different levels.

As Figure 29 illustrates, the mutual modeling accuracy rose a little between the two first levels (MM1 and MM2) and then there was a increase between the two last evaluations (MM2 and MM3). As a clue to this phenomenon, we should look at the moment of the evaluation of the mutual modeling accuracy. The first measure indicated the baseline for the mutual modeling accuracy. MM2 represents it after one level of play and MM3, after two levels. The implication is that perhaps the players needed two game levels (nearly one hour) to become familiar with each other. The surge between MM2 and MM3 might be due to this phenomenon.

Repeated measures analysis showed that **the effect of time on the accuracy of mutual modeling is only a trend** ($F = 3.189$, $p = .084$) as depicted on Figure 29. We then cannot accept our third hypothesis: there is only a marginal effect of time on mutual modeling accuracy. Additionally, there was no effect of the presence of the MLA tool ($F = 0.1$, $p = .75$), which is consistent with the rejection of our second hypothesis. There is also no interaction between time and the presence of the MLA tool (F = 0.05, p = .95). As a consequence, this supports the argument that the sudden increase of the accuracy of mutual modeling is not due to MLA.

Mutual modeling, MLA and collaborative task

We found a positive correlation between the accuracy of the mutual modeling and the group task performance (r = 0.42, *p* = 0.05). Pairs with an accurate mutual model reached better scores. Additionally, a regression analysis has shown a positive and significant relation between the group score and the mutual modeling accuracy (β = 54, *p* = .02). This MM index then proved to be a good predictor of the group task performance. However, post-hoc comparisons on contrasted groups did not show any interactions between MLA, performance and mutual modeling accuracy. Unfortunately, the low number of subjects did not allow us to conduct analyses on contrasted groups to see, for instance, the impact of mutual modeling on score.

Moreover, looking at the percentage of time spent in each view ("scout" or "spaceship") by the pairs in the two conditions as shown in Table 11, we noticed an interesting difference. Teams in the MLA condition spent more time in the "scout view" than teams in the other condition, while the average time spent in the "spaceship view" was similar in the two conditions. Since the distribution of the variable was not normal, we used a Wilcoxon test, which showed that the difference concerning the percentage of time spent in the "scout view" was significant (W = 70, *p* < 0.001). Since the view of the partner's scout was the MLA tool, it was not surprising that players in the tool condition spent more time in this mode. By staying in the scout view, they could give information to their partners about their intentions and their locations.

Table 11. Average percentage of time spent in the "scout view" and in the "spaceship view" by the pairs in the two conditions.

	With MLA	**Control**
Average percentage of time spent in the "scout view"	75.41%	62.54%
Average percentage of time spent in the "spaceship view"	24.59%	37.46%

We then performed a post-hoc split of players into two kinds of participants depending on the time they spent in the scout mode. The split point was the mean of time spent in that mode and it led to the constitution of two groups made up of 12 individuals "short time in scout mode" and 24 individuals "long time in scout mode". A two-way analysis of variance conducted on these contrasted groups revealed that pairs in the awareness condition who spent more time in the scout mode reached higher levels of mutual modeling (F = 8.02, *p* = 0.015) than the others. It implied that **there was an effect of the MLA on the accuracy of the mutual modeling only for teams who spent a long time in the "scout mode"**. Therefore, it seemed that the information conveyed by this awareness tool could be a benefit for team collaboration. This information could help players in order to estimate their partner's strategies if the participants understood that they had to make an effort: spending an accurate time in the scout view. **The teams who did not spend enough time in the scout view had no benefit of the MLA tool**.

Summary of quantitative results

In sum, we found that our main factor (presence of Mutual location-awareness) had a strong positive impact on group performance of the task. It also seemed to have a positive impact on mutual modeling accuracy only for players who used it intensively. Furthermore, we discovered that the accuracy in predicting other's intents was only marginally influenced by time; and overall that when one player in a group guessed the partner's intents accurately, so did the second partner. Finally, the positive correlation between the accuracy of the mutual modeling and the group performance seemed to account for the benefits of the MLA. The next section aims at understanding how MLA has been used and interpreted by players in this experimental condition.

4.3.3 Qualitative results: Mutual Location-Awareness interpretations

We did not perform a quantitative content analysis of pairs' communication. Nevertheless, in order to gain more insights about how MLA has been used by players in the MLA condition, we employed ethnographic methods. Collecting two sorts of qualitative data in the experiments also allowed us to deepen our understanding of the importance of a coordination device such as MLA. Players in the MLA condition were asked in the post-game questionnaire how knowing the partners' location was useful in this game and how they were guessing their partners' intents. Additionally, using dialogues and Interaction analysis (Jordan and Henderson, 1995) enabled us to find and describe occurrences of MLA usage.

Data has been analyzed to look for "**critical moments" in which players' location was meaningful for them**. These moments, as well as the answers to the questionnaire were then transcribed. Then we listed all the topics and potential uses that had been quoted by all the participants. The next step consisted in clustering together similar topics that we used to get back to all transcribed data so that we could find out whether it fitted or whether new topics emerged. In the end, after this analysis, we found 3 broad categories of MLA interpretations and usage has emerged. These descriptions show how a coordination device can be interpreted and employed as a way to perform mutual modeling acts in order to draw relevant inferences for coordinating. In the categories description below, we have translated excerpts from French to English.

Implicit awareness of partners' activity

The simplest form of usage for MLA was that it provided pairs with an **implicit indication of the partner's activity in real time**, in terms of actions and intentions the partner was ready to carry out. This was particularly important in the beginning of each level as attested by numerous answers in the questionnaire: "*I could guess his intentions when seeing his scout*", "*I thought he was exploring the level*" or when a player was thinking about performing a certain action: "*he was quiet for sometimes, I thought he was trying some shootings*", "*it helped me to know where my partners went and dropped his tools*", "*I saw him close to the asteroids, I inferred he wanted to drop a blackhole and I had to help him*".

This last example also shows that MLA was a coordination device used as a resource for the player's own actions. Knowing the position of the partner in space could have two consequences: performing a different action ("*he was close to the first planet so I* *went exploring the other one*", "*he already dropped a blackhole here, so mine should have been positioned somewhere else*") or joining him to give help as in Excerpt 1.

Excerpt 1 (the square brackets shows overlapping communication):

```
J: I see you under the first asteroid, do you need a hand?
M: ah I am trying to drop the gate here,
M:                [hmmmm
B: can you tell me if I am correct?
M: sure, wait I'll stop moving
B: OK
```

In different cases, players underlined the importance of using this tool instead of communicating ("*it allowed me to observe what he was doing without talking about it*", "*while exploring space, we did not lose time talking*"). A passive monitoring of the partner's movement in space was then perceived as a communication economy.

Understanding of the situation

What is also important is that the MLA is not just an implicit cue but **also a resource for communication**. On one hand, we have just seen that MLA enabled players to talk less about certain issues. On the other hand, this coordination device has been used in dialogues as a resource to clarify the situation, what we described as "referential communication" in Chapter 1.

The discussion between the two players indeed mobilized both elements from what they see of the virtual world and MLA information. The combination of dialogues and MLA then allowed the players to have a shared understanding of the situation and an understanding of each other's perspective as can be seen in excerpt 2. This extract shows how a pair explored the world, using the MLA to understand the perspective they each have. Location awareness of each other provided them with a way to understand what their partner was looking at.

Excerpt 2:

```
R: I don't get where is the last asteroid
D: ah, can you see me?
R: hmmmmm
D:          [look at my scout
R: yes, under the planet but can you stop moving?
D: ok, so there's a planet above me and the asteroid is
right after, on the left
R: Aah there, sure, I got it, but can you see the asteroid
close to me?
D: no I cannot, I am too low
```

In addition, the combination of MLA and dialogues enabled them to keep a trace of what had been done in the past (3): "*I knew he left a tool here because I saw him going here*".

A powerful coordination device used with communication

Even though we saw that MLA was useful for communication economy, this does not imply that players did not talk about their own locations. The **position of partners** is often employed to update their shared knowledge about the state of the environment, as a **support to solve coordination problems**, such as adjusting a shot or helping a player to drop an object in space. In this context, a number of participants expressed the view that MLA was used for referential communication to meet this end: "*at some point, he wanted to drop a blackhole, so I helped him, monitoring how close he was from the planet and told him when the blackhole was well-positioned*", "*seeing his scout's position was helpful to agree on tools positioning*", "*looking at his scout's position, I confirmed his that the position of his tool was wrong*"

The MLA tool provided **a continuous feedback to the partner** who could see where was his teammate. This was extremely useful in tasks like object positioning. In such tasks, player A guided player B's movement by giving him instructions about where to drop the object. The team was thus more effective because player A did not need to verbally describe where he was and player B did not need to interpret this description. More precisely, players took different roles that changed over time: one dropped certain tools and the other helped him to position them in space. As can be seen in Interaction analysis excerpt 1, the difference of viewpoints might account for this. In this part of the game, players took advantage of not seeing the same part of the virtual world to help each other. Player G went above player R and guided him to position himself properly to drop a blackhole.

Interaction analysis transcript 1. (Transcript done using the interaction analysis convention of Jordan, see Appendix J in Jordan and Henderson, 1995)

Time	Activity	Talk
14:56:34	R arrived close to the first asteroid	R: there is the first asteroid, I can't see the second because of the planet
14:56:42	G moves his scout above the first asteroid	G: wait, I come over
14:57:05		R: can you see me? G: hmmm, yes I see you between both asteroids R: OK, I want to drop a backhole between them G: hmmm are you sure, you're too close to the asteroid, go on the left
14:57:30	R moves his scout on the left	G: OK, that's better, let me see
14:58:03	G moves his scout higher	G: again R: huh, again what? G: a bit on the left, I went up and I saw you were still too close
14:58:40	R moves his scout on the left	R: and now? G: it's fine! Drop it
14.59:11	R drops a blackhole	R: here we go!

It is important to keep in mind that what allowed the joint action here was the explicit agreement between the two players: the use of MLA as a coordination device was only a resource for action through referential communication. This broader perspective on coordination devices is developed in our next experiments.

4.4 Discussion

The statistically significant differences between the two experimental conditions suggest the **location awareness information helped players finish the three levels more efficiently**. This is consistent with the findings of Gutwin et al. (1996) and (Espinoza et al., 2000). Overall, the findings suggest the benefits of this awareness tool on task completion. The broadcast of a continuous flow of information ("feedthrough") through the MLA tool had multiple functions, as we saw in the qualitative analysis. It provided users with a shared understanding of the situation, an implicit awareness of the partner's activity and a valuable way to solve coordination problems. This finding is consistent with Hindmarsh's study (Hindmarsh et al., 1998) that showed how difficult it is for users to establish mutual orientations in virtual space since there is a lack of a common frame of reference. Where Hindmarsh et al. suggest a 2D map to alleviate this, we think that players could also benefit from the MLA tool to create such a common frame.

Information about others in space, combined with a discussion about the context, seems to be a powerful way to update the shared understanding of the situation. In addition, concerning coordination, MLA was also of importance as a resource for referential communication. The use of this awareness tool leads to the transformation of a task from a verbal to a visual activity; players used conversation to agree on specific issues (when being guided to drop spatial objects for instance) as we saw in Interaction Analysis 1. Referring to Clark's coordination theory, which we described in our framework, mutual location-awareness was a coordination device that has been mutually recognized in the pair's discussion. A common usage we saw was that MLA served as a resource for negotiating the objects position in space through explicit agreement.

We also found that the perception of the intention of one's partner was not facilitated by the information conveyed by the MLA tool. Presumably, this result leads to four possible conclusions. First, the MLA tool, by showing information about the partner's locations may not improve the accuracy of the mutual modeling. One reason for that could be that the information conveyed by the MLA was not useful for that task; maybe what was important in that game was less people's location but rather efficient communication about the spatial environment. Second, it is possible that the game did not require participants to maintain accurate mutual models; they did not have to care much about each other. Third, the task could have been so captivating that players did not have enough time or attention to spend for the MLA tool. And finally, perhaps, our evaluation of mutual modeling was not very precise. However, focusing on the behavioral data that were stored in the log files, we found that pairs in the MLA condition who spent more time in the scout mode reached higher levels of mutual modeling than the others. It implies that there was an effect of the MLA on mutual modeling only for the teams who used it intensively. Awareness information could help players in order to estimate their partner's strategies if the participants understood that they have to make an effort: spending an accurate time in the scout view. The team who did not spend enough time in the scout view had no benefit from the MLA tool. This finding raises a new question: did players really use the awareness tool? Indeed, if there was an effect of the tool on mutual modeling only for the players who used it frequently, it might have been possible that only a few players in the tool condition noticed the advantage of using it.

Now, looking at the functions of MLA described in the qualitative analysis and the potential roles it might play in the mutual modeling process, the qualitative analysis attested to the benefits of the MLA in terms of awareness of partner's activity and its role in the update of the shared understanding as well as its resource for coordination. The main reason for this paradox is the fact that the **groups in the MLA condition were split into those who used the tool** (and described to us the benefits of it, those who built more accurate mutual models of their partners) **and those who did not** use it. Another explanation is the fact that being aware of something is only one part of the coordination process; providing a coordination device such as MLA is not sufficient, that information has to be mutually recognized by the partner (Clark, 1996). The two types of user we found (those who used the tool and those who did not) could possibly explain this situation. Another reason for the absence of acknowledgement or mutual recognition could also be that at certain moments, the information was not relevant to the situation. As Sperber and Wilson would have stated (Sperber and Wilson, 1986), the information was not pertinent in the mutual cognitive environment of the users.

Regarding the effect of time on the accuracy of mutual modeling, there is a slight trend but it is not statistically significant. Our hypothesis was invalidated but the findings call for certain restrictions because of the questionnaire. First, the questionnaire per se could be disruptive and could push players to pay more attention to their partner's intents, which might account for the augmentation of the mutual modeling accuracy over time. Second, the questions we asked are limited in the sense that they only refer to a specific moment in the game.

Our results have certain limitations. On the one hand, the number of participants was quite low: eighteen pairs (nine in each conditions). On the other hand, the method used to measure the accuracy of the mutual modeling might have been imperfect. Using a simple questionnaire to measure the accuracy in predicting partner's answers was indeed subjective. We should have used a more objective method to evaluate this variable. A solution would be to compare what player A thinks B is going to do with what B really does. The only way we can deal with this issue would be to investigate the dialogues and check where they mentioned awareness information related or not to the MLA tool. A systematic comparison of the dialogue between the two groups, with a quantitative coding of categorized utterances, would be very instructive. In order to validate and confirm our results, improving our mutual modeling analyzing tool would also be important. This could be done through an analysis of participants' action. The point would be to compare what player A thinks B is going to do with what B really does which is more precise than just asking the players what they do. We could also consider the redundancy of actions as a coordination index: if player A completed the same actions as player B, that could also mean that they did not coordinate so much.

4.5 Conclusion regarding MLA and coordination

This first experiment in a virtual environment showed the importance of Mutual location-awareness in a collaborative task. Analyses of quantitative data supported the idea that the MLA tool can be beneficial to mutual modeling if two conditions were met: (1) if users properly understand its meaning and use, (2) if users mutually recognize this information in the course of action.

By the same token, qualitative data showed how MLA is used to solve coordination problems. **MLA could indeed be seen as the content of a coordination key that can be mutually recognized as manifest or as an explicit agreement** (in Clark's terminology). As a manifest element, it allowed players to build a shared understanding of the situation (constructing and building the *Common Ground*) or to draw inferences about what the partner is doing or has done. As an explicit agreement, MLA can be mobilized in the discussion about how to achieve goals and subgoals. These three contributions represent how the MLA can foster better mutual model when collaborating. The condition for this is indeed that the users get the added value of such a tool. Noticing the gain due to the MLA was not obvious *per se* since the users had first to understand the task to be performed and which kind of tool it could support (1) the task performance and (2) the collaboration. Then, MLA tool could eventually lead to a better group performance through the positive impacts it had on mutual modeling process.

Chapter 5 • Study 2: Mutual Location Awareness in Pervasive Computing

The present chapter describes the second experiment we carried out to evaluate the influence of MLA on coordination. Unlike the previous experiment, this one has been undertaken in the physical world, using a pervasive game.

5.1 Scope of the study

5.1.1 Motivations and goals

We considered the previous study as a preliminary exploration of the MLA influence on collaboration in the context of a 3D world. This study addresses the same issues using a pervasive game. **Location-based applications give us new opportunities to study the influence of MLA in real space**. The availability of mobile and pervasive technologies offers a relevant platform to address how the perception of others' position in real space changes collaboration. Positioning technologies such as GPS or radio-waves triangulation enable the automatic capture of participants' location and wireless communications allow the broadcast of this information through mobile devices. In sum, ubiquitous computing fosters a new range of techno-social situations in which users' awareness of others can be augmented.

The first aim of this second experiment is to expand from **the first study by looking at the same question in a physical environment.** We indeed aim to see whether the positive influence of MLA on performance and mutual modeling still hold. Will this second experiment confirm that the automatic broadcast of MLA raises group performance and help the players to have more accurate mutual models of their partners?

The second goal is to **further the research questions** we addressed in the previous study: we aim to examine fine-grained interactions within groups and how MLA, as a coordination device, is interpreted and consequently influences the mutual modeling process by enriching the common ground of the collaborators. By exploring the underlying coordination mechanism, this study is directed towards the clarification of the relationship between MLA and mutual modeling.

The third goal of this experiment is **to discriminate the effects of two kinds of MLA** we discussed in the second chapter, based on the time span of the location-awareness displayed to the user: a synchronous awareness tool (which presents information about the current position) and an asynchronous version (which presents information about present and past positions). We aim to understand how the presentation of the path would impact the mutual modeling process, namely, the understanding of the partners' intentions based on the perceived trajectory. A second reason for looking at the differences between the synchronous and the asynchronous version was the lack of research about this issue in the literature, as we saw in Chapter 1.

5.1.2 Hypotheses

The first general hypothesis postulates that **the presence of MLA would improve collaborative task performance**. In addition, since asynchronous location-awareness conveys more information, we hypothesize that it will be a better coordination device. We then expect that group performance will depend on the richness of the coordination devices available: asynchronous MLA will be more efficient than synchronous MLA, and both, in turn, will be allow better performance than no MLA.

The second general hypothesis is that **MLA would also improve the Mutual Modeling** within the group. We indeed hypothesize that the giving of the location of a partner will ease the inferences an individual makes about his or her partners' intents. Here again, we also expect the asynchronous MLA to provide a richer coordination device than the synchronous version.

5.1.3 Rationale

To test our hypotheses, we designed **a second game platform**[9], played on a mobile device that engaged users in a collaborative treasure hunt in a physical space. We used this game in quasi-controlled experiment, carried out in the field.

However, our **goal is not to compare directly the results of study 1 and 2**. Going from a 3D virtual game played on desktop computers to a pervasive game played in the real world on mobile devices leads to drastic changes in the way we could capture the task performance as well as the cognitive processes employed during group collaboration. For example, the way of measuring capture the mutual modeling accuracy and the communication interface deployed were different.

We applied the same quantitative-dominant paradigm as in the previous experiment, but we also deployed qualitative techniques to further our investigations. For the quantitative analyses, we focused on similar processes such as group task performance and mutual modeling. However, we chose to evaluate the mutual modeling in a different way after the group activity. The reason we did so was, on one hand, because of the questionnaires used in the previous experiment might disrupt the collaborative process and, above all, the mutual modeling (since participants might expect to be asked questions about it, it will bias its measure). In addition, potential network flaws in the pervasive game could lead to a lag in the moment of display of the questionnaires. The method we used to access the mutual modeling was instead based on a position recall index: we asked players to draw the path of their partners after the game, without communicating. As we said above, we expanded the methodology of the first experiment by also performing a quantitative content analysis of communication.

[9] implemented at the lab with other colleagues. The PhD candidate designed the game scenario, prototypes of the location-awareness tool as well as the interface and a research engineer implemented the application.

5.2 Material and methods

5.2.1 Participants and design

Ninety students of the Ecole Polytechnique Fédérale de Lausanne (age range: 19-28; mean: 23.1) participated in this experiment. We selected groups who belonged to the same class and who more or less knew each other because different levels of knowledge between partners may impact the representation each of them have about their teammates. Participants spoke French or English but they used the same language within a group. We also checked that players were all familiar with the campus, studying there for at least a year. These experiments were conducted on our campus, one group at a time.

We created 10 groups of 3 persons in each of our **three experimental conditions**: the *Control* condition (*without Mutual-Location-Awareness*) or two experimental conditions: Synchronous Mutual Location-Awareness (*Synchronous MLA*) and Asynchronous Mutual Location-Awareness (*Asynchronous MLA*). These conditions differed by the availability, in the experimental condition, of an awareness interface that allowed participants to see the position of their partner in the virtual space either in real time (synchronous) or in the last 5 minutes (asynchronous). We controlled group gender so that each condition was made up of 25% of female and 75% of male. Within a group, the repartition was generally 2 males or 2 females.

5.2.2 Material

The game platform: *CatchBob!*

CatchBob! is a pervasive game running on Tablet PCs in which groups of 3 teammates have to find an object on our university campus. **Three users have to catch "Bob", a virtual static character**. Completing the game requires the players to **surround Bob with a triangle** formed by each participant's position in the real space. To reach this goal, they employ an application as depicted on Figure 21.

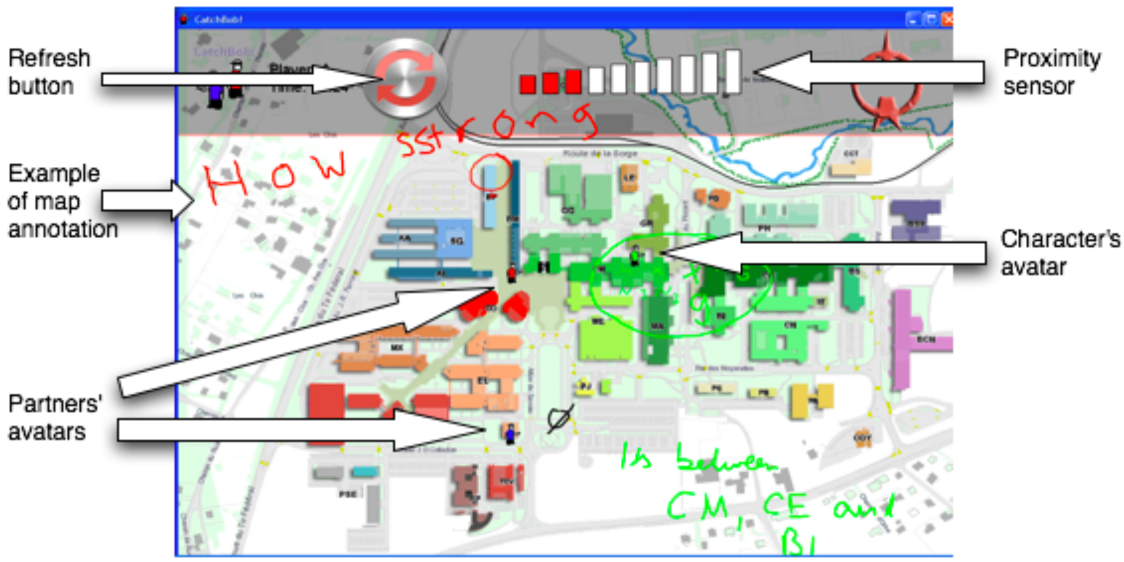


Figure 30. CatchBob! interface as seen by one player

The software displays players as avatars in three colors (blue, green and red) and a refresh button that can only be used by players in the MLA conditions to update the location-awareness information. On the upper part of the interface, an individual proximity sensor indicates whether the user is close to or far from the object through the number of red bars displayed at the top of the interface. There is actually no object on the field; Bob only appears on their display when the users form the proper triangle configuration around it. This triangle should be equilateral with a side length of 20-35 meters. When the players are close to the object, the triangle they have to form appears on the display; they then have to adjust it in the proper way.

In addition, the tool **enables synchronous communication**: players can annotate the map with the stylus. These **map annotations** are reproduced on the two other displays, using a different color for each player. They slowly fade out until they become completely invisible (after 4 minutes). This leads to simple acts of communication and dialogue: for instance a player asks his or her teammate to move to a specific location with an arrow with the message "go there" and the partner acknowledge this advice by writing an "ok, I go there". Audio communication between participants was not permitted by the system (but they have discussions at the beginning of the game).

All the players' interactions with the applications (positions, annotations, refresh of others' positions, connection loss) are logged on a server. We also have a replay tool that allows the path of each player and the messages they wrote to show. This application allows us to confront the players to a replay of their path after the game, as well as the actions they performed.

Game development

The game platform[10] relies on a **client-server communication architecture** restricted to the campus network. Figure 31 summarizes the components of the CatchBob! application. It shows the three mobile clients (in the form of Tablet PCs) that communicate via the WiFi antennas with a server.

As the policy forces the unique use of the TCP (Transmission Control Protocol) port dedicated to HTTP (Hypertext Transfer Protocol) communications, we developed our high-level remote access protocol upon SOAP (Simple Object Access Protocol) as the high-level remote access protocol. Additionally, we selected Java as the client (J2SE) and server (J2EE) programming language to keep the game software component highly portable and interoperable. The versatility of Java and SOAP (i.e. Axis 1.2, the Apache implementation of SOAP) facilitated the iterative process of rapid prototyping and user-centered design required for the development of pervasive software in research. CatchBob! can therefore run on many types of Java-enabled PDAs and Tablet PCs. Our experiments were conducted on the Compaq TC1000 Tablet PC.

[10] developed by Fabien Girardin

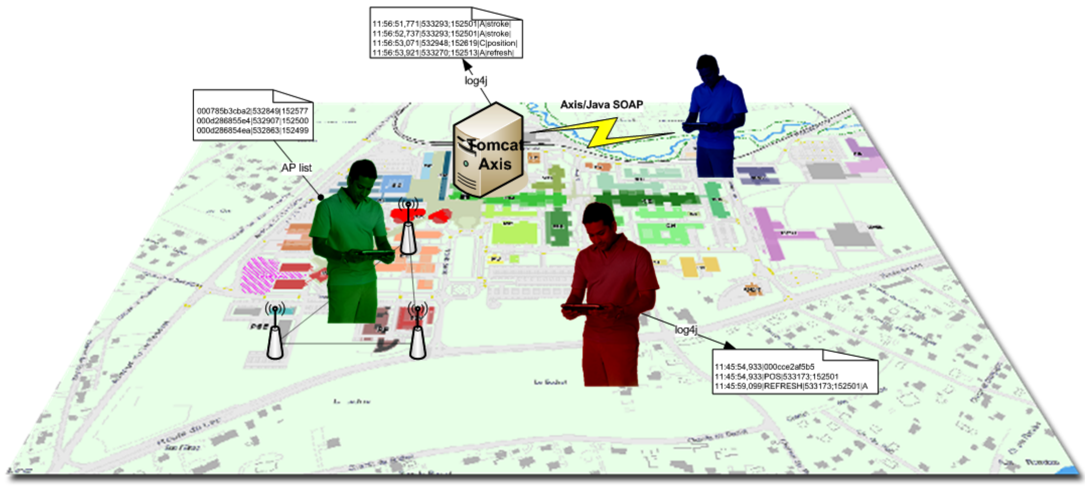


Figure 31. Simplified representation of the CatchBob! application.

The synchronization of the players' positions and annotations occur as follow. First, each mobile device self-computes its position every 5 seconds and the freehand map annotations are kept in a queue as a raw of x and y coordinates. Then, at an interval of 30 seconds, the Tablet PCs send, via WiFi within a SOAP message, the queued data to a centralized server hosting the game logic. The server checks if the positions of the 3 players and "Bob" match the criteria for the game completion and updates the game status. Finally, within the same interval, the mobile clients request the game status with the new positions and annotations of each player for synchronization. The mobile clients generate textual logs of their sensed position, the observed WiFi access points, the sensed positions where each pen stroke was performed, as well as all the potential network and synchronization failures. In addition, screenshots of the interface are stored on the client after each player annotation. Similarly, the server logs the game status, players' positions and actions (e.g. refresh, stroke) during a whole game session.

The mixed indoors and outdoors settings of CatchBob! prevented us from employing GPS (Global Positioning System) to position the players. Indeed, the campus buildings, corridors and hallways do not offer a sufficient line of sight to the sky to acquire reasonable signals to compute a position. We therefore chose to use another **positioning technique based on radio beacons**. It proved to be the only viable solution for the scale of our game as we could take advantage of the approximately 300 WiFi access points deployed on the campus.

Our radio-based (WiFi) positioning relied on an propagation model. In this solution, an algorithm computes the position based on the position of the access points and the signal strength of a radio wave received by the Tablet PCs. The mobile clients self-determine their position by dialoguing with the Place Lab native libraries to retrieve the MAC address and the signal strength of nearby WiFi Access Points. A basic centroid algorithm matches these data with a list of the WiFi access point's MAC address and the label of the room where it is located and its x and y position (based on the Swiss coordinate system). This approach performs a **positioning accuracy of 10-30 meters**, which consistently decreases when the user is in areas of low network connectivity.

The environment

We describe here **the real game environment, namely the physical space** in which players performed the task. The game takes place on the EPFL campus, whose dimensions are a 850x510 meter field. The game area corresponds to the 3 accessible levels (floor, level 1 and 2). Since the higher levels are not always accessible, we did not include them as part of the game. Appendix 2 shows some pictures of the campus topology that illustrate this.

Moreover, one of the reasons we chose to have a task carried out by three players is the fact that the campus has a star configuration. Starting from the main plaza, there are three obvious directions that afford a potential strategy in a spatial task such as CatchBob! as depicted in Figure 32.

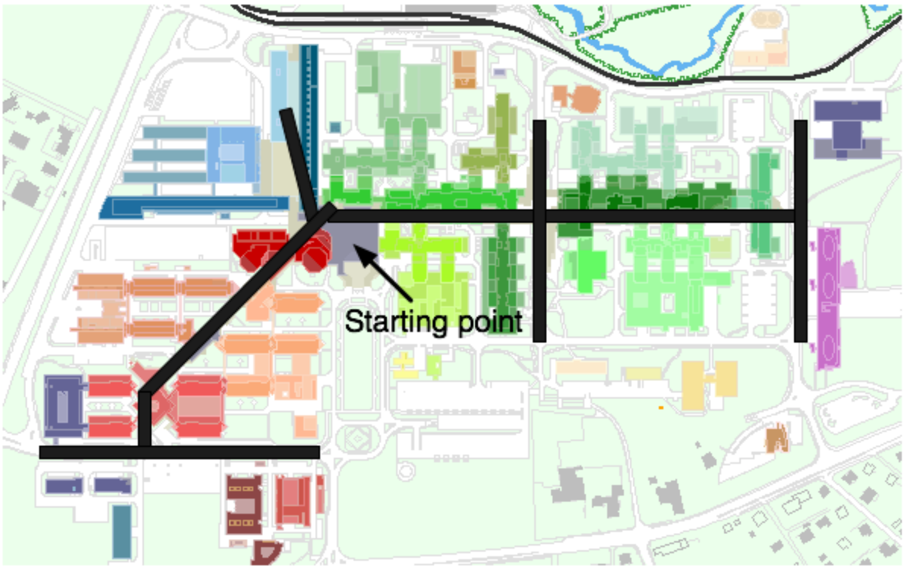


Figure 32. The EPFL campus and its main axes.

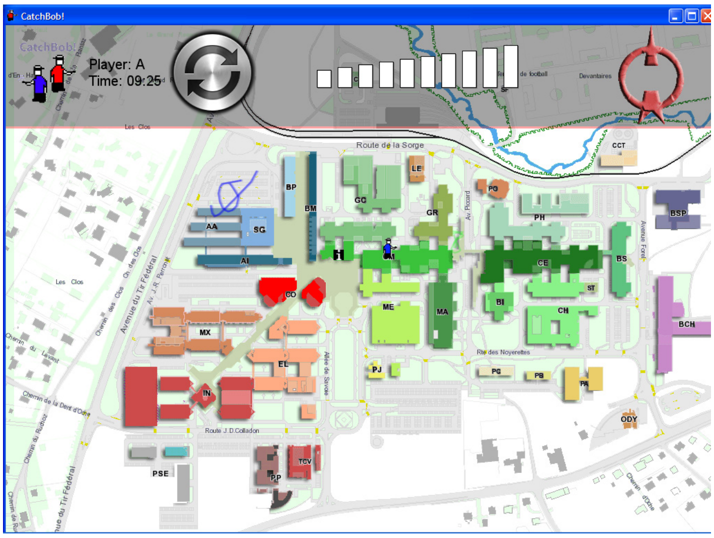
Mutual Location Awareness

As represented on Figure 33, **we tested three types of interface**, each corresponding to an experimental condition:

- In the *Control* condition "without the location-awareness tool", players only see their own character as an avatar on the campus map.
- In the *Synchronous MLA* condition, players could update his or her partners' current positions by clicking on the refresh button. They then see the location of the three avatars.
- In the *Asynchronous MLA* condition, players could update his or her partners' current and past positions (from the last 5 minutes) by clicking on the refresh button.

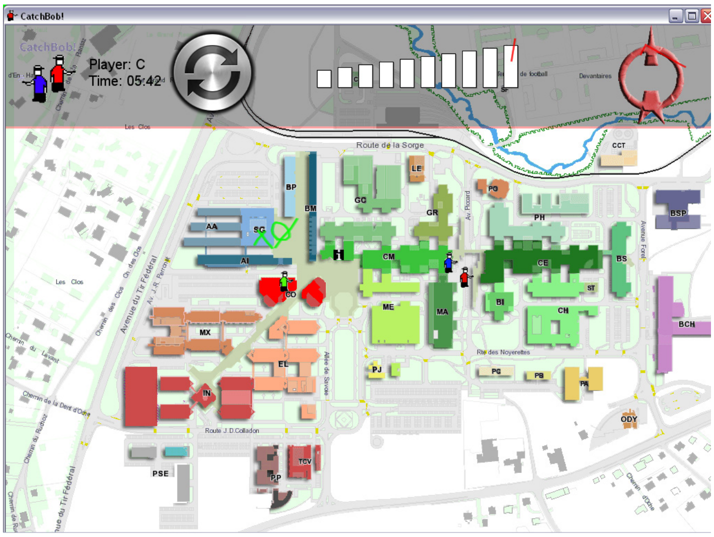
Note that all users within these 3 conditions could write the map annotations, which will be considered as a different form of awareness (as opposed to the MLA, which only convey information about spatial positions).

In the context of this pervasive game, we expected players to use this location awareness tool to monitor their partner's whereabouts and then draw various inferences we were interested in investigating. In this sort of game, the MLA is not strictly necessary to complete the game but we assumed it would facilitate Mutual Modeling among the team-members.

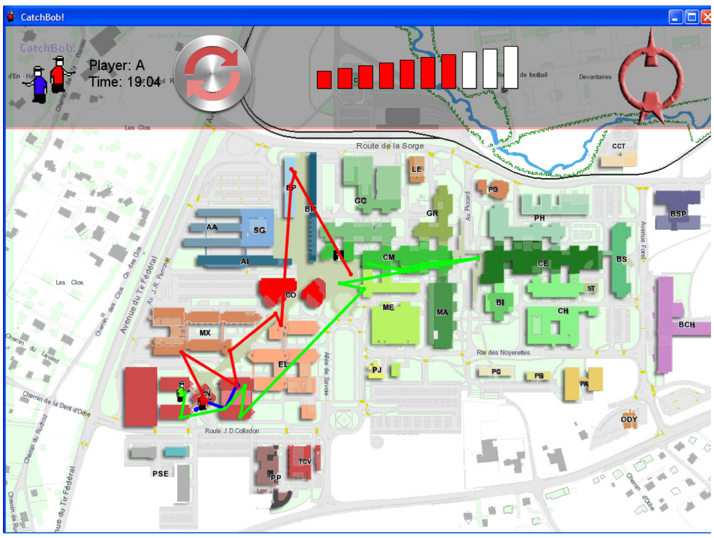


Control condition

(without mutual location-awareness): the blue player only sees his/her own position.



Synchronous MLA (with a synchronous mutual location-awareness): the blue player sees his/her position as well as his/her partners'.



Asynchronous MLA (with an asynchronous mutual location-awareness): the blue player sees his/her position and his/her partners' as well as their path from the last 5 minutes.

Figure 33. The three Catchbob! interfaces.

The collaborative task

In CatchBob!, the task carried out by the players in CatchBob! is not homogeneous, it can be broken into **3 phases**: **exploration, rendezvousing and triangle formation**. The first phase is about exploring the campus: players spread over the campus and try to find the approximate area where Bob is located, using the proximity sensor and communicating their results to their partners (using shared map annotations). The second phase involves rendezvousing: eventually one player find where Bob is approximately located, calls his/her partners who join him/her by taking different paths. And finally, the third phase requires players to form the triangle around "Bob": players then try to form different configurations of the triangle depending on their positions. An efficient way to find the boundaries between the three phases was to look at the group dispersion, namely the evolution of the perimeter of a triangle formed by each of the three players as shown on Figure 34. The three phases of the game can indeed be reflected by the perimeter evolution: in the first part, the players spread over the field (the perimeter increases) and then get closer to each other in the second phase (the perimeter decreases) with a final spread to form the triangle.

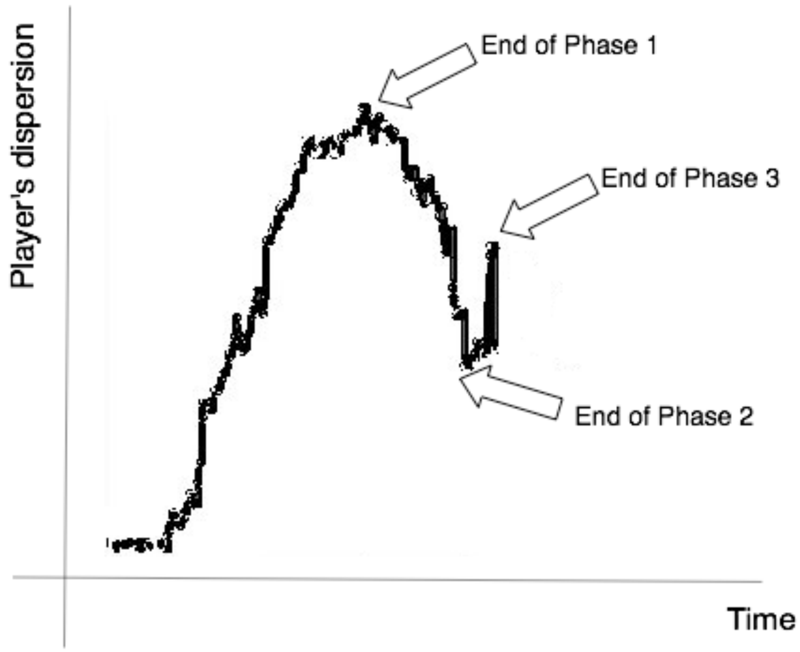


Figure 34. Evolution of the player's dispersion (perimeter of the triangle formed by the three players)

Even though finding the object could be carried out individually, collaboration is required by the fact that players have to form a triangle surrounding the virtual object. That way, we minimize the risk of having a free rider effect.

In terms of collaborative problem solving, this task engaged players in a set of different activities for all these 3 phases:

- The exploration of the environment by each player, which constitutes an individual action meant to efficiently find the object; players report to their partners what they are finding so that the collaborative search would be more efficient.

- Observation of the environment both in the physical space and on the TabletPC display in which the map shows shared annotations and MLA information (for the conditions that have access to them).
- The discussions of the strategy to reach the goal: participants had to discuss what would be the best strategy to complete the game.
- A negotiation about the implementation of this strategy: who will go where, which part of the campus should be searched by whom, how to communicate, how to form the triangle were important parameters they had to discuss.

There was **only one "Bob" per game** but we used two different positions of "Bob" as represented on Figure 35. The distance between the starting point and Bob is the same in these two scenarios. There is the same number of games with these 2 positions in each condition.

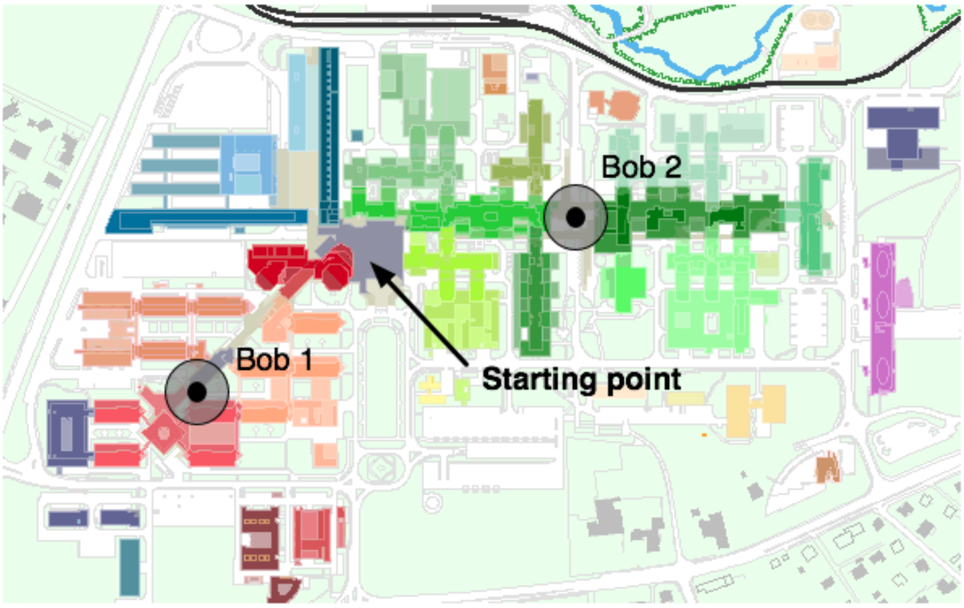


Figure 35. The two positions where Bob was located and the starting point of the game. The black dot represented the object's position and the grey envelope shows the circle in which the player should form the triangle.

Procedure

The whole experiment lasted one hour and participants went through the following steps:

- **Game instruction**. The experimenter presented the instructions at the lab. Participants were asked to find the virtual object and surround it with one constraint in mind: they should take the shortest path to it. We also told them that the time necessary to find the object was not a criterion of success. The reason why we chose the group spatial distance as a performance index is that we wanted this measure to reflect the quality of team coordination and strategy rather than their physical condition. We also let them try a demo of the TabletPC software; users could then try the annotation feature and ask questions about the software interface.
- **Planning phase**. Players were then given 5 minutes to plan their strategy on a paper map, which was then left in the office.

- **The game itself**. The experimenter led the group of 3 players to the common starting point at the centre of the campus. They had 30 minutes to complete the task, which – from the pretests we ran - was sufficient to achieve the goal without much time pressure.
- **Post-game questionnaire**. After completing the game (or reaching the 30 minutes limit), players returned to our lab and filled a paper-based questionnaire during 10 minutes. This questionnaire included 3 maps of the campus on which they had to draw their own path as well as paths followed by their 2 partners.
- **Post-game interview** that we stored as mp3**.** Players were together confronted with a replay of their activity (shown on Figure 36). The replay tool displayed in real time the position of each group member as well as their annotations. Those traces of the activity were presented to help players in giving an account of what happened, an interview technique known as self-confrontation (Theureau, 1992). One person in the group was required to start telling the story of the game using the replay tool to show what happened at different moments selected by either by the player or by the experimenter. In general, the player's answers triggered other comments by partners, turning the interview into a discussion about each of these moments. For each of these moments, the experimenter also asked one player whether she knew what one of his partner was doing; then the partner was asked if this was right. These interpretive questions were used to investigate the quality of the mutual modeling. It allowed us to collect evidences of inferences performed by the participants and upon what they were drawn. Furthermore, the experimenter asked for clarification about who was the first player to find 'Bob' or if there were misunderstandings.

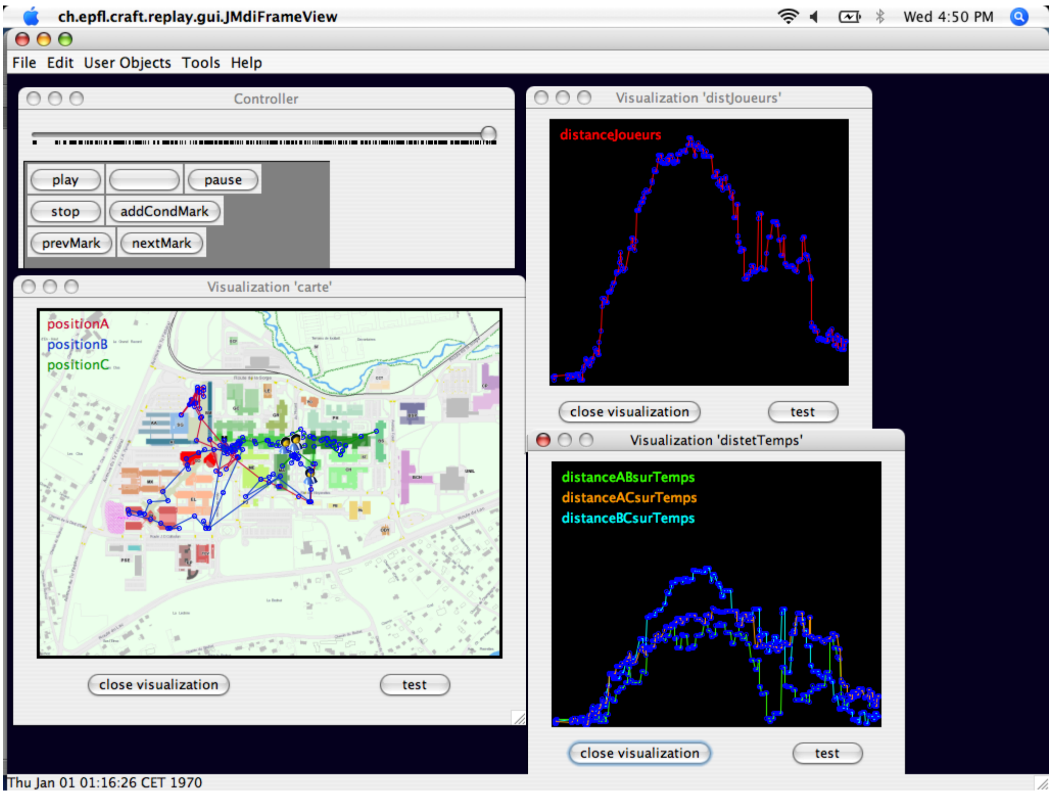


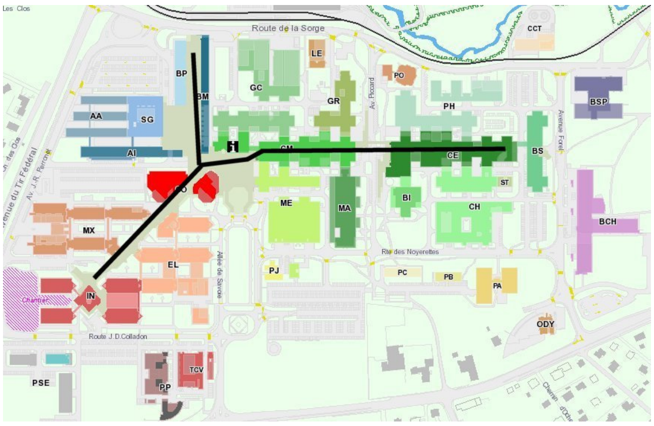
Figure 36. Replay tool allowing to show the past game (player's trails and shared map annotations) as well as various statistics. This picture for example shows a plot of the group dispersion in space (in the top right-hand corner) or player's speed (in the bottom right-hand corner).

5.2.3 Data Collection and analysis

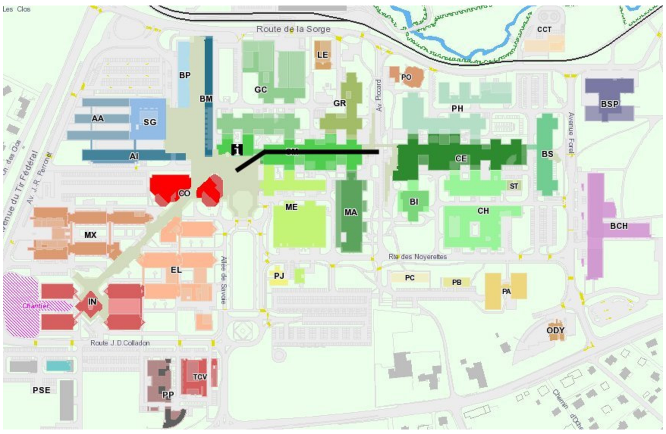
The CatchBob! platform allowed us to **collect a wide set of data** ranging from quantitative measures to player interviews and accounts of the game. This section describes this data and how we used it for different analyses.

Task performance

We measured **task performance** as the **group travel distance** (i.e. sum of the path length over all players in a group). Task performance is thus a group index measured in meters. We did not choose time as a performance variable since we did not want players to run on the campus with a Tablet PC and because finding a proper path was better suited to the discussion of a relevant strategy. We **categorized the different group spatial behaviors** that had been reflected in the paths each individual within a team chose. Looking closely at how players spread over the campus in the first phase as well as how they joined the first one who found "Bob" allowed us to gain insights about the group strategy as well as how the MLA interfaces impacted it. For each of the three parts of the game, players demonstrated various spatial behaviors. In the first phase, there were two possibilities of spreading over the campus as depicted on Figure 37. In the former, players maximized the exploration of the campus by going in three different directions. In the latter, players went all in the same direction, not grouped together but instead heading out together one behind the other.



Strategy A: a way to maximize the exploration



Strategy B: all in the same direction.

Figure 37. Different spatial behaviors to explore the campus in the first phase of the game.

Partners' trails recall

As explained in the procedure section, **we asked players to draw their own path and the one of each of their partners**. This enabled us to calculate the number of errors players made while drawing the path of their partners after the game. We used this "positions recall" measure as an indicator of mutual modeling accuracy.

Since players had to draw the paths of their partners, we could compare the path player A attributed to B with B's real paths and the same for A&C or B&C. This comparison, measured by the number of errors, represents the quality of A's representation of B and C's behavior in space.

Figure 38. (a) Drawing A made of B's path; (b) Real path followed by B as extracted from the logfile.

Calculating the number of errors was made through the use of layers on printed material: the trails drawn on the paper-based questionnaire (Figure 38a) and the real paths generated after the game by the replay tool (Figure 38b). What we counted as an error was either a place where the partner has not been or the omission of a place where he/she went. Two criteria have been defined to describe what constituted an error: distance (if the line was longer than the maximum size of our campus corridor), presence of an obstacle (door/wall/glass). Retracing ones steps was not perceived as an error. Calculating the number of errors an individual made concerning his or her own path was also a way to evaluate one's ability to do it accurately.

We calculated this position recall index for each individual and each group (the sum of the individual measures). An **individual Mutual Modeling accuracy index** is the sum of errors made by a player about his/her two partners' paths. We calculated this MM-accuracy for each individual (M (A,B), M (B,A), M (A, C), M (B,C),…) and for each group (the sum of the individual measures). It is important to stress that subjects made very few mistakes when drawing their own path on the campus (85% made 0 errors). This is why we did not use the number of mistakes made about one's path in the MM measure (to avoid dividing by 0).

Communication

Shared map annotations written on the Tablet PC were the only technological way to communicate within a group during the game; they could however have occasional face-to-face meetings on the field. To help us understand the data, we developed our own coding scheme that we employed to transcribe the annotations. We **coded the content of the messages** (position, direction, strategy, proximity to the object, off-task) and their **pragmatic status** (announcement, order, question, acknowledgement, corrections): each map annotation then had two codes. Figure 39 shows examples of such messages with the corresponding categories. Inter-judge reliability of the coding system (performed on 25% of the sample) has proven to be good as shown by a Cohen's Kappa (1968) of 0.89 for the content variable, a kappa of 0.86 for the pragmatics variable.

This allowed us to count the frequency of each category as well as the total number of messages exchanged by each player (and then each group).

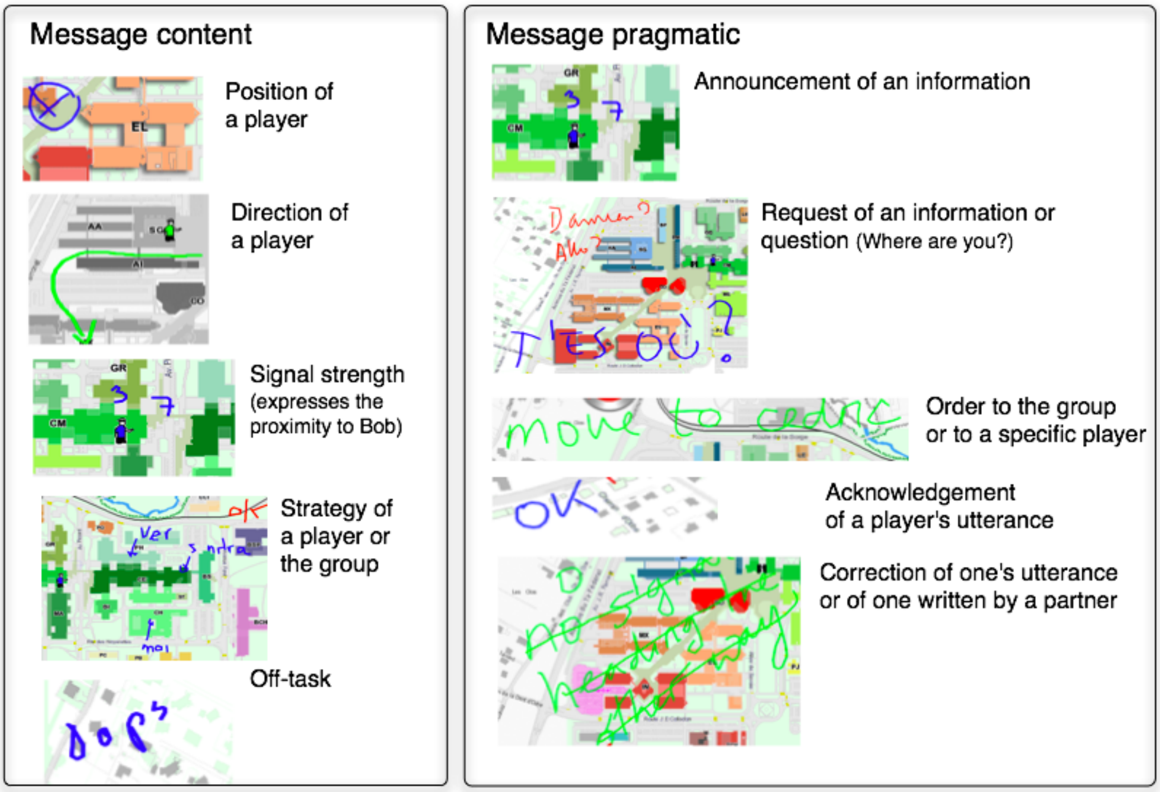


Figure 39. Examples of messages with regard to the two coding schemes: messages content and messages pragmatics.

Other qualitative data

The other qualitative data we collected ranges from players' interviews after the game to individual's spatial trails. The discussion with players when confronted with the replay tool has been used to investigate how players coordinated over time, namely to describe the coordination problems and the solutions. It also enabled us to further the investigation of how MLA has been used, and its role in collaborative problem solving. We employed players' paths to understand the general spatial behavior of individuals and groups, as they reflect the strategy they adopted. We categorized the different spatial strategies to investigate whether the presence of the awareness tool would eventually have an impact. It also enabled us to define roles for each of the players.

5.2.4 Summary of collected data

The table below summarizes all the data we collected and presented previously.

Table 12. Summary of collected data

Data	Scale	Data usage
Path length (sum of the distance traversed by the 3 players)	Group	Task performance
Phase duration	Group	Level of achievement
Partners' trail recall (number of mistakes made while drawing the path)	Individual or Group (sum of the mistakes)	Mutual modeling index
Frequency of messages	Individual or Group	Communication practices
Frequency of messages of a certain content	Individual or Group	
Frequency of messages of a certain pragmatic	Individual or Group	
Path (generated with the logfiles, displayed on the map)	Individual or Group	Group spatial behavior, strategies and individual roles.

5.2.5 Operational hypotheses

Our hypotheses described in the chapter introduction can then be operationalized as follows:

The **first general hypothesis H1 postulates that the presence of MLA would improve collaborative task performance**. This means that we expect players from the MLA conditions to find the object by covering a shorter distance on the campus.

In addition, since asynchronous location-awareness conveys more information, we hypothesize that it will be a better coordination device. We then **expect the group performance to depend on the richness of the coordination devices available**: asynchronous MLA will cover less distance than synchronous MLA, and both, in turn will be allow better performance than no MLA.

The second general hypothesis H2 would be that **MLA would also improve the Mutual Modeling within the group**. We therefore expect players from the MLA condition to make fewer mistakes when drawing their partners' path after the game. Here again, we also expect the asynchronous MLA to provide a richer coordination device than the synchronous version.

5.3 Quantitative results

This section presents the quantitative results we obtained concerning the group performance, the spatial behavior of groups, how they recalled each other's paths and communicated as well as some post-hoc analyses.

We used non-parametric tests such as Kruskal-Wallis test when data were not distributed normally or when the variances of the distributions were not equal. When the distribution was normal, we used regular one way-ANOVA analysis. We also monitored whether the position of 'Bob' had an effect on the dependent variables presented in the next section; which did not prove to be the case: there was no difference in task performance whether Bob was located on the east or on the west position of the campus.

5.3.1 Collaborative task performance

Overall performance

Our first hypothesis posited that the MLA tool would improve the task performance.

Since it was a collaborative game, we analyzed the task performance at the group level, which corresponds to the group travel distance. As depicted on Figure 40, groups in the 3 conditions had a very close performance (*Control*: m = 4859, sd = 1670 ; *Synchronous*: m = 5061, sd = 1568; *Asynchronous*: m = 5192, sd = 1385); the only difference lay in the dispersion that is higher for players without the MLA. This is not the case with the two versions of the MLA. This large variance in performance might account for two sub-population in groups from the *Control* condition: the absence of the tool seems to lead to different behaviors. There might be players who manage to compensate for the lack of MLA and others who had more trouble with this.

A oneway-ANOVA test did not show significant differences ($F[2,17] = 0.11$, $p = .90$) between the performance of the different experimental conditions. This result then **invalidates our first hypothesis**: the MLA tools (be it synchronous or asynchronous) do not facilitate the task performance.

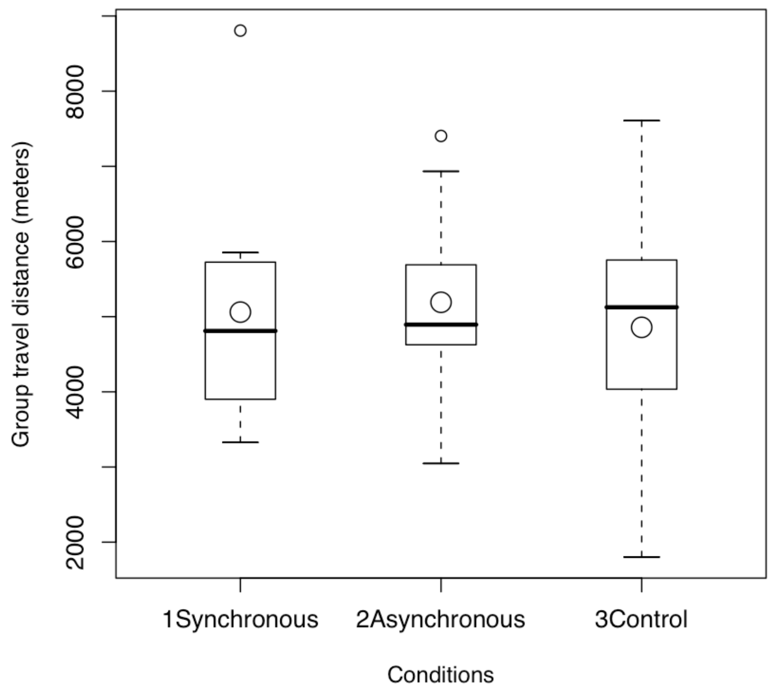


Figure 40. Group travel distance in the three experimental conditions.

Phases duration

Even though we have not used time as a performance measure, we found interesting differences between the experimental conditions, especially while looking at the duration of each phase (exploration – rendezvousing – triangle formation). Table 13 depicts the results of such an analysis, showing the duration of the three phases for groups in each experimental condition.

	Synchronous MLA		Asynchronous MLA		Control			
	Mean	Std Dev.	Mean	Std Dev.	Mean	Std Dev.	Kruskall-wallis Chi-2	*p*
Phase 1	447	224.4	389	126.03	383	161.7	0.21	0.89
Phase 2	237	114.3	327	146.16	262	113.9	1.82	0.40
Phase 3	199	94.9	24	167.6	343	166.4	3.95	0.05*
Total	884	242.6	966	315.2	989	344.7	0.47	0.79

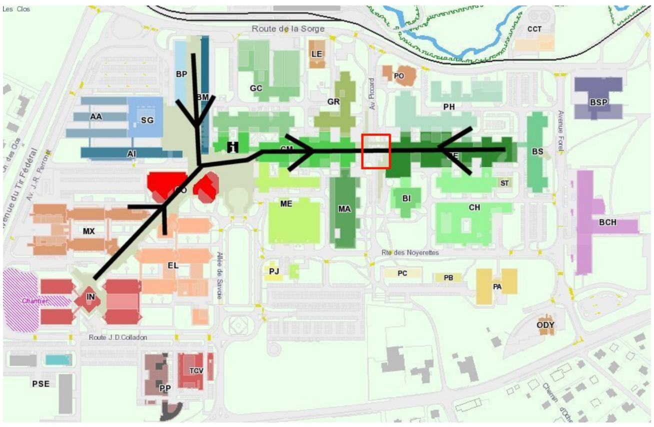
Table 13. Duration of the three phases for each phase (in seconds) in the three conditions.

Results show that groups in the *Control* condition took significantly more time in the last phase. Players in the three conditions took the same amount of time for the two first phases, but not for the forming of the triangle in the third phase. It seemed to require more time for players without the MLA to carry out the triangle formation. **Having both versions of the MLA tool seemed to facilitate this last phase of the game because it requires a finer coordination**. We also verified that there is no correlation between the time factor and our experimental condition.

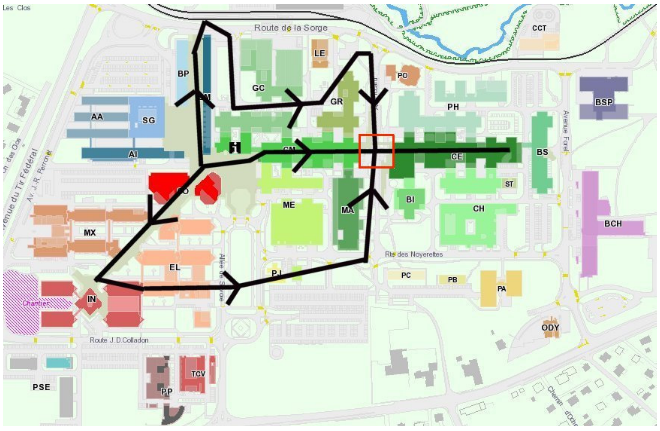
Group spatial behavior

In Section 5.2.3, we described the two strategies chosen by groups to perform the task: either spreading out over the campus or all going in the same direction. In terms of performance the second strategy could be successful only if players found (by chance) the proper direction, which was not the case for one of the group. However, only three groups chose this second strategy (one in the condition *with Synchronous MLA*, two in the *Control* condition). There were thus no differences between experimental conditions (also shown by a Chi Square analysis: Chi = 2.5558, $p = 0.634$).

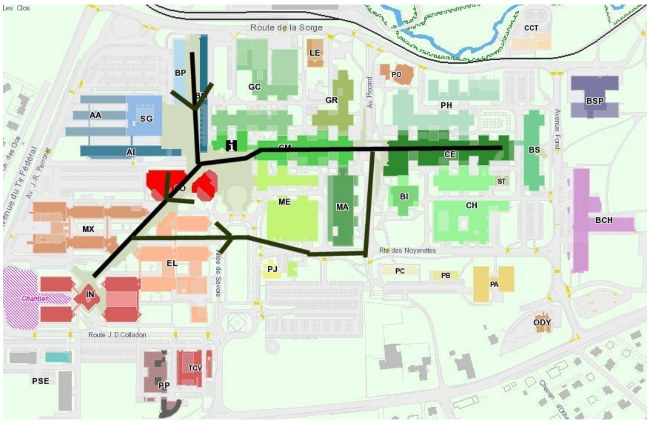
Then, in the second phase of the game, the player who saw that he/she was close to Bob through his/her proximity sensor called the others. The two partners had then two possibilities: either they went back on their path to directly join the "caller" or they joined him/her by taking another path as shown on Figure 41.



No optimization of the return: one caller (on the right) and two followers



Optimization of the return: one caller (on the right) and two explorers.



Optimization of the return: one caller (on the right), one follower (above) and one explorer (below).

Figure 41. Evolution of the strategy after one of the players found Bob's area and called the others.

Consequently, we identified **three roles** that players adopted during the second phase, i.e. **the caller, the follower or the explorer**. The caller was the first participant who saw that he/she was close to Bob through his/her proximity sensor, and therefore called his/her partners. A "follower" was a player who joined the caller taking the same path as to go where the caller was. An "explorer" exploited his return path to the caller by exploring the campus (i.e. took another path). Thus, in phase 2 there was a clear distinction in terms of division of labor. Moreover, there was a difference between the three experimental conditions with respect to role behavior. There were indeed **more 'followers' in the MLA conditions** (Chi = 5.28, p = 0.04). In other terms, in the awareness conditions (be it synchronous or asynchronous), a group was generally made up of a caller and two followers, whereas it could be broken into one caller, one explorer and one follower in the condition without the MLA. The problem is that being a follower is not an efficient way to join the caller. As a matter of fact, in this second phase of the game, the object is still not well localized, which means that the caller needs to keep wandering around to find it. That is why explorers, by visiting parts of the campus close to the caller but that he or she had not visited were more efficient. Followers only backtrack and leave the caller refine the object's position for him or herself, which is not an optimal group strategy. Therefore, giving players a location-awareness tool seems detrimental to the optimization of the strategy.

Since there were no clearly established categories of spatial behavior in the third phase we did not report the results regarding this issue here.

5.3.2 *Partners' trails recall*

As mentioned in the section about the experiment procedure, we measured the number of errors between the path player A drew about B or C to B or C's real paths. This individual index represents the quality of A's representation of B and C's behavior in space. We also computed the number of errors each individual made with his or her own path. In 85% of the case, players made 0 errors. We do not use this variable to consider the representation of partners since a multiplication or a division by zero would lead to a wrong estimation.

As described by Kenny et al. (1998) we checked the non-independence of the results through the computation of intraclass correlation (r = .41), which is significant (p = .01). That expresses the non-independence of the results among groups. It first means that the number of errors made by the subjects is dependent on the number of errors made by the partners (i.e. if one player made a lot of errors about his/her partners, the same goes for the partners). It also led us to use the group as the unit of analysis. To do so, we added the number of errors made by each individual among a group to create a group index. Figure 42 shows the number of errors in each condition per group. This variable has been analyzed at the group level.

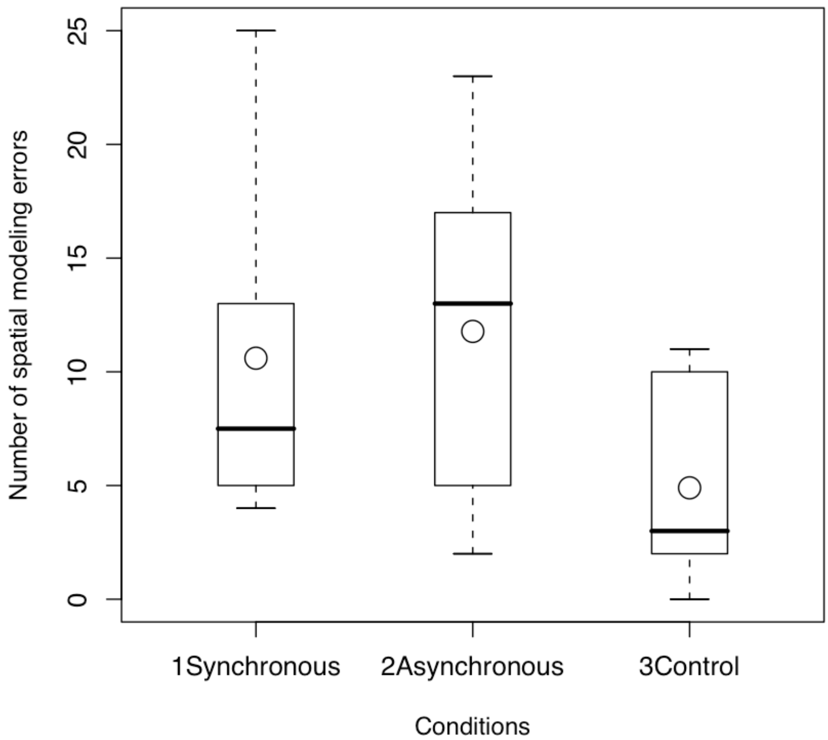


Figure 42. Number of errors made by each group during the post-test (while drawing the path of the partner) in the three experimental conditions.

Players in the *Control condition* made two times fewer errors than those who had the MLA (*Control*: m = 4.90 , sd = 4.12; *Synchronous*: m = 10.60, sd = 7.26; *Asynchronous*: m = 11.78, sd = 7.39). A non-parametric Kruskal-Wallis test showed that the difference between the three conditions was significant (*Chi-squared* = 6.78, p = 0.03). Post-hoc comparisons attested that groups without the MLA interface made fewer errors compared to those with the synchronous version (Tukey HSD, $p = 0.04$) and to those with the asynchronous version (Tukey HSD, $p = 0.04$). There were no significant differences between the two versions of the MLA tool.

In other words, our second hypothesis is rejected: people in groups without the MLA better recalled their partners' trails: **the accuracy of the spatial representations player built about their partners had been diminished by the presence of the MLA tool**. This result, which is quite surprising, will be explained by the next findings about communication through map annotations.

In addition, the significant intraclass correlation is interesting since it shows the coherence of the mutual modeling among a group: when A makes a lot of errors about B's path, B does the same, and vice versa.

5.3.3 Communication through shared map annotations

Annotations frequency

Map annotations have been investigated both by quantitative measures like the frequency and by qualitative content categorization. The shared map annotation frequency has been studied at the individual level since the intraclass correlation within the group was not significant ($r = -0.23$ $p = .89$).

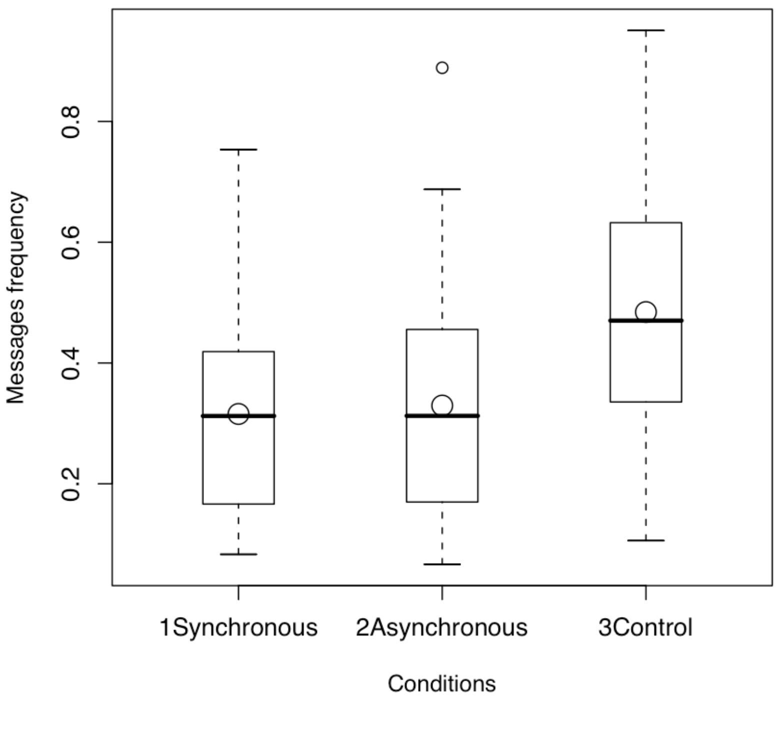


Figure 43. Frequency of shared map annotations written on the Tablet PC by each individual in the three experimental condition.

Figure 43 shows the frequency of messages sent by each player in the three experimental conditions. It appeared that the frequency of messages was higher in the *Control* condition (*Control*: m = 7.83, sd = 3.85; *Synchronous*: m = 4.53, sd = 2.35; *Asynchronous*: m = 5.14, sd = 3.21). A Kruskal-Wallis statistical test showed that this difference is significant (*Chi-squared* = 13.012, $p = 0.001$). Post-hoc comparisons attested that groups without the MLA wrote more messages compared to those with the synchronous version of the MLA (Tukey HSD, $p = 0.002$) and to those with the asynchronous version of the MLA (Tukey HSD, $p = 0.007$). There were no differences in the number of errors between the two conditions with the MLA tool ($p = 0.95$).

We coded the content of the messages and their pragmatics (as described in Section 5.2.3) and Figure 44 depicts the different frequencies for certain categories. On this figure, we only represent the most important messages categories (i.e the one for which the frequency was above 0.5).

Post-hoc analyses **showed a different repartition of messages depending on the presence of the MLA tool**. Players in the *Control* condition sent more messages about position, direction and strategy than those with the synchronous MLA as attested by statistical analyses in Table 14, and they also asked more questions. As for the difference between the players in the *Control* condition and those with the asynchronous MLA, *Control* players also asked more questions and sent more messages about position and strategy. It is also pertinent to note that there was no difference between the *Control* and the asynchronous MLA conditions concerning the frequency of messages about directions. They resulted in almost the same amount of direction messages because MLA does not convey that information.

There were no differences in communication pattern between the synchronous and asynchronous MLA conditions. For all the groups, there were no significant differences concerning the number of orders or acknowledgements.

Table 14. Results from the post-hoc analyses concerning the main differences in terms of messages content and pragmatics.

Conditions	Position	Direction	Strategy	Questions
Control – With synchronous MLA	$p < 0.001$	$p = 0.02$	$p = 0.002$	$p = 0.003$
Control – With asynchronous MLA	$p < 0.001$	$p = 0.81$	$p < 0.001$	$p < 0.01$
Synchronous MLA – Asynchronous MLA	$p = 0.24$	$p = 0.18$	$p = 0.84$	$p = 0.13$

Shared map annotations and trail recall

We computed some correlations to further the investigation between shared map annotations and partners' trail recall. We found **a negative correlation between the frequency of messages about strategy and the number of errors made by the individual when drawing their partners' path** (Pearson bivariate correlation $r = -.51$, $p < 0.001$). This result was also confirmed by a regression analysis that showed a negative and significant relation between the number of errors and the number of strategy messages ($\beta = -0.72$, $p < .001$). Thus, the more players sent messages about strategy the less they made mistakes about their partners' trails.

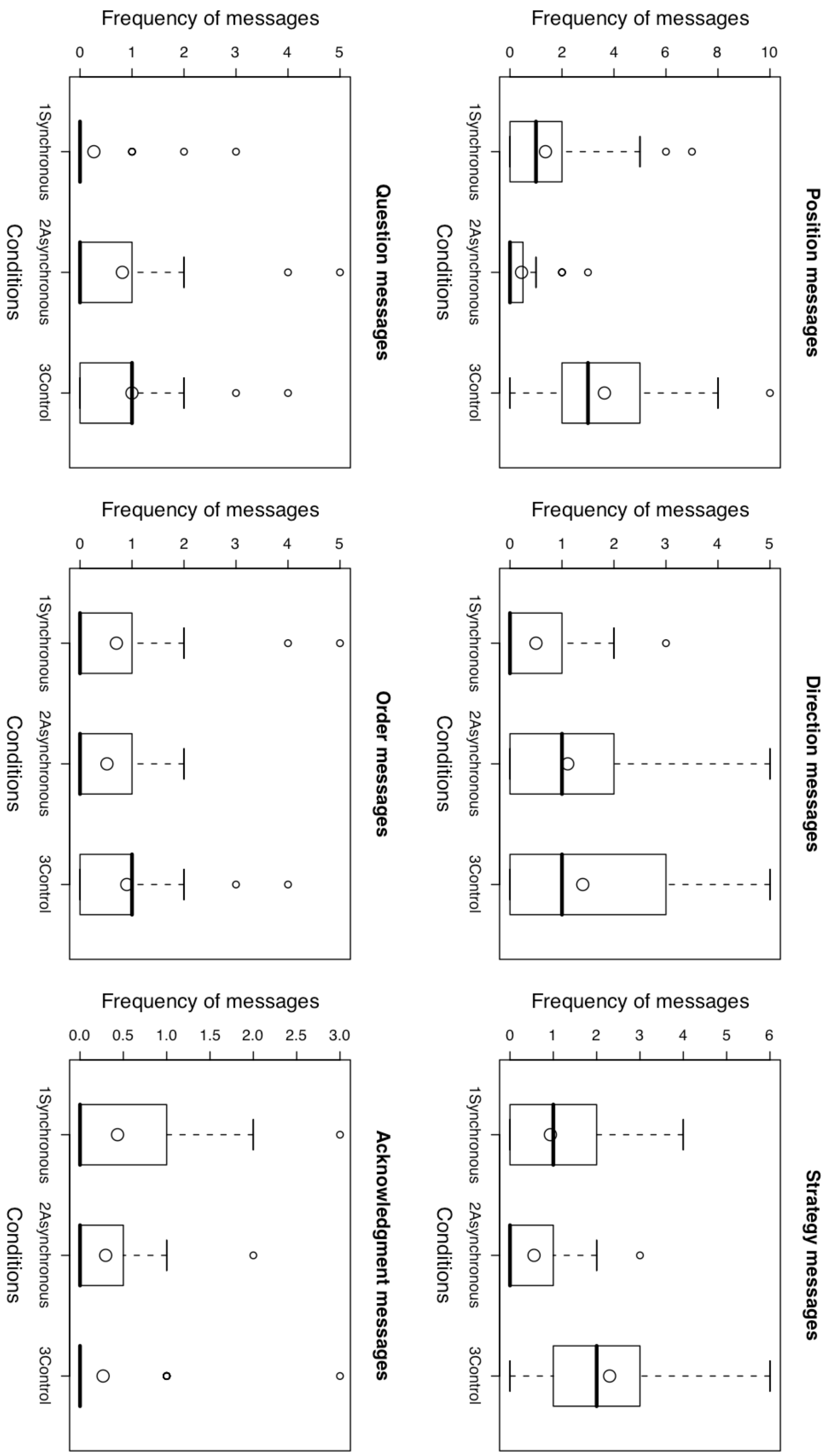


Figure 44. Frequencies of shared map annotations about position, direction, strategy, questions, orders and acknowledgements (written on the Tablet PC by each individual in the three experimental conditions).

However, there is no correlation between the total number of messages and the number of errors made when drawing the partners' path. This means that what is important is not to send a lot of messages but rather to draw relevant map annotations about strategy. In other words, strategy messages seemed to be very important to model the others' paths. This result is important because it poses the question of what is memorized: the path or the strategy. As shown on Figure 45, what we measure with this mutual modeling index might indeed be the reconstruction of the path either based on the memorization of the partners' path OR the memorization of group strategy. The available data do not allow us to draw a conclusion about which of the two might account for this path reconstruction.

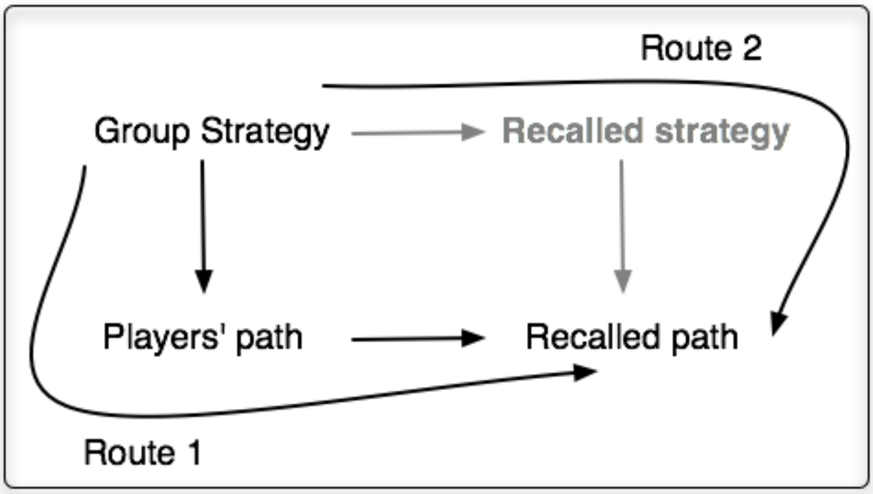


Figure 45. The two possible explanations of the partners' path reconstruction

To further explore this relationship, we performed a post-hoc split of players into two kinds of participants: those with a high versus those with a low mutual modeling index across the three conditions. The split point was the mean of errors for individuals and it led to the constitution of two groups made up of 43 individuals "low trail recall" and 44 individuals "good trail recall". This split showed that persons who had a good representation of their partners' whereabouts sent more messages about strategy (F = 31.33, p < .0001), more questions (*Chi-squared* = 8.81, p = .003) and orders (*Chi-squared* = 5.38, p = .02) according to a Kruskal-Wallis statistical test. We also found an interaction between the experimental variable (MLA presence), the number of errors and the strategy messages as represented on Figure 47 (F = 8.28, p < .01). Players in the *Control* condition wrote more strategy messages, which was also the case of those who better recalled their partners' trails.

However, we did not find any relationship between the accuracy of the partners' trails recall and the task performance: there is no significant difference between the performance of the groups who correctly recalled their peers' trails and the groups who made lots of errors about it (F = 1.45, p = 0.24). Conversely, a post-hoc split of the groups according to their performance did not show any significant differences between efficient teams and less efficient teams for better recalling their partners' trails (F = 1.16, p = 0.29).

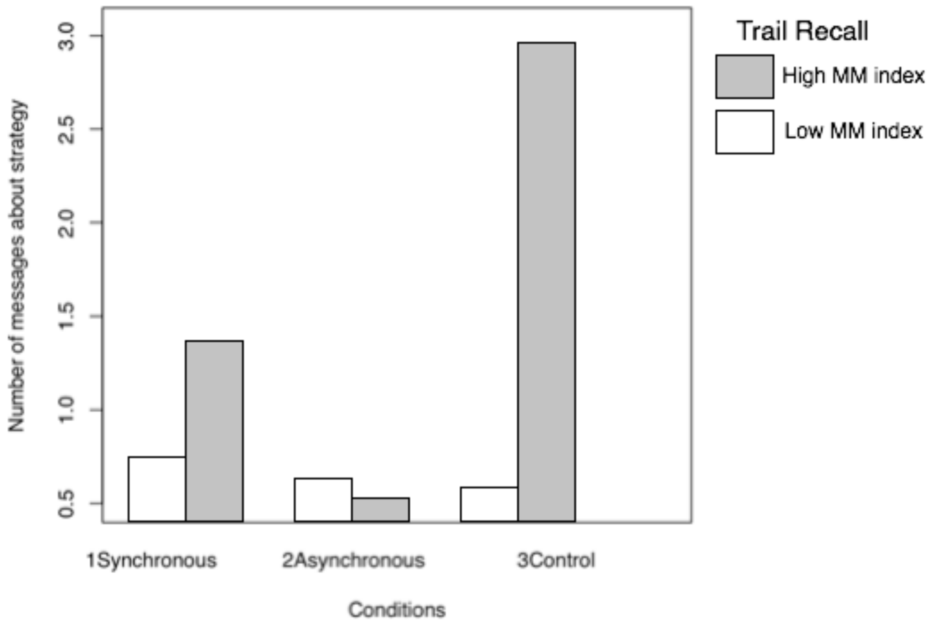


Figure 46. Interaction between the number of strategy messages, the two groups split according to the trail recall index and the experimental condition.

The analysis of the different conditions showed that the differences in terms of strategy messages were significant only for *Control* conditions (Wilcoxon's $W = 174$, $p < .001$). This means that, without MLA, those who had a less accurate spatial representation of their teammates (i.e. who did not recall the path of their partners very well) wrote fewer messages about strategy than those with a high mutual model. This phenomenon did not occur for the other two experimental groups, even though the difference is a bit more apparent for players who had the synchronous version of the MLA. Another striking result is that players with the MLA sent fewer messages about strategy, even when having a good representation of their partners' trails.

These results support the idea that **players in different experimental conditions played differently**. For participants in the *Control* group, there was an important relation between the exchanges of strategy messages and the mutual modeling, which was not the case for those in the MLA conditions (synchronous and asynchronous).

The difference between the frequencies of messages about strategy sent by players without the MLA and those with the MLA might explain the wide dispersion in their performance (as seen on Figure 40a). An important frequency of strategy messages might then account for a better performance.

5.3.4 Summary of quantitative results

In sum, there were no differences in terms of task performance between the groups in the three experimental conditions. It seems, however, that *Control* groups completed the last phase of the game more slowly. This is interesting in differentiating the influence of the MLA tool on game subtasks. In the two first phases, the locational information could be conveyed either verbally (by players in the *Control* condition) or through the awareness tool. In the last phase (i.e. forming the triangle around the object), it seems that the automatic MLA was more beneficial; as if in situations in which tighter coordination was required, the tool was more efficient.

In addition, players in the *Control* condition better recalled their partners' trails. This shows the first negative effect of the awareness tool (in both versions). This can be explained by the shared map annotations drawn on the Tablet PC. Indeed, the frequency of messages was higher in the *Control* condition and different from the two MLA conditions: they sent more messages about position, strategy and also wrote more questions. Control groups also sent more messages about direction than those from the synchronous MLA condition. The presence of these messages then allowed the common ground of the players to be richer since they exchanged more coordination devices. This facilitated the recall of the path since players had more cues and traces of other group member's activities in space. It also appeared that players without the MLA took better advantage of the annotation capabilities, using it to express their path and strategy.

The analysis of the group trajectory accounted for similar strategies within each experimental condition; but it showed that players in the *Control* condition reshaped their strategy more, by adopting "explorers" behavior, rather than backtracking. They did this especially through the use of map annotations that described how they would explore new areas of the campus. The same is true of the role players: we found more active participants in *Control* groups (named "explorers").

Therefore, one of the conclusions for these results was that **players in the different experimental conditions performed the game differently**. While groups with synchronous or asynchronous MLA were similar, it seems that teams in the *Control* condition had different patterns; depending on the influence of the MLA tool. The next section will further those investigations by looking at how various groups coordinated and used MLA information.

5.4 Qualitative results

To gain an understanding of the coordination processes, we first focused on coordination problems that occurred in the game and what kind of inferences were required to solve them. This then lead us to explore which coordination devices had been used at what time in the different experimental conditions. This section finally focuses on one specific kind of inference: the one conveyed by the MLA.

5.4.1 Coordination problems and mutual modeling episodes

In the context of CatchBob!, players were engaged in a joint activity that could be divided into three phases, as we saw earlier. Among those broad phases of activity, individuals were involved in joint actions that provoked coordination problems. The most recurrent coordination problems mentioned by participants were: avoiding visiting the same area at the same time, not visiting an area that has already been visited, discovering where is the closest person to Bob and joining him/her and forming the proper configuration of the triangle.

Players needed to tackle each of these problems in order to perform the individual actions that would eventually constitute the collaborative activity they were engaged in. Each problem corresponds to an episode of mutual modeling in which players perform various inferences to choose an adequate individual actions.

This is where the qualitative analysis of players' interviews with the replay tool comes into play: it allowed us to discriminate what players inferred about their partners in order to solve the aforementioned coordination problems. **Players mentioned seven types of inferences** they had to perform while playing the game, as depicted in Table 15.

Table 15. Typology of inferences carried out by players.

Level of inference	Content of inference about partner(s)	Examples of inferences performed (from the interviews)
Partners' state and actions	Position	A infers that B is located in the CE building.
	Direction/Trajectory	C infers that A is moving to the GR building, B infers that A is moving to the object, A infers that B and C are moving to form the triangle.
	Proximity to meet	B infers that A and C are close and that they will be able to meet face to face
	Proximity to Bob	C infers that A is close to Bob
	Proximity to the triangle	A infers that B is close to the triangle
	Network connectivity	C infers that A has a bad access to the network
Partners' beliefs	Understanding of group strategy/division of labor	B infers that C is exploring the west part of the campus doing more and more narrow circles to refine its investigation.
	Articulation of individual action and group strategy	A infers that B is currently writing a message to the group to reshape the strategy

The inferences about the partners refer to different states (spatial or about network connectivity), actions (spatial movement, exploration) and beliefs about the strategy. It is also noteworthy to say that inferences are made about one specific partner or both.

5.5 Coordination devices

As we described in our theoretical framework, the coordination process is achieved through situated acts of mutual modeling that consist in the exchange of coordination devices. These devices are the concrete material on which the inference process is based. Such information allows a group to mutually predict the individual actions that are going to be carried out by the partners.

Message transcriptions and the players' verbalizations during the confrontation of the replay tool after the game allowed us to have a clear account of how players from the three experimental conditions exchanged coordination devices. Therefore, these transcriptions should be seen as a qualitative description of the coordination devices deployed by CatchBob! participants. The qualitative analysis of the content of these messages allowed the description of the key coordination devices as well as the way they had been mutually recognized by participants within a team. This analysis allowed us to classify the coordination devices used by players into the five categories: pre-game plan, communication acts, knowledge about the partner, knowledge about the environment, use of the MLA and elements from the environment. The description below included excerpts from the post-game interview, all translated from French to English.

Therefore, we could differentiate 5 key types of coordination devices:

1) The **plan that players set before starting the game** was the most often cited resource for coordination. During this short period, players discussed both the strategy they wanted to apply and the communication conventions they would like to use as attested by the following answers: "*we decided that we would begin to send messages only when having some signal on the proximity sensor*" (Group 1, Control condition), "*we planned that the first who had some signal would send it to the other with figure written on the map, before anybody should communicate anything*" (Group 3, Control condition), "*we planned to join the first person to have a good signal on the proximity sensor and really coordinated thanks to what we decided altogether*" (Group 6, Control condition). This shows how players grounded a common plan before playing the game. However, sometimes new face-to-face discussions during the game also allowed some players to set new strategies: "*we saw each other, we discussed a new plan and we split up again*" as said by one of the players from Group 10 (synchronous MLA condition).

2) **Communication acts** were the second most prominent coordination device cited by players. Even though communication was achieved through a narrow medium (map annotations) important discussions about strategies discussion had been undertaken. The excerpts below provides some examples of dialogues players recalled: "*I knew they were joining me because I drew a circle on the map where I thought Bob was, and they said ok we're coming*" (Group 11, synchronous MLA condition), "*at that moment, I asked her what she was doing and she told me that she was backtracking*" (Group 18, synchronous MLA condition), "*he drew an arrow, he marked the reading he was having and the general direction he was heading, she then put her readings close to that, I said ok and asked them if they wanted to stop, she replied that she wanted to keep exploring the area*" (Group 27, asynchronous MLA condition). Dialogue occurrences like these were important for trajectory awareness and division of labor. However, most of the communication acts (as attested by the quantitative analysis in Section 5.3.3) were not proper dialogues but announcements of proximity signal information ("*I was telling them my readings, on a regular basis*": group 22, asynchronous MLA condition) or self-declared positions ("*as soon as I got a reading I would put it and I would tell him where I was*": Group 18, synchronous MLA condition) or trajectories ("*he drew an arrow, he marked the reading he was giving and the general direction where he was heading*": Group 5, Control condition). Messages about strategy were also important (as confirmed by the quantitative analysis in Section 5.3.3). These broadly concerned five topics: (1) advice, orders or request about spatial behavior, (2) indications about the object's possible location or possible area of location, (3) indications of the proper triangle configuration to complete the game, represented with a triangle, (4) meeting point for the group and (5) network problems.

3) The **Mutual Location-Awareness** tool was cited as an important coordinative device by players in the two experimental conditions who had it: "*I saw that he was going in that direction, then I joined him*" (Group 18, synchronous MLA condition), "*I saw Sandra heading to the CE building so I thought we had to join her*" (Group 21, asynchronous MLA condition), "*I knew they were arriving though the IN building because I saw their last positions*" (Group 5, Control condition). Section 5.5.3 will explore more fully the question of how MLA has been interpreted.

4) **Knowledge about the partners** was also a powerful coordination key for some groups as explained by these two players: "*I saw that Sandra was not moving, but I know her, she always moves and she's not lazy, so she was moving*" (Group 26, asynchronous MLA condition), "*I saw he was coming from downstairs but I know him, I thought he would take the lift instead of the stairs*" (Group 3, Control condition). By knowing a partner's habit and behavior, players could infer some meaning about the course of action.
5) **Knowledge about the environment** was also a key to coordination. Here are examples of how two players expressed this: "*there is a bottleneck here between the CE and CM buildings, I knew he could only arrive from there*" (Group 11, synchronous MLA condition), "*I did not know he were joining me or go elsewhere but I knew there were chance that I would meet him at La Coupole* [center of the campus]" (Group 6, Control condition). Concerning the environment, **manifest elements such as topology or network coverage** were also cited as ways to infer partner's behavior. The presence of stairs or visible shortcuts, for instance, allowed players to guess where a partner would appear.

The coordination devices cited actually fit with Clark's model of coordination that we presented in Chapter 2. They all correspond to his typology of devices: knowledge about partners and the environment are "Precedent" (when a precedent experience allows participants to form some expectations about others' behavior). Dialogue acts are "Explicit Agreement" (when the participants explicitly acknowledge the information exchanged). The grounded plan discussed at the beginning is a set of "Conventions" (when conventional procedures are set by the participants). And finally, manifest elements from the environment; topology, network coverage, MLA information and non-acknowledged communication acts are "Manifest elements". Table 16 summarizes these elements, depicting the different sorts of coordination devices we observed as well as the inferences they allowed to perform.

Table 16. Description of the different kinds of coordination devices used to perform the inferences, and their use to perform inferences.

Type of coordination device: Clark's typology	Type of coordination device: Our findings	Content of the coordination devices	Examples
Conventions	Conventions discussed and grounded during the planning phase	Global strategy	During the grounded plan before the game:, when players decided that "A goes to the North, B goes to the East and C to the South" or "let's send information as soon as we get some signal".
Manifest	Manifest (a) information provided by the MLA tool	Location awareness of others	Automatic MLA showing that A was in the SG building
	Manifest (b) information due to environmental/topology constraints	A partner's next move inferred from the environment	Topological elements like levels/stairs.
	Manifest (c) information written by a player	Non-acknowledged messages about position, direction, strategy messages, orders, questions and	A simple message such as "I go to the SG building"

		about network problems.	
Explicit agreement	Messages acknowledged by partners	Acknowledged messages about strategy, next moves, division of labor, position, direction, strategy messages, orders, questions and about network problems.	Verbalizations that are acknowledged and part of a dialogue, grounded plan too. For instance: A: "I go to the CE building" , B: "OK I go to the CM and joint you afterwards." A: OK"
Precedent	Knowledge about the partners from precedent encounters	Partners' habits and behavior	When one player mentioned the fact that "A is not lazy so when he was there I was sure he would move".
	Knowledge about the environment from precedent encounters	A partner's next move inferred from the environment	Campus "bottlenecks" had been mentioned as ways to infer that a partner was moving in a specific direction

5.5.1 Use of coordination devices in different experimental conditions

The description of these coordination devices used by players enables us to discriminate which of them had been deployed by groups in each experimental condition. Since the results partially emerged from provoked verbalizations (answers to a semi-structured interview while showing a replay of their activity on a map of the campus), we did not count and run statistics about them. We rather used the occurrences of mentions of these devices as a marker of how they had been used in each of the experimental groups. Table 17 shows the different use of coordination devices by the three experimental groups.

Table 17. Description of the different kinds of coordination devices used by each group.

Coordination devices mutually recognized	**Experimental conditions: MLA (synchronous and asynchronous)**	**Experimental condition: Control (without MLA)**
Conventions (set in planning phase)	Cited by most groups	Cited by most groups
Manifest (a): information shown by the awareness tool	Cited by most groups	Never mentioned
Manifest (b): manifest information due to environmental/topology constraints	Cited by some groups	Cited by most groups
Manifest (c): message sent but not acknowledged by the partner	Cited by some groups	Cited by most groups
Explicit agreement (messages acknowledged by partners)	Cited by some groups	Cited by most groups
Precedent (knowledge about the partners' habits and behavior)	Cited by some groups	Cited by most groups

One of the most important results is the fact that players from the two MLA conditions presented similar patterns of coordination devices mentions[11]; this is the reason why we represented them on the same column. Drawing from Table 17, we found differences in the way participants from the two experimental conditions exchanged coordination devices. The table shows that players with the MLA mentioned the use of conventions decided before the game and the use of the awareness tool to coordinate. More importantly, they employed them without discussing the use of other coordination devices; the environment is seldom mentioned as being taken into account for inferring what the partners were up to. When looking at the players without MLA, the elements used for coordination were also the plan/convention decided before the game and information about location-awareness (explicitly described because they did not have the MLA) but also the manifest elements of the environment and explicit agreements negotiated over the course of the game. Therefore they better took into account contextual and negotiated elements than players with the MLA.

The strategy inertia we found for groups with the MLA described as a behavioral consistency in Section 5.3.1 can be retrieved in these verbalizations. Players without the MLA had less inertia by better reshaping their strategy. What is striking here is that automating the exchange of a coordination key can be detrimental to task coordination since players with MLA were stuck on it and did not exchange others. What is important for players with the MLA is that the location awareness is the relevant coordination key for the whole task; then they do not renegotiate it for the different phases. And what we saw in Section 5.3.1, the importance of the location awareness information differs depending on the game phase. It might be the case that groups with the MLA wasted cognitive resources monitoring others' positions with the tool and thus discussed less which coordination device would be valuable at that moment. This means that automating awareness can have a negative effect on coordination through the exchange of useless coordination devices (at least during phase 1 and 2).

5.5.2 Use of coordination devices over time

The articulation of this coordination device classification with the map annotations transcriptions and the player's verbalizations during the post-game interview allowed us to classify when each type has been used and for what experimental condition. For each experiment, we graphically described on a temporal axis which coordination devices had been used: either because players have mentioned them during the replay interview or because it was a coordination key we logged (map annotations or usage of the MLA tool). Such a description is depicted on Figure 47; it shows both the coordination devices and the inferences it allowed players to draw based on them.

[11] We intentionally use the term "mentions" instead of "usage" because we drew this conclusion about participants verbalizations after the game and not during it.

Performing the same analysis for every group enabled us to gain **a better picture of the moment of use of different types of coordination devices**. We then aggregated this information in a synthetic model as represented on Figure 48. The figure is a matrix representing horizontally the different phases of the activity (ranging from planning to the triangle formation) and vertically the content of the inferences players had to perform. Each square of the matrix then expresses which sort of coordination devices (conventions, precedent, manifest, explicit agreement in Clark's terminology) players used to draw these inferences in the experimental conditions.

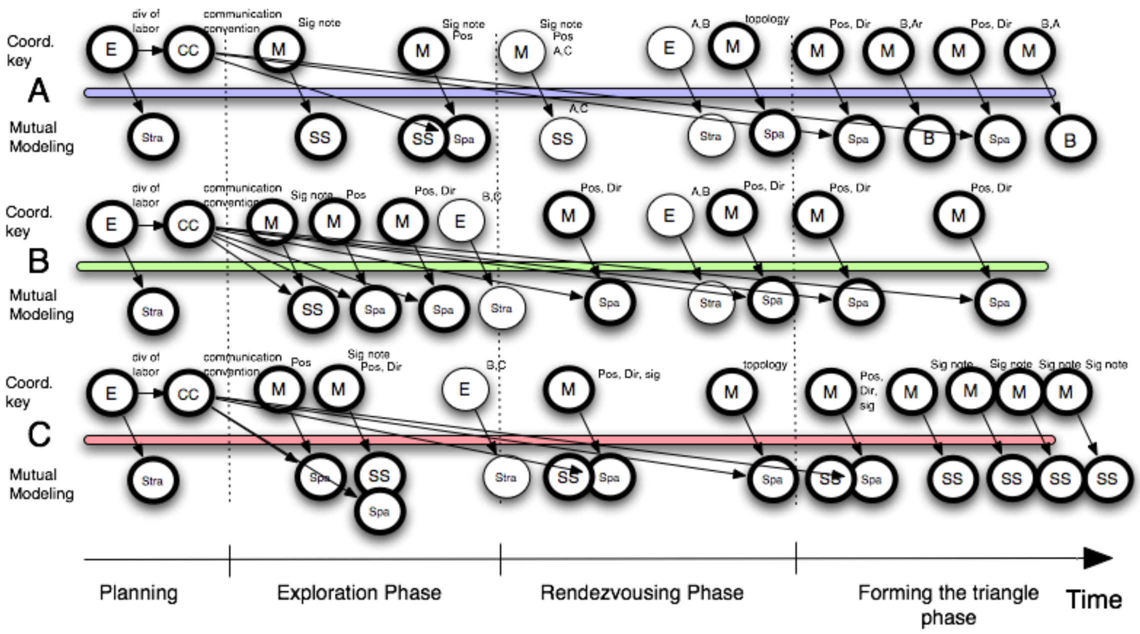


Figure 47. Coordination devices exchanges for one group. It shows for each player which coordination device has been used to infer specific elements in the three phases of the game. We also added the planning phase because it is the moment when conventions are set. Each line represents a player, the upper part depicts the coordination devices that are deployed ("E" corresponds to "explicit agreement", "CC" to "Communication Convention" , "M" is "Manifest"); the lower part represents what is modeled about the partner: his/her strategy ("Stra"), his/her proximity to the object ("SS": signal strength), his/her position/direction ("Spa"), his/her beliefs ("B").

This model provides a description of the coordination devices usage over time; it leads us to several observations. One of the most striking features of this model is that players using the synchronous and asynchronous MLA showed similar pattern of coordination device usage; that is why they are merged on Figure 48. Their use of coordination devices is important with regards to our research question. As opposed to *Control* group, players with MLA interfaces heavily relied on conventions to infer spatial behavior of partners, especially in phases "campus exploration" and "rendezvous". One indeed needs an agreed frame of reference (strategy) to interpret the information seen with the MLA interface.

We also noticed that players in the *Control* group performed more explicit agreement acts. Indeed, there were more occurrences of dialogues even though this was not reflected in the quantitative content analysis. Speaking about the content, as we can see on the figure, players in the *Control* group better explicated which strategy they should apply within the group, and they also exchanged coordination devices to better infer each others' beliefs concerning the division of labor (mostly in phases "campus exploration" and "rendezvous").

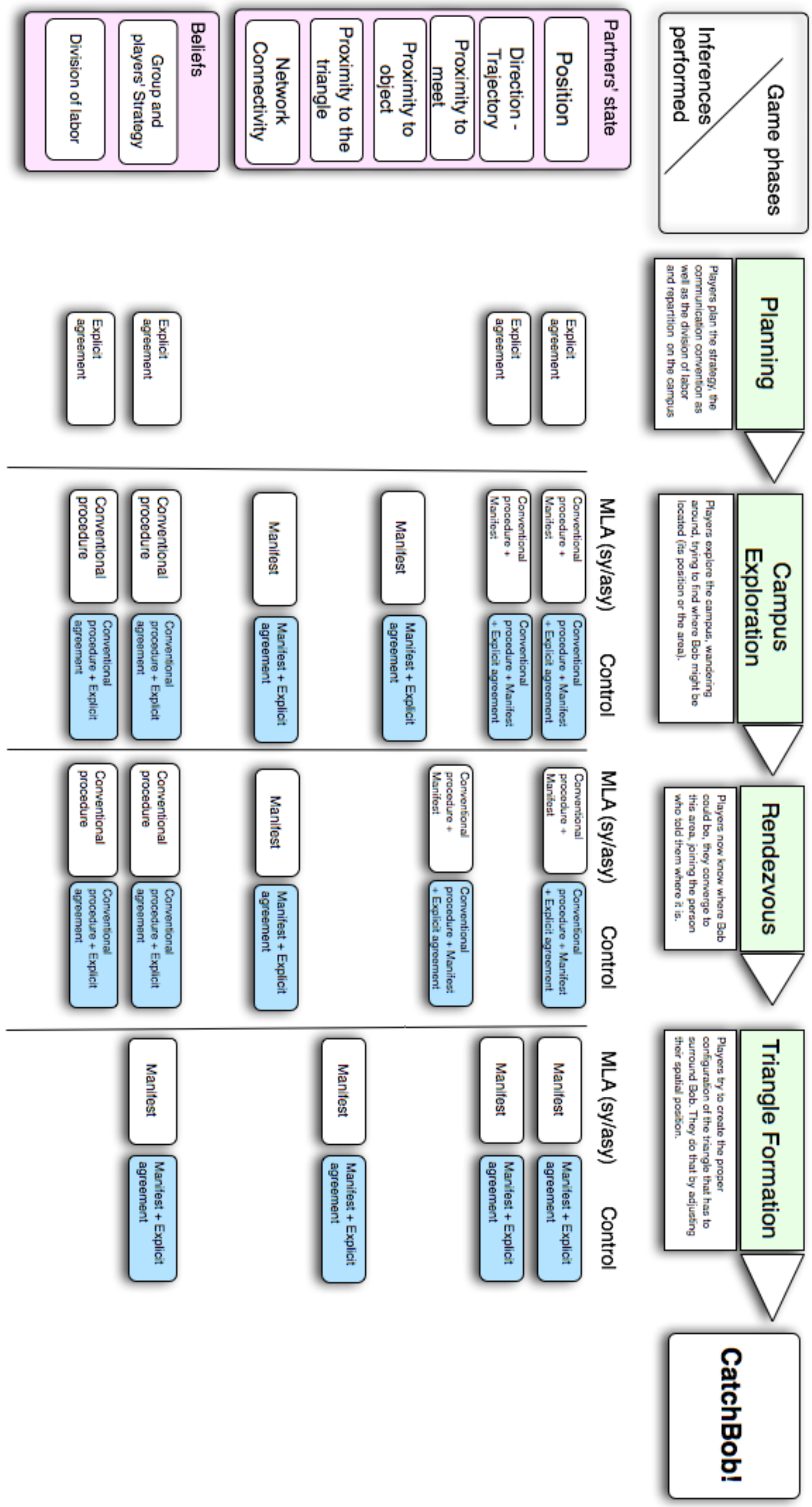


Figure 48. Description of the various coordination devices used by Catchbob! players in the different game phase and in the different experimental conditions.

Another conclusion is that different types of inferences and different types of coordination devices are not present in each phase. For example, conventions are less used in the last phase, precedent are almost never mentioned and manifest elements seem to be less important in the first phase.

We have seen in the quantitative analysis that MLA groups performed better in the last phase. On this figure, one can notice that they only relied on manifest information elements to do so: they indeed used location information conveyed by the MLA interfaces (be it synchronous or asynchronous) and no explicit agreement.

Finally, although this is not represented on this figure, we should remember that coordination is a continuous process and coordination devices are used and re-used over time since they are integrated in the updated common ground.

5.5.3 Interpretations of Mutual Location-Awareness

Now that we have described the set of coordination devices players used to perform the joint actions required by this game, we would like to bring a specific focus on mutual location-awareness. During the post-game interviews, the large majority of players in the experimental conditions had underlined the importance of MLA. This section aims at reviewing the reasons why they thought so: we will describe how players interpreted MLA and what sort of usage they made of it.

Qualitative analysis was achieved by the method proposed by Creswell (1994). We first transcribed parts of the post-game interviews that concerned the use of the MLA (hence with players in the synchronous and asynchronous conditions). Then we listed all the topics and potential uses that had been quoted by all the participants. The next step consisted in clustering together similar topics that we applied again to all transcribed data so that we could find out whether it fitted or whether new topics emerged. After this analysis, **four categories of MLA interpretations and uses emerged**: some were common to the two conditions and others were only for players who had the asynchronous version. In the category descriptions hereafter, player's citations have been translated from French to English.

Four roles of MLA

We describe here the five main roles MLA had in this study. The first four roles are the ones mentioned by players both in the synchronous and asynchronous conditions. The last role was only mentioned by players from the asynchronous condition.

- Activity awareness: the simplest form of MLA use was drawing simple inferences about directions (Group 11, with synchronous MLA: "*to know where my partners were heading*") or proximity (Group 7, with synchronous MLA :"*I knew Susi was close to me, just in case*"). These inferences allowed **activity awareness** to better understand what the partners were doing (Group 24, with asynchronous MLA; "*it helped to get what the others were up to*", Group 11, with synchronous MLA: "*to see that the red was close to the end*"). By **making player's behavior manifest** to themselves, it allowed to let them understand what was happening without communicating: "*I saw red walking, so I understood that he understood the message of Blue* [an arrow with "come over"]" (Group 4, with synchronous MLA).
- An efficient way to react accordingly since a **communication economy** is enabled by the MLA: "*otherwise, we would have been forced to make more*

annotations to orientate each other", "*I saw that he was going in that direction, then I did not communicate that much*", "i*t's convenient to see where partners are, even without communication we knew that the object was not in the South or in the East, we inferred it was in the West*". Information about others' whereabouts replaced a discussion about what to do next, especially when players had to join the "caller". Moreover, in phase 2, the MLA allowed **players to join the person who was close to Bob** because he/she indicated the signal and partners were seeing where those readings were referring to: "*it enabled us to locate the arrival zone and to join up where the one who found Bob was*" (Group 27, with asynchronous MLA), "*we knew where to go to find Bob*" (Group 11, with synchronous MLA), "*when first readings arrived, I knew where to go right away*" (Group 18, with synchronous MLA). Sometimes, the process described by the players was different: "*I saw both of them close to each other with high readings, so I thought I had to go there*" (Group 17, with synchronous MLA).

- A resource for player's joint actions: knowing the positions of partners in space was – as in the previous experiment – a resource for the player's own contribution to the joint activity: either to move into a certain direction or to contact a player to help him or her. For the person who found Bob first, the MLA was **a way to indicate the partners the shortest path**: "*I knew where they were so I was able to indicate to them the shortest path to me*" (Group 11, with synchronous MLA). And it **enabled this caller to know when the partner would appear**: "*I evaluated the time it would require for them to be there, backtracking*" (Group 21, with asynchronous MLA). Additionally, players mentioned how the MLA was **a resource for forming the triangle at the end of the game**: "*it was useful to form the triangle around Bob, I knew where to find my own position*" (Group 18, with synchronous MLA), "*we optimized the triangle formation accordingly, without communicating*" (Group 11, with synchronous MLA).
- Mapping the past… to infer the future: players in the asynchronous MLA condition added three others usages that corresponded to usage of past location of the partners. For them, it gave **them a clear map of what has been visited over time**: "*I haven't taken the same paths as those I saw displayed on the map*" (Group 27, with asynchronous MLA), "*we could see which areas had been explored and did not go back there*" (Group 21, with asynchronous MLA). And a corollary usage was that it allowed **to see the evolution of the triangle** at the end of the game: "*we could track how partners tried to form the triangle*" (Group 28, with asynchronous MLA). But the most important usage of the asynchronous MLA was that the players were able to access to their partners' path with this tool and this helped them **to infer their partner's trajectory**: "*when the green guy noted his reading, I already knew the direction I should took: I had to follow his direction indicated by the continuity of his path*" (Group 24, with asynchronous MLA).

Questioning MLA

An additional issue regarding Mutual location-awareness concerns **how players reacted to discrepancies caused by the system**. As a matter of fact, the information conveyed by the MLA is sometimes imperfect. The reasons for this are diverse: patchy wireless coverage, uneven connectivity, outdoor conditions (e.g. walls, humans, rain) creating disturbances.

Players spontaneously mentioned how they dealt with these uncertainties. When confronted to a discrepancy concerning their partner's position, **three types of reactions** had been mentioned: **believing the system, saying that the system was wrong** (as reported by those players from group 11: "*I saw that it was indicated that B was positioned here but he was not*", "*I saw that B moved on the screen but I know he did not*") **or not understanding** ("*I did not get why he was there*" said a skeptical participant from t group 21 with the asynchronous MLA).

When asked why they questioned the system, players said that this information was contradictory with what they had in mind. For instance, a participant told us that "*judging from my experience, the network coverage in the MX is low, so I though that was why player A was not moving*" (Group 17, with synchronous MLA): this shows how another coordination device (knowledge about the campus drawn from a precedent experience or a discussion with others) could make him doubtful of the MLA information. To some extent, it also brings forward the fact that **coordination devices can be conflicting**, by providing divergent information.

Therefore, facing a potential discrepancy, participants reacted using the information available from other coordination devices they had (knowledge about the network, explicit agreement, conventions, precedent experience with participants).

5.6 Discussion

5.6.1 Result summary

Our study has revealed the **underwhelming effects of automating mutual location-awareness** in a mobile collaboration context. We found that participants in the two MLA conditions did not perform the task better than participants in the *Control* groups. In addition, people among groups without the location information built a more accurate mutual model since they made fewer errors when drawing the path of their partners after the game. Interestingly, we found that a good mutual model is shared within the group: when one of the teammates had a good representation of the others' whereabouts, it also held for the partners. These results can be explained by the messages exchanged. First the number of messages is more important in the group without the location-awareness tool: players had then more devices to rely on in order to recall the others' trails. And when we look at the content, we see that players without MLA sent more messages about position, direction or strategy. They also wrote more questions. Strategy communication was certainly the most important factor for the construction of the mutual modeling as attested by the post-hoc analysis.

Furthermore, a very intriguing result is the **strategy persistence caused by the MLA interface**, in terms of communication and spatial movements. Looking at the players' strategy, players with the MLA interfaces reshape their strategy less often during the game and were stuck to the division of labor they decided before playing. MLA created certain inertia within the group, probably due to a reduced communication: subjects were indeed less articulate about their strategy. Participants who relied on the automatic positioning wrote fewer messages, i.e. were less explicit the situation and how they could deal with it. In summary, automatic awareness information led to more "passive" players. This why we used the term 'underwhelming', we indeed referred to the fact that automating the location-awareness process not only undermined the exchange of messages about position but also about other kinds of information such as strategy or direction, which was not provided by the system. As a consequence, the automatic awareness tool seems to make users more passive.

This result has been confirmed by the qualitative analysis of the coordination devices exchanged by players. The model we described showed the various distributions between the control and the MLA groups. The control group interestingly used more of the available coordination devices, with a peculiar emphasis on explicit agreements. The next section will use these findings to discuss how the groups played differently in the two conditions.

As for the **synchronous and asynchronous MLA** interfaces, the quantitative results showed **similar patterns of use**: there was no significant difference between those two conditions regarding the task performance, communication or mutual modeling. The only difference lay in the inferences people drew from the two versions of the mutual-location awareness tool. Participants explained how they used synchronous MLA as an activity awareness of others and thus as a way to react accordingly. They also employed synchronous MLA to locate the object they had to find at the end of the first phase: MLA was interpreted as a resource for choosing the right action to perform. Players who had the asynchronous version used it as an indicator of the division of labor among the group, namely to see what had been explored or simply to infer partner's trajectory from the past positions.

5.6.2 Two ways of playing

We already mentioned that players from the *Control* condition and players in the *MLA* conditions played differently. Indeed, even though their task performances were similar, the differences lay in the cognitive processes involved during collaboration as well as the employment of manifest elements in the environment. Since there were no important differences between the two MLA conditions, we will consider them as equivalent in the discussion below. Discussing these differences is a good way to describe the influence of mutual location awareness on coordination.

The inhibition of communication

One of the most striking differences we described in the quantitative analysis was certainly the communication pattern. We have seen how players in the *Control* groups exchanged overall more shared map annotations, mostly about positions, direction, strategy and questions. This had been confirmed by the qualitative analysis in which we saw more explicit agreement and discussion for this group.

These results show how **the presence of the MLA interface** (be it synchronous or asynchronous) **led players to take for granted that it would be sufficient** to achieve their joint activity. This can be explained by a variant of the least collaborative effort principle (Clark, 1996): participants used the coordination devices that were available (mostly the plan and the MLA) and were less bothered to send more information through shared map annotations. Players in the *Control* condition only had the plan as a coordination device. The cost to exchange messages was the same but the necessity was higher for players in the *Control* group: one accepts this cost if there is a real need to exchange coordination devices.

It also means that *Control* players anticipated something: they had to send more information otherwise the room for interpretation would be too great for the other players. That is why they sent messages about their direction and about strategy: the other teammates could then better infer what to do, and consequently build a more accurate mutual model. This is then bound to the importance of the perception of what is relevant or not and how it should be communicated to the partners: the capacity of agency.

The importance of human agency

By agency, we refer to the capability of an individual to decide whether or not to act. In the context of coordination, agency describes the process by which a partner does or does not make manifest a sign of mutual intelligibility by exchanging a coordination device. This is where the main difference lay between the different experimental conditions**: automating MLA is different than sending one's position in space**. Indeed, participants from the *Control* condition chose the information they perceived as relevant (position, direction and strategy) for the time being and sent them to their partners. This fact raises an important issue regarding communication and spatial information: compared to automatic positioning in which location is just information**, self-declared positioning is both an information and an act of communication act, intentional by definition**. If A tells B where he or she is located, not only B knows A's location but he or she also knows that A considers that it is useful for B to know it.

It appeared that players without MLA took better advantage of the annotation capabilities, using it to express their path and their strategy. The players with the awareness tool were able to annotate as well but did not use this opportunity. As we mentioned, there was a certain inertia caused by the presence of location awareness information. We can then conclude that in the context of this experiment it was better to leave users without the location-awareness tool, and instead with a broad channel of communication. Players in the *Control* groups chose the information they perceived as relevant (position, direction and strategy plus asking questions) and sent them to their partners at the moment they wanted it to be known by the others. They perform more acts of ostensive communication as described by Sperber and Wilson (1986): the self-expressed position is both an attractor for others' attentions and a way to show the communicator's intent through messages about strategy or directions. Users could indeed express what they found relevant for the current task: with regard to the content (their position, direction, strategy messages) and to the pragmatic level (questions).

Using Clark's words, this result can be explained with the *principle of joint salience*. According to this principle, players deployed the coordination devices that would be the most salient and prominent with respect to the common ground of all participants. And, as we will see in the next section, there are differences between the groups in terms of the common ground.

A decreased quality of the common ground

The qualitative analysis of the data showed **the different set of coordination devices used by players from the various experimental conditions**. The accumulation of coordination devices over time by the team-mates of the *Control* groups was richer than that of the *MLA* groups. Since players without the MLA exchanged more map annotations, they collected more information about the situation, which would be why the richness of communication had a positive on the mutual modeling index for them.

The location awareness of others (conveyed by an interface in the *MLA* condition and by shared map annotations in the *Control* condition) was wrapped in more information and context in the Control groups. This location information made sense for them in conjunction with other information: mostly the readings each of them noted and, the decision they made during the plan with explicit agreement about what strategy to apply. This helped in constituting a richer common ground. It appeared that automating MLA could be problematic in performing mutual modeling acts based on this common ground.

Moderating the criticism of MLA

Another factor of differentiation between the two different ways of playing is to look at the performance of each group for each phase. This discrimination allows us to moderate the critique of the location-awareness tool.

Actually, we saw that when looking at the task performance for each phase, the MLA interfaces had different effects. For phase 1 and 2, the giving of one's location could be replaced by verbal communication, which was not the case in the last phase where people had needed a tight coordination. Therefore, as Espinosa et al. (2000), we conclude **that awareness information impacts differ depending upon the task**. This is obviously a starting point for new field experiments in order to investigate the articulation between tasks and levels of automation with awareness information.

The omnipresence of the plan

Though we insisted on the different ways of playing in the different experimental conditions, we have to conclude by putting forward a pertinent common aspect between them. For both *MLA* and *Control* players, the presence of the 5 minutes plan was a very important feature that we can describe through the lens of our framework.

The qualitative analysis of the coordination device showed that **players from all the conditions heavily relied on this planning phase** since it provided them with an important source of information to perform mutual modeling acts. Indeed, during this planning phase, they discussed explicitly how the group should act, when and why. This discussion then allowed each group to set conventions that we can define as "local" (i.e. only for the local context of this game). The plan could thus be defined as the encapsulation of explicit agreements and convention and coordination devices.

5.6.3 Limits

Apart from issues regarding the field experiment paradigm, one of the limits of our study is that each group played only one game, which might be problematic in terms of interface learning. One possible response to see whether the results still hold over time is repeated play as described in the experiment performed by Barkhuus et al. (2005). In this experiment, the authors let people play three times and they observe the evolution of their behavior over time. Another solution would be to conduct crossed experiments in which players from one condition play a second game in the other condition (hence mixing the three conditions).

However, the most important limit to the generalization of these results is the task. Its nature is both very simple and based on spatial reasoning as opposed to, for instance, a police investigation in which space is both where cues and the information on which one can perform complex inferences about past actions can be found. The semantic of the inferences that can be performed upon the MLA is therefore low. We would definitely benefit from the investigation of the same issues in a more ecological task such as firefighter missions for instance.

In addition, collaboration in this case is very decentralized, involving a low number of persons and without any prior knowledge required. It is thus difficult to generalize to bigger groups or those who have with normative workflows.

5.7 Conclusion regarding MLA and coordination

Whereas the first experiment supported the idea that mutual location-awareness could improve mutual modeling, the current field study in physical space showed that in some situations things could be more complicated. This second experiment highlighted an important characteristic of coordination devices such as MLA: their **automation could be an impediment to collaboration**. We also noticed how coordination was a continuous process and how coordination devices were used and re-used over time since they were integrated in the updated common ground.

Our analyses showed that a coordination device, when automated, could influence other coordination devices by inhibiting their exchange. Such a phenomenon can lead to a poorer common ground and consequently fewer possibilities to perform mutual modeling acts. This is why a peculiar coordination device can diminish the accuracy of the mutual modeling. Further, **broadcasting information about MLA can also have a negative impact on coordination** since users substituted a non-pertinent information (others' locations) to more relevant information (explicit agreements about strategy changes, paying attention to environmental features such as bottlenecks for instance).

As we saw, the plan set by the participants seemed to play an important role in each of the experimental conditions. The next study will focus on the role of the plan and how it affects the way players with MLA can perform the game.

Chapter 6 • Study 3: Mutual-Location Awareness without a Plan

This chapter describes the third study we carried out: we used again the CatchBob! environment to better understand the players' coordination and to deepen our understanding of how the most important coordination device, the plan, influences collaboration.

6.1 Scope of the study

6.1.1 Motivations and goals

In the previous chapter, we saw how the automation of a coordination device such as MLA could be detrimental to the exchange of other coordination devices. We also described the importance of the planning phase as a key moment in which players set conventions that can be used to draw inferences during the game.

Therefore, to continue our investigation of how MLA influences collaboration, we want to **suppress this planning phase** and explore how this modifies players, coordination and the use of the MLA tool. We zoom in on one of the experimental conditions from the previous experiment in carrying out a new field experiment.

The importance of the plan is due to two aspects. On one hand, it is a moment during which players might understand the task they are asked to carry out through discussion. On the other hand, the plan enables the establishment of a specific type of coordination device that will be used afterwards to mutually predict partners' behavior: conventions agreed among the team. As we have seen in Chapter 2, the literature about coordination puts the emphasis on conventions as the most important and recurrent coordination device used in many situations. By agreeing on specific issues before the joint activity, conventions allow for a decrease in the need to communicate and, eventually, for the sharing of precise mutual expectations. There are also many situations in life where we suddenly coordinate with somebody with whom we had no previously established plan. Thus, we want to explore how removing this planning phase influences the group task performance and whether there might be some compensation for the removal of the plan through communication or the usage of the MLA interface. Additionally, this experiment will also allow us to describe what constitutes the planning phase and what players discuss during this moment.

Moreover, this second experiment has **another purpose**: it will help us to **refine our description of the coordination devices used** by partners of teams. To do so, we modified the CatchBob! interface, proposing suggested communication conventions that correspond to the content of coordination devices that we have observed in the first experiment. This allows a quantitative analysis of the information used by players who had the MLA interface during the three phases of the game. Such an analysis will be discussed in regards to the model of coordination we described in the previous chapter.

We used the same pervasive game environment to address the role of the plan for players who had the MLA tool. In order to increase our understanding of the importance of the plan, we developed two experimental conditions: with or without the planning phase before the CatchBob! game.

6.1.2 Hypotheses

Based on the literature and the previous study, we can postulate:

- Hypothesis 1: The suppression of the plan will decrease the group performance.
- Hypothesis 2: The suppression of the plan will reduce the mutual modeling accuracy within groups.
- Hypothesis 3: The suppression of the plan will be compensated by a more thorough discussion during the first phase of the game.

Additionally, this study is also exploratory: our interrogation also lies in how the absence of the plan might be compensated for by the use of other coordination devices, such as the MLA interface or other types of devices (e.g. manifest elements from the environment, explicit agreement during the game).

6.2 Material and methods

6.2.1 Participants

Sixty students of the Ecole Polytechnique Fédérale de Lausanne (age range: 19-24; mean: 20.5) participated in this experiment. We selected groups who belonged to the same class and therefore knew each other; because different levels of knowledge between partners may impact the representation each of them have about their teammates. Participants spoke French or English but they used the same language within a group. We also checked that all players were familiar with the campus, studying there for at least a year. These experiments were conducted on our campus, one group at a time.

We created 10 groups of 3 persons in each of the experimental conditions: “with a planning phase” and “without a plan”. The 20 pairs were assigned randomly to either the *Control* condition (*without preliminary plan*) or the *Plan* condition. The *Plan* players had the possibility of having 5 minutes of discussion with each other before the game using a map of the campus and pins representing each character. We controlled group gender so that each condition was made up of 25% of female and 75% of male. Within a group, the repartition was generally 2 males or 2 females.

6.2.2 Task and interface

We used the same task in this experiment as we did in the previous one (see Section 5.2.2 for a description). The situation was identical but the interface differed since a communication tool represented on the left of Figure 49 has been added: a palette that contained symbolic representations of communication conventions. This palette gave examples of shared map annotations that players were invited to use when playing together. This was not intended to improve communication behavior among players but instead to help us in refining the coordination model we described at the end of the previous chapter. We will count what symbols from this palette players used in each phase of the game. This will allow us to discuss the model of mobile coordination we defined in the previous study.

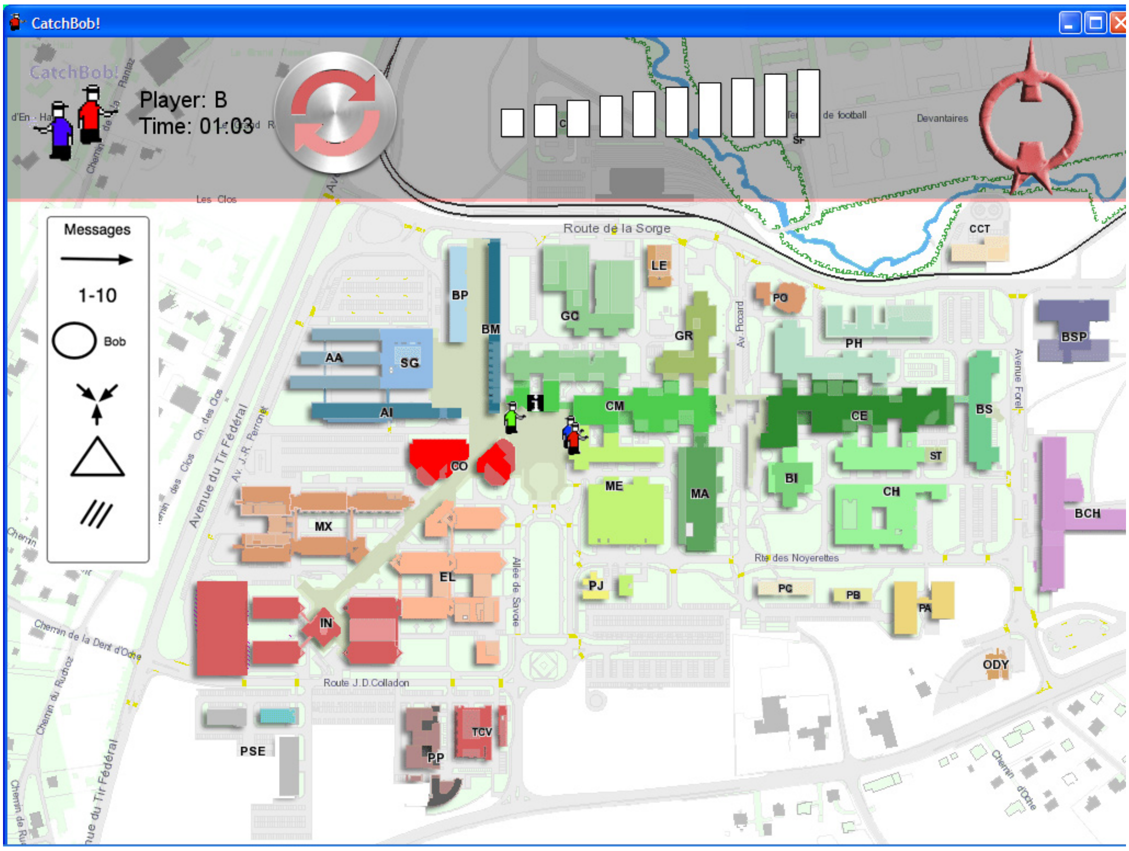


Figure 49. Tablet PC interface with the communication conventions on the left represented in a palette.

The definition of these communication conventions has been made through the analysis of the previous experiments. We saw the importance of directions and strategy messages both in the quantitative and qualitative analysis. A closer look at these strategy messages showed that they were made up of **broad categories of coordination devices** that were of particular importance:

- Advice, orders and requests about spatial behavior addressed by one person to the group, to his or her two partners or to one partner. This is often made through arrows with the name of the persons concerned or with a written annotation like "Arthur, go to the CE building and wait Pascal", "let's stay on that level" or "let's meet on the bridge".
- Indications about the object's possible location or possible area of location: with a dot, a circle and the mention "It's there" or "Here it is".
- Indications of the proper triangle configuration to complete the game, represented with a triangle.
- Meeting point for the group, often drawn as three arrows converging to the same dot.
- Network problems with a written annotation like "network troubles" or by striking out a map area with slanted lines.

These broad categories enabled the **definition of communication primitives that we decided to include in the palette** shown in Figure 49: (1) arrows to depict positions, directions or send request of spatial behavior, (2) Figure numbers to give the partners information about the object's location in terms of proximity, (3) A circle to represent

"Bob" s location, (4) 3 converging arrows to depict a "meeting point", (5) the triangle to be formed around "Bob", (6) slashed lines to show areas without a network. As described in Figure 50, these communication primitives represent the content of coordination devices the player can use and rely on make inferences about their partners. Nevertheless, the palette is not a clickable menu, it is only an example of possible symbols to be used for communication.

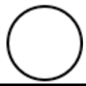
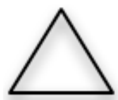
Inferences performed		Coordination device
Position		Signal strength indication dropped where the player is located
Direction/trajectory		
Network connection problems		
Proximity	To the caller	
	To the triangle	
	To meet	

Figure 50. The correspondence between the coordination device we suggested and the inferences they could foster.

The point of pushing players to use them was to ease the collection of coordination devices player used to investigate when they exchanged information to address the coordination problems we described in the previous experiment.

6.2.3 Procedure

The point of forcing players to use these primitives was to facilitate the collection of coordination devices players used when they exchanged information in addressing the coordination problems we described in the previous experiment.

6.2.4 Procedure

The experiment procedure was **similar to the previous experiment**. Players were given the same briefing, the experiment lasted the same duration and after the game, they also had to complete paper-based questionnaire to draw their paths and their partners'. We then had a similar post-game interview using our replay tool.

The **main difference between the experimental conditions lay in the beginning of the game**. For the condition with the plan, participants behaved as in the previous experiment: they came to the lab and had the experiment briefing there. They had 5 minutes of discussion with each other using a map of the campus and pins representing each character. After 5 minutes, the experimenter led them to the center of the campus and the game started. Players in the Control condition (without the plan) had to join the experimenter directly at the center of the campus and received the experiment briefing, they were then placed at 3 positions (25 meters from each others) and had to start the game without any face-to-face communication. Finally, both groups had the same synchronous MLA interface.

6.2.5 Collected data and analysis

We collected the same data as in the previous experiment. Task performance was still the group travel distance and map drawings allowed the calculation of the recall index of partners' trails. As for the analysis of player's map annotations, we used the same coding scheme as in the experiment 1. The only difference is that we added a new category depending whether the messages has been written as suggested by the conventions or freely. We were also interested in which phase each of messages suggested had been used so that we could modify the coordination model accordingly.

Players in the *Plan* condition were also video-taped to perform a qualitative analysis of what had been discussed and what constituted a plan.

6.2.6 Hypotheses

In this field experiment, we posited three hypotheses.

Our first hypothesis H1 postulated that **the group task performance would be negatively impacted by the absence of plans**. We expected that the distance covered by groups would be shorter in the *Plan* condition. We based this expectation on the assumption that the plan was of primary importance in setting the conventions of coordination and that suppressing the plan would be detrimental to the task performance.

As a second hypothesis H2 is that **the suppression of the plan would lower the accuracy of mutual modeling within groups**. In other words, we expect that players from the *Control* condition would make more mistakes when drawing their partners' paths.

Finally, we assumed as a third hypothesis H3 that **the suppression of the plan would be compensated for with a more frequent discussion during the first phase** of the game. We supposed that the absence of plan discussion would be replaced by more shared map annotations at the beginning of the game. Thus we made the hypothesis that the number of shared map annotations would be higher in the first phase of the game. A corollary expectation was that there would also be more messages about strategy in this first period for groups in the *Control* condition since the players did not have the opportunity to discuss division of labor among them and other strategic issues.

6.3 Results

This section presents the quantitative results we obtained concerning the group task performances, how they recalled each other's paths and exchanged coordination devices over time. We also describe the content of the discussed plan as well as some new affordances of the MLA interface.

6.3.1 Collaborative task performance

As in the second study, we analyzed the task performance at the group level, which corresponds to the group travel distance. Figure 51 depicts this index for both experimental conditions.

As can be seen on this figure, the groups in the *Control* condition (m = 6576, sd =1805) walked more than the groups in the *Plan* condition (m = 5097, sd =1298). An ANOVA test showed that the *Plan* groups performed the task significantly better than the *Control* groups ($F(1,16) = 4.2621$, $p = 0.05$). The first lesson we can draw here is that **the absence of a grounded plan negatively impacts the group performance of the task**, which corresponds to our first hypothesis.

An additional lesson is that the outliers are very spread out for groups in the *Control* condition, which might reveal different players' behavior.

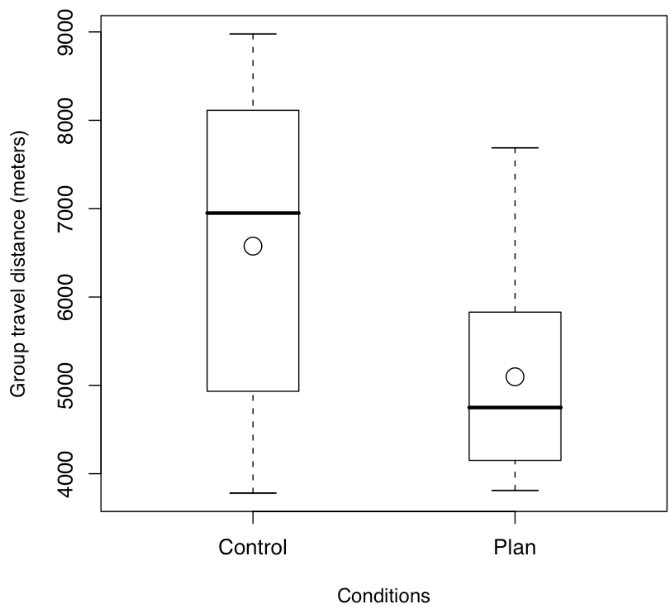


Figure 51. Group travel distance in the two experimental conditions.

Even though we have not use time as a performance measure, we found interesting differences between the experimental conditions, especially while looking at the duration of each phases (exploration – rendezvousing – triangle formation). The difference between the two experimental conditions was that groups who did not have the plan took more time (m= 679.9, sd = 364.7) to complete the first phase (m = 540, *p* = .03) than those in the Plan condition (m = 513.2, sd = 208.8). But we have not found any differences between the two experimental conditions for phases 2 and 3. Concerning the spatial strategy adopted by players (see Section 5.2.3 in the previous chapter), they all used the same one: each player went into one of the three directions of the campus. We have not found any significant differences concerning the roles players had (caller/follower/explorer, see Section 5.2.3 in the previous chapter).

6.3.2 *Recall of partners' trails*

As in the previous experience, we measured the number of errors between the path produced by player A when drawing B or C to B or C's real paths. This individual index represents the quality of A's representation of B and C's behavior in space. We checked the non-independence of the results through the computation of intraclass correlation ($r = 0.70$), which was not significant ($p < .001$). This expresses the non-independence of the results among groups. It means that the number of errors made by the subjects is dependent on the number of errors made by the partners (i.e. if one player made a lot of errors about his/her path, the same goes for the partners). It also led us to use the group as the unit of analysis. To do this, we added the number of errors made by each individual within a group to create a group index. Figure 40 shows the number of errors in each condition per group.

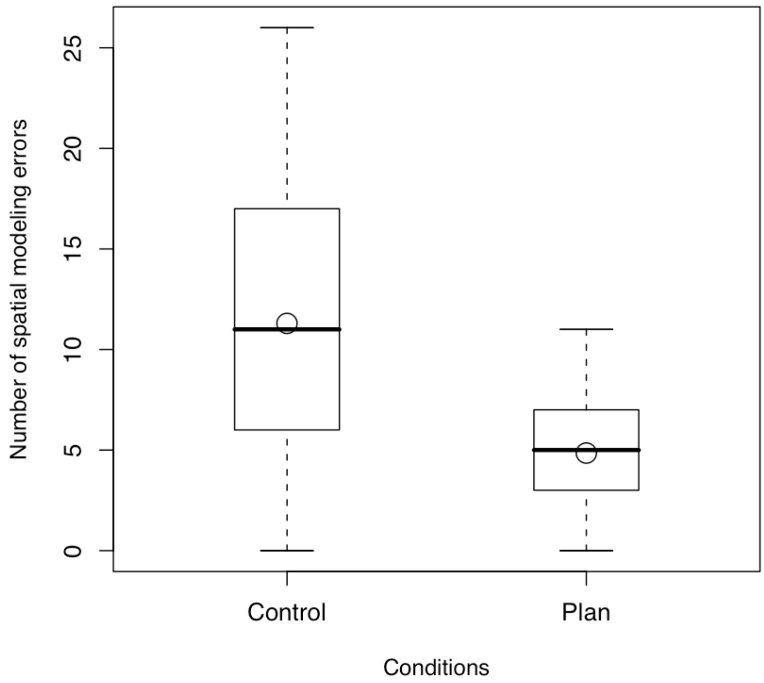


Figure 52. Number of errors made by each participant during the post-test (while drawing the path of the partner) in the two experimental conditions.

Players in the *Control condition* made more than half the errors of those who had the Plan (*Control*: m = 33.90, sd = 17.3; *Plan*: m = 14.56, sd = 6.58). A non-parametric test showed that this difference was significant (W = 655.5, $p < .0001$). In other words, **not giving a plan to the players significantly diminished the accuracy of the player's representation of their partners' trails**. This is what we expected in our second hypothesis.

6.3.3 Communication through shared map annotations

Annotations frequency

Map annotations have been investigated both by quantitative measures like the frequency and content categorization. This variable had been studied at the individual level since the intraclass correlation among the group was not significant (r = 0.29, p = .09). Figure 53 shows the frequency of messages sent by each player in the two experimental conditions.

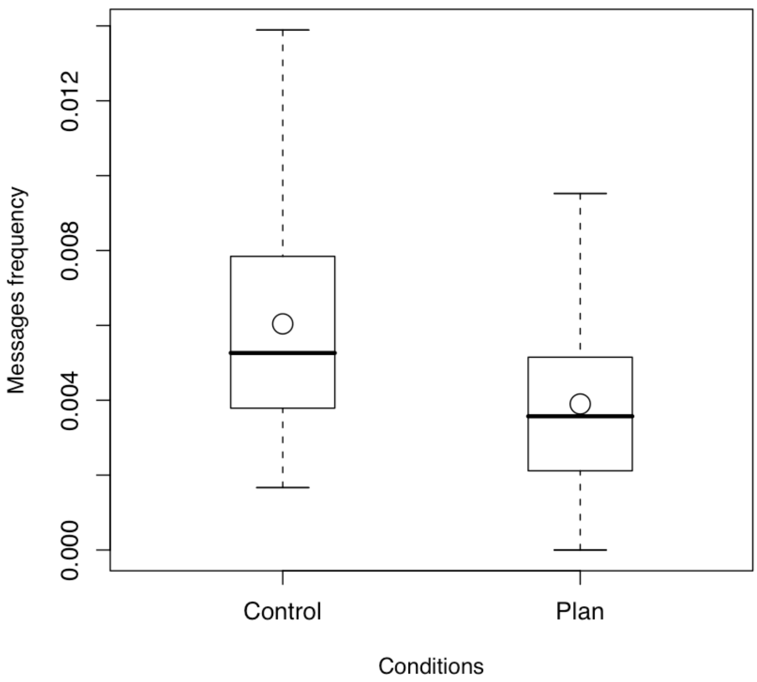


Figure 53. Frequency of shared map annotations written on the Tablet PC by each individual.

The frequency of map annotations was higher in the *Control* condition (m = 7.47, sd = 4.94) than in the *Plan* condition (m = 4.07, sd = 2.83). A one-way ANOVA test showed that this difference was significant ($F(1, 54) = 8.2096$ $p < .05$): **players who had not had discuss a plan face-to-face wrote fewer shared map annotations**.. Our third hypothesis is then validated.

We coded the content of the messages and their pragmatic status using the same coding scheme described in the previous chapter. Statistical analyses[12] showed that the players in the *Control* condition sent more messages about strategy ($W = 690.5$, $p < 0.0001$) orders ($W = 524$, p-value = 0.03490) and more acknowledgements ($W = 540$, p-value = 0.009117). We did not find any significant correlation between these variables and performance or position recall indexes.

Having the MLA interface, all groups (with or without plan) did not discuss their own position and direction because the tool conveyed this information. However, it seems that players from the *Control* condition who had no opportunity to discuss strategy issues took better advantage of the annotation capabilities to share messages about strategy. The next part will further our understanding of how coordination occurred in

[12] Given that the distribution of the data was not normal, we used a non-parametric test (Wilocoxon's test)

the different conditions by looking at the exchange of communication primitives over time.

Coordination devices use over time

Based on the seven communication primitives we listed in Section 6.2.2, we can count when the players used them, for each group in the two experimental conditions,. Of course, sometimes these primitives were not sufficient to convey meaning and players employed more verbal comments. We also counted these verbal descriptions or questions that addressed strategic issues and division of labor. We have represented in Figure 54 the exchange of these communication primitives in each of the three phases of the game. Based on the qualitative analysis of the previous experiment, the figure also shows which inferences can be performed based on these communication primitives. The point of this figure is to depict the total number of messages exchanged at a particular moment by each group, and to show the potential differences between conditions. We counted the symbols accurately reproduced and those different from the ones proposed in the palette. Overall, the percentage of symbols accurately reproduced by players from the *Control* condition is 52% and 73% for those from de *Plan* condition. This difference might be explained by the fact that players from the *Control* condition needed to discuss the strategy more thoroughly and symbols are too limited for this.

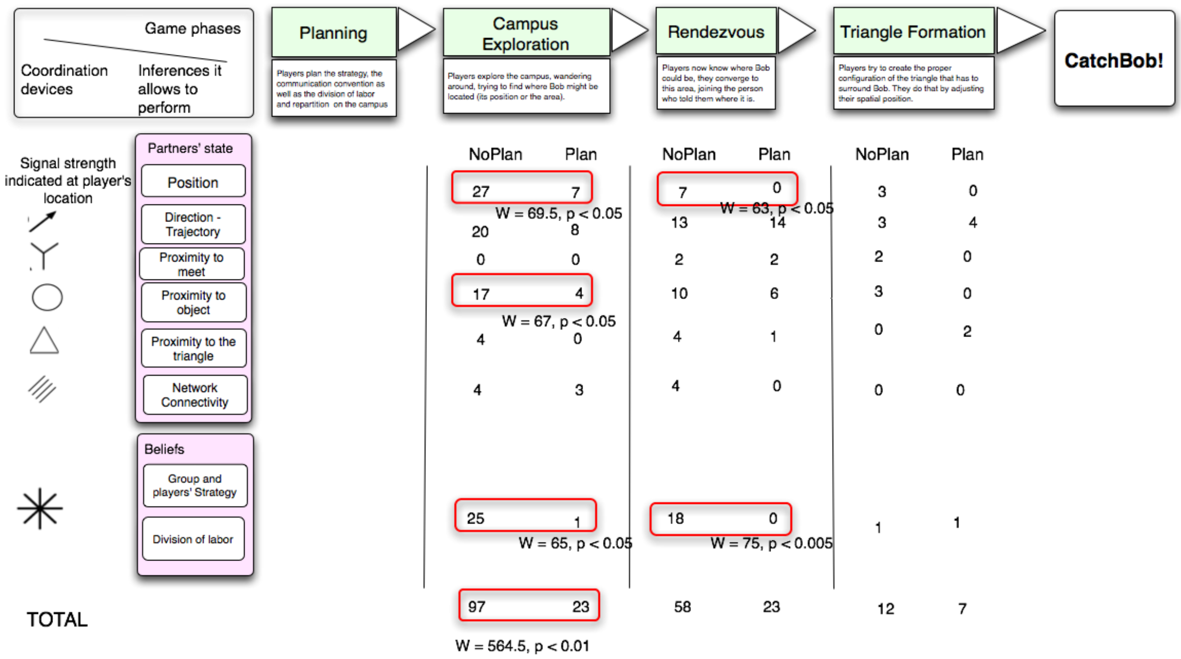


Figure 54. Exchange of coordination devices over time, with the main differences between experimental conditions expressed as boxes (numbers under the boxes indicates the Kruskall Wallis W as well as the p-value to show the significance of the test). The numbers for each coordination device is the sum for all groups. We also indicated the inferences each coordination devices allowed players to perform, based on the results from the last experiment.

The most striking result is certainly the **unbalanced repartition of messages over time**. As we saw in the preceding section, the groups in the *Control* condition sent more messages. The time analysis here shows that the difference was significant only for the first phase of the game ($W = 564.5$, $p < .01$): players from the *Control* groups sent more messages in phase 1 (m = 3.23) than those from the *Plan* condition (m =

0.76). And we found no significant differences for phase 2 ($W = 506.5$, $p = 0.09$) or phase 3 ($W = 424$ $p = 0.73$). This result matches our expectations: since the players did not have the opportunity to discuss the plan, they needed the first phase of the game to compensate for this by using the shared map annotations.

As one can see on this figure, in phase 1, players in the *Control* condition exchanged more messages about position (m = 0.9, $W = 69.5$, $p < 0.05$), the location of the object (m = 0.43, $W = 67$, $p < .05$) and strategy information (m = 0.83, $W = 654.5$, $p < 0.01$). In phase 2, there were only significant differences for messages about signal strength (m = 0.23, $W = 63$, $p < .05$) and strategy information (m = 0.6, $W = 75$, $p < 0.005$). Interestingly, when we look at the repartition of coordination, what is also striking is that the differences between the two experimental conditions tend to diminish over the course of action. This might be due to the last subtask, which is different and less bound to coordination devices exchange, as we saw in the previous experiment.

In the first phase, players in the *Control* condition exchanged more information about the proximity sensors than those in the *Plan* condition. They indeed dropped more messages about the figures they read on the proximity sensors and they left these messages at their position at the time. These messages also allowed partners to infer their positions (which were already conveyed by the MLA tool anyway). Without a plan, in phase 1, there were also more messages about the objects' location (drawn as a circle); this can be explained by the fact that they had more difficulties in locating the objects, since they were still discussing how to solve the problem through strategy messages.

As shown on Figure 54, most of the **differences between the exchanged coordination devices occur in the first phase**, some remain in the second one and the third phase shows very similar patterns of communication. This leads to two possible explanations: On the one hand, even though the three phases were different in terms of task content, the absence of the plan seemed to be compensated with more messages after two game phases. On the other hand, the last phase, as we saw in the last chapter, did not require a lot of verbal communication, which can explain why the two conditions showed similar patterns of coordination device use.

Strategy messages

The previous experience has shown the importance of strategy messages for mutual modeling and task performance. The analysis described in the previous section also shows an interesting difference between players who had a plan and those who did not concerning the exchange of strategy messages that were not conveyed by the communication primitives, especially in phase 1 and 2. We looked at their repartition in both of these phases. Figure 55 depicts the number of strategy messages sent by players in both conditions.

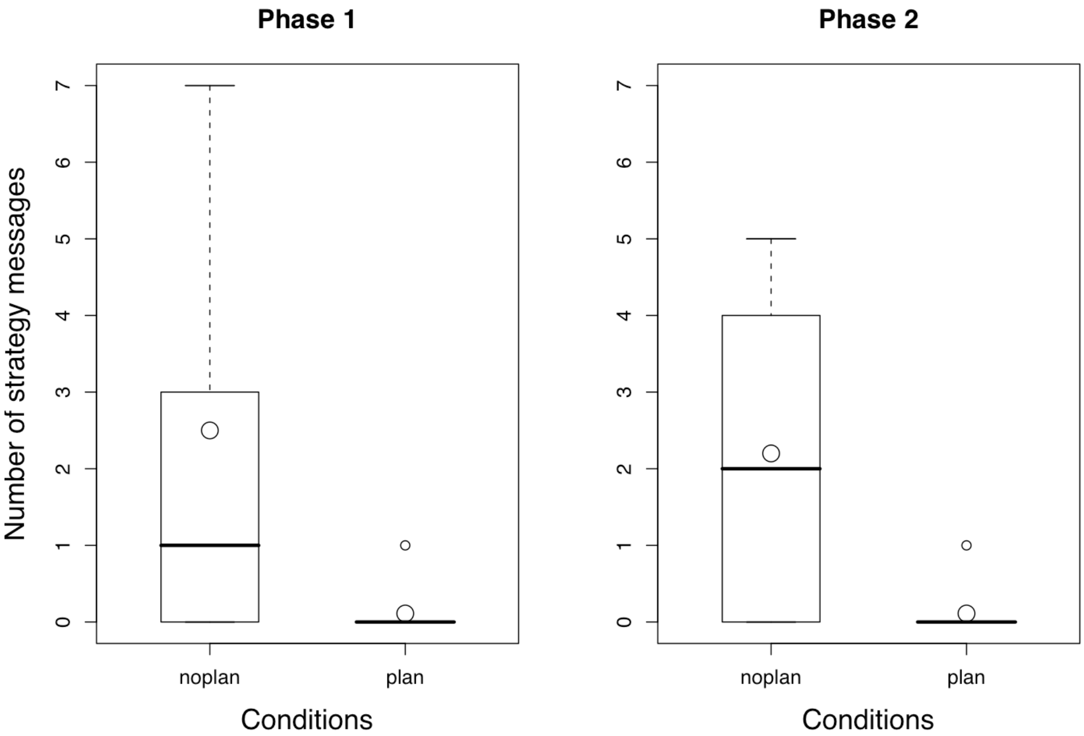


Figure 55. Boxplots showing the number of strategy messages verbally described (not using the communication primitives) by players in the phase 1 and 2.

Groups who had a planning phase sent almost no strategy messages, which is consistent with the second study. For *Control* groups, the absence of a plan was compensated for by the exchange of strategy messages in the first and second phase but things are more complex. What these boxplots highlight is that the variations of behavior within *Control* groups are important: some of them exchanged many coordination devices and some did not.

Furthermore, there is a strong and significant correlation between the number of strategy messages in the first phase and the task performance ($r = 0.50$, $p = 0.02$), which is not the case for the second phase. This correlation might explain the broad range in performance for groups in both conditions: better teams exchanged more coordination devices in the form of strategy messages. However, since the groups in the *Plan* condition shared almost no strategy messages, this correlation is more pertinent in explaining the broad variety of performance for the players in the *Control* condition.

Finally, in terms of the pragmatics of the strategy messages sent by players in the *Control* condition, we found that they were mostly based on announcements and questions acknowledged by the partners. Players, for instance, proposed various strategies like staying on one level or spreading rapidly around a building. However, they never tried to state conventions; the coordination devices they exchanged through these strategy messages were, in Clark's words, only explicit agreements.

6.3.4 Qualitative analysis of the grounded plan

In order to gain more insights about the role of the plan, we additionally **videotaped planning sessions** of players in the Plan condition. Dialogues and interaction analysis (Jordan and Henderson, 1995) enabled us to describe what has been discussed and how the available tools (such as the maps and pins) had been used. Videos were analyzed to look at the content of the plan discussion. We listed all the topics that had been mentioned and clustered together similar issues raised by the players. Then we transcribed the **critical moments** that exemplified the topics. We found that players discussed **three recurrent topics**. In the categories description below, we translated excerpts from French to English. These three topics are described in the same chronological order that the players –introduced them in the planning phase. Nevertheless, if the two first topics are always discussed, the last one is not always addressed.

The first topic that is always mentioned and brought up at the beginning of the discussion is a **discussion of the general strategy the group should adopt**. In most of the cases, one of the player reformulated in his or her own words the mission they have been asked to complete by pointing at the map: starting from the departure point and showing a possible ending point as described in the beginning of Interaction Analysis 1. The players also deconstructed the whole task they are required to do into 3 objectives: finding the object, regrouping and then forming the triangle. Rephrasing the task and de determining the subtasks was a way to set the group goals, what Clark terms the "public goals".

Interaction analysis transcript 1. (Transcript done using the interaction analysis convention of Jordan, see Appendix J in Jordan and Henderson, 1995)

Time	Activity	Talk
10:24:45	B take the three pins in her hands	B: So, we have to chase Bob and surround it. The three of us will form a triangle
10:25:16	B drop the pins at the departure point on the map (center of the campus)	B: we start from here
10:25:45	A points the CM building on the map	A: let's imagine Bob is there
10:26:05	B puts the pins where A pointed, forming a triangle	B: the goal is then to go here and to position ourselves as a triangle.
10:26:46		A: okay
10:27:20		B: so the first thing is to find Bob, then to regroup and finally to form the triangle.
10:27:47		C: yes, so we need to spread over first
10:28:12	A takes the 3 pins and drop the green and blue one at the center of the campus. He takes the red one and slide it over the table in the west direction	A: I'll head that way
10:28:34	A takes the green one and slide it over the table in the east direction	A (to B): you'll go in the CM direction B: okay with that
10:28:57	A takes the blue one and slide it over the table in the south direction	A (to C): and you will visit the south
10:29:12	C takes the blue pins, put it back to the campus center and slide it in the south west direction	C: I'd better go south west since there are more buildings here, the object should be closer to a building because the network is better there.

The second part of the plan is to **discuss the division of labor within the group**, which is derived from the "public goals" stated by the players, as exemplified by the part between 10:27:20 and 10:28:57 in the transcript above. In this case, there is only one player who is giving orders to the others who acknowledged them or not. Sometimes, the negotiation of the division of labor is more collaborative with people proposing their own directions. This is bound to the emergence of a leader within the group: for the 10 experiments in the Plan condition, we found 4 groups in which there was a clear leader who set the plans for the others as in the aforementioned example. In 5 groups, there was no clear leader and the discussion of the division of labor was more collaborative. In one group, there were two leaders arguing about this topic and a third player who was passive and acknowledged the final strategy proposal.

And the final part of the planning phase, which as not always discussed, was about **communication conventions**. Even though we provided players with symbols that they could use to communicate with each other through shared map annotations, some of the groups stated when they should write different type of messages and where on the display. They for instance chose that "*As soon as we get a signal on the sensor, we send it to the others*" or "*The first of us to have red bars write and tell them where he is standing*".

In terms of Clark's vocabulary of coordination, these three steps allow the group to define the **local conventions** they would rely on to form mutual predictions during the game. What is interesting is to note that these conventions are set by explicit agreements or orders by one or two leaders. In both cases, players explicitly acknowledge that they will follow these conventions even when they did not participate actively in the discussion about them.

6.3.5 MLA interpretations

We performed the same qualitative analysis of MLA usage as in the previous experiment. Players in the *Plan* condition did not adopt new MLA uses. Nevertheless, players in the *Control* condition added **two relevant uses**. These have never been cited in the previous experiment and probably result from the absence of grounded plan at the beginning of the game. Since experiments have been conducted in French, we translated the excerpts into English.

The most recurrent use of MLA cited by players in the *Control* condition was that it afforded **division of labor**. They mentioned how it helped the optimization of the research in the first phase "*to optimize my trajectories and research in different areas, to avoid places my colleague were visiting*" (Group 9, Control condition), "*to know how to divide the possible paths among us*" (Group 4, Control condition), "*I could react accordingly*" (Group 5, Control condition). Of course, some participants understood that having a pre-game plan would have been different: "*it was very important at the beginning to know who would explore what because we haven't discussed that*" (Group 8, Control condition).

Four players also mentioned that MLA was **a resource in comparing one's actions to the partner's actions:** "*with the other's position, you see where they are in terms of task achievement: I saw that Red was close to the end of the campus, so I thought I had to speed up*" (Group 4, Control condition), "*it allows one to see the state of the advancement of the task: you can see who is going around in circles*" (Group 7, Control condition).

6.4 Discussion

6.4.1 Results summary

This second experiment with the CatchBob! environment **confirmed the importance of the planning phase as a powerful resource for coordination**. The absence of the plan led to lower group task performance. However, among groups who did not have a planning phase, we found that a good level of performance could still be reached if they exchanged valuable coordination devices, in the form of strategy messages during the first phase of the game. But in any case, having no plan was detrimental to the mutual modeling: its absence led to worse position recall. We also found that the lack of plan made players more verbose: those groups communicated more, especially in phase 1 and 2. Communication was most important in giving information about the signal strength (that allows to infer both players' positions and proximity to the object), the objects' location and strategy messages.

The qualitative analyses show the importance of the plan as a way to **set local conventions about the general strategy, the division of labor and when to communicate**. Regarding Mutual Location-Awareness, the absence of a plan led players to use this coordination device in many ways (in addition to those observed in the previous study): to both infer the division of labor among them and as a potential resource to compare one's action to the partners' actions. What was interesting in this experiment was that suppressing a very important coordination device led to a new usage of another coordination device, namely the MLA.

6.4.2 Discussion

Even though we have seen new uses of the Mutual Location-Awareness interfaces, the tool did not compensate for the lack of a plan: its suppression was detrimental to the task completion as well for the mutual modeling. The planning phase proved to be the most important coordination device: what we assumed in the previous experiment has been confirmed by the present study. Nevertheless, **the way to compensate for the absence of plan was to exchange strategy messages during the first phase of the game**. In Clark's terms, those players without a plan used explicit agreements during the task instead of local conventions which they were unable to set without a planning discussion. It is interesting to note that players did not set conventions when communicating with the shared map annotations, they only exchanged information and agreed on them. A possible reason for this is the least collaborative effort principle (Clark and Brennan, 1991): since the cost of writing those annotations is high, it was simpler to propose an action or to order something and wait for an answer rather than arguing about conventions.

What is also important to notice is that, unlike the situation in which players have the MLA interface and a plan, players from the *Control* condition shared more map annotations. **As opposed to the previous experiment, there was no "overfocus" on this coordination device**. In other words, the detrimental effects of the MLA on communication are not systematic. In situations in which there is clearly a need to communicate (as in this case because no plan has been stated) players exchanged coordination devices. But, as we have seen in the evolution of the coordination device over time, the difference between groups from both conditions tends to diminish; and in the third phase they showed similar patterns. We can account for this diminished use of the MLA by noting that verbal communication was not an efficient way to perform the last phase of the game, as seen in the previous experiment.

Finally, without a proper planning phase with copresent individuals and tools to help them, players have worse mutual modeling, they make many errors when recalling the spatial position of their partners. We could then assume that the plan is a very important resource in in recalling others' paths, but confirmation of this assumption requires further experiments.

6.5 Conclusion regarding coordination and MLA

There are relevant consequences about the links between MLA and coordination for our research questions. This experiment shows that the **relations between coordination devices are very intricate**: their manipulation can have unexpected consequences. Suppressing the plan in this experiment or removing the MLA interface in the previous one led to tangible effects on coordination devices. First, local conventions were never established where there was no planning or discussion phase, they were replaced by explicit agreement during the game. Second, the MLA was used in novel ways to perform other mutual modeling acts: players without the plan used it differently to infer division of labor issues and to compare their actions to those of their partners.

A second interesting consequence is the fact that **the problem of the awareness tool we described in the previous experiment: it can be overcome**. We indeed found that the overemphasis on the MLA tool by players in the *Plan* condition led them to communicate less. This effect has not been seen with players in the *Control* condition: suppressing the most important coordination device fostered more communication within the group.

Chapter 7 • Visualizing Coordination and MLA Usage

This chapter describes how we designed and deployed visualizations of coordination devices in our pervasive game, based on Clark's model. The point of these representations was to further our investigation of how a MLA interface affects the exchange of coordination devices.

7.1 Representing coordination: underlying principles

In the third chapter, we saw that coordination was an exchange of elements that enabled participants in a joint action to perform mutual modeling acts, and make inferences about each others' behavior. Of course, due to methodological issues, some devices are more difficult to comprehend than others; precedents, for example are much more intricate and less easily grasped.

The experiments we conducted show interesting results with regards to the role of these coordination devices. We indeed managed to detail the patterns of use in the two last studies. The most pertinent result is certainly the fact that the manipulation of available devices could lead to important consequences in terms of the devices that will be exchanged and consequently on the socio-cognitive processes at stake in collaboration. In the first experiment, the availability of a coordination device (conveyed by the MLA interface) was not perceived and used by every player. The second experiment highlighted the negative effects of the automatic MLA on communication; it made players more passive and less able to remember their partners' path. The third experiment attested to the fact that some coordination devices were more prominent than others: suppressing a fundamental element such as the plan was detrimental to the group task performance but increased the amount of communication between participants to compensate for the lack of common ground. In addition, this experiment was meant to facilitate the collection of coordination devices through the use of communication symbols since it allowed us to refine the moment of use of certain coordination device exchanges through explicit agreement.

Overall, in this thesis, the underlying research issue that emerged was the influence of coordination devices on each other. In order to advance this analysis, we aim at developing **new ways to express and investigate the intricate relationships arising from the use of coordination devices within groups**. This leads us to define graphical and synthetic representations of the coordination device exchanges over time in the context of our second and third study. The main goal is to define a tool for analyzing collaborative interactions in the context of the CatchBob! game.

The work reported in this chapter belongs to an area at the crossroad of **information visualization** and "**interaction analysis**". We use the term interaction analysis in a broad sense[13], meaning that we do not only focus on the interactions that occur between the participants of a group, but also on their own actions in the environment (e.g. movement in space) and how these actions contribute to the joint activity. Interaction analysis focuses on how to aggregate, sort and analyze interaction data (qualitative or quantitative) in order to present them as high-levels indicators, often in the form of visual representations (Dimitracopoulou et al., 2005). It is potentially of interest for three kinds of people: researchers, designers and community managers. Researchers use it to study collaborative processes and the influence of certain features (for instance how a representation of the group activity enhance learning). Environment designers deploy interaction analysis because they are concerned with evaluating or optimizing the spatial environment. Finally, community managers take advantage of interaction analysis to regulate groups or train participants in performing a certain activity.

Therefore, the purpose of this chapter is, first to describe the tool we designed to obtain these visualizations of coordination. We then show how we applied it practically in the context of CatchBob!, and how the tool can help the researcher in analyzing how coordination devices influence one another. In conclusion, we discuss to what extent these visualizations are relevant in the context of studying MLA influences as well as the potential our tool has for further applications.

7.2 Related work in the visualization of coordination

Interaction analysis is a vast and multidisciplinary field that is nurtured by two domains: CSCW and CSCL rely on interaction analysis to study collaboration in computer mediated settings (in virtual environments or in pervasive computing and sport research, mostly in soccer and rugby. In these sports, the main purpose of interaction analysis is to provide players and coaches with tools to help them refine their group processes and performance. Most of the research in this field is very applied and not academic. In addition, both domains have been inspired by concepts and methods coming from robot research (Joiner, Issroff and Demiris, 1999). These fields all offer relevant propositions for visualization.

Before entering into more details about which approach we want to favor, we will present some projects about the visualization of coordination that exemplify the most relevant ideas with regards to the representation of group interactions in a spatial environment.

7.2.1 Different types of representations

Reviewing the projects about group interactions in space led us to distinguish **two dimensions** that can be represented: **users' interactions with each other** (mostly

[13] This definition is totally different from the term "interaction analysis" used by ethnographers (Jordan and Henderson, 1995) that we already used in our studies as a qualitative method to define the MLA roles.

communication) and **actions in the environment** (mostly spatial behavior and interactions with artifacts). Whereas the former is addressed by diverse techniques such as thread-based representations of discussions (Donath et al., 1999), social network analysis (Wasserman and Faust, 1994), timeline (Plaisant et al., 1996) or treemaps (Johnson and Schneiderman, 1991) and represented as graphs, networks and nodes, the latter is depicted a 2D or 3D maps.

The review of projects presented afterwards is not meant to be exhaustive; it only aims at showing some of the solutions used by researchers from the aforementioned domains to deal with visualizations of multi-user application/situation issues. We define three types of representation depending on whether they display interaction spatially or not and if they show the communication patterns between users.

7.2.2 Spatio-temporal representations

The simplest examples of such visualization are spatio-temporal studies of groups in peculiar kinds of contexts to study problems such as navigation in supermarkets or a pervasive games as well as group coherence in a virtual world (among other research issues). It is used by researchers who investigate **spatial behavior over time in order to reveal hidden patterns**.

Figure 56a, for example, shows a tool that displays the evolution of the population inhabiting 3D virtual environments to address the distribution of the virtual inhabitants over time and space, the formation and diffusion of groups, the influence of group leaders, and the environmental and social influences on chat and diffusion patterns (Börner and Penumarthy, 2003). The designers of this tool employ spatial maps to investigate the influence of a world layout and positions of other users on the diffusion of inhabitants. Virtual community managers and game designers deploy this kind of application in order to understand which parts of their environments are explored or not.

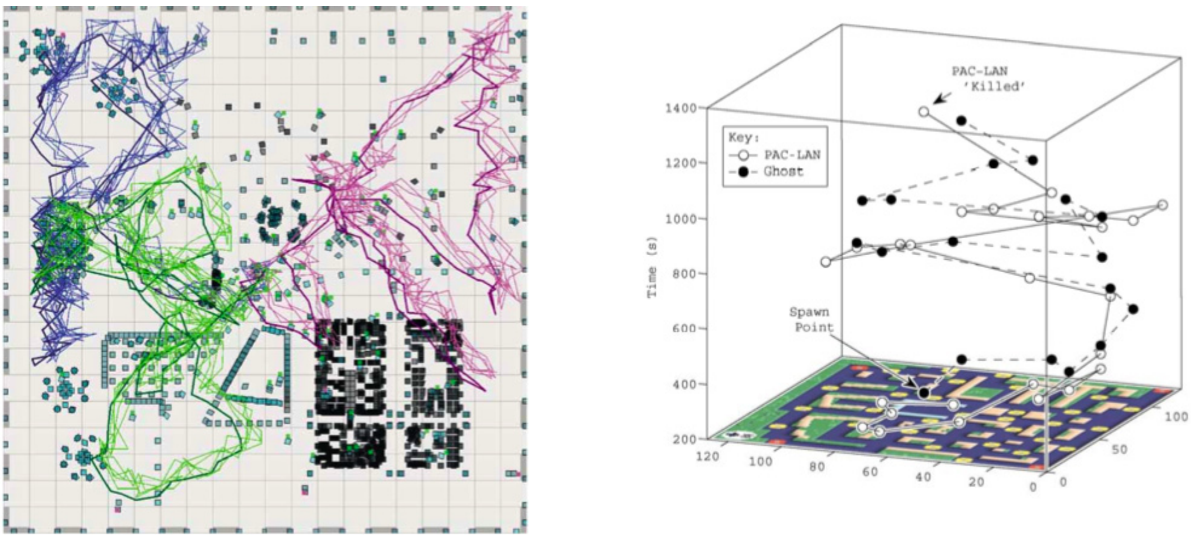


Figure 56. (a) Visual representation of group path in a virtual world over a long period of play (Börner and Penumarthy, 2003) (b) Rashid et al., 2006.

Rashid et al. (2004) adopted a different approach, as shows by Figure 56b: the authors used a space-time plot to investigate the players' behavior of a pervasive game called PACLAN. Participants played a Pacman game in a real-world setting: a "ghost" player chased a "pacman" player. These visualizations were used to identify the tactics that emerged during gameplay through spatial patterns. The added value of the 3D conveyed by space-time plot is of interest here because there are only two players and the game only lasted a short amount of time (this would not be possible in the context of the first example because the duration of the activity way a lot longer and the tool did not include the possibility to have a complete overview of the game). The 3D facilitates the depiction of the players' path over a long period of time.

Both of these examples are **based on a map metaphor**, in which there is a direct correspondence between the spatial behavior of users and their representation on the map. A similar approach is the one deployed in "replay tools" used in the context of sport training (see for instance Prozone[14]) and in pervasive game research. These tools allow for the "replay" of data stored by game researchers such as a video of the players or the movements of players on a map (as we used it in Catchbob!). One of the most interesting example is the "Replayer" (Tennent and Chalmers, 2005): a tool that synchronizes the different sources of information we mentioned above as well as a plot of players' actions and statistics like time-series as pictured on Figure 57. In this case, it is a complex representation rather than a synthetic visualization of collaboration. However, the advantage of "Replayer" is that it uses a map metaphor for certain types of data and when there is no sense in adding other data on the map, there are dedicated windows synchronized to the map.

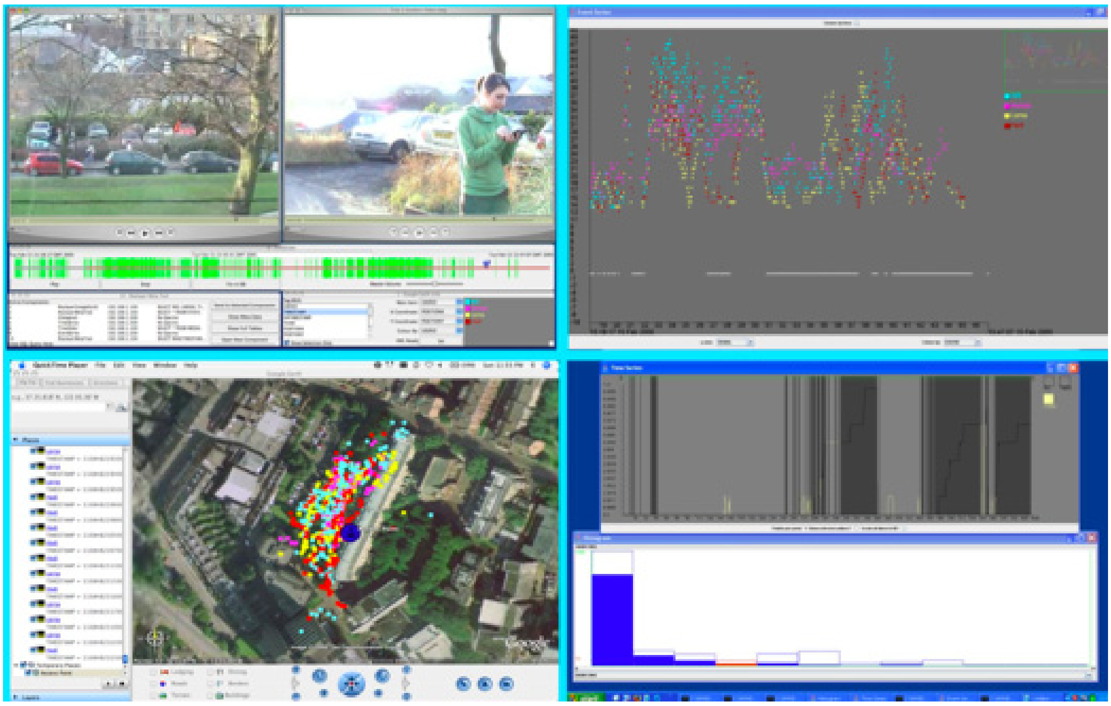


Figure 57. The Replayer (Tennent et al., 2005). Each of the four quadrants depicts different representations of data sources: videos of players on the top left hand corner, a mapping of player's actions on the bottom left hand corner. On the right, different plot and statistics depict the evolution of players' action over time.

[14] http://www.pzfootball.co.uk/

This is a relevant approach to investigate players' behavior. We used it in the second and third study to categorize the roles of players as well as to compare the path they drew of their partners to the real paths they took, which is shown on these maps. We also adopted the "replay tool" approach for players' interviews and to analyze the players' message written on the screen. Nevertheless, this tool has shortcomings in the sense that it does not provide the researcher with a proper representation of the interactions among the group over time: it only shows snapshots at different moments in time. Since our purpose is to depict coordination over time, we need a more synthetic representation.

7.2.3 Social network analyses presented in context

In the previous examples, the representation does not include any account of the communication between participants. This **visualization of communication** is largely favored by the social network analyses techniques that show and quantify, in the form of graphing who interacted with whom. Most of the work in that domain des not take the spatial dimension into account. However, some projects, mostly in the sport industry try to map social network representation on a map. This is the case of the FAS visualizations[15] as shown on Figure 58: their graph shows a soccer field, the players (nodes) and the number of passes (arrows).

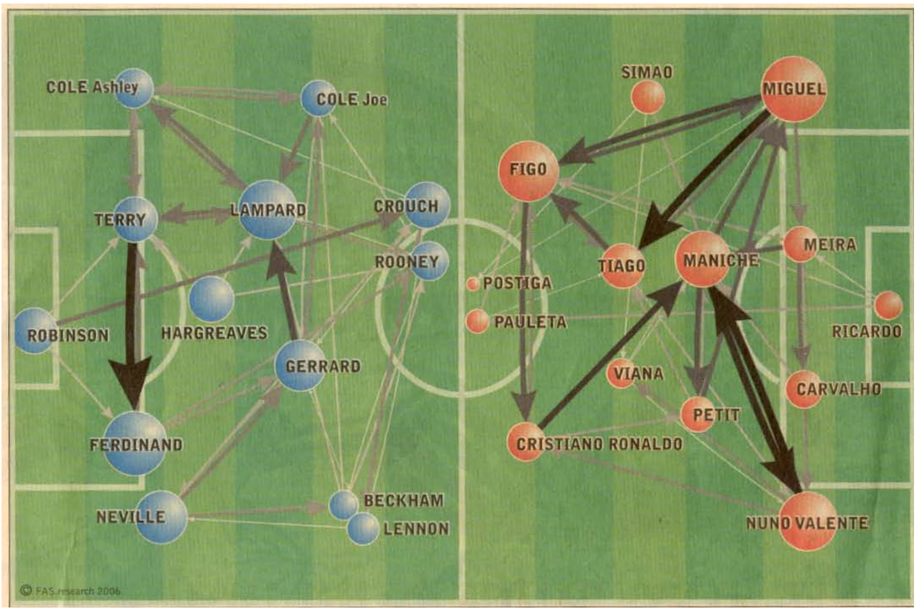


Figure 58. A visualization of a social network analysis applied to the 25 first minutes of the England versus Portugal soccer game in the World Cup 2006, by FAS Research.

This picture for example depicts what happened in the first 25 minutes of the England-Portugal game during the 2006 World Cup. Team managers employed it to infer information about players' behavior such as which player initiated the most passes,

[15] http://www.fas.at/news/meldungen/en_20060620094735_29305.html

which players were involved in the most combination pass plays, who played together with whom and who did not, or which players had a similar role?

What is interesting in this diagram is that the interaction analysis is presented in context, so it is possible to link the roles and the actions of a player to his position in space. Compared to the previous representations we presented, Figure 58 is a synthetic depiction of players' interactions but what is still lacking are the continuous aspects of the interactions. Actually, this picture only shows what happened after 25 minutes and it is already very messy: it would be very difficult to show a whole game.

7.2.4 *Removing the map metaphor*

Other researchers took a different approach and, **though keeping a spatial metaphor, got rid of the map representation**. Liqun and Banks (1997) proposed another sport visualization that enables tennis coaches and players to review, browse and analyze the overall structure of their matches represented on Figure 59. Their work however only focused on computer-generated tennis matches.

Figure 59. Representation of tennis playing by Liqun and Banks (1997) for a whole match (5 sets).

As one can see on Figure 59, they used a representation of two tennis players based on colored rectangles (red for A and green for B). Under the title bar, the rectangles had been vertically divided into sub-rectangles that correspond to sets. The horizontal division of the rectangle represents each game of the set. Since the rectangles only represent the hierarchical structure of the match, the competition between players is captured through a colored grammar. The color of the match rectangle is red because the red player won: since he got the first, third and fifth set, these rectangles are also red. Each sub-rectangle also depicts which game has been won by the green or the red players. This representation is of interest because the authors provided a synthetic overview of the interactions among a small group of players over a long time, without using the map metaphor. Representing exchanges as in the soccer example we described would have been tedious since the number of interactions is huge and therefore difficult to depict in a legible way. This visualization favors a more compact approach, which allows comparisons and the understanding of the evolutions of interactions (unlike the snapshot-based approach with maps) during games.

7.2.5 Conclusion

The different types of representations described previously are interesting for various reasons. They all provide **solutions to show users' interactions and movements in space**, which correspond with what we aim at visualizing. The use of map metaphors in the soccer example enables the contextualization of interactions whereas the tennis depiction is a powerful way to compare and trace the evolutions of interactions over time in a compact way.

However, the work presented above on interaction analysis differs from our context in three main ways. First, even though we presented examples of small teams, a large amount of the work in the domain of interaction analysis is devoted to very large groups; for instance the evolution of on-line communities through the analysis of emails. Our focus is instead about small groups such as the one that played CatchBob!. A second problem is that we are interested not only in communication between partners but also in their actions and spatial behavior. The only approach which favored that direction was the use of a replay tool, but as we have shown it only gave an instant depiction (which does not allow easy comparisons). Finally, the correspondence between an x and y coordinate on the map to an x and y coordinate on the field may not always the most relevant solution to depict coordination. In the project presented above about soccer, the use of the map often leads to a single time representation of interactions or movements in space: we have an overall picture, but we cannot see the dynamic of the interactions. This is mostly due to the fact that it would overload the map with lots of overlapped arrows.

The next section will describe how we tried to find a solution to these problems; our design choices will thus clarify how to develop the representations we described further.

7.3 Visualizations of coordination in CatchBob!

7.3.1 Design choices

The purpose of the visualizations we designed is to express in a novel way the exchange of coordination devices between participants of the Catchbob! pervasive game, based on the data we have from the experiments. In a sense, the overall goal is to make explicit to the researcher what is invisible and implicit about collaboration, namely about how the MLA affected coordination. We explain here the design choices we made and what motivated them in order to meet our goal of moving beyond the kind of visual representation shown in the FAS visualization and Liqun and Banks' tennis representation.

The first issue is that we want to **go beyond the use of map** representations to show coordination phenomenon. The “snapshot” problem of the map metaphor to visualize interactions motivated this need for **alternative depictions**. Secondly, we are interested in coordination, which is by definition a process that occurs over time. Therefore, we want to have a **time representation** to show the succession of coordination devices exchanged, when and by whom.

Moreover, we do **not have only log data** extracted from the game server and clients. We also wanted to integrate **data interpreted by the researchers** such as the qualitative analysis of annotations exchanged during the game, so that we could describe the content of the coordination devices at stake. Therefore, the visualization process will not be automatic. We would like to benefit from indicators that include both measurable data (like people’s position in space for instance) and more qualitative data (player’s role, players’ message). This then means that we would consider the merging of automatically-collected data (calculated from system logs) as well as interpreted sources of information.

7.3.2 What we want to visualize

Since the purpose of the visualization is to represent the exchange of coordination devices over time, let us clarify what we want to represent. Table 18 describes the 4 types of elements we want to visualize.

Table 18. Summary of data we aim at visualizing.

<table>
<tr><th colspan="2">What to visualize</th><th>Description</th></tr>
<tr><td rowspan="3">Exchange of coordination devices</td><td>Content</td><td>Whether the message sent is about direction, signal strength, network problems, meeting points, the triangle shape, the objects’ location or more elaborate discussion.</td></tr>
<tr><td>Pragmatic</td><td>Whether the message is an announcement, a question, an order or an acknowledgement.</td></tr>
<tr><td>Link between coordination devices sent by players</td><td>Whether the message belongs to the same coordination device, i.e. if it is part of a dialogue or a discussion. The message can hence be an answer or a completion of a previous one.</td></tr>
<tr><td colspan="2">Duration of each phase</td><td>The Catchbob game is made up of three phases that have precise boundaries.</td></tr>
<tr><td colspan="2">Role of each player in phase 2</td><td>In phase 2, one player is a “caller” when he or she is the first one to find “Bob”. The two other partners are either “followers” or “explorer” depending on whether they backtrack or keep exploring the campus while joining the caller but this is differentiation is not represented on the visualization (see Chapter 6).</td></tr>
<tr><td colspan="2">Division of labor (spatial dispersion of each character)</td><td>Since the task is spatial, the division of labor is represented by the amount of space visited. The further a player goes from his or her partner, the better he or she explores.</td></tr>
</table>

The most important element is of course the shared map annotations displayed and broadcast on the TabletPC screens, which constitute the only apparent coordination devices we could record. Others such as mentions of precedent or conventions cannot be included in the logfile; they were only collected in post-game interviews and not bound to a log event. Therefore, they will not be represented in these visualizations. Regarding the map annotations, logfiles provided us with the moment of their occurrences, which were analyzed qualitatively by the researcher as described in

Chapter 6. This consisted of a categorization in terms of content or pragmatic, as described in the table above. Additional information that the analysis of messages highlighted were whether or not a shared map annotation is linked to another and thus part of the same coordination device. For example, an order sent by player A may receive an acknowledgment from player B, and possibly a question by player C. Visually representing all these coordination devices is also a good way to see how they accumulated during this activity and, as a consequence, how they formed the local common ground.

A second important element to be visualized is the boundary between the game phases. As a reminder, the game engaged players in three parts: (1) wandering around to locate the object, (2) joining the first person who found the object, and (3) testing different configurations of the triangle around the object. Phase boundaries are interesting to represent since we have seen that players from the different experimental conditions adopted different roles and behavior in each phase. We then wanted to see how the exchange of coordination devices occurred in these three phases.

The division of labor among the group is also of interest: since the CatchBob! task is inherently spatial, it is represented by the way players spread out over the campus. Given that the task is collaborative, a good way to visualize the division of labor is to show the dispersion of the group.

7.3.3 Data structure: an XML-based representation of mobile coordination

In order to visualize the above four elements as well as to properly meet the expectations described in the design choices, there is a need to have **a structured data representation**. As opposed to the raw data generated by the game clients and server, it is more efficient to have a representation of data sources that is suitable for further processing by analysis systems, a central element of interaction analysis, as stated by Jermann, Sohler and Mühlenbrock (2001).

Figure 60 summarizes the sources of data we have, which consists in collected data from the game clients as well as the interpreted data by the researchers. Collected data corresponds to occurrences of events.

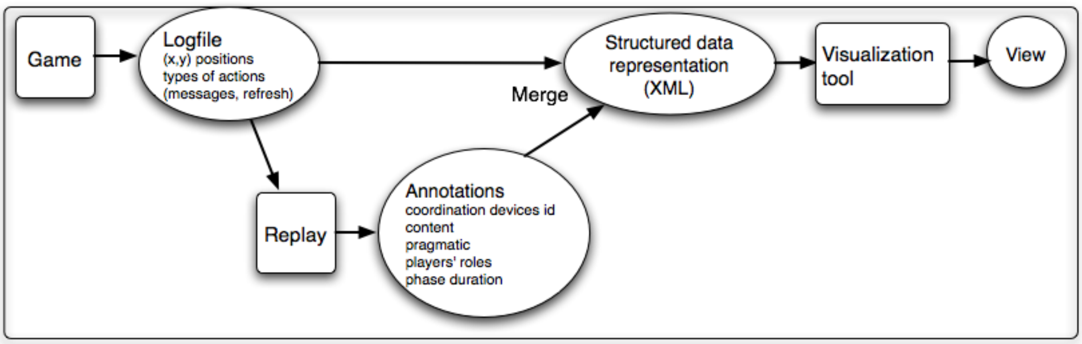


Figure 60. Data sources to be merged in the XML file.

We chose to describe this computational representation of our data sources by developing **our own grammar derived from the XML standards** described by Martinez et al. (2003). These authors indeed proposed a generic framework of description that is flexible, standardized and adaptable to a different spectrum of analytical perspective, mostly for the study of collaboration.

In this structure, we propose a syntactic model for the representation of our data sources that we have expressed using a DTD (Data Type Definition). Figure 61 depicts the structure we chose according to our design choices and the data sources available. As can be seen, a game consists in two main elements: a SITUATION and a LOG. The former expresses general information that concerned the whole game: it is first defined by a set of generic attributes (identification, data of experiment and experimental condition). It is further defined by sub-elements such as DESCRIPTION (a mobile situation in the case of CatchBob!), ROLES and PHASES. The "ROLE" elements correspond to the roles taken by players in the joint activity; in CatchBob!, it is mostly what roles players had in the second phase of the game (caller, follower or explorer). The PHASES elements, defined both by the time boundaries and a sub-element called DISTANCE, gives a summary of the distance covered by the three players.

The second main element of the DTD is the LOG that can be constituted of two types of sub-elements: POSITION EVENT or COORDINATION EVENT, which corresponds to the difference between traces of people in space (so that we could map their paths) and the succession of coordination devices. POSITION EVENTs are defined by the time the event occurred and to which agent the position corresponds. Similarly, COORDINATION EVENTs have a time and an agent but they are more complex since they have a coordination identificator and a type (in CatchBob: a refresh or a message). The COORDINATION ID is relevant to show how a coordination device can be constituted of several events. For example, an explicit agreement between two players is composed of a starting utterance followed by an acknowledgement.

As well, both POSITION or COORDINATION events are defined by a sub-element POSITION (that has x and y position coordinates). Finally, COORDINATION EVENTS also have a DEVICE sub-element that refers to the content and the pragmatic status of the coordination device employed by the player.

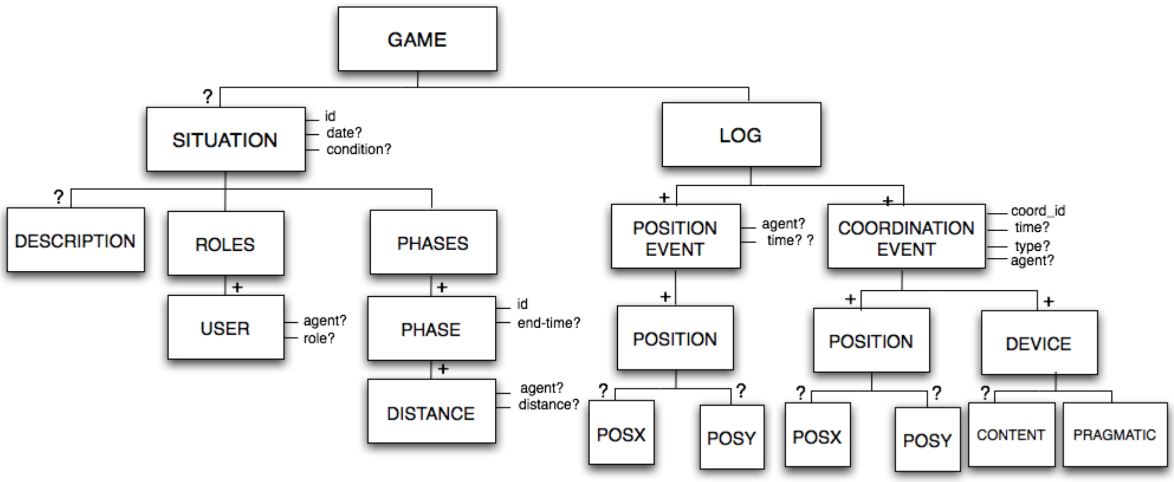


Figure 61. Scheme of XML logfile representation. It shows the structure for a logfile as defined in the XML Schema. The symbol "?" shows that the elements can be present 0 or 1 time. The symbol "1" corresponds to the fact that the elements can be present 1 or more times.

The figure below shows an XML extract of the corresponding logfile that illustrates how this DTD was applied to the beginning of a game.

```
<GAME>
  <SITUATION id=”3” date=”21-05-2006” condition=”mla”>
    <DESCRIPTION>Mobile</DESCRIPTION>
    <ROLES>
      <ROLE agent="A">caller</ROLE>
      <ROLE agent="B">follower</ROLE>
      <ROLE agent="C">explorer</ROLE>
    </ROLES>
    <PHASES>
      <PHASE end_time="0:4:47" id="1">
        <DISTANCE agent="A" dist="187.18132043627406"/>
        <DISTANCE agent="C" dist="447.2892660144392"/>
        <DISTANCE agent="B" dist="514.6006147226891"/>
      </PHASE>
      <PHASE end_time="0:7:45" id="2">
        <DISTANCE agent="A" dist="72.48812166617536"/>
        <DISTANCE agent="C" dist="428.2511274431928"/>
        <DISTANCE agent="B" dist="314.8837068002182"/>
      </PHASE>
      <PHASE end_time="00:16:02" id="3">
        <DISTANCE agent="A" dist="1219.986192151451"/>
        <DISTANCE agent="C" dist="763.5447157046046"/>
        <DISTANCE agent="B" dist="734.1557201812898"/>
      </PHASE>
    </PHASES>
  </SITUATION>
  <LOG>
    <COORDINATION_EVENT    coord_id="1"    agent=”B”    time="00:00:00"
type="refresh">
        <POSITION>
        <POSX>533068</POSX>
        <POSY>152496</POSY>
      </POSITION>
    </COORDINATION_EVENT>
    <COORDINATION_EVENT    coord_id="2"    agent=”C”    time="00:00:00"
type="message">
      <POSITION>
        <POSX>533054</POSX>
        <POSY>152504</POSY>
      </POSITION>
    <DEVICE>
        <PRAGMATIC>1</PRAGMATIC>
        <CONTENT>7</CONTENT>
      </DEVICE>
    </COORDINATION_EVENT>
    <POSITION_EVENT time="00:00:03" agent=”C”>
     <POSITION>
        <POSX>533054</POSX>
        <POSY>152504</POSY>
      </POSITION>
    </POSITION_EVENT>
...
  </LOG>
</GAME>
```


Figure 62. Excerpt of a XML file representing (1) the contextual information (2) the succession of events. This file corresponds to the visualization depicted on Figure 64.

7.3.4 A graphical grammar to express coordination

A Java application parses the XML files to generate a corresponding GIF file according to a **visual grammar** we describe below. Given our design choices, the data source structure we described and the description of what we aim at representing, we chose to take on a timeline approach with a line representing each player. We **drew some inspiration from the musical score**, which efficiently shows how certain types of events (described by characteristics such as their length or their note) are organized in time. Interestingly, some musicians have also extended the way one can write annotations by proposing “graphical musical notations” (Evarts, 1968). Figure 63 depicts two examples of such concepts that show the way connections between notes are revisited and displayed on the score**: notes can be used as a metaphor for our coordination devices**. In line with this metaphor, there is a correspondence between notes and coordination devices that could be positioned at a certain moment in time and possibly connected. Each player could also be mapped as a line of the score.

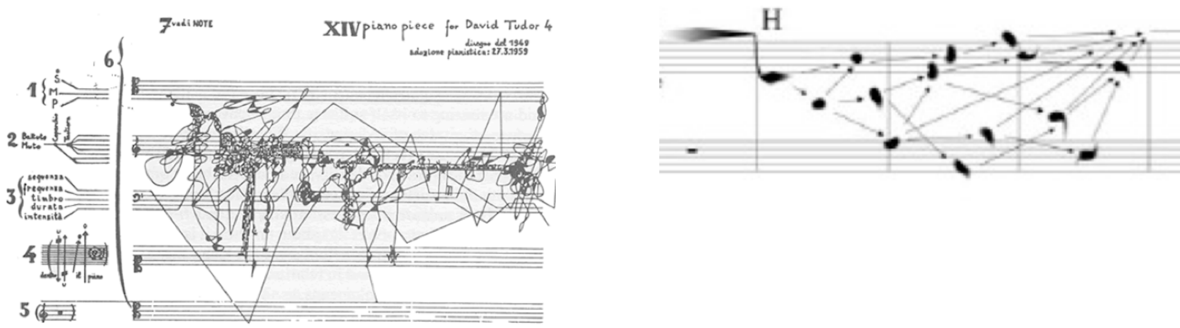


Figure 63. Two examples of graphical music notations (a) by Sylvano Bussoti (b) by Joe Malloch

This said, we aim at visualizing what has been described in Section 7.3.2 using these “graphical music notation” principles. Table 19 summarizes the correspondence between the data we want to represent and the elements from the visual representation.

Table 19. Summary of data we aim at visualizing.

What to visualize		**How to visualize**
Who did what		Each line represent a character
Duration of each phases		Two vertical lines sets the boundaries between the 3 phases
Exchange of coordination devices	Content	Represented as symbols
	Pragmatic	Represented as colors
	Dialogues: Link between coordination devices sent by players	Dashed line between coordination devices
Role of each player in phase 2		The “caller” is the central line. The line above and the one under represent the two other characters.
Division of labor (spatial dispersion of each character)		The y axis represents the distance from the character to the “caller”

As for the symbols that represent the coordination devices, we re-used the ones employed in the palette described in the previous chapter. They correspond to specific coordination devices as shown on Table 20. The color of each of these symbols depends upon the pragmatic of the coordination device: blue for announcements, green for questions, red for orders and violet for acknowledgements.

Table 20. Correspondence between the coordination devices and the symbols we used.

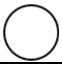
Visual representation	Coordination devices
S	Signal strength indication dropped where the player is located
	Indication of direction
	Indication of a patchy network area
	Indication of the area where 'Bob' might be located
	Drawing of the configuration of the triangle to be formed around 'Bob'
	Request for a face-to-face group meeting
	Message conveyed by drawings and annotations different than the symbols
	Use of the MLA tool: the user push the "refresh" button (to get others' location)

Figure 64 illustrates a representation that combines all these elements. It depicts a CatchBob! game played by three players who had a MLA tool and a planning phase.

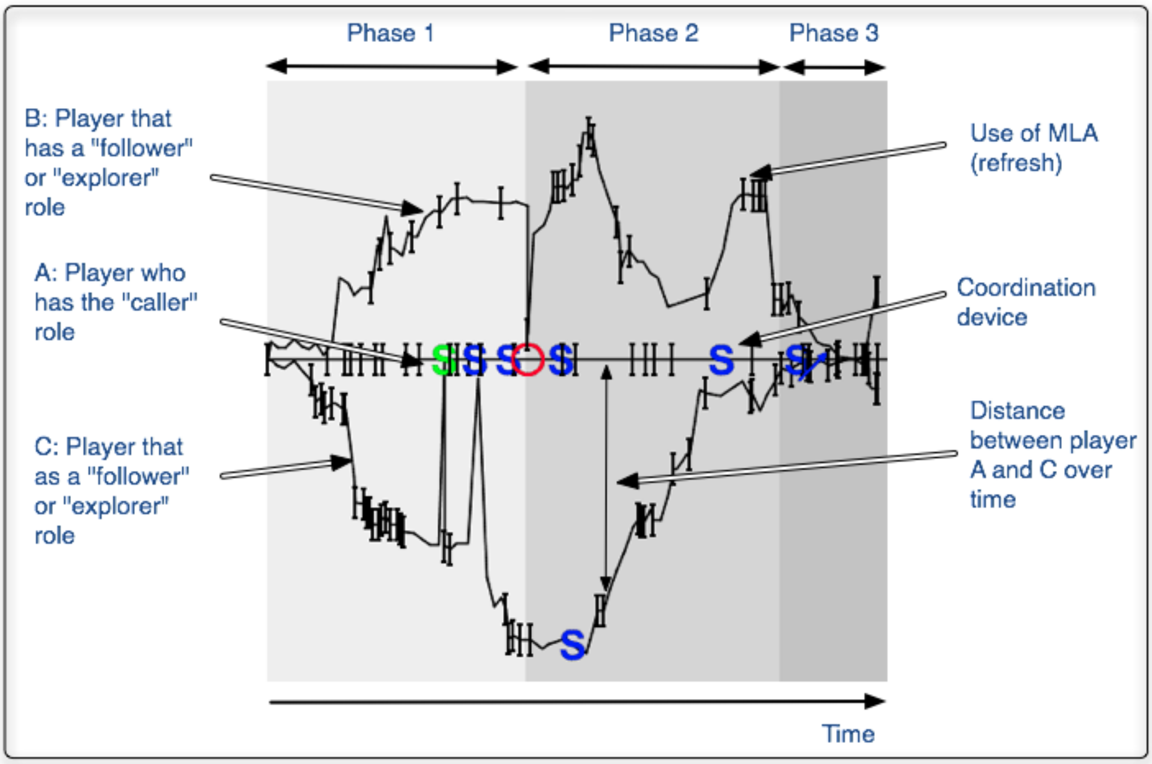


Figure 64. Example of visualization.

As we have already said, the horizontal central line corresponds to the "caller" player: the first one who sees where 'Bob' is and who calls his or her partner. The line above and the one under it represent the two other players without any specific code depending on their role (explorer or follower): the choice of putting one above and another below is therefore arbitrary. Since there can be only one caller, we chose to use this player as the reference on all the visualizations. A pertinent reason for this is that it allows comparisons between the different visualizations since there is an arbitrary order among the players; we thus avoid a random distribution of the players that would change the shapes of the visualizations. In addition, the three game phases are represented as three grey boxes and one can see which coordination device was deployed during which phase.

The interest of these visualizations lies in the comparisons it allows us to make between different groups who played the game. We can compare the coordination effort of groups depending on various factors such as the presence of the MLA tool, the absence of the plan or the accuracy of the mutual modeling within groups.

The comparisons we make will thus be based on the following topics:

- Game and phase duration: whether or not groups reached the end of the game in the same amount of time, or whether the duration of the phases were different.
- Communication: did players send the same number of messages? Were there differences in terms of the content or the pragmatic? Did they send more messages in a specific phase? Were there occurrences of dialogues or more elaborated coordination devices re-used over the course of action?
- Use of the MLA tool: did the players use the MLA tool? In what phase?
- Spatial behavior: was the spatial repartition in line with the Catchbob! activity: did the players spread to find 'Bob' then joined each other and spread again to form the triangle? Or were there more complex patterns of movements?
- Overall, the most pertinent usage of this visualization is to examine the dynamic of the process.

The next section exemplifies these comparisons by contrasting different CatchBob! groups.

7.3.5 Commented visualizations

As a first comparison, let us examine the influence of the MLA tool on groups who made a low number of mistakes when drawing their partners paths (MM+: accurate Mutual Model) and who had a planning phase before playing the game. We compare a group with MLA (MLA: experiment 1, group 6) and another without (Control: experiment 1, group 15).

The first thing one notices on the visualization shown in Figure 65 is that this Control group took more time to complete the CatchBob! game, especially in the last phase. The reason why it is slower comes from the last phase. They seem to have trouble forming the triangle: the curves depict 2-3 cycles of moving away and getting closer. Nevertheless, the player represented above the horizontal line representing the caller seems to have more trouble than the one below this line (her curve has more peaks). We can however see that one player performed used the refresh tool a lot: the caller, since she was waiting for the others and trying to track where they were to join her. Since the Control group did not have an MLA tool, there is no refresh represented on the screen and we cannot compare the two groups on this subject. Regarding the messages, the Control group sent more messages: there are more questions and more occurrences of dialogues. The main difference also lies in the third phase in which Control players tried to compensate for the lack of mutual location-awareness by writing more messages. In the two first phases, the content and the pragmatic status of the messages are quite similar and then in the third phases the situations are different.

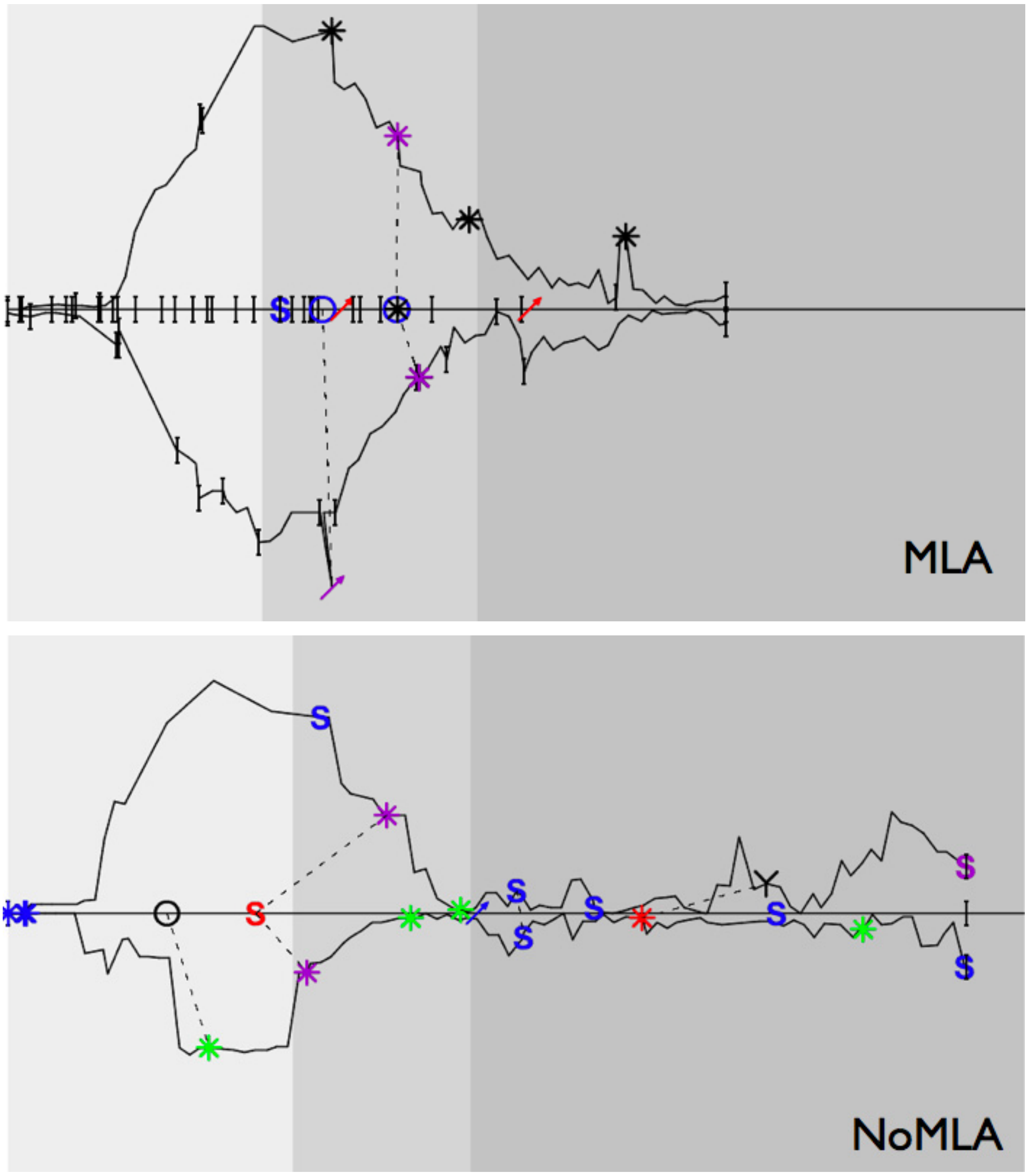


Figure 65. Confrontation of two visualizations of groups who had and accurate mutual model and a planning phase: (a) with a MLA, (b) without MLA (Control group).

One of the most striking features is the fact that Control players needed to communicate in this last phase; this was not the case of the players who had the MLA, we only see two messages sent by two players. Control players all had to share map annotations because even though they were close they did not manage to coordinate easily in completing the game. What is remarkable in Phase 3 is the link between the type of coordination devices exchanged and the difficulty in making the triangle. Players from the Control group indeed sent lots of messages about signal strength; till the end of the game, they had to send messages that indicated their proximity to Bob, which was definitely not the case for players with MLA. Looking at the moment during which these players were sending annotations is also intriguing: Control players seem to send messages only when they were close to each other (there are indeed no messages on peaks); this might be accounted for by the fact that the peaks correspond to moments when that they attempted triangle configuration, which did not fit and then immediately tried to refine it. Compared to the MLA group, the exchange of these map annotations was not as efficient as having the automatic MLA; this is also confirmed by the fact that they even had to set a face-to-face meeting (seen at the middle of phase 3) to refine their plans.

As we have seen in the first CatchBob! experiment, this visualization depicts the influence of the MLA tool: the inhibition of communication, fewer questions, fewer dialogues or a shorter third phase (during which the MLA tool made more sense).

Figure 65 concerned groups with or without MLA who made a low number of mistakes when drawing their partners' paths (MM+). Now let us have a look at players with the MLA and a good versus a bad modeling of their partners paths. We thus selected two groups with MLA that match these criteria: a group that made a low number of mistakes when drawing the partners' path (MM+: experiment 1, group 6) and a group that made a lot of mistakes (MM-: experiment 2, group 14). The resulting visualizations are represented in Figure 66. As we can see, the two groups performed the task in approximately the same amount of time, the only difference is that the MM+ group completed phase 2 more rapidly. The number of messages is very low in the two groups (they have the MLA tool, which explained this communication inhibition). However, the MM+ shows two occurrences of dialogue and acknowledgement whereas we do not see that for the MM-. We can also notice the communication asymmetry: there is indeed a silent player in the MM- group (the one above the horizontal line representing the caller) who never sent any message. Besides, most of the messages have been sent in the second phase, the one, which, lasted the longest. As for the use of the MLA, it is very interesting to see that MM+ players did almost no refresh in the last phase: their mutual modeling might be accurate enough so that they did not need to know where they were located. Most of the refreshes were also done by the caller player in the second phase, which makes sense since he called his two partners and waited for them to join him in forming the triangle. Finally, though the spatial behavior is similar in phase 1 and 3, MM- players seem to have trouble in phase 2: they move away from each other, get closer and one player moved away again. This shows that players from this MM- group had trouble joining each other before forming the triangle. We can consider this to be a miscoordination indicator.

Overall, based on the experiments results we discussed in the previous chapter, what this visualization seems to indicate is that an efficient exchange of coordination devices, with dialogues and acknowledgements, led to better mutual modeling within players of a group. When this does not occur, players may have trouble coordinating spatially, for instance, when trying to meet each other in the second phase.

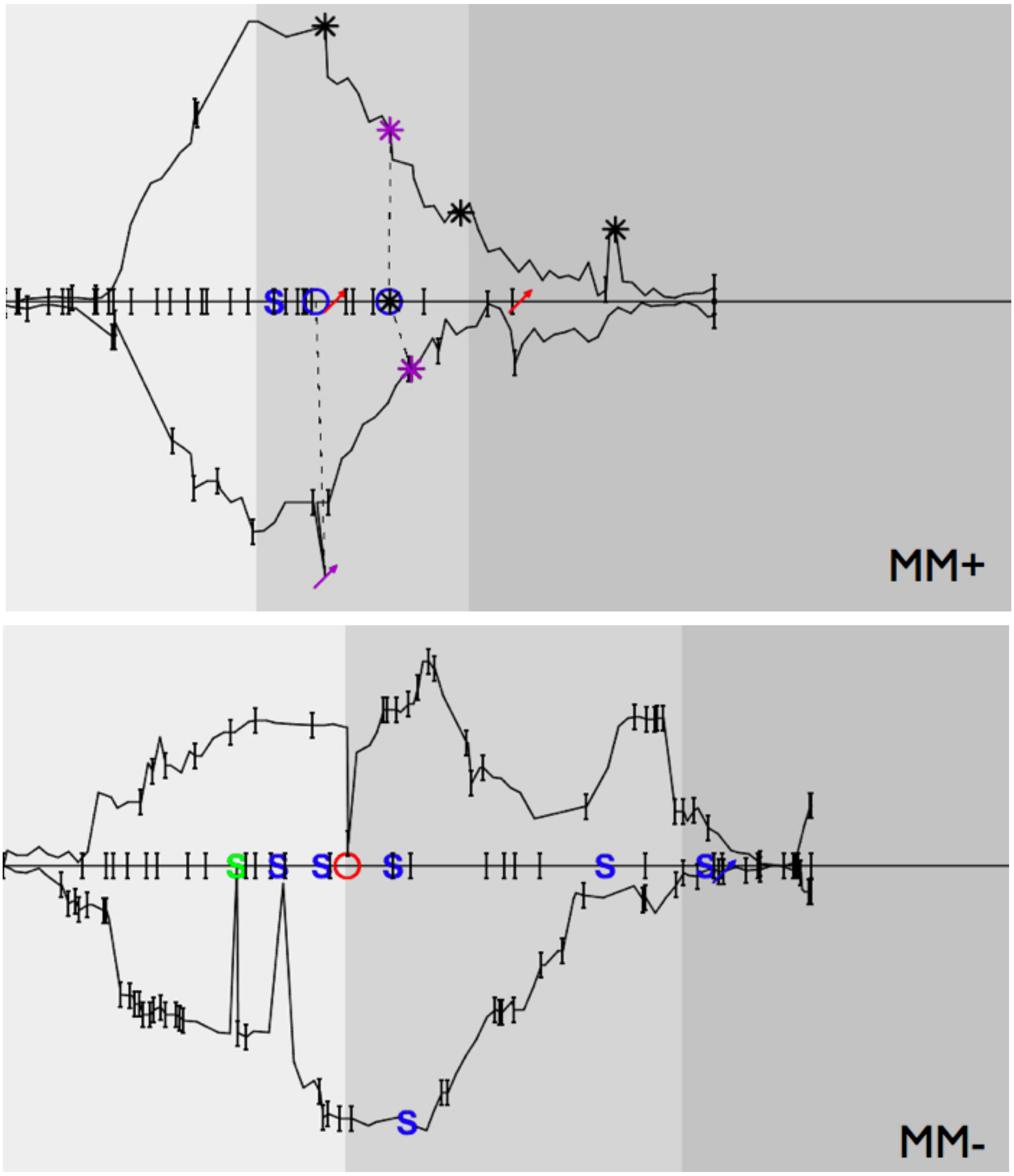


Figure 66. Confrontation of two visualizations of groups with MLA and a planning phase: (a) with a good mutual model, (b) with a bad mutual model.

Finally, we are also interested in what happened when we suppressed the plan. We compared groups that gave a MLA and accurate mutual modeling. We chose two groups: one with a planning phase (Plan: experiment 1, group 6) and one without it (NoPlan: experiment 2, group 5) as shown on Figure 67. The main difference concerns the duration of the game: it lasted longer for the NoPlan groups, especially in the first phase. In terms of the messages exchanged, the NoPlan players sent a lot more messages, not only because the first phase lasted longer but overall because they compensated for the lack of planning phase. There are more dialogues and use of coordination devices about Bob's position, direction and also more messages not conveyed by the symbols we proposed in the palette. This is logical since the palette has been designed with the coordination devices used by players who had the planning phase. Regarding the spatial behavior, the differences are also very prominent in the first phase: players have trouble finding a proper strategy to localize the object: they move away from each others, get closer, and move away again and this happens 2 or 3 times. The second and the third phase are more or less similar in the two visualizations in terms of messages, duration and spatial behavior. This last comparison attests to the importance of the plan, especially regarding what happens in the first phase of the game. From all the comparisons we performed, the suppression of the plan is the most detrimental to collaboration and eventually led to worse performance. Nonetheless, it shows that the inhibitive effect the MLA tool had on communication in our second study is not visible here because the suppression of the plan made the exchange of communication devices absolutely necessary as this compensated for the lack of plan.

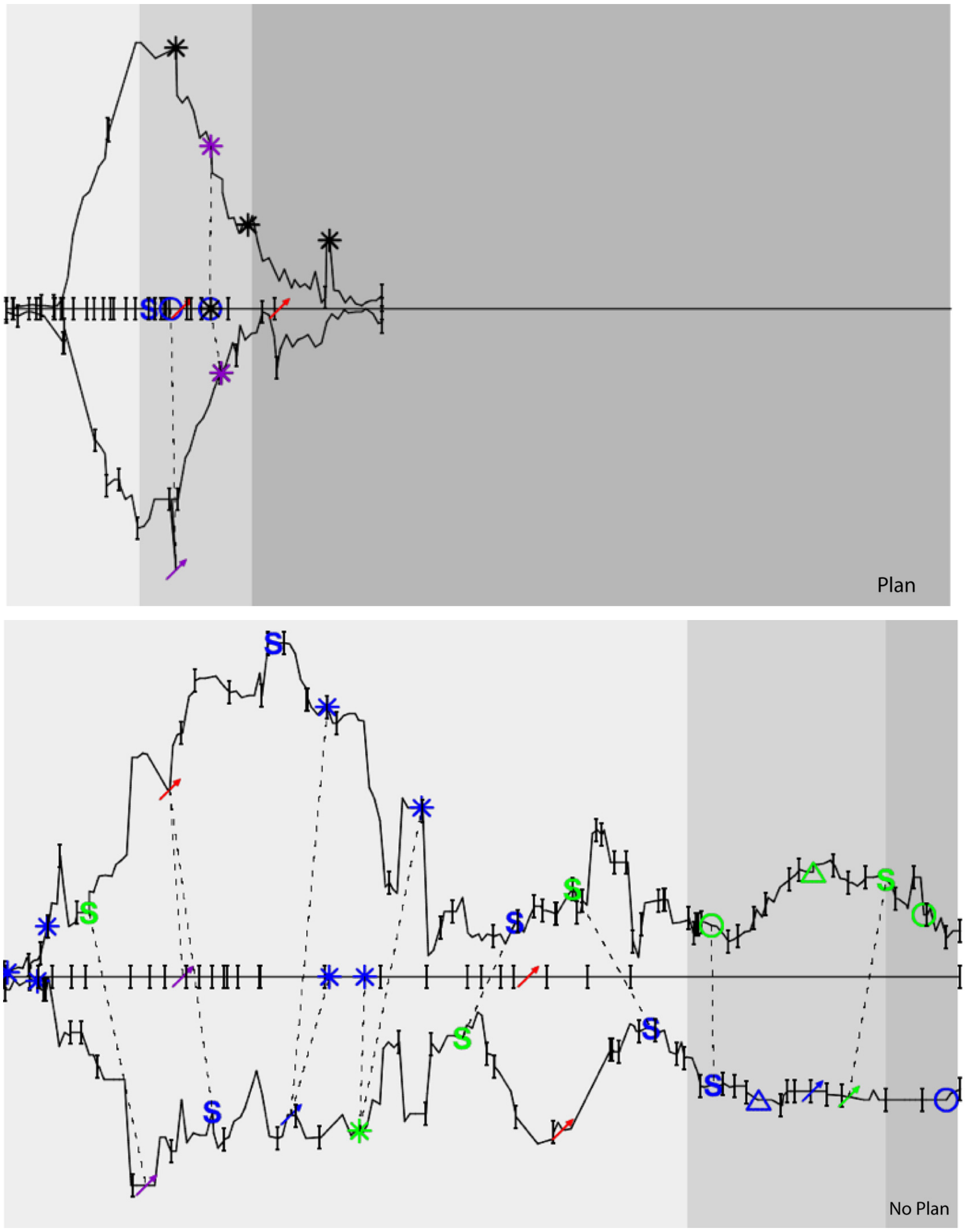


Figure 67. Confrontation of two visualizations of groups with MLA and a good mutual model: (a) with a planning phase, (b) without a planning phase.

7.4 Discussion

This chapter has described how we combined the different data sources from the CatchBob! experiment so that we can visualize coordination in a mobile context. To do so, we chose to go beyond a map representation and to integrate both logged and interpreted data to represent the exchange of coordination devices. This led us to define a data structure and a visual grammar that enabled us to generate these visualizations based on manual coding. The last section showed how we used these visualizations to depict mobile coordination and draw comparisons between groups from the different experimental conditions. They offered an interesting way to graphically illustrate the main conclusions of the two CatchBob! studies.

Visualizations are **of interest not only to researchers** and analysts but also to **the users** either after the game during interviews or during the activity itself. We can indeed think about real-time visualizations of the users' activities that would enable what Jermann et al. (2001) called **a "virtual mirror" of the group** to both evaluate users' contributions and to give the group a representation of itself over time. Of course, this does not mean that we should give those previous visualizations as such to the player; this might indeed be disruptive and complex. A simplified version of these visualizations should be designed with the idea of using the visual grammar and the data structure to give users an awareness of the group coordination. It could indeed allow users to see when they're close to each other and whether communication within the group is efficient or if there is left over player. This simplified visualization would eventually take the form of an awareness tool that would go beyond MLA because the awareness it can convey would be more integrated, structured and less easily replaced by communication. For example, each Catchbob! player could have the size of his or her avatar modified depending on the number of coordination devices that had been sent. A timeline interface could also depict a player's dispersion to the partners as well as the accumulation of coordination devices already sent.

Chapter 8 • General discussion

This final chapter summarizes the results, limits and contributions of this thesis and describes the potential implications for the design of collaborative applications.

8.1 Summary of the contribution

The contributions of this thesis to the field of CSCW focus on the influence of mutual awareness on collaboration and on the process of mutual modeling.

8.1.1 MLA and coordination

Our main hypothesis was that MLA – as a coordination device – may enrich the shared understanding of the group and consequently, facilitate the modeling of each others' intents, a process called 'mutual modeling'. We also hypothesized that enhancement of the mutual modeling by a MLA tool would also improve the collaborative task performance. This question was investigated through three controlled experiments and the design of visualizations to make these influences more explicit.

Qualitative analyses of **how MLA has been perceived and interpreted by players** showed how it could contribute to the common ground of the groups. Figure 68 describes **the five main uses players made of a MLA coordination device**.

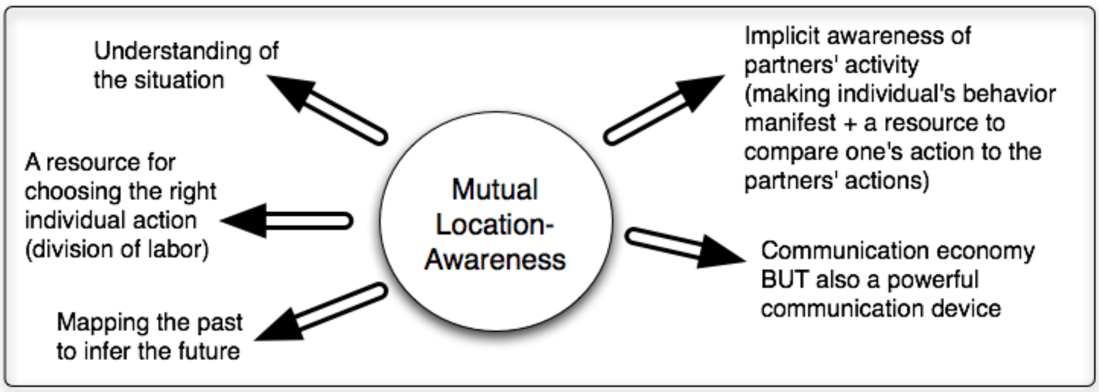


Figure 68. Roles of Mutual-Location Awareness in the three experiments.

The first use of MLA was to understand the situation and therefore to have a shared understanding. We observed a more elaborate role for MLA in that knowing others' whereabouts allowed participants to gain an implicit awareness of their partners' activities by making them manifest and comparable to previous actions. As a consequence, players made decisions about what they should do next based on the information supplied by this awareness tool: it was used a resource for division of labor in terms of choosing the next relevant course of actions for individuals involved in collaboration. Though MLA meant players communicated less about certain information because it was automatically conveyed by the tool (e.g. the location of others in the environment), the MLA was also a resource that fostered discussion within groups. The location of a player could indeed be used in a verbal interaction to acknowledge a partners' utterance or to give an order to a partner. And finally, asynchronous versions of the tools had an additional role since traces of past positions were important in drawing hypotheses about the future behavior of partners. This was of importance especially regarding directions because past traces enabled players to determine possible future trajectories. All those interpretations of MLA attest to its importance in performing the mutual modeling acts depicted on the figure.

However, though the range of inferences enabled by MLA is important, **the quantitative analyses of the three studies elucidates the positive influence of MLA on coordination**.

The first experiment in a virtual environment showed the importance of Mutual Location-Awareness in the coordination process. We found positive impacts of the tool on group performance but the results regarding the influence of MLA on the mutual modeling process are intricate. We only find the positive influence of the MLA on groups who effectively used the awareness tool. The results supported the idea that **the MLA tool can be beneficial to mutual modeling** if two conditions were met: (1) **if users properly understand its meaning and use**, (2) **if users mutually recognize this information in completing their joint action**.

The second experiment in physical space also supported the idea that in some situations the **MLA influence could be detrimental to collaboration in the presence of a rich synchronous communication medium**. Results of this experiment showed no differences in terms of task performance between groups who had the awareness tool and groups who did not have it. Moreover, the presence of the MLA tool proved to be detrimental to collaborative processes such as communication, division of labor and mutual modeling. The players without the MLA were indeed more verbose, especially regarding strategy planning during the task, which led them to better mutual modeling. As a matter of fact, this experiment highlighted an important characteristic of coordination devices such as MLA: their automation could be harmful to successful collaboration. The information about others' whereabouts indeed inhibited the exchange of other coordination devices and subsequently lead to a poorer common ground in the groups who had the MLA tool. This diminished the possibilities to perform mutual modeling acts. Furthermore, the presence of that information conveyed by the awareness tool substituted less pertinent information (others' locations) for more relevant information that players had to discuss (such as strategy changes for example).

The third experiment showed that suppressing the plan definition phase is more detrimental to completion of a joint task than removing the MLA interface. In this third experiment, players' performance was diminished when they had no planning phase because they had no opportunity to set up the local conventions of how to behave as a team. Nevertheless, the underwhelming effect of the MLA tool on communication disappeared: suppressing the most important coordination device (in the form of a plan) fostered more communication within the group.

In addition, our investigation of two kinds of MLA tools in the second experiment did not show any significant differences between synchronous and asynchronous location-awareness. However, this result is limited as we only did one experiment contrasting synchronous and synchronous location-awareness.

Overall, one of the main results of our research is that the manipulation of the availability of coordination devices can lead to important changes in collaboration processes. This was exemplified by the visualizations described in Chapter 7, which are tangible representations of the consequences arising from little changes such as adding a MLA interface or suppressing the plan.

8.1.2 The inter-dependence of Mutual Modeling

This contribution was not directly connected to the research question but it emerged from the studies we conducted. The first and the second studies indeed revealed a correlation between the models peers build about each other's behaviors and intentions. Simply stated, if team member A builds an accurate model of his or her partner B, partner B also tends to build an accurate model of A. The conclusion we draw at this point is that the activity of **modeling the partner is not reciprocal but mutual**. A reciprocal relationship means that modeling is mainly an individual activity where A infers a model M (A,B) from B's actions and utterances. A mutual relationship implies that M(A,B) and M(B,A) are jointly constructed through interactions. The term 'mutual' may mean that not only A builds M(A,B), but he also builds M(A, M (B,A)). We will not enter here into the extensive debate on the possibility of an infinite regress of nested models (discussed in Smith, 1982 or in Clark, 1996). Another interpretation is that team members actually build a model of the group-in-interaction, something like M (A, AB). We are not able to choose among different hypotheses at this stage, since the reported experiments were not designed for exploring these issues.

This correlation was observed in two different contexts: virtual space in study 1 versus real space in study 2 and groups of 2 in study 1 versus groups of 3 in study 2. Moreover, this correlation between how A model B and how model A was also observed using different methods: on-task in study 1 versus off-task in study 2, subjective validation (comparing A's model to B's answer) in study 1 versus objective validation in study 2 (comparing A's model with B's behavior). This diversity of settings consolidates our results but we still face serious methodological difficulties.

8.2 Limits of these studies and further work

While the three studies presented here provide a description of how a coordination device such as MLA affects coordination, they are subject to limitations. Overall, there are five main limits described hereafter. The question of generalization to other settings or populations must be considered in light of these limitations.

First, there might be **concerns with the type of collaboration settings** we deployed in those three studies. The two games we designed only immersed small groups of people in a decentralized collaboration activity. Unlike many other collaborative tasks, there was no formal and normative procedure to solve the joint problem. In some collaborative situations (firemen, army), coordination is more controlled because for some there is a control room or a central command group that receives information and then dispatch orders to field participants. This is often the case in collaborative situations that involve spatial activity. An additional way to constrain coordination devices is the development of very precise procedures that we could describe as conventions. A further limitation to the setting for collaboration that we developed is that tasks lasted a short amount of time and as a consequence only required synchronous coordination between peers. Additionally, it is important to state that the semantics of the two tasks proposed is quite simle. For example, in CatchBob!, the spatial nature of the game makes it very simple and based on spatial reasoning: it is therefore less possible to draw complex inferences between the environment (spatial layer) and the problem space. Finally, for the first game, a potential limitation arises from the task and the nature of the experimental studies. An experimental session held in a computer lab or in a quasi controlled physical environment is indeed not likely to represent a "real" experience and the computer games we designed for the manipulation was necessarily limited in scope. While this potential limitation exists in the second experiment, the interviews after CatchBob! revealed that participants believed they were participating and evaluating a real game. We would definitely benefit from the investigation of the same issues during a more ecological task such as firefighter missions or police investigations for instance. In these contexts, collaboration would be bound by complex inferences about the spatial environment based on people's norms and procedure as well as their socio-cultural background and a richer common ground would arise.

A second limit is **the sample of participants who participated**. The degree of familiarity of players within groups was vaguely controlled in the two experiments. In the first experiment, people did not know each other, whereas the contrary was true in the CatchBob! studies. Furthermore, in this game, we also controlled the fact that people knew the physical environment since they were all students of the school. Such a controlled sampling diminished the ecological validity of the task since in real settings the relationships between people are more mixed and the level of knowledge regarding the physical environment should also be more diverse. It would then be interesting to conduct field experiment with mixed groups who have different degrees of familiarity with each other and with the environment.

Thirdly, in these three experiments, **each group only played one game**, which might be an issue in terms of learning the different elements of the situation: the interface, the task and its rules. One possible response to see whether the results still hold over time is repeated play as described in Barkhuus et al. (2005) or a crossed experiment in which players from one condition play a second game in the other condition. We could then imagine making participants play multiple sessions of Spaceminers or CatchBob! with different intervals of times between the game sessions so that we could see how results hold over time.

The fourth main limit refers to the **methodological choices we made in order to understand mutual modeling and coordination**. In the first study, the measure of mutual modeling accuracy was made during the task and through a simple and subjective questionnaire. In the second and third studies, we used a different indicator, namely the number of mistakes made about the partners' spatial behavior. Both measures are different, which does not allow the comparison between the three experiments, and have shortcomings. Having mutual modeling measured during the game can be disruptive or can trigger a modeling process that could alter the natural modeling process. Evaluation of mutual modeling after the game may imply mnemonic and rationalization biases ; it can also make the researcher evaluate recall rather than in-task modeling. In other words, the abstract and unobservable characteristics of the mutual modeling process imply methodological challenges that call for indirect measures and assessment methods. Furthermore, mutual modeling in everyday life involves a large variety of mental states to be represented such as knowledge, behaviors, beliefs, desires, intentions, emotions, traits, attitudes, etc. Three of these mental states are particularly relevant in collaborative learning situations, namely inferences about partners' knowledge, behavior, goals (intentions). Study 1 focused essentially on inferences about partners' intentions by using an 'on-task' questionnaire. In Study 2 we investigated inferences about partners' behavior by using an 'after task' assessment method. We should use a more objective method to evaluate this variable. That is the reason why future work should be directed towards finding a solution to compare what player A says B is going to do with what B really does during the game. This solution might allow researchers to benefit from both approaches.

The final limit is our testing of awareness tools with pairs or triplets; in the context of multi-user systems with 4 to 50 users, the use of awareness tools should change. Paying attention to awareness cues left by 50 users would be more complicated and difficult than testing those left by groups of two or three, but more study regarding the use of awareness tools by large groups of people is needed.

8.3 Design implications

Although these experiments were semi-controlled studies that engaged participants in simple tasks, we believe that these results can have relevant consequences to the design of location-awareness tools for tasks requiring coordination. The issues described below remain at a high level of abstraction: we produced principles not recipes.

8.3.1 Thinking awareness as a systemic process

First and foremost, what these studies have shown is **that awareness should be thought as a global and systemic issue**. The awareness tools such as the ones we described in this thesis are not simple channels of information; **the information they convey are part of a system**. We have indeed seen that simple modification in the initial conditions can lead to tremendous changes in participants' behavior: the automation of MLA lowered the mutual modeling within groups, inhibited group communication and made users less active. This point is even more important given the fact that the theoretical framework in CSCW and psycholinguistics do not account for such phenomena: they highlighted the added value of awareness tools but consider less how awareness tools can reshape the exchange of other coordination devices.

This is related to the critical discourse about cognitive augmentation and so-called "cognitive prostheses". MacLuhan used to say that "*Any invention or technology is an extension or self-amputation*" (1964:45), which highlight how extending human capabilities through technology often undermines other skills. This phenomenon has also been discussed in the field of Human-Computer Interaction by researchers such as Woods (1997) who advocates against "*clumsy automation*", which is exactly what we observe here. Reducing the effort to perform an action to develop a competence or to be aware of others' activities is of course important but when this effort reduction is too pronounced, there is a less acute self-awareness in performing these activities.

Take-away #1: When designing an awareness tool that conveys location-awareness, designers should keep in mind that this type of tool should be closer to interfaces that allow communication than simply being an element present in the background. Even though the user cannot control an MLA tool (simply because its behavior depends on the partners' movements), it should not be designed as a simple background element. Moreover, since its presence might affect the exchange of coordination devices, the communication interface should be designed in conjunction with the awareness tool development. For example, it could be relevant that the communication interface engages users in a discussion related to the location-awareness tool.

8.3.2 Awareness Tool presence does not mean it will be used

The results from our first study showed that the availability of a coordination device such as the MLA tool did not lead all the participants to use it. Several users did not really notice the potential of this tool and thus did not benefit from it.

Designers should not take for granted that users will systematically employ an AT simply because it is available. In addition, noticing the benefits of the awareness tools is not obvious per se since the users have first to understand the task to be performed and which kind of tool could support a) the task performance and b) the coordination process. Therefore awareness tool design should take this into account through the clarification of how it is related to the task and the collaborative processes required to complete the task.

Take-away #2: Designers should make either teach users or make explicit the added value of an awareness tool that would convey mutual location-awareness. They should show the tool's importance to the task performance as well as to coordination. A possible way to do it is to give the awareness tool a peculiar type of interface, different from the other elements.

8.3.3 Self-disclosure versus automation

A third design issue with regards to awareness is certainly **the trade-off between automation and human agency** (i.e. the capability of an individual to decide whether or not to act). In the CatchBob! experiment we saw the **difference between self-positioning and having a MLA interface**. In the first CatchBob! study, we found that automatically giving the location-awareness information to participants was not always fruitful in terms of collaborative interactions. It was better with regards to the modeling of the partners' intentions to let users express what they estimated to be relevant through a broader channel of communication: the map annotations. The players with the awareness tool were able to annotate as well but did not use this opportunity. Letting people build their own representation of the spatial information appears to be more efficient than broadcasting mere location information. To some extent, not giving location-awareness information was a way to support collaboration more effectively; since players communicated more and better explained their activity and intents, which led interestingly to the reshaping of their strategy.

This fact is of particular importance because it shows the difference between automatic positioning in which location is just information versus self-declared positioning, which is both information and an act of communication act, intentional by definition. Both are coordination devices in Clark's sense but the self-disclosure seems to better facilitate the construction of the common ground. The reason for this is due to the important difference between self-disclosure, which convey intentionality, and automatic awareness that is purely informational. This distinction corresponds to the one made by Malle (2003) between "observability" and "intentionality" as two dimensions that frame people's understanding of their partners' behavior. We can then complement Clark's definition of coordination devices with this distinction between purely observable events that occurred in the environments and events that express the intentionality of the person who produced them. The awareness tools makes things observable but since they are automated, the receiver cannot detect any intentionality (unlike self-disclosure of one's location). As a conclusion we can thus state that our second study showed that the intentional coordination devices are more important to collaboration than those that are automated. This also has interesting consequences for Computer Supported Collaborative Learning. These results are close to what socio-constructivist theories (Brown et al., 1989) value in an educational context (i.e. elaborated explanations, self-regulation, strategies explicitations). In particular, there seems to be two **advantages in not providing collaborative mobile users with a location-awareness tool**:

- To facilitate knowledge elicitation: Without the automatic location-awareness, subjects were more articulate about their strategy. It seems that the tool created a certain inertia within the group, with regards to communication. Participants who relied on the automatic positioning wrote fewer messages, which led them to be less explicit about the situation and how they could deal with it.
- To ease conflict solving though a better explanation of what players wanted to do or achieve in order to progress in the task completion. Being more verbose raised more conflicts, which is good for learning as stated by Doise and Mugny (1984).

Another advantage for self-disclosing one's location is that it allows people to employ the location names that make sense for the participants. This is related to the distinction between 'space' and 'place' (Harrison and Dourish, 1996). The difficulty of location-based applications in conveying a meaningful semantic of places makes it more efficient to let users express their location by using their own description, a topic already discussed by Persson and Fagerberg (2002).

This finding, that it is better to let people express their own location, is confirmed by what Benford et al. (2005) revealed: self-reported positioning could be reliable low-tech alternative to automated systems like GPS. However, our findings go further by proving that letting users declare their position themselves is better with regards to various processes like communication or the construction of a mental model about the partners.

However, there are **two disadvantages to self disclosure of location**. A potential critique is that putting too much emphasis on self-location makes it more vulnerable to connectivity and lag problems. As a matter of fact, packet loss containing automatic location information with a timestamp (automatic location-awareness) is less prejudicial than losing free-hand annotations or voice interactions because an automated broadcast of information is expected and we know there is something wrong if it does not come. Another drawback is the additional workload that is created by such an approach since users would have to send explicit information. Further, scholars have reported how people are very poor at remembering to update system representations of their own state (Bellotti and Edwards, 2001). Nevertheless, given that in our case the participants do not only update a system but also intentionally give information to other people one can imagine that this drawback will be diminished.

A second major consideration is of course the context of the activity. Let us transfer it from the Catchbob! game to a real-world situation. If we had two groups of airplanes in flight, one with radar and one without, the planes without radar would certainly spend a lot more time communicating with one another to check on their mutual locations. The new fangled airplanes that had adopted radar would lack the mutual awareness that the non-radar group had. The issue, in other words is that it matters a great deal what Catchbob's equivalents are in actual distributed workplaces and what sorts of work mutual awareness tools are supporting or disrupting. The number of collaborators and the level of decentralization is certainly of importance. For some workplaces letting the user declare where they are is fine but for something like air traffic control or the navigation of shipping lanes it is not a practical possibility.

Take-away #3: Given these elements, the future of location-awareness applications might go beyond the opposition between self-disclosure of one's location or automating MLA and lie in the **combination of both**. Figure 69 depicts two possible ways of combining them in CatchBob! depending on which interface we want to improve. If we take the current synchronous MLA interface of CatchBob! (Figure 69a), that displays the partners' location as dots; it would be interesting to add a circle around these dots when a player explicitly give his or her location. This way, the intentional part of the message about position is conveyed. If we use an interface without MLA (Figure 69b), it is possible to add the location of a player to the map only when the player sends a message. This might then help clarify the annotation written by the player: supplying this location can potentially narrow the shared context of the users.

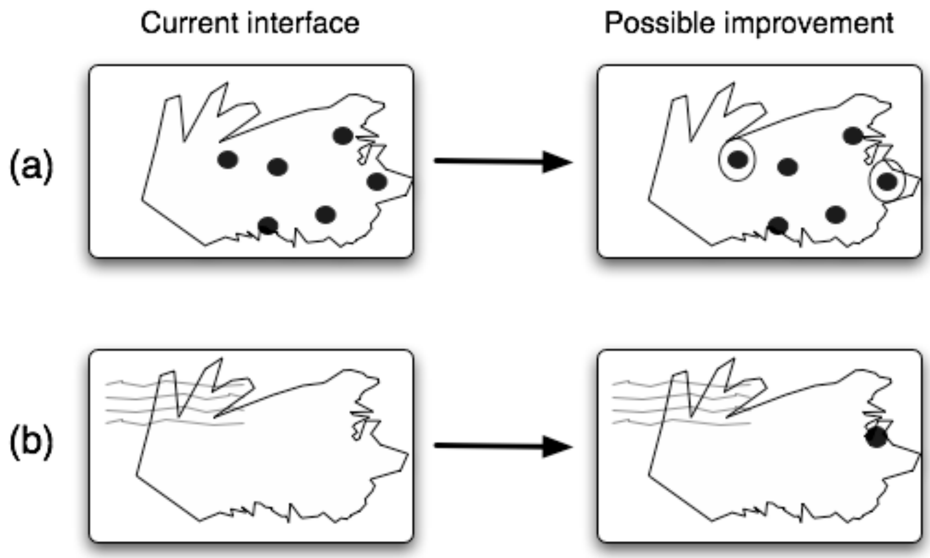


Figure 69. Two possible ways of improving a MLA interface: (a) starting from the current MLA interface that automatically displays the location of others and by putting a circle around the position of a person when he/she communicates it (b) starting from the control condition without MLA and displaying the partner's position when he/she write a message on the display.

8.3.4 An optimal collaborative effort

The final issue raised by the studies we carried out is the notion of "optimal collaborative effort" that would apply to MLA but also all other awareness tools.

The advantages and drawbacks of self-disclosing information about one's state (be it a position or something else) we have described in the previous section can be considered in regards to the effort individuals put into contributing to a joint activity. We can thus describe this with the notion of 'cost'. We have already used it in the third chapter with the idea of "least collaborative effort" developed by Clark and Brennan (1991): the fact that people tend to produce messages, signs and cues by expending the least effort so that the partners can also understand them with the least effort.

We can therefore **describe awareness tools as artifacts that manage the global effort of coordination**. As represented on Figure 70, the two lines represent the effort expended over time depending on whether there is an awareness tool (that conveys MLA in this example) or when people self-disclose their own location. This figure shows that collaboration is efficient when participants are involved in an optimal collaborative effort. Depending on the task, the awareness tool can reduce this effort. For example, in CatchBob, forming the triangle was more efficient with the MLA tool. But below a certain effort threshold, the MLA also had the opposite effect. This is what happened in the two first phases of Catchbob: self-disclosure using written annotations was more efficient than the MLA because it allowed players to communicate more information than simply location. In this case, the awareness tool had underwhelming effects because it inhibited other efforts such as exchanging other coordination devices. In other cases, It is also possible for the awareness tool to overload the players. This might happen in activities that engage a very large number of participants, when too much information is represented about their activity; the effort to perceive and understand the information is then too great.

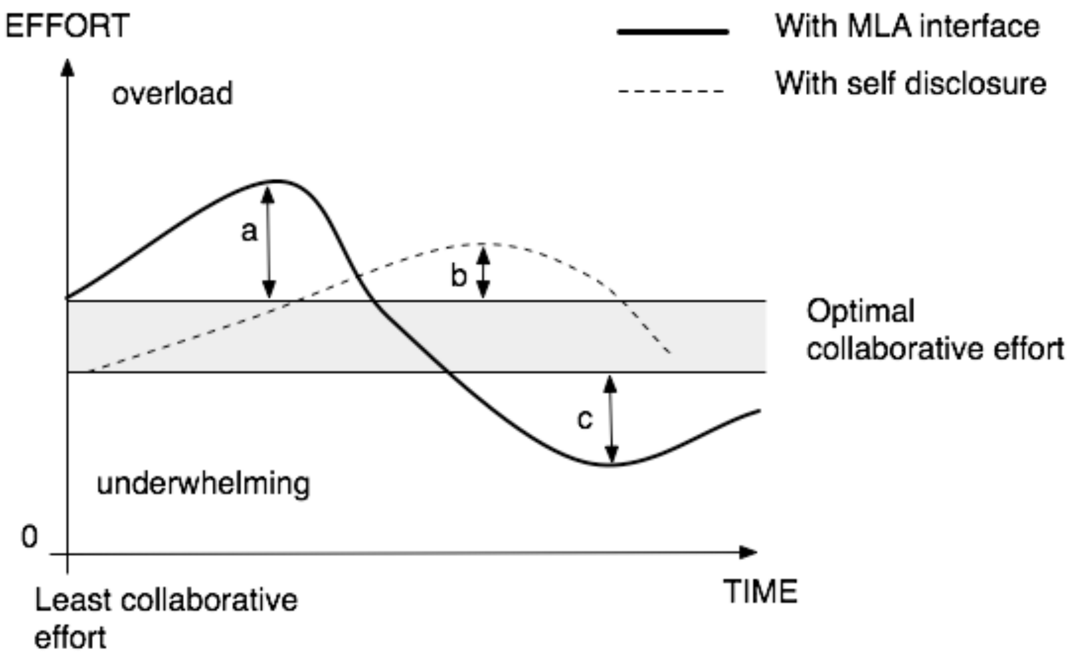


Figure 70. The different kinds of effort fostered by self-disclosure or automatic awareness over time. The two lines show different efforts since tasks can evolve over the course of action and hence require different types of effort. The “a, b and c” arrows depicts the difference between the effort due to the interface and the optimal collaborative effort.

As discussed by Dillenbourg and Traum (2006), the minimal cost is not always the optimal cost for collaborative learning. What our experiment showed is that the reduction of the collaboration cost, through the introduction of an awareness tool like the MLA interfaces, was indeed not always optimal.

Furthermore, this “**optimal collaborative zone**” that we describe **reflects two efforts** depending on who is considered:

- The **producer of a coordination device** provides the partners with elements that he or she thinks are relevant with regards to the situation and the common ground of the group. For this player, the cost is lower when there is an awareness tool because he or she does not have to produce coordination devices.
- The **addressee(s) perceives those coordination devices**, integrates them in their common ground and potentially performs mutual modeling acts based on them. For an addressee, it is preferable to have punctual and intentional coordination devices, and not a continuous broadcast of information. This is because the intentional messages have more weight in the common ground; they indeed convey the implicit cue that they have been sent out because they would help the partner(s) to have mutual expectations.

With intentional acts of communication, one can also say that the producer has assessed the importance of the information and that this lowers the effort for the addressee. The optimal collaborative effort then reflects the **effort asymmetry between the producer and the addressee**. What this thesis proves is that the intentionality of the coordination devices sent by the producers is more relevant than information from automated devices. They are more efficient from a collaborative standpoint because they facilitate the recognition of pertinent information versus noise.

Take-away #4: Designers should not aim for the maximum reduction of the collaborative effort. The challenge is to provide producers with an interface that decreases the effort of sending a coordination device but that lets addressees give the right weight to this information. For that matter, a timely exchange of coordination devices is better than a continuous one. For instance, in CatchBob, it is better to give a partners' location when he/she undertakes a specific action (like sending a message) than continuously broadcasting it. This way, it reduces the noise caused by the permanent positioning of others.

8.3.5 Concluding remarks

In sum, the key conclusion of this thesis is that coordination is a multiform process, in which multiple coordination devices are exchanged. Throughout our work, we have shown how mutual location-awareness is a specific type of coordination device and that its manipulation can lead to unexpected changes in group cognitive processes such as communication and mutual modeling. We therefore encourage designers to perceive awareness as a component of coordination and not forget that automating the broadcast of such information is not trivial.

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Appendix 1 • Study 1 data

The table below summarizes the main quantitative data we used for the statistical analysis of the Spaceminer experiment.

cond	score	camviewA	camviewB	camview	shipviewA	shipviewB	mmoab	mmoba	mmo1	mmo2	mmo3	mmog
MLA	127	5495.36	5568.23	11063.59	1837.76	1807.92	1.67	1.33	2.5	1	1	1.5
MLA	130	4162.14	4597.38	8759.52	1676.88	1246.88	1	1	1	1	1	1
MLA	169	4509.51	5642.79	10152.3	2758.03	1441.73	2	1.67	2	1.5	2	1.83
MLA	290	4960.32	5020.85	9981.17	721.51	983.57	1	1.33	2	1	0.5	1.17
MLA	293	5024.97	4962.86	9987.83	1491.6	1411.05	2.33	1	0	2	3	1.67
MLA	304	4440.3	5307.5	9747.8	2592.02	1746.83	1.33	1.33	1	1.5	1.5	1.33
MLA	322	5177.35	5275.13	10452.48	2090.71	1196.21	2.33	1.33	2	0.5	3	1.83
MLA	333	4602.34	5274.89	9877.23	1813.65	1071.72	2	3.33	1.5	3.5	3	2.67
MLA	360	4942.16	5800.26	10742.42	2399.95	1730.09	1.67	1.67	0	1.5	3.5	1.67
Control	51	4482.25	4664.01	9146.26	3400.05	3150.83	1	0.67	1	0	1.5	0.83
Control	84	2712.9	2563.88	5276.78	1109.31	1225.48	1	0.67	1.5	0	1	0.83
Control	152	3275.18	3511.1	6786.28	1164.37	822.71	2	0.33	1	1	1.5	1.17
Control	183	1688.3	1841.08	3529.38	5445.26	5350.9	2.33	2	0	2.5	4	2.17
Control	198	5611.43	6076.23	11687.66	1729.02	1337.07	1.33	1.33	1	2	1	1.33
Control	213	3582.17	4020.62	7602.79	2014.14	1512.72	0	2.5	1.5	0.5	0.5	1.25
Control	232	5003.02	4642.84	9645.86	1763.88	2097.97	3	3.33	3	3	3.5	3.17
Control	233	4094.47	4154.70	8249.17	2371.32	2252.92	2.67	2.67	2	3.5	2.5	2.67
Control	235	1509.83	1348.40	2858.23	1426.90	1404.18	1	0.67	1	0.5	1	0.83

Appendix 2 • Campus space

The campus is made of three levels: the first one is the road level that leads to facilities and delivery points. The second and the third correspond to the main accesses and entrances to labs, auditoriums and rooms. Most of the action in CatchBob happened on the second level, which was also the one where the objects were located. Players also started from the second level.

This picture shows an example of the stairways to navigate between the 3 levels.

This picture represents one of the main corridors that can be found on level 2.

Appendix 3 • Study 2 data

The tables below summarize the main quantitative data we used for the statistical analysis of the first CatchBob! experiment for the three experimental conditions. The data corresponds to the measures for each individual.

Condition	Time	Path Length	Number of errors	Role in phase 2	Messages frequency	Position message frequency	Direction message frequency	Strategy message frequency
Asynchronous	1320	2220.88	5	explorer	0.50	0.05	0.14	0.14
Asynchronous	1320	1695.25	5	explorer	0.36	0.00	0.09	0.00
Asynchronous	1320	1706.33	13	caller	0.55	0.00	0.00	0.09
Asynchronous	540	963.95	2	caller	0.89	0.22	0.00	0.11
Asynchronous	540	1096.57	0	follower	0.56	0.11	0.22	0.00
Asynchronous	540	986.24	0	follower	0.44	0.00	0.22	0.11
Asynchronous	600	1385.71	1	caller	0.40	0.00	0.10	0.00
Asynchronous	600	1239.11	2	follower	0.10	0.00	0.10	0.00
Asynchronous	600	1153.30	0	follower	0.10	0.00	0.00	0.00
Asynchronous	660	1261.56	9	explorer	0.18	0.00	0.00	0.00
Asynchronous	660	1813.25	4	caller	0.64	0.00	0.09	0.09
Asynchronous	660	1653.51	3	follower	0.18	0.00	0.00	0.00
Asynchronous	900	1774.82	1	follower	0.07	0.00	0.07	0.00
Asynchronous	900	1291.57	4	caller	0.07	0.00	0.00	0.00
Asynchronous	900	1827.70	0	follower	0.47	0.00	0.20	0.07
Asynchronous	1200	2243.14	7	follower	0.20	0.00	0.05	0.05
Asynchronous	1200	2577.95	6	follower	0.15	0.00	0.00	0.00
Asynchronous	1200	2112.81	5	caller	0.15	0.05	0.10	0.00
Asynchronous	1380	2577.95	7	caller	0.39	0.00	0.00	0.04
Asynchronous	1380	2713.58	4	follower	0.35	0.00	0.04	0.04
Asynchronous	1380	2112.81	2	follower	0.22	0.00	0.00	0.04
Asynchronous	1140	1785.52	3	caller	0.16	0.00	0.00	0.00
Asynchronous	1140	1648.28	1	explorer	0.26	0.00	0.05	0.05
Asynchronous	1140	2256.39	5	follower	0.21	0.00	0.05	0.00
Asynchronous	960	2256.39	8	follower	0.69	0.19	0.31	0.06
Asynchronous	960	1351.33	4	follower	0.31	0.13	0.13	0.00
Asynchronous	960	1018.72	5	caller	0.31	0.13	0.06	0.00

Condition	Time	Path Length	Number of errors	Role in phase 2	Messages frequency	Position message frequency	Direction message frequency	Strategy message frequency
Synchronous	783	1238.31	3	caller	0.61	0.38	0.00	0.15
Synchronous	783	1924.49	0	follower	0.15	0.15	0.00	0.00
Synchronous	783	2562.79	2	follower	0.46	0.23	0.00	0.15
Synchronous	778	1035.05	0	caller	0.46	0.15	0.00	0.31
Synchronous	778	1192.62	3	follower	0.15	0.00	0.00	0.00
Synchronous	778	1919.56	1	follower	0.15	0.00	0.00	0.00
Synchronous	1440	2531.53	4	explorer	0.08	0.04	0.00	0.04
Synchronous	1440	2560.69	7	caller	0.29	0.08	0.08	0.04
Synchronous	1440	3714.09	2	explorer	0.13	0.00	0.08	0.00
Synchronous	721	1336.03	5	explorer	0.08	0.00	0.00	0.00
Synchronous	721	1128.67	3	caller	0.33	0.00	0.00	0.00
Synchronous	721	1346.96	4	follower	0.17	0.00	0.00	0.00
Synchronous	876	1713.92	8	caller	0.75	0.07	0.21	0.21
Synchronous	876	1138.25	7	follower	0.34	0.00	0.14	0.00
Synchronous	876	1803.29	6	follower	0.27	0.00	0.07	0.07
Synchronous	721	1390.46	0	follower	0.42	0.00	0.08	0.17
Synchronous	721	1309.42	3	caller	0.33	0.08	0.08	0.17
Synchronous	721	1201.12	4	follower	0.17	0.00	0.00	0.00
Synchronous	1078	1713.92	6	caller	0.39	0.33	0.00	0.00
Synchronous	1078	2160.07	11	follower	0.28	0.28	0.00	0.00
Synchronous	1078	1544.23	8	follower	0.39	0.39	0.00	0.00
Synchronous	992	1969.08	2	caller	0.42	0.12	0.00	0.06
Synchronous	992	1627.29	5	explorer	0.18	0.06	0.00	0.00
Synchronous	992	2256.54	1	explorer	0.24	0.06	0.06	0.06
Synchronous	573	1475.91	2	follower	0.42	0.10	0.10	0.31
Synchronous	573	747.10	2	caller	0.42	0.10	0.00	0.10
Synchronous	573	1104.23	0	follower	0.21	0.00	0.10	0.00
Synchronous	884	2009.37	1	follower	0.48	0.00	0.00	0.07
Synchronous	884	1477.76	5	follower	0.20	0.00	0.00	0.07
Synchronous	884	1478.52	1	caller	0.48	0.00	0.00	0.14

Condition	Time	Path Length	Number of errors	Role in phase 2	Messages frequency	Position message frequency	Direction message frequency	Strategy message frequency
Control	1245	3130.04	4	explorer	0.39	0.24	0.10	0.05
Control	1245	1749.51	2	follower	0.48	0.34	0.24	0.14
Control	1245	1327.47	5	caller	0.82	0.48	0.19	0.00
Control	1073	2182.18	2	follower	0.34	0.00	0.00	0.17
Control	1073	1748.38	0	explorer	0.62	0.11	0.06	0.28
Control	1073	1318.66	0	caller	0.45	0.28	0.06	0.11
Control	1700	3191.41	0	follower	0.11	0.07	0.00	0.00
Control	1700	1525.35	4	caller	0.49	0.28	0.00	0.07
Control	1700	2891.14	0	explorer	0.32	0.07	0.11	0.21
Control	1218	1977.10	2	follower	0.69	0.34	0.00	0.15
Control	1218	2023.21	0	follower	0.30	0.10	0.05	0.15
Control	1218	1753.26	0	caller	0.39	0.15	0.00	0.10
Control	929	1868.27	6	caller	0.52	0.32	0.06	0.00
Control	929	1608.32	3	explorer	0.65	0.32	0.19	0.13
Control	929	1923.45	1	explorer	0.52	0.26	0.19	0.13
Control	540	595.91	3	explorer	0.11	0.11	0.11	0.00
Control	540	1007.54	0	caller	0.78	0.56	0.00	0.22
Control	540	1144.37	0	follower	0.44	0.11	0.00	0.22
Control	854	1648.37	2	follower	0.63	0.42	0.28	0.14
Control	854	2137.30	5	caller	0.35	0.21	0.00	0.00
Control	854	995.17	12	explorer	0.28	0.21	0.00	0.00
Control	1010	1824.91	3	caller	0.30	0.30	0.06	0.00
Control	1010	1740.80	0	follower	0.95	0.42	0.12	0.36
Control	1010	1436.00	0	explorer	0.65	0.00	0.18	0.30
Control	638	283.62	0	explorer	0.28	0.09	0.00	0.19
Control	638	1035.85	0	caller	0.47	0.09	0.19	0.19
Control	638	482.70	0	explorer	0.47	0.00	0.09	0.28
Control	686	1104.51	1	follower	0.61	0.26	0.00	0.44
Control	686	1520.04	1	follower	0.44	0.26	0.09	0.17
Control	686	1410.44	1	caller	0.70	0.26	0.26	0.35

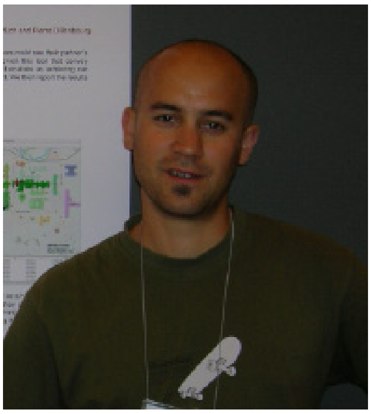
Appendix 4 • Study 3 data

The tables below summarize the main quantitative data we used for the statistical analysis of the second CatchBob! experiment for the two experimental conditions. The data corresponds to the measures for each individual.

Condition	Time	Path length	Number of errors	Role	Frequency of messages	Frequency of position messages	Frequency of direction messages	Frequency of strategy messages
Control	1140	2316.50349	14	follower	0.00526316	0.00087719	0	0.00263158
Control	1140	2662.32959	17	caller	0.00526316	0.00087719	0.00087719	0.00072464
Control	1140	1852.54339	20	explorer	0.00438597	0.00175439	0.00087719	0
Control	1320	1226.87126	26	caller	0.00227273	0	0.00075758	0.00070423
Control	1320	2082.20751	11	explorer	0.00378788	0	0.00151515	0
Control	1320	1623.96732	12	follower	0.00530303	0	0.00227273	0.00140845
Control	1020	2775.64978	6	explorer	0.00686275	0.00098039	0.00098039	0.00081433
Control	1020	2828.65444	8	caller	0.00980392	0.00098039	0.00098039	0.00162866
Control	1020	2161.55669	5	explorer	0.00784314	0	0.00098039	0.00081433
Control	900	1622.88632	5	follower	0.00555556	0	0	0
Control	900	533.645808	7	caller	0.00777778	0	0	0.00286123
Control	900	1624.22718	0	follower	0.00333333	0	0.00111111	0
Control	1800	3280.64576	16	caller	0.00555556	0	0	0.00055556
Control	1800	3374.27552	18	explorer	0.00888889	0.00166667	0	0.00055556
Control	1800	1521.62272	14	explorer	0.00444444	0	0.00111111	0.00055556
Control	1080	2753.85529	11	follower	0.00925926	0	0.00185185	0.00416667
Control	1080	2138.82385	21	caller	0.01203704	0	0.00185185	0.0025
Control	1080	2177.50844	14	follower	0.00740741	0	0.0037037	0.00083333
Control	1200	2546.22268	11	explorer	0.00166667	0	0	0.00076864
Control	1200	3228.9354	14	caller	0.005	0	0.00083333	0.00153728
Control	1200	2338.41391	9	explorer	0.0025	0	0.00083333	0.00153728
Control	1800	2849.98773	18	explorer	0.00277778	0	0.00166667	0
Control	1800	3307.91369	17	caller	0.00944444	0.00055556	0.00166667	0.00277778
Control	1800	2818.86703	17	explorer	0.01388889	0	0.00055556	0.00444444
Control	960	1873.95606	4	follower	0.00520833	0	0.00104167	0.00080321
Control	960	2732.60192	2	explorer	0.00520833	0	0.003125	0.00080321
Control	960	1399.6387	6	caller	0.009375	0.00104167	0	0.00401606
Control	900	1321.31843	4	caller	0.00444444	0	0.00111111	0.00220022
Control	900	1383.65611	6	follower	0.00333333	0	0	0.00110011
Control	900	1404.82001	6	follower	0.00333333	0	0.00333333	0

Condition	Time	Path length	Number of errors	Role	Frequency of messages	Frequency of position messages	Frequency of direction messages	Frequency of strategy messages
Plan	540	1160.67395	3	explorer	0.00185185	0	0	0.00157729
Plan	540	1246.38337	2	caller	0.00925926	0	0	0.00473186
Plan	540	1494.5935	7	follower	0.0037037	0	0	0
Plan	1560	1639.01916	4	follower	0.00512821	0.00064103	0	0.00185414
Plan	1560	2329.52412	4	caller	0.0025641	0	0.00064103	0.00123609
Plan	1560	2355.72398	5	explorer	0.00448718	0	0.00064103	0.00185414
Plan	900	1415.12039	7	follower	0.00444444	0.00111111	0.00222222	0.00106157
Plan	900	1444.14796	1	caller	0.00333333	0	0	0.00212314
Plan	900	1291.03927	7	follower	0.00555556	0	0.00111111	0.00106157
Plan	840	1509.8914	3	follower	0.00238095	0	0.00119048	0.00115875
Plan	840	1631.21839	5	follower	0	0	0	0
Plan	840	670.02254	8	caller	0.00714286	0	0.00119048	0.00463499
Plan	780	1684.83347	5	caller	0.00641026	0	0.00128205	0.00229095
Plan	780	1739.78367	2	follower	0.00512821	0	0.00384615	0.00114548
Plan	780	1324.71463	0	follower	0.00128205	0	0	0.00114548
Plan	1740	2980.21889	5	follower	0.00344828	0.00114943	0.00057471	0.00166667
Plan	1740	2716.1792	8	caller	0.00517241	0.00057471	0	0.00333333
Plan	1740	1993.12692	6	explorer	0.00287356	0	0.00114943	0.00111111
Plan	1200	1407.3352	3	caller	0.00833333	0	0	0.00412882
Plan	1200	2828.9792	3	follower	0.00083333	0	0.00083333	0
Plan	1200	1592.9211	2	explorer	0	0	0	0
Plan	1500	2207.59782	9	caller	0.004	0	0.002	0.00123001
Plan	1500	706.372407	11	follower	0	0	0	0
Plan	1500	2203.62037	9	follower	0.00133333	0	0	0.00061501
Plan	840	1490.51953	6	explorer	0.00357143	0	0.00119048	0.00205128
Plan	840	1800.8747	4	caller	0.00952381	0	0	0.00615385
Plan	840	1010.39506	2	explorer	0.00357143	0.00119048	0.00119048	0.00102564

Curriculum Vitae



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Nicolas Nova obtained a "Maîtrise de Sciences Cognitives" from the University of Lyon in 2000, a "DESS de technologies éducatives et interaction homme-machine" form the University of Geneva in 2002. Before his position at CRAFT, he was a research assistant at the University of Geneva. In addition to his research activities, he has been working as a consultant (within the company he co-founded: Simpliquity SàRL) and he is one of the co-organizer of the LIFT tech-conference in Geneva.

Selected Publications

Nova, N. (2005). A Review of How Space Affords Socio-Cognitive Processes during Collaboration. Psychology, Vol. 3, No 2, pp. 118-148.

Nova, N., Girardin, F., Molinari, G. & Dillenbourg, P. (2006): The Underwhelming Effects of Automatic Location-Awareness on Collaboration in a Pervasive Game, International Conference on the Design of Cooperative Systems (May 9-12, 2006, Carry-le-Rouet, Provence, France).

Nova, N., Girardin, F. & Dillenbourg, P. (2005): 'Location is not enough!': an Empirical Study of Location-Awareness in Mobile Collaboration. Proceedings of the third IEEE International Workshop on Wireless and Mobile Technologies in Education, November 28-30, 2005, Tokushima, Japan, pp. 21-28, IEEE Press: Los Alamitos, California (Acceptance rate: 11.6%)

Nova N., Wehrle, T., Goslin, J., Bourquin, Y. & Dillenbourg, P. (2006): Collaboration in a Video Game : Impacts of Location Awareness. Journal of Multimedia, Tools and Applications.